



ECOLOGY OF THE AFRICAN MAIZE STALK BORER, *Busseola fusca* (Fuller)
(LEPIDOPTERA: NOCTUIDAE) ON MAIZE (*Zea mays* L.) IN SOUTHERN ETHIOPIA

PhD DISSERTATION

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HAWASSA UNIVERSITY,
HAWASSA, ETHIOPIA

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ECOLOGY OF THE AFRICAN MAIZE STALK BORER, *Busseola fusca* (Fuller)
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HAWASSA UNIVERSITY
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First, I declare that this dissertation is my true work and those all resources of materials used for this dissertation have been duly acknowledged. This dissertation has been submitted in partial fulfillment of the required for an advanced PhD degree at Hawassa University and is deposited at the University library to be made available to the borrowers under rules of the library. I sincerely declare that this dissertation is not submitted to any other institute anywhere for the award of any academic degree. Brief quotations from this dissertation are allowable without special permission provided that accurate acknowledgement of the source is made. Requests for permission for extended quotation from or reproduction of this manuscript in whole or in part may be granted by the head of the major department or the Dean of the School of Graduate Studies when in his judgment the proposed use of the material is in the interest of scholarship. In all other instances, however, permission must be obtained from the author.

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DECLARATION

I, Abrham Taddele Terefe, hereby declare that this research is an outcome of my own investigation under the supervision of Ferdu Azerefegne (PhD) and Yibrah Beyene (PhD). This thesis has not been previously presented in any application for a higher degree of this or any other University. All citations and sources of information are clearly acknowledged by means of references

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DEDICATION

I like to dedicate this work to my late co - advisor Yibrah Beyene (Dr). He always kept me energetic and hardworking during my thesis work.

FOREWORD

In order to comply with regulations of general policy guidelines for graduate Studies Hawassa University, this doctoral thesis consists of a series of original research papers which have been published, submitted and in preparation for submission to peer-review journals. I would like to apologize to the reader for the inconvenience caused by the repetition of some sections dictated by this kind of presentation. Details for identification of these publications are listed below. As these publications have been prepared to fit the regulations of the different peer-reviewed scientific journals, the style, citations and the layout of the sections may vary between chapters.

PAPER / MANUSCRIPT TITLES

This dissertation consists of the following papers / manuscripts

1. Abrham Taddele, Ferdu Azerefegne, Yibrah Beyene. 2020. Spatial Distribution and Sampling Size for African Maize Stalk Borer, *Busseola fusca* (Fuller) (Lepidoptera: Noctuidae) in Southern Ethiopia. African Journal of Agricultural Reaserch, 15(2):203-211
2. Abrham Taddele, Ferdu Azerefegne, Yibrah Beyene. 2020. Phenology of African Maize Stalk Borer, *Busseola fusca* (Fuller) (Lepidoptera: Noctuidae) in Southern Ethiopia
3. Abrham Taddele, Ferdu Azerefegne, Yibrah Beyene. 2020. Population Density and Termination of Diapause African Maize Stalk Borer, *Busseola fusca* (Fuller) (Lepidoptera: Noctuidae) larvae in Southern Ethiopia
4. Abrham Taddele, Ferdu Azerefegne, Yibrah Beyene. 2020. Crop Injury and Yield Losses in Maize by the African Maize Stalk Borer, *Busseola fusca* (Fuller) (Lepidoptera : Noctuidae) in Southern Ethiopia (Submitted)

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LIST OF ABBREVIATIONS

CSA	Central Statistical Agency
EARO	Ethiopian Agricultural Research Organization
FAO	Food and Agricultural Organization
GPS	Global Positioning System
Ha	Hectare
ICIPE	International Center of Insect Physiology and Ecology
IITA	International Institute of Tropical Agriculture
KARI	Kenya Agricultural Research Institute
M	Meter
MASL	Meter Above Sea Level
MoA	Ministry of Agriculture
SAS	Statically Analysis Software
SNNPRS	Southern Nations, Nationalities and peoples Regional State
SPSS	Statistical Package for the Social Sciences
SSA	Sub-Saharan Africa
USAID	United States Agency for International Development
USDA	United State Department of Agriculture

1. ECOLOGY OF THE AFRICAN MAIZE STALK BORER, *Busseola fusca* (Fuller) (LEPIDOPTERA: NOCTUIDAE) ON MAIZE (*Zea mays* L.) IN SOUTHERN ETHIOPIA

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ABSTRACT

Maize (*Zea mays* L.) is an important crop in sub-Saharan Africa (SSA) and the developing world. In Ethiopia, smallholder farmers almost in all regions of the country dominantly produce maize. In sub-Saharan Africa, maize suffers from various biotic and abiotic constraints resulting in considerable yield loss. Among the biotic factors, insect pests particularly fall armyworm and stem borers are currently the most important pests of maize. Stem borers attack maize from seeding up to maturity. The sampling number and unit are important features of any empirical study in which the goal is to make inferences about a population. The number of sampling number and unit could vary with insects being sampled, their distribution patterns purpose of sampling, infestation pattern and economic considerations. Diapausing *B. fusca* larvae live in maize stem during unfavorable conditions. Environmental factors such as temperature influence the duration of *B. fusca* larvae development, intensity and time of pest outbreak varied between localities. Information on pest incidence, injury and yield loss in the different agro-ecologies will facilitate strategic decisions with regard to selection of management practices. This study provides information on *B. fusca*, spatial distribution pattern, sampling size, phenology, population density and termination of diapauses larvae, crop injury, and yields losses in maize in southern Ethiopia.

During the study periods, *B. fusca* was present and injurious to maize in all study areas. The spatial distribution pattern of *B. fusca* was determined by using four distribution indices namely, Taylor's power law, Iwao's mean crowding regression, Lloyd's mean crowding, and index of dispersion. At the mid-whorl stage of maize, the distribution of *B. fusca* infestation was aggregated and uniform at both silking and maturity stages. At silking as well as mid-whorl stage of maize, *B. fusca* larvae exhibited an aggregated distribution pattern but, larvae at maturity stage and pupae in both silking and maturity stages of maize found randomly distributed. To set control options for *B. fusca* at its economic threshold level in maize farm, required sampling units was determined using four precision levels and Iwao's patchiness regression. The required sample units to estimate 5 to 30% mean infestation of maize by *B. fusca* ranged from, 101 - 73, 45 - 32, 25-18 and 16 to 12 in 2015 and 104-76, 42-30, 26-19 and 17 to 12 in 2016, for 10%, 15% , 20% and 25% precision, respectively. For 10% infestation, which is considered as action threshold level for stem borers management on maize, 22 sampling units (660 plants) per hectare at the precision of 20% are required.

The phenology of *B. fusca* was studied at Hawassa and Wolaita Sodo using sowing date and pheromone traps. Three generations of *B. fusca* per year were observed in southern Ethiopia between May and September. In Hawassa, the first moth flight which emerged from diapause larvae was started at mid-April in 2015 and mid of March, 2016. In Wolaita moth flight started at early May and April in 2015 and 2016, respectively. The potential of crop residues as sources of carry-over populations of the insect was also assessed. Flight period and population density of adult *B. fusca* from diapause state were significantly varied between seasons. Access to water did not enhance pupation during the diapause. Planting of maize at the beginning of April and May

in Hawassa and Wolaita Sodo, respectively could be no longer suitable for oviposition and consumption by second-generation *B. fusca* larvae.

Population density of *B. fusca* larvae and pupae were significantly different among years, locations and crop stages. Early and highest infestation of *B. fusca* on maize was observed in Gurage followed by Wolaita as compared in Sidama Zone. Higher population density, injury variables and grain yield losses due to *B. fusca* on maize were recorded from chemical treated plots as compared with untreated. Tunnel length, hole number, bored internode, larvae and pupae population had a negative effect on grain yield of maize. Increase in altitude positively affected the population density of *B. fusca* and the resultant infestation and yield loss. Cultural practice such as crop diversification; disposal of crop residues after maturity can reduce initial establishment of stem borer infestation. Chemical control is one of the components of integrated pest management and should be used only when necessary combined with other management practices. This study provides information on the distribution, biology, pest status and yields losses due to *B. fusca* on maize in southern Ethiopia.

Keywords: Stalk borer, spatial distribution, sample size, phenology, crop residues, diapause larvae, population density, crop injury, yield loss, maize

1.1. GENERAL INTRODUCTION

Maize (*Zea mays* L.) is the third most important cereal crop next to wheat and rice worldwide (FAOSTAT, 2016). It is the most important food security crop in sub-Saharan Africa (SSA) and low income countries in various parts of world (De Groot et al., 2013). It is the most widely-grown staple food crop in sub-Saharan Africa (FAO, 2015). The crop occupies a pivotal role in the world economy and is traded widely. From total area under cereal production in Africa, maize accounts 19 % in West Africa, 61 % in Central Africa, 29 % in Eastern Africa and 65 % in Southern Africa (FAO, 2015). Among cereal crops, maize has the highest average yield per hectares and remains third after wheat and rice in total area and production in the world (FAO, 2015).

Maize is the most widely cultivated crop and one of the few crops that have profound effects on the livelihoods of people in sub-Saharan Africa (SSA) (Shiferaw et al., 2011). It continues to be a significant contributor to the economic and social development of Ethiopia (FAO, 2018). Maize is originated from South America, is first introduced in Ethiopia in the 16th to 17th Century (Abdissa et al., 2001). Ethiopia is the fourth largest maize produce in Africa next to South Africa, Nigeria and Egypt (FAO, 2015). In Ethiopia, maize is used as a staple food for human consumption, cash crop, feed for livestock and as raw material for industrial uses (CSA, 2017/18). In Average productivity of maize is 6.7 t/ ha in developed countries and 2.4 t/ ha in developing countries (Khalily et al., 2010). Despite the importance of maize in SSA, current production is not sufficient in most countries and yields remain among the lowest in the world (Ray et al., 2012) because of an array of biotic and abiotic constraints (Shiferaw et al., 2011).

1.2. Statement of the problem and justification

Ethiopia is the fourth largest maize producing country in Africa, and first in the East African region in terms of production (FAO, 2018). The major maize producing regions in Ethiopia are Oromia, Amhara, and Southern Nations Nationalities and Peoples' Regional State (SNNPRS) (CSA, 2017/18). Although the crop plays a leading role in maintaining food security with a high population growth, productivity remains low with an average yield of 3.9 t/ha (CSA, 2017/18) compared to global average of 5.8 t/ha (USDA, 2018). The productivity of maize in study areas (SNNPRS) is also lower (3.6 t/ha) (Cochrane and Bekele, 2018) than the national average yield (3.9 t/ha) (CSA, 2017/18). Maize productivity is limited by biotic and abiotic factors. Among biotic factors diseases, weeds, insect pests and other arthropod pests are the predominant biotic constraints of maize production in Ethiopia (Mosisa et al., 2012). Among insect pests, the stem borers pests of cereal crops in sub - Saharan African comprise the larvae of a number of members of Lepidoptera, both indigenous species such as maize stalk borer, *B. fusca* (Noctuidae), and non-indigenous stem borers such as spotted stem borer, *C. partellus* (Crambidae) (Kfir et al., 2002). *Busseola fusca* is distributed through sub – Saharan Africa, whereas *Chilo partellus* is mainly found in eastern and southeastern African countries (Kfir et al., 2002).

The stem borer insect pest can cause an average yield loss of 20–50% and, in some cases, a complete loss of maize and sorghum crops in Ethiopia (Getu et al., 2002). In Ethiopia, maize yield loss due to stem borer ranges from 20 to 50% (Demissie et al., 2012). Maize stalk borer, *B. fusca*, spotted stem borer, *C. partellus* and pink stem borer, *S. calamistis* have been recorded attacking maize and sorghum in Ethiopia (Wale and Ayalew, 1993; Tadesse et al., 1993; Getu et al., 2001). *Busseola fusca* and *Chilo partellus* are distributed and damaging species in Ethiopia

(Abate, 2012). Gebre-Amlak (1985) reported that *C. partellus* was a predominant species at lower elevation of less than 1700 m and *B. fusca* was dominant at high elevation of 1160 - 2600 MASL and in cooler areas. *Chilo partellus* widened its distribution from 500 - 1700 to 1030 - 1900 MASL whereas *B. fusca* was recorded between 1030 - 2320 MASL (Getu et al., 2001)

Knowledge about dispersion pattern of an organism provides a better understanding of the connection that exists between organism and its environment which may be useful in scheduling efficient sampling programs for population estimates, development of population models and pest management strategies (Soemargono et al., 2008). Understanding the distribution and phenology of insects in a different environment is important to plan management practices (Searle et al., 2013). The sizes of the sampling units are dependent upon the insects being sampled, their distribution patterns, and other factors (Pedigo and Van Schaik, 1984; Southwood and Henderson, 2000). If insects are concentrated in one spot and not in others, subsamples should be made in that region to determine the extent and severity of the problem more accurately (Unlu and Bilgic, 2004). No field sampling can be efficient without understanding the underlying spatial distribution (Taylor, 1984). Spatial distribution allows for the estimation of densities and in turn forms the basis for deciding on pest management programs (Khaing et al., 2002).

The spatial distribution of stem borers vary among and within host plants possibly due to their suitability for ovipositor and larval development (Addo - Bediako and Thanguane, 2012). The number of samples size and units could be varied purpose of sampling, infestation pattern, severity and economic considerations (Frisbie and Whorter, 1986). Too few samples will reduce the value of the estimate (Vlug and Paul, 1986) and too many will increase the cost of the program (Blackshaw and Hicks. 2013). Knowledge on the spatial distribution and sampling size

for *B. fusca* is fundamental requisite to implement control options through adherence to thresholds and also to developing basic foundational knowledge of pest dynamics (I).

Busseola fusca females oviposit up to 600–800 round and flattened eggs in batches of 30–100 eggs inside leaf sheaths (Unnithan, 1987; Harris and Nwanze, 1992). Van Rensburg et al. (1987) indicate that a single moth lays 7–8 egg batches. The larvae hatch about a week later and migrate to the whorl where they feed on the leaves or balloon off to other plants. The larval stage, consisting of six to eight instars, lasts between 24 and 45 days depending on temperature. Adults emerge about 13-14 days after pupation (Onyango and Ochieng'-Odero, 1994; Ratnadass et al., 2001). Two-four generation of *B. fusca* in growing season have been reported from different part of Africa countries (USUA, 1968). In Ethiopia, *B. fusca* had 2-3 generations in different part of the country like in Southern Ethiopia (Awassa) (Gebre-Amlak, 1989) three generations, in Eastern Ethiopia (Alemaya) (Yitaferu and Gebre - Amlak, 1994) two generations and in Northern Ethiopia (Sirinka) (Yirga, 2006; Dejen et al., 2012) two generations

Environmental factors such as temperature influence the duration of *B. fusca* larvae development (Harris, 1962), intensity and time of pest outbreak varied between localities (Van Rensburg et al., 1987). Warm and wet conditions favour the growth and development of a range of insects, diseases and weed species (Juroszek and von Tiedemann, 2013; Svobodova et al., 2014) and thus potentially cause large crop losses. Mohamed et al. (2004) reported that *C. partellus* could complete one to two or more generations per year, depending on the location and the number of maize crops or availability of alternative hosts through out the year. Wolaita zone (Sodo Zuria) is one of the major maize producing areas. Maize stalk borer has been identified as one of the major pests in this area (SNNPR livelihood profile, 2006), but the phenology of the *B. fusca* has not been studied. Also except Gebre - Amlak (1989), others the phenology of *B. fusca*

in Ethiopia studied on sorghum crop. Hawassa and Wolaita Sodo had moderately warmer and cooler climate conditions, respectively. There is a clear difference in vegetation, rainfall, temperature, and altitude between the two areas. But current information on the phenology *B. fusca* in different localities is lacking **(II)**

African maize stalk borer, *B. fusca* enters aestivation diapause at the final larval instar (USUA, 1970). Diapause is a state of arrested development that allows insects to survive unfavorable conditions and synchronize their life histories with conditions conducive to growth and reproduction (Tauber et al., 1986; Danks, 1987). Diapause is one of the major adaptations that have evolved in insects to synchronize activity with biotic resources and environmental constraints (Tauber et al., 1986; Denlinger, 2002). Environment factors may vary greatly from one location to another and even between seasons at the same location. Duration of diapause maintenance period is highly variable among the species and dependent up on environmental conditions before or during diapause (Tauber et al., 1986).

Environmental factors, such as temperature and rainfall play dominant roles in regulating the onset and termination of diapause (Denlinger, 1986). It has been shown for some tropical stem borers that the key environmental factors influencing diapause are rainfall, temperature, photoperiod and food (Harris, 1962; Kfir, 1993). Onset of rains frequently coincides with termination of diapause *B. fusca* (Denlinger, 1986). The main factor enabling diapausing *B. fusca* larvae to survive adverse condition appears to be efficient water conservation (Kfir et al., 2002). It was reported that 10 mm of rain fall per day could terminate the diapause of *B. fusca* (Walker, 1983). However, other studies suggested that an incidental contact with water be not the cause of abrupt termination of the diapause (Kaufman, 1983) and that provision of water be necessary only after the completion of the diapause development (Okuda, 1990). Although, little

information on the biology of *B. fusca* is available from southern Ethiopia region there is no information on the effect of ecology on diapause of *B. fusca* larvae in Ethiopian condition **(III)**.

Stem borers are responsible for losses ranging between 5-73% of potential yield under different agro ecological conditions (De Groote et al., 2003). In Ethiopia, the average yield loss of maize caused by cereal stem borers can be estimated between 20 - 50% (Boeke et al., 2004). *Busseol fusca* and *Chilo partellus* are considered to be the most damaging insect pests, with reported yield losses of 0 to 100, 39 to 100, 10 to 19 and 2 to 27% from South, North, East and Western Ethiopia, respectively (Wale and Ayalew, 1993; Wale et al., 2006). Knowledge of pest incidence and damage levels in different ecologies would facilitate strategic decisions with regard to selection of crop cultivars and management practices, and prediction of probable life of resistant cultivars. Stem borer infestation is severe in Southern Ethiopia, where maize production is further limited by declining soil fertility (Corral-Nunez et al., 2014) and unpredictable rainfall (Muluneh et al., 2015). However, data on the quantitative relationships among larval population, injury variables and yields of maize due to *B. fusca* in southern Ethiopia are scanty **(IV)**.

1.3. Objectives

The general objective of this study was to generate information on ecology and importance of the African maize stalk borer, *Busseola fusca* in Southern Ethiopia

The specific objectives were:

- To determine the spatial distribution and sampling size for monitoring of African maize stalk borer, *Busseola fusca*
- To understand the phenology of African maize stalk borer, *Busseola fusca* in Southern Ethiopia

- To determine the level of population density and examine the termination of diapause African maize stalk borer, *Busseola fusca* larvae
- To determine the crop injury and yield losses in maize by the African maize stalk borer, *Busseola fusca*

1.4. Hypothesis of the study

The following research hypotheses were formulated that guided the separate objectives of individual studies.

- ✓ The spatial distribution patterns of African maize stalk borer, *Busseola fusca* vary between areas, years and growth stages of maize and insect growth stages
- ✓ The phenology of African maize stalk borer, *Busseola fusca* vary between areas and seasons
- Variation in temperature and rainfall influence the population density, survival, body weight and termination of diapause African maize stalk borer, *Busseola fusca* larvae
- ✓ Crop injury and yield loss of maize due to African maize stalk borer, *Busseola fusca* vary between areas, years and maize varieties

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2. LITERATURE REVIEW

2.1. Importance and production of maize (*Zea mays* L.)

Maize (*Zea mays* L.) is one of the most important cereal grains grown worldwide in a wider range of environments (Kogbe and Adediran, 2003). It is the most important staple food in sub-Saharan Africa, particularly in East Africa (De Groote et al., 2013). It is grown in diverse regions of sub-Saharan Africa (SSA) under various ecological conditions (Ureta et al., 2013). Among cereal crops, maize has the highest average yield per ha and remains third after wheat and rice in total area and production in the world (FAOSTAT, 2014). Maize is the third most important cereal in the world (Chomba et al., 2015). It is one of the most important crops around the world because of its importance as food and feed in man life (Valdez-Ortiz et al., 2007). It ranks third in world's cereals after wheat and rice (Imran, 2015). It is the main staple and cash crop for smallholder farmers in SSA (Mathenge et al., 2014). Maize is originated from South America and first introduced in Ethiopia in the 16th to 17th Century (Abdisa et al., 2001). Ethiopia produces more of maize than any other crop (CSA, 2010).

2.2. Constraints on maize production

The average yield of maize in Ethiopia is 3.9 t/ha (CSA, 2017/18) which is below the world average of 5.8 t/ha (USDA, 2018). The major constraints to maize production in sub-Saharan Africa (SSA) include both biotic and abiotic factors. The poor performance of maize in Africa in general, and Ethiopia in particular could be attributed to abiotic factors (drought, low soil fertility) (Stevens and Winter-Nelson, 2008) and the prevalence of numerous biotic factors (insect pests, weeds and diseases) (Araya, 2007; Shiferaw et al., 2011).

2.2.1. Abiotic factors

The most common abiotic factors to maize production in sub-Saharan Africa (SSA) are drought, heat, low soil fertility particularly low soil nitrogen, high soil aluminium toxicity, flooding, and salinity (Tuberosa et al., 2007). The low adoption of improved varieties by farmers (Sibiya *et al.*, 2013) and the non- use of appropriate farming techniques (Etoundi and Dia, 2008) are also important factors contributing to low yield. The most abiotic factors for maize production in Ethiopia are incident production methods, low soil fertility, drought, and small landholdings (Geta et al., 2013). Abiotic factors for maize production include poor soil fertility, drought and heat stresses (Shiferaw et al., 2011). The low adoption of improved varieties by farmers (Sibiya et al., 2013) and non-use of appropriate farming techniques are also important factors contributing to low yield (Etoundi and Dia, 2008).

2.2.2. Biotic factors

Among the biotic constraints, insect pests represent an important challenge and lepidopteran stem borers (*Busseola fusca* (Fuller), *Chilo partellus* (Swinhoe) etc. being the most injurious pests that occur when maize and sorghum are cultivated in East Africa (Songa et al., 2001; Kfir et al., 2002; Ongamo et al., 2006; Mwalusepo et al., 2015). In Ethiopia, biotic for maize production includes insect pests, weeds and diseases (Keno et al., 2018). Diseases of economic significance in maize production systems of Ethiopia are TLB (caused by *Exserohilum turcicum*), GLS (caused by *Cercospora zea-maydis*), streak disease of maize (maize streak virus), CLR (caused by *Puccinia sorghi*) (Mosisa et al., 2012; Tilahun et al., 2012) and the recently emerged viral disease, MLN caused by the combination of maize chlorotic mottle virus (MCMV) and sugar cane mosaic virus (SCMV) (Mahuku et al., 2015). Besides direct competes with plant for water, soil nutrients, CO₂, space and light, weeds also cause indirect damage by

harboring insect pests, rodents, diseases, and crop pathogens, as well as reduce wildlife habitat and crop quality (Bubl, 2010).

2. 2.1. Stem borers

Lepidopteran stem borers are considered to be the most damaging insect pests of maize in Africa (Overholt et al., 2001). In sub-Saharan Africa, lepidopteran stem borers are the main insect pests attacking cereal crops (Kfir et al., 2002) for both small and large scale farmers, with losses ranging from 5 to 75% of potential crop yield (Kfir et al., 2002; Kipkoech et al., 2006; Moolman et al., 2013). Several species of maize stem borers have been reported worldwide. Maize stem borers are destructive pests of maize in Sub-Saharan Africa (SSA) (Insect Resistant Maize for Africa (IRMA), 2001). Stem borers interfere with the movement of water and metabolites through the plant's vascular system, which stunts its growth and development (Bosque-Perez, 1995).

In Africa, about 23 species of stem borers were reported from cultivated plants (Maes, 1997; Kfir et al., 2002; Ong'amo et al., 2013). However among these borer species, the most economically important and widely distributed species are the spotted stem borer *Chilo partellus* (Swinhoe), maize stem borer *Busseola fusca* (Fuller), pink stem borer *Sesamia calamistis* Hampson, sugarcane stem borer *Eldana saccharina* Walker, coastal stem borer *Chilo orichalcociliellus* (Strand), spotted sugarcane borer *Chilo sacchariphagus* (Bojer), greater sugarcane borer *Sesamia cretica* Lederer and Mediterranean corn borer *Sesamia nonagrioides* Lefèbvre (Seshu Reddy, 1998; Getu et al., 2001; Kfir et al., 2002; Ong'amo et al., 2006; Gofishu et al., 2016).

In Ethiopia, seven stem borer species were reported from cereals and sugarcane (Yoseph et al., 2006; Getu et al., 2001; Mengistu and Selvaraj, 2013; Gofishu et al., 2016). Of the known

stem borer species causing economic yield losses in sub-Saharan Africa, the indigenous noctuids *Busseola fusca* (Fuller) and *Sesamia calamistis* Hampson and the exotic crambid *Chilo partellus* (Swinhoe) are the most important in Ethiopia (Gebre-Amlak, 1985; Getu et al., 2001; Wale et al., 2006; Dejen et al., 2014; Gofishu et al., 2017). *Busseola fusca* occurs throughout sub-Saharan Africa while *C. partellus* occurs widely through eastern and southern Africa (Overholt et al., 2001). *Sesamia calamistis* is only economically important in West Africa (Ajala et al., 2010). The pink stem borer *S. calamistis* (Noctuidae) is generally less important than *B. fusca* and *C. partellus* as a pest of cereal crops in Africa but may be locally abundant (Van Hamburg, 1979). It does not often attain economically important status in eastern and southern Africa in spite of its wide occurrence on several crops (Overholt et al., 2001).

The abundance and distribution of stem-borer pests and their main natural enemies are expected to vary considerably among different agroecological zones (Getu, 2002; Tefera, 2004; Wale et al., 2006; Dejen et al., 2014) with climate variability (Batalden et al., 2007; Trnka et al., 2007). The distribution of cereal stem borers in Africa generally depends on rainfall, temperature, elevation, hosts and natural enemies (Getu, 2002). The distributions of the stem borer pest species *B. fusca*, *C. partellus* and *S. calamisti* are different but often overlap in space and time (Overholt et al., 2001). Geographic distributions of *B. fusca* and *C. partellus* in East and southern Africa are generally thought to be dependent on elevation (Seshu Reddy; 1983; Harris and Nwanze, 1992). Temperature, rainfall and humidity were the factors responsible for the distributions of *B. fusca* and *C. partellus*, with temperature being the most important (Sithole, 1987). In Ethiopia, *C. partellus* was a predominant species at lower elevation of less than 1700 m and *B. fusca* was dominant at high elevation of 1160 - 2600 MASL and in cooler areas (Gebre-Amlak, 1985).

2.2.1.1. The spotted stalk borer (*Chilo partellus*) (Swinhoe) (Lepidoptera: Pyralidae)

Chilo Partilus is the most important problem to maize and sorghum growers in various maize and sorghum growing countries of the world (Sylvain et al., 2015). It is the most serious pest of maize and sorghum in eastern and southern Africa (Getu et al., 2001; Songa et al., 2001). In Africa alone, this pest is reported to have infested maize and sorghum from different countries including Kenya, Ethiopia, Somalia, Lesotho, Mozambique, South Africa, Swaziland, Zambia, Botswana, and Zimbabwe (Overholt et al., 2001; Getu et al., 2002; Kfir et al., 2002). In Ethiopia, Assefa Gebre-Amlak (1985) recorded *C. partellus* at an elevation range of 510 to 1700m and in warmer areas of the country. However, Tamiru et al. (2012) reported that, *Chilo Partilus* occurred at elevations as high as 2088 meters above sea level. *Chilo partellus* prefers sorghum to maize (Mushore, 2005).

Serious economic losses occur in maize crop due to *C. partellus* which may reach up to 100%, especially in Africa and Asia (Bergvinsion et al., 2004; Arabjafari and Jalali, 2007). However, the losses may vary in different regions depending on the pest density and phenological stage of the crop infested. The neonates of *C. partellus* prefers feeding on young leaves whorls causing scars and holes; then advance towards growing point of plant by boring into the central whorl (Kfir et al., 2002), which leads to a partial or complete drying of the whole Plant (Kfir et al., 2002). Depending on the level of infestation, losses due to this insect pest could reach up to 100% in Ethiopia (Getu and Abate, 1999; Dejen, 2008). Even though the pest is most known for its severe damage to grain sorghum, it has the potential to attack other important crops such as pearl millet, finger millet, rice, wheat, sugar cane, foxtail and various grass species including Sudan grass and Napier grass (Kfir et al., 2002 and Matama-Kauma et al., 2007).

2. 2.1.2. Pink stem borer *Sesamia calamistis* Hampson (Lepidoptera: Noctuidae)

Although *S. calamistis* is the stem borer species with the widest distribution of all stem borer species on the African continent (Van den Berg and Van Wyk, 2007) this species is not economically important on crops in the eastern and southern parts of Africa (Overholt et al., 2001). The general biology of *S. Calamistis* is similar to that of other stem borers; there is one major difference in larval behaviour (Ajala et al., 2010). The larvae of *S. calamistis* do not feed on plant leaves but penetrate plant stems shortly after egg hatch (Bosque-Perez and Schulthess 1998), whilst the first and second instar larvae of *B. fusca* and *C. partilus* (Harris, 1990; Holloway, 1998; Maes, 1997) migrate from the emergence site to the leaf whorl where they feed on young leaf tissue causing foliar damage (Bosque-Perez and Schulthess, 1998). Unlike other stem borer species, larvae of *S. calamistis* do not enter into diapause, but develops throughout the year, even during the dry season (Van den Berg and Drinkwater, 2000). The life cycle of *S. calamistis* takes 53-54 days to complete when kept at 28 °C and a relative humidity of 65 - 70% (Songa et al., 2001). *Sesamia calamistis* distributed in the intermediate altitude, 1200 m to 1750 m (Gebre - Amlak et al., 1989; Tadesse et al., 1993).

2. 2.1.3. Africa maize stalk borer, *Busseola fusca* (Fuller) (Lepidoptera: Noctuidae)

Busseola fusca belongs to the Noctuidae family, which includes serious pests of field crops such as cutworms, bollworms and various other stem borer species and is generally regarded as the most important pest of maize (Anneck and Moran, 1982). It is a common pest in many sub-Saharan African countries where maize is grown (Wale et al., 2006) and largely occurs at medium to high elevations.

2. 2.1.3.1. Origin and distribution

Busseola fusca originated in Africa (Matthee, 1974) and it is not known to occur anywhere outside the African continent (Harris and Nwanze, 1992). It was first recognized as a pest of maize in South Africa, and has become economically important in many of the maize growing countries on the African continent (Haile and Hofsvang, 2002; Kfir et al., 2002). It is also known to occur in West Africa (Benin, Burkina Faso, Cameroon Cote d'Ivoire, Ghana, Guinea, Mali, Nigeria and Sierra Leone), eastern Africa (Ethiopia, Kenya, Somalia, Tanzania and Uganda) and southern Africa (Angola, Botswana, Lesotho, Malawi, Mozambique, Rwanda, Swaziland, Zaire, Zimbabwe, Zambia and South Africa) (Harris and Nwanze, 1992; Gebre-Amlak, 1985; Getu, 2002). In East Africa, *B. fusca* is the most damaging in the high potential yield areas, which include the highland tropics and moist transitional zones (De Groote, 2002; Ong'amo et al., 2006). The spatial distribution of stem borers vary among and within host plants possibly due to their suitability for ovipositor and larval development (Addo - Bediako and Thanguane, 2012). Insect populations may follow a random, uniform or aggregate distribution, but the degree of aggregation often varies among the population and species (Root and Cappuccino, 1992).

2. 2.1.3.2. Biology and behavior

Busseola fusca moths are seldom seen in the field as they are inactive during the day resting on plants and plant debris (Harris and Nwanze, 1992). Eggs of *B. fusca* are laid behind leaf sheaths (Barrow, 1989; Azerefegne and Gebre-Amlak, 1994) and under the ear husk leaves of maize plants (Barrow, 1989). The eggs, which are laid in batches of 30-100, are hemispherical with about 70 ridges on the egg shell (Harris and Nwanze, 1992). The eggs are 0.6 mm in diameter (Matthee, 1974) are laid within the sheaths of any one of the fifth to tenth leaves on maize plants ranging in height from 26 to 75 cm with a distinct preference for plants between 26 to 45 cm

(Barrow, 1989). Eggs hatch after several days after which larvae migrate upwards on the outside of the plant (Kfir, 1998). The young larvae have a dark brown color which turns lighter on maturity. Larvae prefer to feed on young rolled furl leaves. The larvae may disperse to adjacent plants and may infest three neighboring plants. During the third instar, larvae bore into stem tissues and maize ears (Kfir, 1998). Under optimum conditions the duration of the larval stage is six weeks.

Many cereal stem borers have a resting period toward the end of the cropping season, which they spend as fully grown larvae in dry crop residues in the fields. The fully grown larvae of *B. fusca* spend the dry season in a state of diapause in tunnels made in dry maize or sorghum stalks (USUA, 1973). In southern Africa, *B. fusca* and *C. partellus* pass winter in diapause, in the lower parts of the dry stalks, where they are well protected from natural enemies and adverse climatic conditions (Kfir, 1991). In Ethiopia, *B. fusca* larvae survive in diapause in stalks and stubbles after maturity (Gebre-Amlak, 1989). Pupation always occurs in stems (Kfir, 1993). Mating activity takes place the same night after eclosion (Unnithan, 1987). Female moths are bigger than male moths release a pheromone to attract males (Harris and Nwanze, 1992). Unnithan (1987) reported that the adult male and female moths of *B. fusca* live for 8.7 and 6.9 days respectively.

2.2.1.3.3. Host range

Host plants recorded for *B. fusca* are maize, sorghum, pearl millet, finger millet, sugarcane (Harris, 1989). However, sorghum and maize are the most important host plants for stem borers. Stem borers have different preferences in terms of host plants (Kfir et al., 2002). For instance, *B. fusca* prefers maize to sorghum (Mushore, 2005). *Busseola fusca* often the most serious stem borer of maize in the wet, mid and higher elevation areas of Africa (Yoseph, 2015).

The pest thrives on wide number of other cultivated and wild host plants, mostly of the grass family (Khan et al., 1997).

2.2.1.3.4. Damage symptoms

First instar larvae feed in whorls and may cause "shot holes", which are the first indication of infestation after the furl leaves have unfolded. In young plants, larvae may also damage growing points, which can cause "dead heart" symptoms. From the 3rd instar onwards larvae bore into the stems and relocate to adjacent plants searching for suitable shelter in the whorl or stems (Van Rensburg et al., 1987). Migration of larvae to adjacent plants is a continuous process and more plants show signs of damage when ageing while the level of primary larval infestation largely remain unchanged (Van Rensburg et al., 1987).

2.2.1.3.5. Pest status and yield loss

The pest status of *B. fusca* varies from one region to another. In East and southern Africa it occurs mainly above 600 MASL (Sithole, 1989). The quantitative yield loss varied from season to season at a specific level of oviposition varies due to genetic differences between maize hybrids as well as climate change (Van den Berg and Robe, 2001). Yield losses vary with crop and borer species as well as agro-ecosystem, ranging from 15 to 100% (Gebre-Amlak, 1989; Tadesse, 1989; Ayalew and Wale, 1996). *Busseola fusca* can cause 100 % yield loss under favorable conditions (Van den Berg et al., 1991). Average yield losses due to stem borers in Ethiopia range from 12% - 40% of the total production depending on borer species, as well as agro-climatic zone, maize variety, cropping system, and soil fertility level (Kfir et al., 2002, Mgoo et al., 2006). Getu and Abate (1999) reported that 20-50 % grain losses can be caused by stem borers in maize and sorghum in Ethiopia. In Burundi, *B. fusca* occasionally cause

yield losses of 30-50% (Muyango, 1987). In Zaire, losses of 8-9% in early-planted maize and 22-25% in late-planted maize have been reported (Cardwell et al., 1997). In Cameroon, grain weight losses of 4.6 g per borer in lowland fields and 8.7 g/borer in highland fields were reported (Harris and Nwanze, 1992; Cardwell et al., 1997). Yield losses in Ethiopia due to stem borers generally range from 10-50% (Getu et al., 2002; Getu et al., 2008; Wale et al., 2006; Demissie et al., 2011).

2. 2.1.3.6. Sampling

Sampling is related with the selection of a subset of individuals from within a population to estimate the characteristics of whole population. The two main advantages of sampling are the faster data collection and lower cost (Kish, 1965; Robert, 2004). According to Shah (2011), researchers must calculate the sample size before starting of any study. The sample size should be carefully fixed so that it will be adequate to draw valid and generalized conclusions (Singh and Masuku, 2014). The sample size is an important feature of any study or investigation in which the aim is to make inferences about the population from a sample (Singh and Masuku, 2014). The sample size used in a study is determined based on the cost of data collection, and based on sufficient statistical power (Singh and Masuku, 2014).

Reliable sampling methods for stem borers are needed for decision making in an integrated pest management. Stem borer control using of pesticides recommended (Warui and Kuria, 1983), and an economic injury level has been defined for maize (Seshu Reddy and Sum, 1992). For research purposes, enumerative counts of insects based on destructive plant sampling are usually necessary, particularly for ecological studies where accurate identification of the pest species and estimation of levels of parasitism and predation are important (Overholt et al., 1994). However, destructive sampling is time consuming, and is unlikely to be accepted by the farmer

or IPM decision-making. Sampling plans, based on presence/absence data obtained from visually inspecting plants in the field for outward signs of insect presence, may be more appropriate (Overholt et al., 1994)

2. 2.1.3.7. Management methods

Various stem borer management approaches, such as, cultural practices particularly crop residue management (Gebre-Amlak, 1988; Dejen, 2004), intercropping (Tsehaye et al., 2007; Wale et al., 2007; Belay et al., 2009), trap cropping (Belay and Foster, 2010), and modification of planting dates (Gebre-Amlak, 1989; Dejen, 2004); synthetic insecticides (Getu et al., 2008) and natural insecticides (Dejen, 2008; Dejen et al., 2011; Tilahun and Azerefegne, 2013; Wondimu and Dejen, 2014) and natural enemies (Getu et al., 2001; Dejen et al., 2013) have been recommended for minimizing the damage caused by cereal stem borers in the country.

2. 2.1.3.7.1. Cultural practices

Cultural practices, such as crop residue management (Gebre-Amlak, 1988; Dejen, 2004), intercropping (Tsehaye et al., 2007; Wale et al., 2007; Belay et al., 2009), trap crops (Belay and Foster, 2010) and modification of planting dates (Gebre-Amlak et al., 1989; Dejen, 2004), have been recommended for reducing the damage caused by cereal stem borers in Ethiopia. Many cultural control practices are labor intensive, but they have little adverse effects on the environment and are readily available without extra investment in equipment (Kfir et al., 2002).

2. 2.1.3.7.1.1. Intercropping

Crop diversification strategies may contribute to reducing crop losses by limiting the ability of stem borer to locate host plants (Poveda et al., 2008), by repelling pests via plant mediated semiochemicals (Bakthavatsalam, 2016), or by stimulating the abundance and diversity of natural

enemies that may provide top down control (Mailafiya et al., 2011; Pickett et al., 2014). Intercropping is already practiced in many low input agricultural systems in Africa (Overholt et al., 1994). In Ethiopia farmers intercrop maize and sorghum with sesame, haricot bean, sweet potato, mustards, and sometimes other cereals, depending on the region (Getu, 2002). In Ethiopia, maize-mustard intercropping significantly reduced borer density and damage caused by *B. fusca*, especially at the vegetative stage (Wale et al., 2007).

2. 2.1.3.7.1.2. Planting date

Adjustment of planting dates could be an effective method for the control of stem borers in maize (Seshu, 1983). In Tanzania, found that late sowings of maize largely escaped damage by *B. fusca* compared with earlier sowings (Kihara et al., 2015). In Nigeria, planting sorghum late in the season resulted in severe stem borer damage and reduced yield (Macfarlane, 1990). Timely sowing is the major control measure (Gebre-Amlak, 1989; Gebre-Amlak et al., 1989; Tadesse et al., 1993). Manipulation of sowing dates indicated that early planted maize suffered less attack of *B. fusca* in Ethiopia (Gebre - Amlak et al., 1989; Ebenebe et al., 2001). Ayalew and Wale (1996), reported that infestation and damage of *B. fusca* increased progressively with delay in planting dates. However, sowing date is strongly dependent on rainfall and cannot be greatly modified.

2. 2.1.3.7.1.3. Management of crop residues

Crop residues are important for carrying over stem borer larval populations from one growing season to the next (Kfir et al., 2002). In Ethiopia, *B. fusca* larvae survive in stubble (Yitaferu and Gebre-Amlak, 1994). In Uganda, crop residues were used to mulch, borers from the old stalks constantly infested the newly planted crops (Mohyuddin and Greathead, 1970). The destruction of crop residues after maturity may decrease the abundance of stem borer since these

insects spend their entire immature life on or in plant (Pats, 1996). Tillage is recommended to control larvae or pupae in post maturity maize stubbles by exposing stubbles to the sun or by burying them in the ground (Pats, 1996). An effective control option would be to reduce the first generation of adult population by destroying the larvae in old stalks (Kfir, 1990). Ploughing in order to bury maize stubble was an effective control measure in Kenya to control *B. fusca* (Unnithan and Seshu Reddy, 1989). In Zimbabwe, it was observed that *B. fusca* moths emerging through 5 cm of soil were crippled and that deeper burial of the stalks under 10–15 cm of soil ensured that no adult moths emerged (Mohyuddin and Greathead, 1970). In South Africa (Kfir, 1990), tillage practices are viable options for *B. fusca* and *C. partellus* control. Burning of crop residues was also reported to be effective against *C. partellus* and *B. fusca* (Ingram, 1983). Burning or composting old stalks before the onset of the rains is effective against *B. fusca* (Harris, 1962).

2. 2.1.3.7.1.4. Push and pull strategy

Push-pull technology is appropriate, environmentally friendly and fits well with resource-poor smallholder farmers of traditional crop-livestock mixed farming systems as it uses locally available and adapted bio-resources (Khan and Pickett, 2004). The push-pull system is a crop diversification strategy based on intercropping maize with a legume species such as *Desmodium* spp., whose semiochemicals repel stem borers (push effect), bordered by a trap crop (e.g., *Pennisetum purpureum* or *Brachiaria* spp.), which attracts stem borers ('pull' effect) (Cook et al., 2007; Khan et al., 2010). The mechanism involves the push where desmodium repels stem borers and suppresses and the pull where Napier grass attracts and kills stem borers (Cook et al., 2007).

Several plants have been identified which could be used as trap or repellent plants in a 'push pull' strategy (Khan et al., 2000). The combination of toughness, hairiness and the production of sticky substances are believed to be responsible for the high mortality rate among larvae feeding on Napier grass (Ogol et al., 2005). Sudan grass (*Sorghum bicolor drummandii* L.) Moench has the ability to attract stalkborer parasitoids along with stalk borer moths. Molasses grass (*Melinis minutiflora* Beauy) has been reported to attract parasitoids and Silver leaf Desmodium (*Desmodium uncinatum*) to repel *B. fusca* moths (Ogol et al., 2005). Dramatic reductions in stalk borer infestations on maize crops were recorded in cases where non-host grasses were intercropped with maize (Ogol et al., 2005). Thousands of farmers in east Africa are now using push-pull strategies to protect their maize and sorghum (Khan and Pickett, 2004).

2. 2.1.3.7.2. Biological control

Biological control is the action of natural enemies (parasites, predators, parasitoids and microbial agents) including naturally occurring agents which are introduced and managed by humans for pest control (Dent, 1991). Fungi are potentially the most versatile entomopathogens. Some produce toxins with the potential for causing mortality in insects, but they are slow in their action (Fuxa, 1987). In Ethiopia, *Metarhizium anisopliae* (Metschnikoff) and *Beauveria bassiana* (Balsamo) strains have been identified from different parts of the country, well-studied and proved to be effective against a broad range of insect pests (Seneshaw et al., 2003; Tesfaye et al., 2012).

The success of several predators and parasitoids was reported in managing cereals stem borers in Africa. In Zimbabwe, *Bracon sesamiae* Cameron (Hymenoptera: Braconidae), which attacks larvae of *B. fusca* (Chinwada et al., 2001). In South Africa, two parasitoids (*Cotesia sesamiae* and *Bracon sesamiae*) of the maize stalk borer, *B. fusca* are reported (Kfir, 1995). Five

hymenopterous parasitoids, *Bracon sesamiae* (Cameron), *Cotesia sesamiae* (Cameron), *Dolichogenidea* sp., *Pediobius furrus* (Gahan) and *Procerochasmius nigromaculatus* (Cameron) and one dipterous parasitoid (*Sarcophagasp.*), are attacking larvae and pupae of *B. fusca* were identified at Alemaya, eastern Ethiopia (Yitaferu and Gebre-Amlak, 1994). Three larval parasitoids of maize and sorghum stem borers, *Cotesia flavipes*, *Dolichogenidea fuscivora* and *Megaselia scalaris* were found in eastern Ethiopia (Tefera, 2004).

2. 2.1.3.7.3. Host plant resistance

Host plant resistance to insects is the genetic property that enables a plant to avoid, minimize, tolerate or recover from injury caused by insects (Bosque-Perez, 1995). Host-plant resistance has potential to provide effective control of *B. fusca* (Van Rensburg and Van Rensburg, 1993) and has been indicated to be compatible with other control methods (Bosque-Perez and Schulthess, 1998). However, maize varieties resistant to this pest are still not available in Africa (Kfir, et al., 2002). Evaluation of maize and sorghum genotypes for resistance to *B. fusca* was performed in South Africa (Van Rensburg and Van Rensburg, 1993). After mass screenings and elite line developments, 42 stem borer resistant maize breeding red lines were released in South Africa during 2004 (Van Rensburg and Klopper, 2004). Host-plant resistance has potential to provide effective control of *B. fusca* (Van Rensburg and Van Rensburg, 1993) and has been indicated to be compatible with other control methods (Bosque-Perez and Schulthess, 1998).

2. 2.1.3.7.4. Genetically modified maize

Genetically modified (GM) maize expressing insecticidal Cry proteins (*Bt*-maize) have been deployed with success against *B. fusca* in South Africa (Van Rensburg, 2007). *Bacillus thuringiensis* (*Bt*) maize cultivars have provided effective control of *Chilo partellus*, *Sesamia*

calamistis and *B. fusca* (Tende et al., 2010). Bt-maize, expressing CryIAb insecticidal proteins was introduced for control of two stem borer species, *B. fusca* and *C. partellus* in South Africa (Archer et al., 2001). Yield advantage of Bt maize hybrids over conventional iso-hybrids of up to 32 % has been reported from smallholder Bt maize farms (Gouse et al., 2006). The availability of maize genetically modified (GM) to express *Bacillus thuringiensis* (Bt) proteins constitute an important *B. fusca* management tool (Van den Berg et al., 2015). In South Africa, GM maize provides convenient and cost-effective options for mitigating yield losses (Brookes and Barfoot, 2014) caused by *B. fusca*. Additional benefit of Bt crop is reduced insecticide use in commercial farming systems (Brookes and Barfoot, 2014).

2. 2.1.3.7.5. Chemical insecticides

Among other management strategies, chemical control has its own effectiveness due to its rapid knock down effect (Tende et al., 2010). Several natural and synthetic materials (Getu et al., 2008) have been recommended for the control of stem borers. Successful control of stem borers of sorghum and maize has been achieved through the use of conventional insecticides in Ethiopia (Getu and Abate, 1999)

2. 2.1.3.7.5.1. Natural insecticides

Gebre-Amlak and Azerefeagne (1999) studied the insecticidal activity of chinaberry, endod and pepper tree seeds against the maize stem borer in southern Ethiopia and obtained a significant reduction in the levels of *B. fusca*-induced damage in maize, with a significant increase in yield. Tilahun and Azerefeagne (2013) stated that, application of two to three times the aqueous seed extract of *M. ferruginea* in Ethiopia significantly reduced the number of *B. fusca* larvae in maize plants compared with the untreated.

2. 2.1.3.7.5.2. Synthetic insecticides

Larvae are vulnerable to pesticide and/or many natural enemies only during the first instars stage, when they are feeding exposed on the leaves before they enter in to stems (Davies et al., 1995). Synthetic insecticides have been shown to be effective for the control of stem borer species at 10% of plant infested when used before young larvae enter in to stem and in repeated application. The timing of insecticidal application is crucial, as control measure are effective against young larvae only. Older larvae penetrate the stalk and are difficult to control with insecticides (Kfir, 1998). Pyrethroid, the most frequently used pesticides and account for more 1/3 of the insecticides currently marketed in the world (Lei et al., 2017)

2. 2.1.3.7.6. Integrated pest management

Integrated pest management of stem borers combines cultural, biological, host plant resistance and chemical control methods to manage them. The used of insecticides is always the last resort in IPM control (Bosque-Perez, 1995). The combined effects of several components (intercropping, adjustment of sowing date, crop-residue disposal, and host-plant resistance) were reduce *B. fusca* damage (Saxena et al., 1989). Farmers in Ethiopia, and elsewhere in Africa, traditionally use a combination of several pest management practices of cultural control, biological, botanicals, chemicals, and host plant resistance is the option for managing stalk borers in maize under a smallholder production system (Abate et al., 2000).

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3. SUMMARY OF MATERIALS AND METHODS

The ecology of maize stalk borer, *Busseola fusca* was studied in field and laboratory conditions. The field works were conducted in Halaba, Gurage, Sidama, and Wolaita zone (Figure 1 and Table 1), Southern Ethiopia. Phenology of *Busseola fusca* was studied in Hawassa Zuriaia and Wolaita Sodo, maize variety; BH540 was used in the main rainy season of May to September, 2015 and 2016. To make the plant available for oviposition subsequent plantings were made with 15 day intervals. Delta white Pherobank, sticky and selective lures were used to collect the moths and study the flight period of *B. fusca*. Diapause *B. fusca* larvae studied in Halaba, Gurage and Sidama zone, in small scale maize farms by collecting the diapause larvae from stalk and using pheromone traps during 2015/16 and 2016/17. The laboratory experiments were conducted in Hawassa University Crop Protection Laboratory.

The spatial distribution, crop injury, population density and yield losses of *Busseola fusca* in maize were studied in Sidama, Gurage and Wolaita zones. Twenty four maize farms were visited in six districts (12 localities) at three growth stage of maize during 2015/16 and 2016/17. Data were collected on percent of infestation, number of larvae and pupae, crop injury variables (borer exit holes, injured internodes, tunnel length) and grain yield. The spatial distribution pattern of *B. fusca* was determined by using four indices, namely Taylor's power law, Iwao's mean crowding regression, Lloyd's mean crowding, and index of dispersion. Optimal sample size determined using four fixed precision levels and Iwao's regression coefficients. Data on infestation, population density and damage variables were subjected to statistical analysis. Analyses of variance between districts were carried out using SAS software. Comparison between cropping years, varieties, chemical treated and untreated were analyses using t- test. The level of significance was set at $p = 0.05$ and the means were separated using student Newman-Keuls test (SNKT).

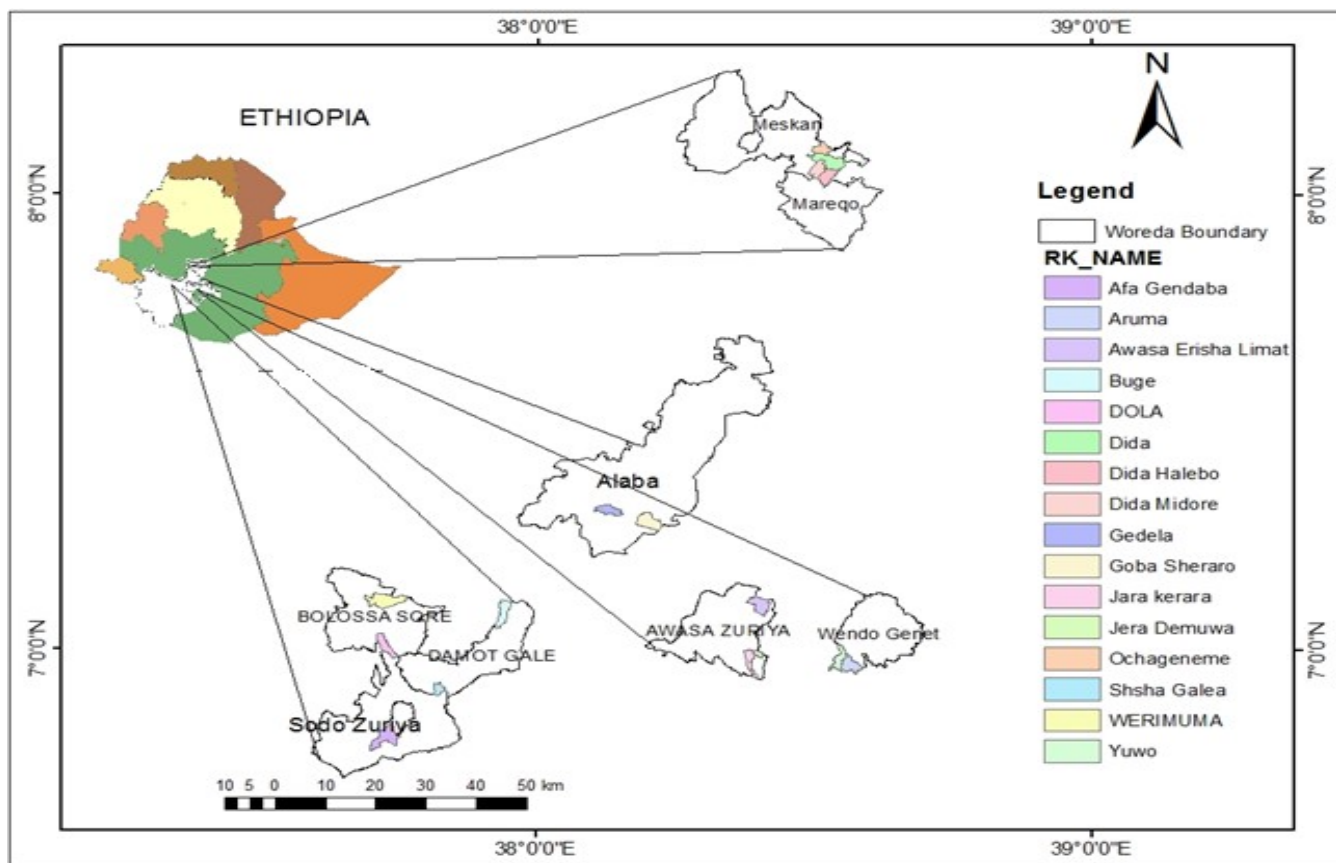


Figure 3.1. Map of the study areas

Table 3. 1. Description of the study areas in Southern Ethiopia

Zone	Districts	Altitude (MASL)	Annual Average air temperature ($^{\circ}$ c)		Annual Average rainfall (mm)	
			Minimum	Maximum	Minimum	Maximum
	Halaba special district	1792	17.0	20.0	700	1100
Gurage		1001- 3600	13.0	30.0	600	1600
	Mareko	1820	18.5	22.0	800	1600
	Meskan	1850	10.5	17.5	1000	1200
Sidama		501-3000	10.0	25.0	800	1600
	Wondo Genet	1723	15.0	20.0	1000	1800
	Hawassa Zuria	1697	18.5	25.0	800	1300
Wolaita		1200 - 2950	15.1	25.1	1200	1300
	Wolaita Sodo	1850	14.7	25.5	1400	1800
	Damot Gale	2050	12.0	20.0	1000	1400
	Boloso Sore	1800	14.5	18.5	1100	1500

Source: SNNPRS resource potential and investment opportunities, 2008.

4. SPATIAL DISTRIBUTION AND SAMPLING SIZE FOR MONITORING OF AFRICAN MAIZE STALK BORER, *Busseola fusca* (Fuller) (LEPIDOPTERA: NOCTUIDAE) ON MAIZE (*Zea mays* L.) IN SOUTHERN ETHIOPIA

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ABSTRACT

*The African stem borer (Busseola fusca) is one of the important biotic constraints to maize production in sub-Saharan African. This study determined the spatial distribution and sampling sizes for African stem borer in southern Ethiopia. Twenty four maize farms were visited in 12 localities at three growth stage of maize. Data were collected on the number of infested and not-infested plants, the number of larvae and pupae. There were variations in the levels of infestations and population density of larvae and pupae in the different study locations and years. Percent infestation at mid-whorl stage of maize ranged from 13.6 % to 25.9% and 19.5% to 41.4% in 2015 and 2016, respectively. The level of infestation increased through time and at maturity stage reached to ranges of 36.8% to 68.8% in 2015 and 65.5% to 80.7% in 2016. The spatial dispersion was analyzed using the variance-to-mean ratio (s^2/x), Lloyd index, Taylor's power law and Iwao's regression methods. The optimal sample size with four fixed precision levels of 0.10, 0.15, 0.20 and 0.25 were estimated with Iwao's regression coefficients. The distribution pattern of *B. fusca* varied between maize growth stages, locations and years. At mid-whorl stage of maize, *B. fusca* infested plants were aggregated but in both at silking and maturity stage uniformly distributed. At mid-whorl and stage of maize the distribution of *B. fusca* larvae were aggregated but, larvae at maturity stage and pupae in both silking and maturity stages of maize randomly distributed. The required sample units to estimate 5 to 30% mean infestation of maize at mid whorl stage ranged from, 101 - 73, 45 - 32, 25-18 and 16 to 12 in 2015 and 104-76, 42-30, 26-19 and 17 to 12 in 2016, for 10%, 15% , 20% and 25% precision, respectively. For 10% infestation, which is considered as action threshold level for stem borers management on maize, 22 sampling units (660 plants) per hectare at the precision of 20% are required.*

Keywords: Stalk borer, maize, spatial distribution, sample size, infestation, precision level

4.1. INTRODUCTION

Maize (*Zea mays* L.) is one of the main food and feed crops in Ethiopia and worldwide (FAO, 2018). In Africa, maize is among the most important field crop providing food, feed and fuel (Smale et al., 2011). Ethiopia is the fourth largest maize producing country in Africa, and first in the East African region (FAO, 2018). Maize is mainly grown in Oromia, Amhara, Southern Nations, Nationalities, and Peoples' Region (SNNPR), and Tigray (CSA, 2017/18). In SNNPR,

the average productivity of maize is 3.8 t/ha (CSA, 2017/18) which slightly less than the national average yield of 3.9 t/ha (CSA, 2017/18) but much lower than the world average of 5.8 t/ha (USDA, 2018). The low productivity of maize could be attributed to many abiotic and biotic factors (Getu et al., 2001; Tilahun et al., 2012).

Among the biotic factors, insect pests, particularly stem borers are responsible for the low yield of maize crop (Getu et al., 2001; Wale et al., 2006). Yield losses in Ethiopia due to stem borers vary with agro ecology, but generally range from 15 to 100% depending on infestation by the pest species, crop and crop growth stage attacked (Wale et al., 2006). In East Africa, the noctuid *Busseola fusca* (Fuller) and the crambid *Chilo partellus* (Swinhoe) are the most important insect pests associated with maize (Mwalusepo et al., 2015). The two lepidopterous stem borers are economic pests of maize in Ethiopia (Wale and Ayalew, 1993; Wale et al., 2006). Gebre-Amlak (1985) reported that *C. partellus* was a predominant species at low elevation (less than 1700 m) and *B. fusca* was dominant at elevations between 1160-2600 MASL and cooler areas of Ethiopia.

Spatial distribution is one of the characteristic properties of insect populations; in most cases, it allows us to define them, and is a typical trait in insect populations and is an important characteristic of ecological communities (Debouzie and Thioulouse, 1986). Understanding the distribution and phenology of insects in a different environment is important to plan management practices (Searle et al., 2013). No field sampling can be efficient without understanding the underlying spatial distribution (Taylor, 1984). Spatial distribution allows for the estimation of densities and in turn forms the basis for deciding on pest management programs (Khaing et al., 2002). The appropriate sampling pattern depends on the spatial distribution of the insect or disease (Lin et al., 1979). Insect populations may follow a random, uniform or aggregate

distribution, but the degree of aggregation often varies among the population and species (Root and Cappuccino, 1992). The spatial distribution pattern of organisms is an intrinsic characteristic of the species and it is shaped by behavioral and environmental factors (Taylor, 1984). Thus, knowledge on the spatial distribution patterns of insect populations may provide information on the behavioral traits of the insect species and on the effects of environmental factors on the populations (Southwood and Henderson, 2000). It provides useful information not only for theoretical population biology but for field monitoring programs (Binns et al., 2000). The spatial distribution of stem borers varies among and within-host plants possibly due to their suitability for oviposition and larval development (Addo - Bediako and Thanguane, 2012).

Management method cannot be implemented effectively without accurate estimates of insect population and its effects on yield (Nabil, 2010). Sampling allows to obtain a representative picture about the population, without studying the entire population. To estimate insect density, sampling time, sampling unit and sampling size are crucial (Southwood and Henderson, 2000). The number of samples size and units could be varied with insects being sampled, their distribution patterns (Southwood and Henderson, 2000); purpose of sampling, infestation pattern, severity and economic considerations (Frisbie and Whorter, 1986). Too few sample sizes will reduce the value of the estimate (Vlug and Paul, 1986) and too many will increase the cost of the program (Blackshaw and Hicks, 2013). Therefore, the present study was designed to determine the spatial distribution patterns and the sampling size for monitoring of *B. fusca* on maize.

4.2. MATERIALS AND METHODS

4.2.1. Study areas

The study was conducted in Wolaita, Sidama and Gurage zones (Table 4.1) which are found in southern Ethiopia during 2015 and 2016 main cropping seasons of May - October. The number of districts, localities, sampling farms, sampling plots and plants in each zone were described in Table 4.1. Districts and localities were selected based on road accessibility and intensity of maize production.

Table 4.1. Discription of the study areas during the study periods, number of sampling farms, sampling spots and plants

Zone	Districts/ Kebeles	Elevation (masl)	Rainfall (mm)		Temperature (°C)				Number of Sampling		
			2015	2016	2015		2016		farms/ localities	plots/farm	plants /sampling plots
					min	max	min	max			
Gurage	Mareko		724.1	953.6	12.4	26.3	13.4	26.7			
	Dida Halibo	1821-1824							2	5	10
	Dida Midore	1825-1834							2	5	10
	Meskam		657.4	828.2	13.2	27.5	13.4	25.8			
	Dida Ochageneme	1835-1836 1839-1845							2 2	5 5	10 10
Sidama	Wondo Genet		648.3	1133	13.7	27.6	12.5	24.3			
	Aruma	1704-1708							2	5	10
	Youwo	1819-1837							2	5	10
	Hawassa Zuria		670.9	1072	14.3	28.5	14.5	27.9			
	Jara Kerara Jara Demuwa	1687-1690 1693-1697							2 2	5 5	10 10
Wolaita	Damot Gale		775.5	1207	14.2	25.7	14.6	24.8			
	Shasha Galea	2176-2216							2	5	10
	Buge	1887-1890							2	5	10
	Bolloso Sore		1094.9	1482	14.7	26.4	15.5	27.4			
	Wermuma Dola	1716-1721 1834-1846							2 2	5 5	10 10

4.2.2. Sampling procedures

In this study, twenty-four maize farms in twelve localities having similar inputs and management practices were covered. The farms did not receive any insecticide treatment and grew the popular maize varieties BH540 and Shone. In each maize farm five sampling spots with a size of 9m² each were measured in 'X' pattern at mid-whorl, silking and maturity stages of maize. In each spot, the total number of plants (30 plants on the average) and those infested by stem borers (characterized by dead heart, scarified leaves, and larval entry and exit holes in stems, the presence of frass) were recorded and percent of infestation (%) calculated using the formula $IP \% = \frac{IP*100}{TP}$ Where, IP = infested plants, TP = total plants. When infestations were observed, ten plants were randomly selected from each spot and dissected to record the number of larvae and pupae. The same fields were used for samplings at different stages of maize.

4.2.3. Spatial distribution pattern determination

The spatial distribution pattern of *B. fusca* was determined by using four indices, namely Taylor's power law, Iwao's mean crowding regression, Lloyd's mean crowding, and index of dispersion. Percent of infested plants and numbers of insects per spot were used.

4.2.3.1. Taylor's power Law

$\text{Log}(S^2) = a + b \log(\bar{X})$, where S^2 is the variance, \bar{X} is mean, a is intercept and b is the slope. When $b = 1$, $b < 1$ and $b > 1$ the distribution is random, uniform and aggregated, respectively.

4.2.3.2. Lloyd's means crowding

$X^* = \bar{X} + S^2/\bar{X} - 1$, where S^2 is variance and \bar{X} is the sample mean. To remove the effect of changing in density, the ratio of mean crowding to the mean was used and $X^*/\bar{X} = 1$ random, < 1 uniform and > 1 aggregated

4.2.3.3. Iwao's regression

Iwao's regression method was used to quantify the relationship between mean crowding index (X^*) and mean density (m) using by solving the following equation: $X^* = \alpha + \beta \bar{X}$. Where α indicates the tendency to crowding (positive) or repulsion (negative) and $\beta = 1$, $\beta < 1$ and $\beta > 1$ the distribution is random, uniform and aggregated, respectively.

4.2.3.4. Index of dispersion

Variance (S^2) to mean (\bar{X}) ratio was calculated to determine the spatial distribution and values 1 random, < 1 uniform and $>$ aggregated distribution. The index of dispersion (ID); $ID = (n-1) S^2 / \bar{X}$, where n denotes the number of samples. The index was tested by Z value as follows:-

$Z = \sqrt{2I_D} - \sqrt{(2v - 1)}$, where $v = n - 1$ if $1.96 \geq Z > - 1.96$ and the distribution is random but if $Z < - 1.96$ or $Z > 1.96$, it would be uniform and aggregated, respectively (Patil and Stiteler, 1978).

4.2.4. Sample size determination

At mid-whorl stage of maize, the number of required sampling units per field were determined using proportion of infested plants and Kuno (1969) formula $n = (a + 1/\bar{X} + \beta - 1)/D^2$, Where n = number of sampling units; \bar{X} means of infestation; a and β are coefficients obtained from Iwao's regression, D = precision level. The allowable precision levels (10, 15, 20 and 25 %) in ecological research (Southwood and Henderson, 2000) were used.

4.2.5. Data analysis

Data on percent of infested plants, number of larvae and pupae per plant in each zone and maize growth stage were compared. Comparison, distribution indices and sampling size were

generated by using SPSS 21.0 software. Comparison and distribution indices were done separately for each year (2015 and 2016).

4.3. RESULTS

4.3.1. Levels of infestations and population density of *B. fusca* larvae and pupae

There were variations in the levels of infestations and population density of larvae and pupae in the different study locations and years (Table 4.2). Percent infestation by *B. fusca* at mid-whorl stage of maize ranged from 13.7 % to 25.9% and 19.4% to 41.4% in 2015 and 2016, respectively. The level of infestation increased through time and at maturity stage ranges from 36.8% to 68.8% in 2015 and 65.5% to 80.7% in 2016. The numbers of larvae were higher at mid-whorl stage (4.14 to 5.8 / plant in 2015 and 4.05 to 7.7 /plant in 2016) than the subsequent stages of maize (Table 4.2). Pupae were recovered starting the silking stage of maize and there were 0.5 to 1.14 and 0.7 to 1.55 pupae per plant in 2015 and 2016, respectively.

Table 4.2. Levels of infestations and population density of *B. fusca* larvae and pupae

Location (Zone)	Stage of maize	2015			2016		
		Infestation (%)	Larvae/ plant	Pupae/ plant	Infestation (%)	Larvae/ plant	Pupae/ plant
Gurage	Mid-whorl	25.9±4.7	5.8±0.24		41.4±1.2	7.7±0.14	
	Silking	42.3±4.8	3.0±0.18	1.2±0.08	67.3±4.8	2.7±0.15	1.6±0.09
	Maturity	68.8±5.2	1.2±0.08	0.6±0.06	80.7±5.4	1.3±0.11	0.7±0.08
Sidama	Mid-whorl	13.6±2.7	4.2±0.21		19.5±2.1	4.1±0.21	
	Silking	21.3±2.1	2.5±0.17	1.1±0.06	33.0±3.9	2.3±0.14	1.4±0.12
	Maturity	36.8±1.5	0.9±0.07	0.6±0.5	65.5±6.5	0.9±0.09	0.8±0.07
Wolaita	Mid-whorl	21.5±2.5	4.7±0.18		32.0±1.6	6.0±0.17	
	Silking	45.0±1.2	3.0±0.19	1.3±0.07	60.8±2.3	2.3±0.08	1.6±0.14
	Maturity	60.8±1.7	1.3±0.08	0.9±0.07	72.7±3.4	1.5±0.12	0.8±0.08

4.3.2. Spatial distribution of infested maize plants with *B. fusca*

In both years, at mid-whorl stage the index of dispersion and Lloyd's mean crowding (S^2/\bar{X} and X^*/\bar{X}) for percent number of infested plants were greater than one and the coefficients of Taylor's power law (b) and Iwao's patchiness regression (β) were significantly greater than one (Table 4. 3). Index of dispersion (S^2/\bar{X}) ranged from 0.99 to 1.81; Lloyd's mean crowding (X^*/\bar{X}) from 1.18 to 1.72; coefficients of Taylor's power law (b) from 1.10 to 1.91 and Iwao's regression (β) from 1.40 to 2.40. Whereas at silking as well as maturity stage of maize, all the distribution indices were less than one. The study showed that at the mid-whorl stage of maize, the distribution pattern of *B. fusca* infestation was aggregated and uniform at both silking and maturity stages of maize.

4.3.3. Spatial distribution of *B. fusca* larvae at mid-whorl stage of maize

During the study periods, *B. fusca* was the only stem borer species recorded in the three zones of the study areas. In both years, at the mid-whorl stage of maize, the index of dispersion (S^2/\bar{X}) for *B. fusca* larvae was greater than one (1.46 to 2.64); Z value was greater than 1.96 and Lloyd's mean crowding (X^*/\bar{X}) ranged from 1.10 to 1.51 (Table 4.4). The coefficients of Taylor's power law (b) and Iwao's (β) were significantly greater than one and ranged from 1.82 to 3.88 and 1.14 to 1.7, respectively. All the dispersion values indicated that at the mid-whorl stage of maize *B. fusca* larvae had an aggregated distribution.

Table 4.3. Distribution of *B. fusca* infestation in maize field derived from two distribution indices and two regressions at three growth stages of maize

Zone	Maize growth stage	Year	Indices of dispersion	Lloyd's crowding	Taylor's power			Iwao's regression		
			S^2/\bar{X}	X^*/\bar{X}	a	b	P-value	a	β	P-value
Gurage Sidama Wolaita	Mid-whorl	2015	1.67	1.59	-0.71	1.40	0.04	0.71	2.40	0.01
			1.48	1.72	-0.20	1.20	0.06	-0.60	2.40	0.03
			1.91	1.18	-1.12	1.91	0.03	0.51	1.90	0.02
Gurage Sidama Wolaita		2016	0.99	1.31	-0.40	1.70	0.03	0.24	1.90	0.02
			1.04	1.57	-0.62	1.50	0.02	0.60	1.40	0.05
			1.81	1.35	-0.50	1.80	0.00	0.50	2.30	0.00
Gurage Sidama Wolaita	Silking	2015	0.81	0.75	0.19	1.04	0.21	-0.51	0.92	0.13
			0.70	0.88	0.77	0.72	0.15	0.23	0.75	0.22
			0.82	1.12	0.35	0.59	0.11	0.31	0.83	0.10
Gurage Sidama Wolaita		2016	0.93	0.92	-0.03	0.94	0.06	-0.32	0.84	0.08
			0.87	0.97	0.08	0.87	0.07	-0.11	0.97	0.21
			0.76	0.83	0.07	0.66	0.09	-0.21	0.86	0.09
Gurage Sidama Wolaita	Maturity	2015	0.99	0.55	0.03	0.78	0.12	0.03	0.85	0.19
			0.79	0.68	0.23	1.12	0.09	-0.13	0.69	0.21
			0.74	0.54	0.16	0.83	0.07	-0.15	0.74	0.13
Gurage Sidama Wolaita		2016	0.88	0.57	-0.02	0.65	0.73	-0.10	0.91	0.62
			0.83	0.74	-0.13	0.76	0.06	-0.14	0.93	0.51
			0.66	0.67	-0.33	0.75	0.17	-0.21	0.60	0.42

P-values test whether or not b and β values for Taylor's power law and Iwao's are significantly different from 1; "a" stands for the intercept ; "b and β " stands slope values for Taylor's power law and Iwao's regression, respectively

Table 4.4. Spatial distribution of *B. fusca* larvae derived from two distribution indices and two regressions at three growth stages of maize

Zone	Maize growth stage	Year	Indices of dispersion		Lloyd's crowding	Taylor's power law			Iwao's regression			
			S^2/\bar{X}	Z	X^*/\bar{X}	a	b	p-value	R ²	a	β	P-value
Gurage	Mid-whorl	2015	1.87	2.67	1.27	-2.41	3.88	0.01	0.86	1.40	1.7	0.01
Sidama			1.46	2.23	1.10	-1.83	2.16	0.03	0.63	1.03	1.20	0.04
Wolaita			1.77	2.40	1.23	-3.03	3.46	0.04	0.72	1.40	1.40	0.00
Gurage		2016	2.64	2.82	1.25	-0.88	2.37	0.01	0.79	2.30	1.45	0.03
Sidama			2.02	2.57	1.51	-0.43	1.62	0.04	0.92	1.00	1.16	0.01
Wolaita			2.20	3.05	1.33	-0.50	2.17	0.03	0.92	1.20	1.14	0.00
Gurage	Silking	2015	2.30	3.20	1.52	-2.12	3.54	0.00	0.91	0.20	1.30	0.00
Sidama			1.24	1.87	1.21	-0.87	1.97	0.03	0.48	0.95	1.13	0.06
Wolaita			1.93	2.65	1.38	-2.28	2.37	0.02	0.76	0.52	1.26	0.01
Gurage		2016	1.34	2.21	1.35	0.25	2.31	0.06	0.76	0.28	1.20	0.04
Sidama			1.30	1.98	1.08	0.37	1.21	0.03	0.94	0.38	1.17	0.07
Wolaita			1.74	2.35	1.53	-1.20	1.50	0.04	0.91	1.14	1.12	0.02
Gurage	Maturity	2015	1.09	1.19	1.21	0.21	1.18	0.56	0.87	-0.59	1.01	0.12
Sidama			0.97	1.08	0.99	0.14	1.00	0.49	0.50	-0.03	1.08	0.26
Wolaita			1.07	1.05	1.08	-0.56	1.29	0.12	0.76	-0.12	1.02	0.08
Gurage		2016	1.18	1.43	1.38	-0.01	1.36	0.08	0.65	-0.12	1.10	0.06
Sidama			1.26	1.21	1.33	0.85	1.05	0.12	0.73	-0.28	1.03	0.19
Wolaita			1.19	1.39	1.21	-0.56	1.14	0.07	0.86	-0.22	1.04	0.05

P-values test whether or not b and β values for Taylor's power law and Iwao's are significantly different from 1; "a" stands for the

Intercept ; "b and β" stands slope values for Taylor's power law and Iwao's regression, respectively

4.3.4. Spatial distribution of *B. fusca* larvae and pupae at silking stage of maize

Similar to mid-whorl stage, at silking stage of maize, *B. fusca* larvae distribution indices (S^2/\bar{X} and X^*/\bar{X}) were greater than one; Z values greater than 1.96; Taylor power and Iwao coefficients were significantly greater than one (Table 4.4). In both years, the index of dispersion (S^2/\bar{X}) ranged from 1.24 to 2.30; (Z) from 1.87 to 3.20; Lloyd's mean crowding (X^*/\bar{X}) ranged 1.08 to 1.52 and the Taylor power coefficients (b) ranged from 1.21 to 3.54. Index of dispersion (S^2/\bar{X}) of pupae ranged from 0.84 to 1.26; with (Z) values from 0.90 to 1.31; Lloyd's mean crowding (X^*/\bar{X}) ranged from 0.82 to 1.30 and coefficients of Taylor's power law (b) ranged from 0.94 to 1.34 (Table 4.5). The slopes of the regression of Iwao's were near to one and ranged from 0.89 to 1.24. All the indices indicated that at silking stage of maize *B. fusca* larvae had aggregate and pupae a random distribution pattern.

4.3.5. Spatial distribution of *B. fusca* larvae and pupae at maturity stage of maize

Unlike mid-whorl and silking stages, at maturity stage of maize *B. fusca* larvae distribution indices (S^2/\bar{X} and X^*/\bar{X}) were near to one; Z values less than 1.96; Coefficients Taylor power (b) and Iwao values (β) were not significantly different from one (Table 4.4). The larvae index of dispersion (S^2/\bar{X}) ranged from 0.97 to 1.26; Z values from 1.08 to 1.43; Lloyd's mean crowding (X^*/\bar{X}) from 0.99 to 1.38 and Taylor power coefficients (b) ranged from 1.0 to 1.36. Similarly, the slopes of the regression lines of Iwao's regression (β) were not significantly greater than one and ranged from 1.01 to 1.20. The index of dispersion (S^2/\bar{X}) for pupae ranged from 0.93 to 1.21 with (Z) values from 0.90 to 1.53; Lloyd's mean crowding (X^*/\bar{X}) ranged from 0.86 to 1.15 and the coefficients of Taylor's power law (b) ranged from 0.68 to 32; Iwao's coefficients (β) from 0.82 to 1.09 (Table 4.5). These results indicate that in both years, the distribution of *B. fusca* larvae and pupae at maturity stage of maize was random.

Table 4.5. Spatial distribution of *B. fusca* pupae derived from two distribution indices and two regressions at two growth stages of maize

Zone	Maize growth stage	Year	Indices of dispersion		Lloyd's crowding	Taylor's power				wao's regression		
			S^2/\bar{X}	Z	X^*/\bar{X}	a	b	p-value	R ²	a	β	P-value
Gurage	Silking	2015	1.15	1.31	1.15	-0.09	1.21	0.05	0.86	0.33	0.89	0.08
Sidama			0.84	1.15	0.82	0.22	0.94	0.12	0.63	-0.21	1.24	0.04
Wolaita			1.08	1.21	1.09	-0.44	1.34	0.20	0.71	0.50	1.16	0.07
Gurage		2016	1.00	1.09	1.30	0.62	1.34	0.14	0.67	0.53	1.02	0.15
Sidama			0.94	0.90	1.00	0.83	1.00	0.06	0.70	0.83	0.94	0.15
Wolaita			1.26	1.01	1.09	-0.21	1.03	0.11	0.88	-0.43	1.06	0.06
Gurage	Maturity	2015	1.21	1.53	1.04	0.04	1.42	0.33	0.61	-0.06	1.09	0.63
Sidama			0.93	1.14	0.86	0.42	0.68	0.43	0.56	0.61	0.82	0.50
Wolaita			1.02	1.22	1.07	-0.05	1.09	0.13	0.74	0.20	1.07	0.11
Gurage		2016	1.03	1.06	0.93	-0.16	1.36	0.05	0.89	0.16	0.99	0.42
Sidama			0.95	0.90	0.89	0.06	0.85	0.12	0.77	-0.38	0.84	0.15
Wolaita			1.12	1.15	1.15	0.21	1.14	0.09	0.82	-0.21	1.03	0.12

P - Values test whether or not b and β values for Taylor's power law and Iwao's are significantly different from 1; "a" stands for the intercept ; "b and β" stands slope values for Taylor's power law and Iwao's regression, respectively.

4.3.6. Sampling size based on percent infestation of maize at mid-whorl stage

Sample size estimates were similar for the two years. The required sample units to estimate 5 to 30% mean infestation of maize by *B. fusca* ranged from, 101 - 73, 45 - 32, 25-18 and 16 to 12 in 2015 and 104-76, 42-30, 26-19 and 17 to 12 in 2016, for 10%, 15% , 20% and 25% precision, respectively (Figure 4.1). For 10% infestation, which is considered as action threshold level for stem bores management on maize, 85, 38, 22 and 14 sampling units per hectare were required for 10%, 15%, 20% and 25% precision, respectively.

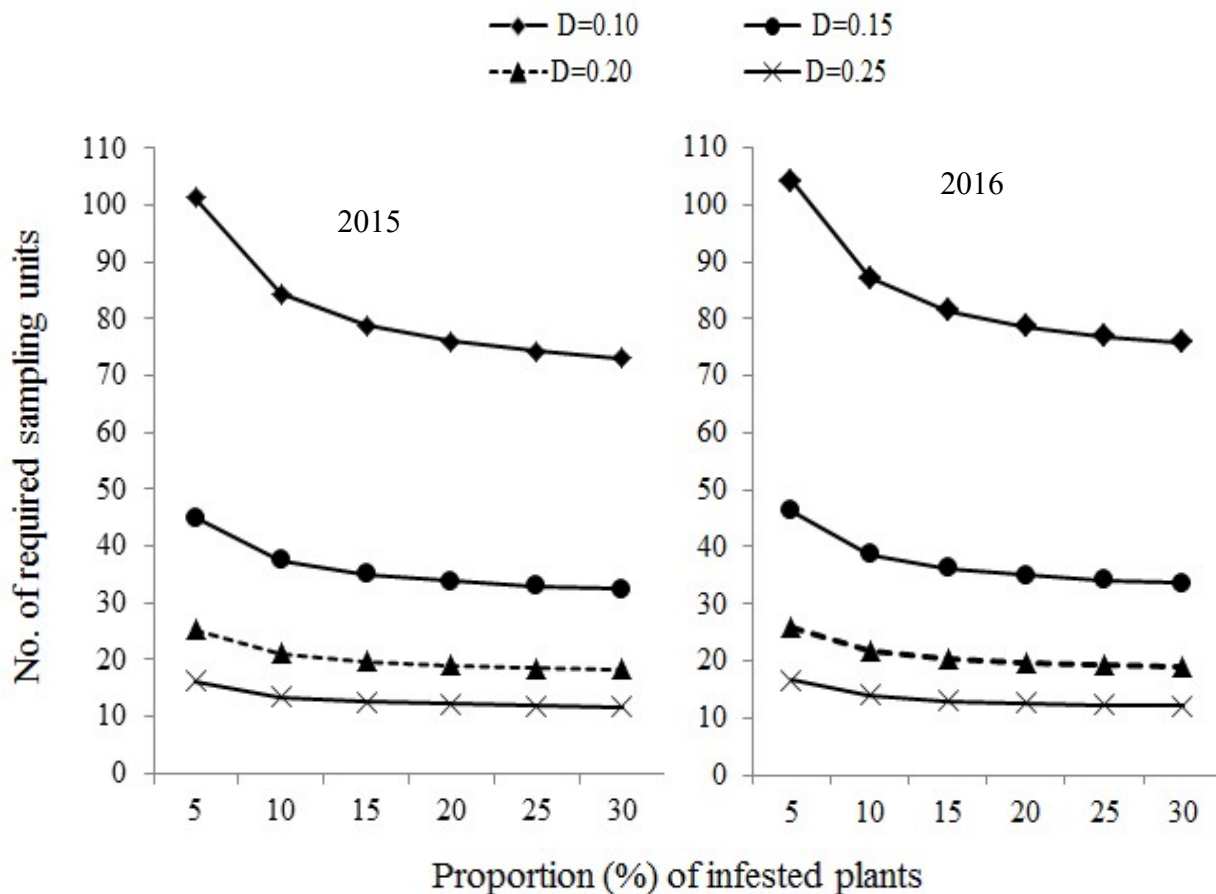


Figure 4.1. Relationship between number of required sampling units and proportion of infested maize plants by maize stalk borer in 2015 and 2016 for four levels of precision (D = 0.10, D = 0.15, D = 0.20, D = 0.25 and D = 0.30) based on Kuno's (1969) method.

4.4. DISCUSSION

Infestation of maize with *B. fusca* was aggregated at mid-whorl stage but uniform at silking and maturity stage of maize. *Busseola fusca* larvae were aggregated at both mid-whorl and silking stage of maize. The aggregated distribution pattern of larvae has been reported in *C. partellus* on maize and sorghum (Overholt et al., 1994), *C. infuscatellus* on sugarcane (Kumar et al., 2007). Aggregated distribution pattern is a predominant form of arthropod distribution (Argov et al., 1999). Unlike mid-whorl and silking stage, at maturity stage the distribution pattern of *B. fusca* larvae was random. In both years, at silking and maturity stage of maize the distribution pattern of *B. fusca* pupae was random.

Insects may not have one type of spatial distribution for all their life stages (Rajabi, 2003). Spatial distribution of insects may change to a different type during their lifetime. Overholt et al. (1994) and Ndemah et al. (2001) reported that the distributions of stem borers become progressively less aggregated as the insects aged. Pedigo and Buntin (1994) stated that changes in distribution pattern during season could be caused by changes in population density or movement of larvae. *Busseola fusca* females oviposit a highly variable number (from 100 up to 800) of round and flattened eggs in batches (Kruger et al., 2012); larvae migrate to neighboring plants throughout the larval stages (Van Rensburg et al., 1987; and Calatayud et al., 2014). Sun and Du (1991) reported that rice stem borer, *Chilo suppressalis* larvae have an aggregated distribution pattern in the active seasons but the dispersal rate of larvae changes with developmental stages.

The numbers of the required sampling units are dependent upon the insects being sampled, their distribution patterns, and other factors (Pedigo and Van Schaik, 1984). The required sampling size typically increased with higher precisions and for lower levels of infestations. An

action threshold for *B. fusca* 10% infested plants has been recommended (Ongamo et al., 2016, Van Rensburg et al., 1988). Maize stalk borer infestations occur within a limited range of crop growth stages, with the result that re-infestations after treatment of any particular planting is very rare (van den Berg, et al., 1991). Control measures based on an economic threshold of 10% of the plants showing visible damage proved to be superior to a preventative spray with regard to both larval control and grain yield (van Rensburg, 1990). For 10% infestation 14 to 85 sampling units were required for precision ranges of 10%, to 25%. A 25% level of precision is acceptable for scouting programs (Southwood, 1978). Taking a higher precision of 20%, for the 10% infestation 22 sampling units (660 plants) are required. In this study the required sample units were estimated with Kuno's (1969) method which is based on Iwao's patchiness regression. Many studies used Taylor's power to estimate sample sizes. The Taylor's method reduces the necessary sample size when compared with Iwao's method (Darbemamieh et al., 2011; Ifoulis and Savopoulou-Soultani, 2006).

4.5. SUMMARY AND CONCLUSION

Techniques of scouting which are easy to follow, save time and effort, and avoid needless insecticide applications are required. Although various studies have established the relationship between density of larvae of stem borers and yield loss in maize, count of larvae which employs destructive sampling is time consuming and not feasible to scout and decide on the management of stem borers. Van Rensburg and Pringle (1989) developed a sequential sampling method for egg surveys (based on the negative binomial distribution) and the method saved on time and effort required for sampling while allowing for more timely application of insecticides. I used presence and absence of infestation on maize by the stem borer which is easy to execute in the field. Hence, the sample size recommended in this study could be considered as optimum. For

10% infestation, which is considered as action threshold level for stem borers management on maize, 22 sampling units (660 plants) per hectare at the precision of 20% are required.

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5. PHENOLOGY OF AFRICAN MAIZE STALK BORER, *Busseola fusca* (Fuller) (LEPIDOPTERA: NOCTUIDAE) IN SOUTHERN ETHIOPIA

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ABSTRACT

The African maize stalk borers, Busseola fusca is one of the most damaging pests of maize and sorghum in Ethiopia. The phenology of Busseola fusca was studied in Hawassa Zuria and Wolaita Sodo in 2015 and 2016. Moth's flight and oviposition period, larvae and pupae population density of B. fusca varied between seasons and areas. Three generations of B. fusca per year were observed in southern Ethiopia. In Hawassa Zuria, the first moth's flights from diapause state started in mid-April and March in 2015 and 2016, respectively, whereas in Wolaita Sodo in early May and April. The first generation larvae in Hawassa Zuria were observed starting at the end and early May and peaked in early July and June in 2015 and 2016, respectively. In Wolaita Sodo, the first generation larvae were observed starting in early June and end of May and peaked in early July and end of June in 2015 and 2016, respectively. Depending upon environmental conditions, from larvae to pupae B. fusca lasts four to five weeks. In both years, adult moth's flight and egg oviposition of B. fusca commenced at least two weeks earlier in Hawassa Zuria than in Wolaita Sodo. The population density of moths, egg mass, larvae and pupae of B. fusca were higher in the 2016 cropping season as compared to 2015. The population densities of B. fusca were higher in the second-generation than first and third generations. Depending on the rainfall, planting of maize at the beginning of April and May in Hawassa Zuria and Wolaita Sodo, respectively, could lead to infested with low population of the first generation but escapes the higher population of the second generation.

Keywords: Diapause, flight period, number of generation, climate change, Ethiopia, Zea mays

5.1. INTRODUCTION

Ethiopia is the fourth largest maize producing country in Africa, and first in the East African region (FAO, 2012). However, the production and productivity of maize is hampered by various biotic and abiotic factors. Maize stem borer (*Busseola fusca* (Fuller)), spotted stem borer (*Chilo partellus* (Swinhoe)) and pink stem borer (*Sesamia calamistis* (Hampson)) have been considered among the major biotic constraints of maize and sorghum in Ethiopia (Gebre-Amlak, 1985; Wale and Ayalew, 1993; Tadesse et al., 1998; Wale et al., 2006). *Busseola fusca* and *Chilo partellus*

are considered to be the most damaging insect pests, with reported yield losses of 0 to 100, 39 to 100, 10 to 19 and 2 to 27% from South, North, East and Western Ethiopia, respectively (Wale and Ayalew, 1993; Wale et al., 2006). *Busseola fusca* is probably the most wide spread and damaging to maize in Africa (Walker and Hodson, 1976).

The female usually prefers young plants for oviposition though eggs can also be laid on older plants (Azerefegne and Gebre- Amlak, 1994). Single *B. fusca* moth lays 7–8 egg batches (Van Rensburg and Bate, 1987); oviposit up to 600–800 round and flattened eggs in batches of 30–100 eggs inside leaf sheaths (Unnithan, 1987; Harris and Nwanze, 1992). The larvae hatch about a week later and migrate to the whorl where they feed on the leaves or balloon off to other plants. The larval stage consists of six to eight instars, lasts between 24 and 45 days depending on conditions. Adults emerge about 13-14 days after pupation (Harris and Nwanze, 1992; Onyango and Ochieng'-Odero, 1994; Ratnadass et al., 2001).

Two to four generation of *B. fusca* have been reported from different part of Africa countries (USUA, 1968). In Ethiopia, *B. fusca* had 2-3 generations in different part of the country like in South Ethiopia (Awassa) (Gebre-Amlak, 1989) three generations, in Eastern Ethiopia (Alemaya) (Yitaferu and Gebre-Amlak, 1994) and two generations in Northern Ethiopia (Sirinka) (Yirga, 2006 and Dejen et al., 2012). Van Rensburg et al. (1988) reported that three generations and rarely small population of larvae pupated and gave rise to the fourth adult generation in relatively humid areas of South Africa. In Hawassa, most of the second generation larvae of *B. fusca* entered in to diapause and some larvae pupate to give rise to the third generations (Gebre-Amlak,1989) and the fate of this generation is not known.

Weather has a great effect on the population of invertebrate pests like insects, mites, and other species; and affects their development, reproduction, and dispersal (Sutherst, 1991). Insect phenology can be highly variable and show contradictory trends within and among species, seasons, and localities (Hodgson et al., 2010). With such change, insect pests may be varied in population growth rates, changes in geographical distribution and interspecies interactions (Hance et al., 2007). The life cycle of *B. fusca* is completed within 7-8 weeks if the conditions are favorable (Harris and Nwanze, 1992). Temperature plays an important role in the development and growth rates of an insect, the duration of its life cycle and survival (Roy et al., 2003). *Busseola fusca* larval stage is about 24 - 54 days long depending on the temperature (Calatayud et al., 2007).

Understanding the distribution and phenology of insects in a different environment is important to plan management practices (Searle et al., 2013). Study on the phenology of *B. fusca* in Ethiopia showed varied number of generations (Gebre-Amlak, 1989; Yitaferu and Gebre-Amlak, 1994; Yirga, 2006; Dejen et al., 2012). In Ethiopia, except Gebre-Amlak (1989), others studied the phenology of *B. fusca* in Ethiopia on sorghum. Wolaita zone (Sodo Zaria) is one of the major maize producing areas. Maize stem borer has been identified as one of the major pests (SNNPR livelihood profile, 2005), but the phenology of the *B. fusca* has not been studied. Hawassa Zuria and Wolaita Sodo had moderately warmer and cooler climate conditions, respectively. There is a clear difference in vegetation, rainfall, temperature, and altitude between the two areas. Therefore, the current study focused on the effect of weather and seasonal variations on the phenology of the African maize stalk borer, *B. fusca* in Southern Ethiopia.

5.2. MATERIALS AND METHODS

5.2.1. Description of the study areas

Phenology of *B. fusca* was studied during 2015 and 2016 at Hawassa Zuria and Wolaita Sodo. Hawassa Zuria and Wolaita Sodo are found in Sidama and Wolaita zone, respectively, in South Nation Nationalities and People Region (SNNPR), Ethiopia. Hawassa Zuria is located at 7°3' N and 38°28' E with an elevation of 1697 MASL. It receives 800- and 1300-mm rainfall per year. Annual average minimum and the maximum air temperature is 18.5°C and 25°C, respectively. Wolaita Sodo is located at 6°43'N 37°51'E and altitude of 1850 MASL. It receives an annual rainfall of 1400 to 1800 mm per year and minimum and a maximum air temperature of 14.7°C to 25.4°C, respectively. Weather data (rainfall and temperature) of the study areas during study periods were obtained from the Ethiopian metrological agency.

5.2.2. The flight period of *B. fusca*

Delta traps white Pherobank, sticky and selectivelures impregnated with 5mg Z11-14: Ac+1mg E11-14+Ac+1mg Z9-14: Ac per dispenser were obtained from Molenvliet 1c.3961MT Wijk bij Duurstede, Netherlands and used to collect the moths. In both years, from early January until end December of 2015 and 2016, two traps were placed at opposite border of each field. Each trap was mounted on a wooden post at a height of 1.5 m above the ground. Each trap was visited weekly and adult *B. fusca* moths were recorded. Sticky floors and lures were placed in each trap and changed monthly.

5.2.3. Oviposition, larvae, and pupae of *B. fusca*

In both years and fields, maize variety BH540 was sown on 10 m x 5 m plot in the main rainy season (Ma-September). To make the plant available for oviposition staggered plantings were

made biweekly from May 7 to September, 20 in 2015 and from March, 26 to September, 27 in 2016. The space between rows and plants were 0.70 and 0.30 m, respectively. In each plot 238 plants were planted. All plots received optimal agronomic practices like fertilization, hoeing, weeding, etc. but didn't apply any pesticide. Starting one week after crop emergence plots were inspected for eggs weekly to determine the onset of oviposition. Once the stalk borer infestation symptom/signs were observed ten plants per plot were randomly taken and split every week and the number of larvae and pupae were recorded. The number of adult *B. fusca* moths, eggs, larvae, and pupae per week were summarized for each year and location using figures.

5.3. RESULTS

5.3.1. Moth flight period

Flight periods and duration of *B. fusca* moths from diapause larvae varied between seasons and areas (Fig. 5.1). In both years, three *B. fusca* moth flight periods were observed in Southern Ethiopia. In Hawassa Zuria, the first moths flight period (from the diapause larvae) was between mid-April and June in 2015; between the end of March and May in 2016. In 2015, adult moths flight peaked in the end of May, mid-August, and early October. Whereas in 2016, peak adult flight was observed in early May, end of July, and mid-September (Fig 5. 1A). In Wolaita Sodo, first moth's flight was observed between early May and July in 2015 and between early of April and end of June in 2016 (Fig. 5.1B). The adult flight peaked in the end of June, mid-August and October in 2015 and in early- June, mid-August, and end of October in 2016. Flights of the moth started at least one - month earlier in 2016 than in 2015.

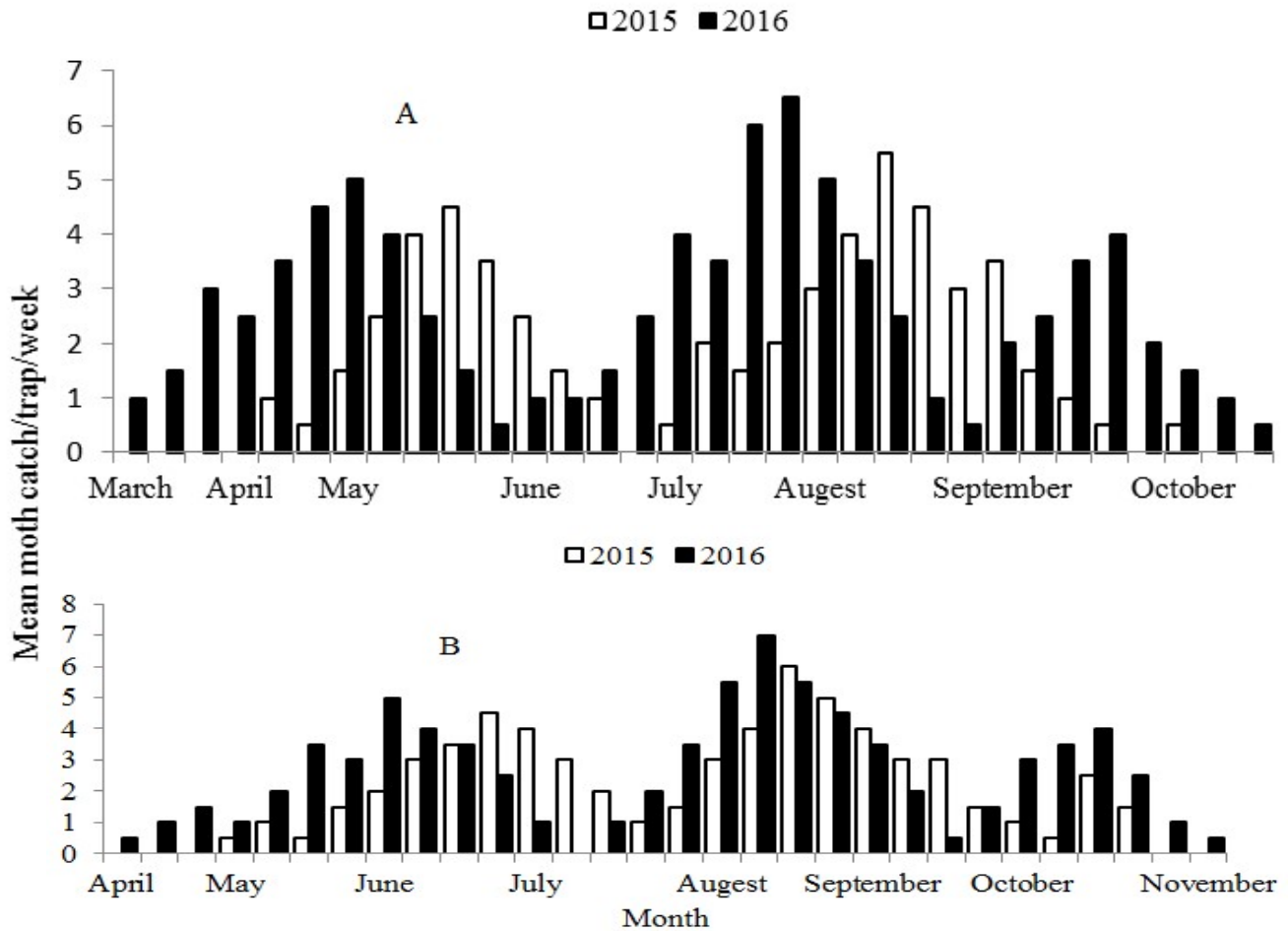


Figure 5.1. Flight period and duration of *B. fusca* in Hawassa (A) and Wolaita Sodo (B)

5.3.2. Oviposition of *B. fusca*

Three generations of the maize stalk borer, *B. fusca* per year were observed in the study areas. Oviposition period and the number of eggs laid by *B. fusca* varied between seasons, areas (Fig. 5.2 and 5.3). In Hawassa Zuria, the first - generation eggs were laid from mid-May until the end of June in 2015; from mid-April until end of May in 2016 (Fig. 5.2A). Peak oviposition of the first generation was in early June and mid of May in 2015 and 2016, respectively. The onset of second-generation eggs was in the early August and end of June in 2015 and 2016, respectively. In Wolaita Sodo, the first - generation eggs were laid from end of May until the end of June in 2015; from early May until mid-June in 2016 (Fig. 5. 2B).

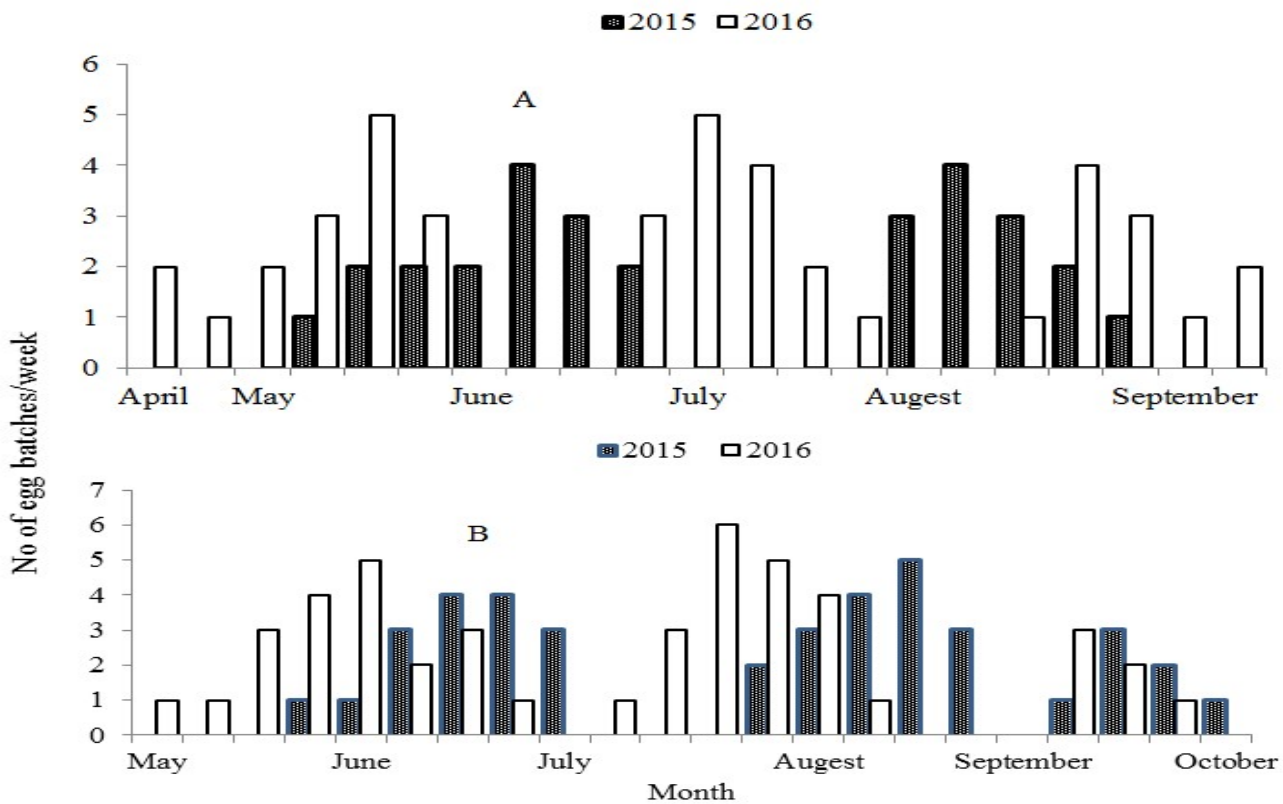


Figure 5.2. Number of *B. fusca* egg batches per week in Hawassa (A) and Wolaita Sodo (B)

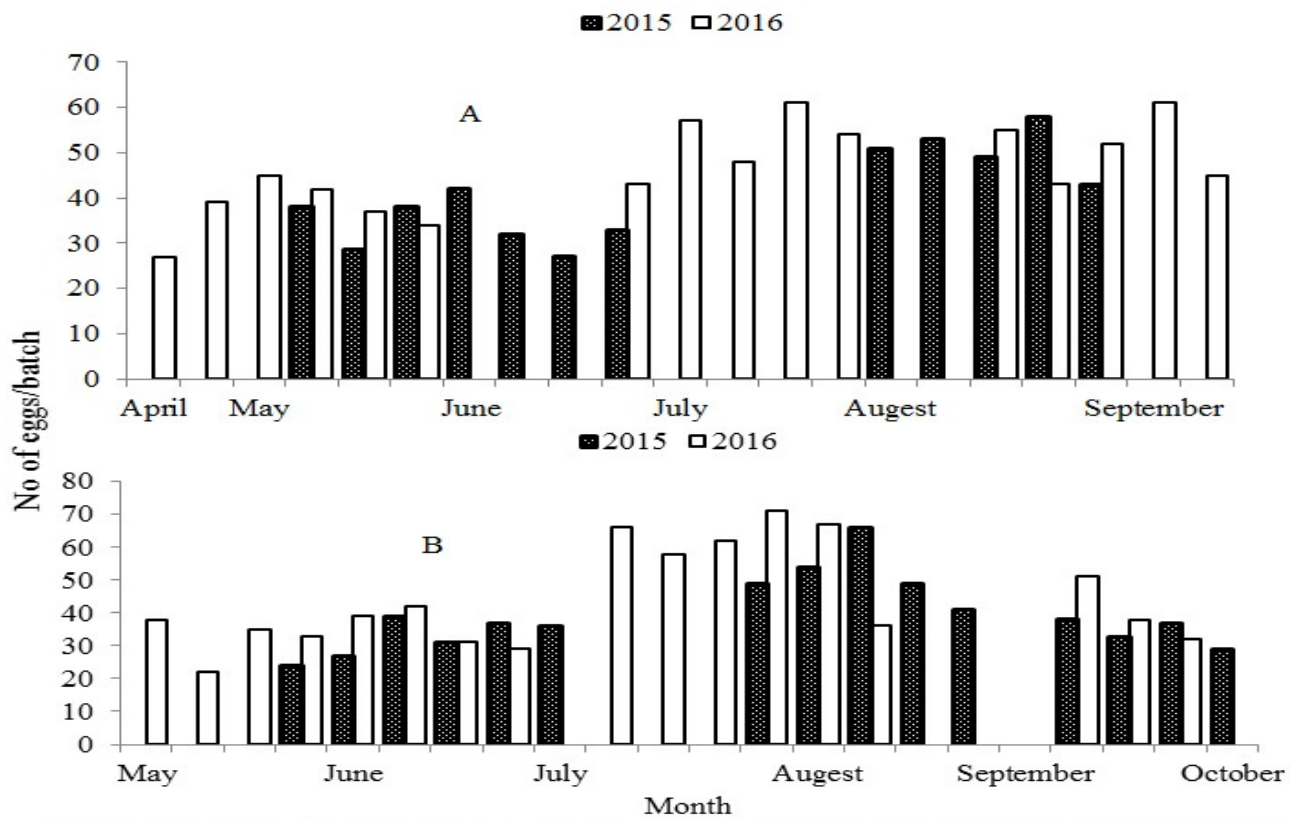


Figure 5.3. Number of *B. fusca* eggs per batch in Hawassa (A) and Wolaita Sodo (B)

Peak oviposition of the first-generation was in mid - June and early of June in 2015 and 2016, respectively. In both areas, a higher number of egg batches were recorded in 2016 compared to 2015. Higher number of egg batches per week and eggs per batch were recorded in the second generation than both first and third generations (Fig. 5.2 and 5.3).

5.3.3. Occurrence, population density of *B. fusca* larvae and pupae

Busseola fusca larvae were found throughout maize cropping seasons in southern Ethiopia (Fig. 5.4 and 5.5). In Hawassa Zuria, first-generation larvae were observed starting at the end of May and peaked in early July in 2015 (5.4A). Whereas, in 2016 the first - generation larvae were observed in early May and peaked in early June. Pupation of first-generation larvae started at mid-June, early June and peaked in early August and end of July in 2015 and 2016, respectively (5.4 A and 5.4B). In Wolaita Sodo, the first - generation larvae observed in early June and peaked in early July in 2015 (Fig. 5.5A). Whereas, in 2016 the first - generation larvae were observed at the end of May and peaked in the end of June (5.5B). Pupation from the first generation started in early July, early July and peaked in early August and mid- July in 2015 and 2016, respectively. In both areas, larvae and pupae population of *B. fusca* was higher in 2016 as compared with the 2015 cropping season. Population density of second-generation larvae and pupae was higher than both the first and third generations.

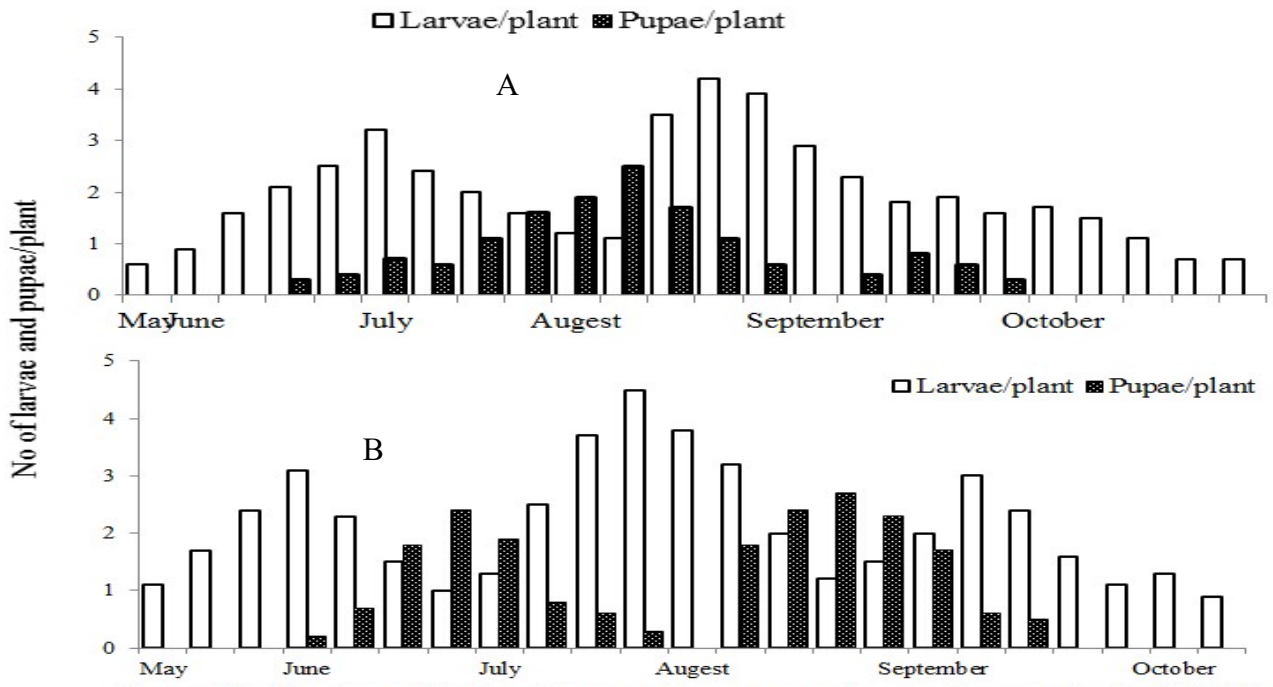


Figure 5.4. Number of *B. fusca* larvae and pupae per plant in Hawassa during 2015(A) and 2016(B)

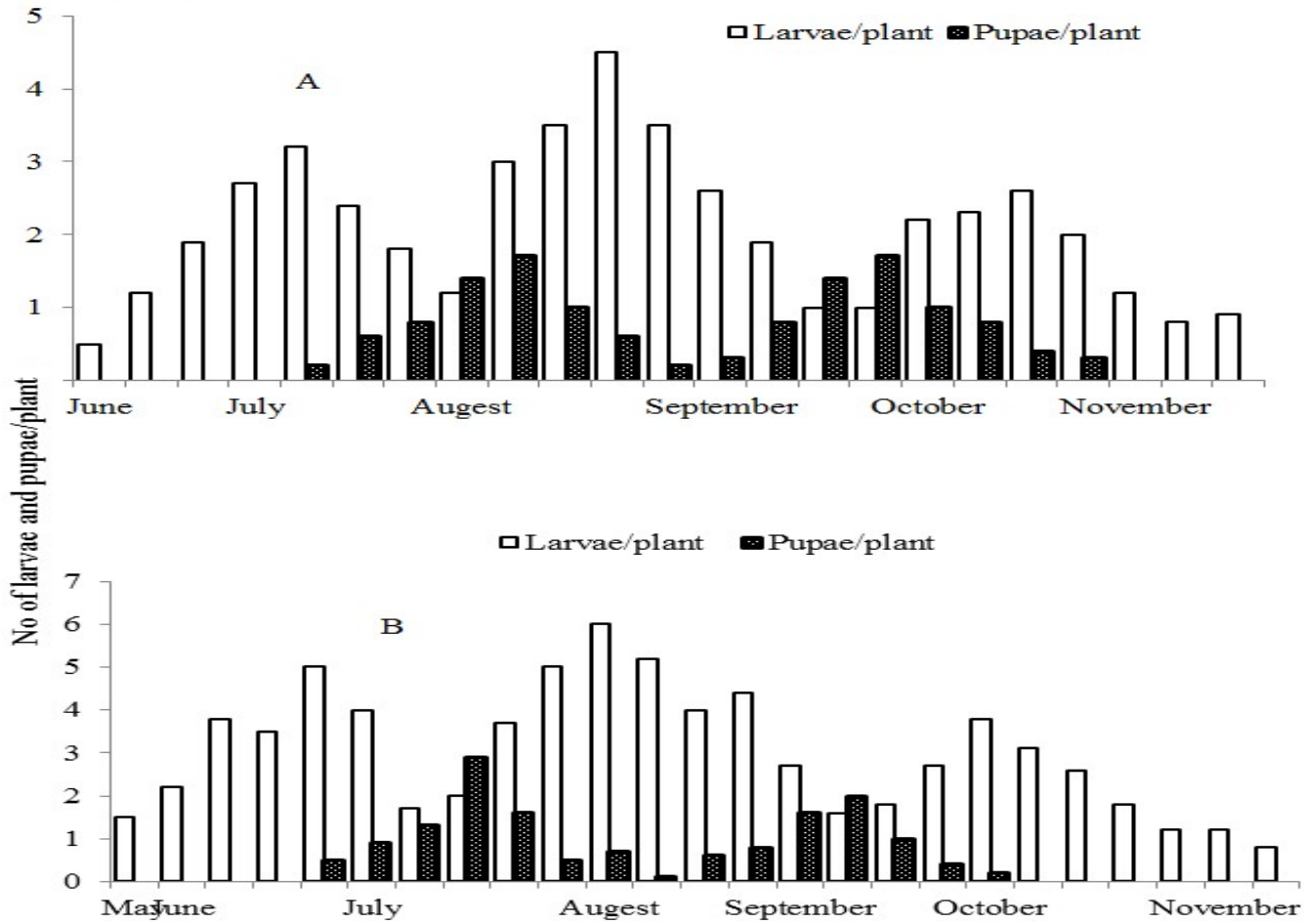


Figure 5.5. Number of *B. fusca* larvae and pupae per plant in Wolaita Sodo during 2015(A) and 2016(B)

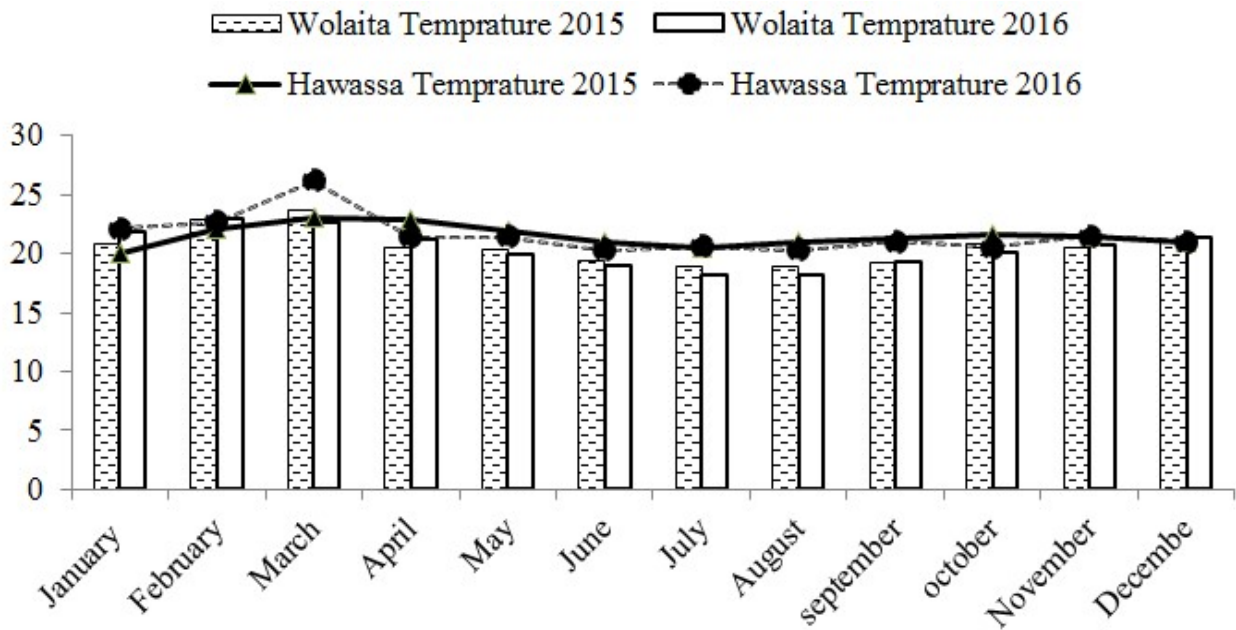


Figure 5.6. Mean monthly temperature ($^{\circ}\text{C}$) of the study areas in 2015 and 2016

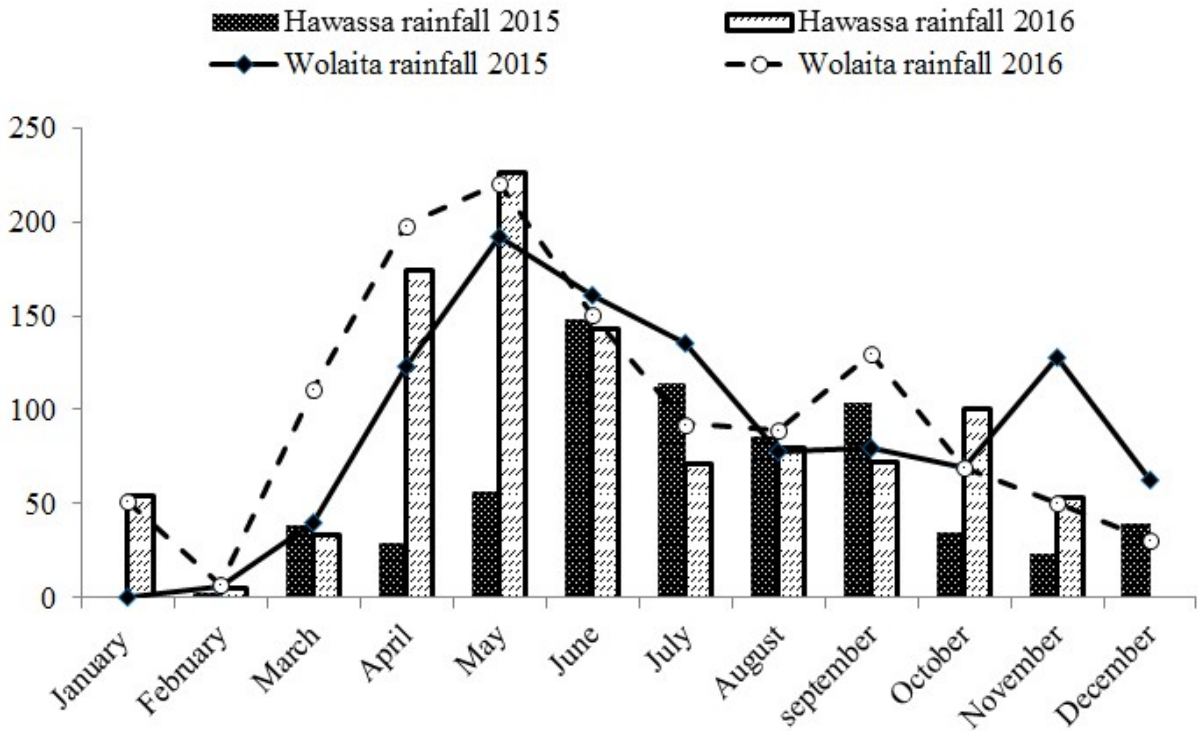


Figure 5.7. Mean monthly rainfall (mm) of the study areas in 2015 and 2016

5.4. DISCUSSION

There was a marked variation in the time commencement and duration of moth's flight, egg oviposition, larvae and pupae time occurrence and a population density of *B. fusca* between seasons and areas. *Busseola fusca* had three flight periods in southern Ethiopia. In Hawassa Zuria the first moth flight, which emerged from diapause larvae, started at mid-April and end of March, whereas in Wolaita Sodo moth flight activity started at early May and April in 2015 and 2016, respectively. The study showed that patterns and periods of *B. fusca* moth flight of the different generations are clear and predictable and can be used in adjusting planting time of maize or making management decisions. These results disagree with Van Rensburg and Bate (1987) who indicated that no clear separation of moth flight peaks was possible in small-farming areas.

In both areas, higher number and earlier flight moths were observed in 2016 as compared with 2015. Mean monthly rainfall also was higher and longer in 2016 than in 2015. This result is in line with Van Rensburg and Van Rensburg (1987) and Ebenebe et al. (2000) who stated that low rainfall, results in a reduction of seasonal abundance of *B. fusca* moths, while the daily flight activity and survival of moths are enhanced by cool and humid conditions (Van Rensburg and Van Rensburg, 1987). Although the onset of diapause could be favored by the aging of maize plants, there was evidence that the rainfall gradient could contribute indirectly to geographic variation in population dynamics, and in the number of generations produced (USUA, 1973). The first flight period of adult *B. fusca* moth in Hawassa Zuria was at least two weeks earlier than Wolaita Sodo. Higher average temperature per month was recorded in Hawassa Zuria than Wolaita Sodo. This result is in line with Glatz et al. (2017) who reported that that first generation moth flight commences approximately 2-3 weeks later in the cooler area. This result agrees with

Harris (1962), the temperature is known to influence the elapsed time between moth flights at different localities.

The current study showed that the onset and duration of egg oviposition by *B. fusca* varied between seasons and areas. In Hawassa Zuria, first egg oviposition was observed between mid - May and end of June in 2015; between end of April and May in 2016. Oviposition of the second-generation started in early August and end of June in 2015 and 2016, respectively. In Wolaita Sodo, first oviposition started at the end of May and early of May 2015 and 2016, respectively. Gebre-Amlak (1989) reported that in Hawassa Zuria the first generation eggs oviposition of *B. fusca* was recorded from early April to May and onset of oviposition by the second generation at the end of June. In the current study, three generations of *B. fusca* per growing season were observed in southern Ethiopia. This result is in line with Gebre-Amlak (1989) who observed three generations per year in Hawassa, Ethiopia.

In both years, eggs incubation and larval development time were at least one week shorter in Hawassa areas as compared to Wolaita Sodo. This could be in part explained by the relatively higher average temperature in Hawassa compared to Wolaita Sodo. In laboratory condition, development time for *B. fusca* eggs incubation and instars were inversely related with temperature (Glatz et al., 2017). Total development of *B. fusca* took 152.6 days at 15 °C and 52.6 days at 26°C. Development rate decreases as the temperature decreases or deviates from the optimum (Begon et al., 2006). Rising temperatures may lead to earlier infestations by pests (Sharma, 2010).

There was variation in population density of larvae and pupae of *B. fusca* under different environmental conditions. In both years, density of larvae and pupae were higher in Wolaita

Sodo than in Hawassa area. During this study, higher and long rain season was recorded in Wolaita Sodo than in Hawassa Zuria. This result has a close agreement with Dejen et al. (2014) who found that the distribution of *B. fusca* had a positive relationship with rainfall. Borer populations are strongly influenced by the amount and distribution of rainfall (Ndemah et al., 2001). Temperature, precipitation, humidity, wind speed, and other climatic parameters can directly influence pests by affecting their rate of development, reproduction, distribution, migration, and adaptation (Porter et al., 1991).

5.5. SUMMARY AND CONCLUSION

There was a marked variation in the time commencement and duration of adult *B. fusca* flight, egg oviposition, larvae and pupae population between seasons and study areas. Three flight periods and generations of *B. fusca* were recorded in southern Ethiopia. The first flight period of adult *B. fusca* moth in Hawassa Zuria was observed at least two weeks earlier than in Wolaita Sodo. Similarly, in both years eggs incubation time was shorter in Hawassa Zuria areas as compared to Wolaita Sodo. *Busseola fusca* larvae also had at least one week shorter development time in Hawassa Zuria than in Wolaita Sodo. In both areas, larvae and pupae population of *B. fusca* was higher in 2016 as compared with the 2015 cropping season. Population density of *B. fusca* larvae and pupae was higher in Wolaita Sodo than Hawassa Zuria. In both years and areas, the flight moths of second generation were higher than the first and third generations. In Hawassa Zuria, first egg oviposition was recorded between mid-May and end of June in 2015 and between the end of April and end of May during 2016. While in Wolaita Sodo first oviposition from diapause state was started at the end of May and early of May 2015 and 2016, respectively. Planting of maize at the beginning of April and May in Hawassa Zuria and Wolaita Sodo, respectively may encounter infestation by the first generation, but could be no longer

suitable for oviposition and consumption by second-generation *B. fusca* larvae. The second generation, therefore, could be regarded as slight economic importance on early planted maize in both areas.

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6. POPULATION DENSITY AND TERMINATION OF DIAPAUSE OF AFRICAN MAIZE STALK BORER, *Busseola fusca* (Fuller) LARVAE IN SOUTHERN ETHIOPIA

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ABSTRACT

Because of its importance in the annual cycle, the state of diapause of Busseola fusca larvae in maize stalks was studied during 2015/16 and 2016/17. The study was carried out in three districts in Southern Ethiopia namely Halaba, Hawassa Zuria, and Mareko where maize is the most important crop and B. fusca is the major pest. The study involved 12 small scale maize farms and laboratory experiments. Diapause B. fusca larvae were found in maize stalks during off- seasons in southern Ethiopia. Population density, moth flight period, mortality and time of pupation of diapause B. fusca larvae varied between areas and seasons. Highest number of diapause B. fusca larvae in dry maize stalks was recorded in Halaba followed by Mareko. Pupation of diapause B. fusca larvae was earlier in Hawassa Zuria than in both Mareko and Halaba. Likewise, the moth flight period in Hawassa Zuria was at least one month earlier than in both Halaba and Mareko. In 2016 moth flight started in the beginning of March; end of March and mid of April in Hawassa Zuria, Mareko and Halaba, respectively. In 2017 also flying moths were observed in mid of March in Hawassa and the beginning and mid of April in Mareko and Halaba, respectively. Population density of diapause larvae was higher at the beginning of sampling and as collection date advanced the number of diapause larvae decreased and pupation increased. In both years and all areas, more than 50% pupation of B. fusca occurred in April and 80 to 100% pupation occurred in May. Water did not show significant effect on time of diapause termination but affected the weight and survival rate of diapaused B. fusca larvae. Diapause B. fusca larvae kept in wet condition were heavier than those kept in dry condition. The emerged adult moths from diapause larvae lost about 33 to 34 % and 56 to 59 % of initial body mass of diapause larvae when kept under wet and dry conditions, respectively.

Keywords: Diapause, flight period, weight loss, maize,

6.1. INTRODUCTION

African maize stalk borer, *Busseola fusca* is a major insect pest on sorghum (Van den Berg et al., 1991) and maize (Kfir et al., 2002) in Africa. Through the timely onset and termination of diapause, insects are able to synchronize the time of growth and breeding with the favorable season of the year (Sinzo, 1961). Diapause larvae of *B. fusca* larvae survive in stalks and stubbles after maturity (Harris, 1962; Gebre-Amlak, 1989). Diapause not only allows insects to

survive in an unfavourable environment, but also synchronizes reproduction and metagenesis with desirable seasons, thus ensuring effective resource utilization (Taumber et al., 1986; Danks, 1987). USUA (1973) has suggested that decrease in food quality (decrease in protein and moisture and increase in carbohydrate content) of the late instar larvae is the main factor inducing diapause in *B. fusca*.

Although diapause responses in insects may be genetically controlled (Beck, 1989), environmental conditions play a precise and critical role in determining whether, and to what degree, diapause will develop in a given population (Masaki, 1980; Tauber et al., 1986). The main factor enabling diapause *B. fusca* larvae to survive adverse condition appears to be efficient water conservation (Kfir, 1991). Continuous moisture during the long rainy season has a significant role in the termination of diapause of *B. fusca* (Adamu et al., 2015). Walker (1983) reported that 10 mm of rainfall per day could terminate the diapause of *B. fusca*. On the other hand, Kaufman (1983) stated that incidental contact with water could not cause for termination of the diapause. Diapause larvae of *B. fusca* have two distinct periods; the diapause maintenance and the post-diapause periods (Gebre-Amlak, 1989). Water appeared to be essential for successful and timely pupation of the larvae during the post-diapause period. In Ethiopia, cumulative rainfall of 80 mm (from 1 March) is necessary for induction of pupation (Gebre-Amlak, 1989). On the other hand, Harsimran et al. (2017) indicated that provision of water is necessary only after the completion of the diapause development.

Kfir (1991) reported that, during diapause *B. fusca* and *C. partellus* molt up to seven and six and the resulting moths retained only 30% and 20% of the body mass, respectively. Weight reductions have a dramatic effect on the fecundity of first - generation moths. Female moths that emerge from non-diapause larvae were heavier and their ovaries contained more eggs and

oocytes than moths that emerged from diapause larvae (Kfir, 1991). The size of the pest population at the beginning of each year depends on the number of diapause larvae that survive long enough to emerge as adults during the season. The environmental factors that change largely through a year are monthly precipitation, temperature, and humidity. Thus, this study focused on population density and termination of diapause of the African maize stalk borer, *B. fusca* larvae in southern Ethiopia

6.2. MATERIALS AND METHODS

6.2.1. Study areas

This study was conducted in three major maize producing districts (Halaba, Hawassa Zuria and Mareko) in Southern Nations, Nationalities, and Peoples' Region (SNNPR) during the off-seasons of 2015/16 and 2016/17. Halaba receives the minimum and maximum rainfall of 700 and 1100 mm per year, respectively. The annual average minimum and the maximum temperature is 17°C and 20°C, respectively. Hawassa receives the minimum and maximum rainfall of 800 and 1300 mm per year and annual average minimum and the maximum temperature is 18.5°C and 25°C, respectively. On the other hand, mareko receives the minimum and maximum rainfall of 800 and 1600 mm per year and annual average minimum and the maximum temperature is 18.5°C and 22°C, respectively. From each districts two localities, and from each locality two small sized (≤ 1 ha) farms were selected. The farms were not treated with insecticides against insect pests and at least 5 km apart.

6.2.2. Data collection

6.2.2.1. Population density and termination of diapause larvae

In mid-November 2015 and 2016, about 2000 BH 540 maize stalks, harboring diapausing larvae of *B. fusca* were cut from the ground and stacked for at least seven months in twelve farms. At a monthly interval, starting from the end of November to the end of May 100 stalks was randomly sampled from each stack and dissected. Data on the number of alive, dead or pupated, *B. fusca* larvae were recorded.

6.2.2.2. Adult moth flight period

Delta trap white Pherobank, sticky and selective lures were obtained from obtained from Molenvliet 1c.3961MT Wijk bij Duurstede, Netherlands. From 1st January to the end of June a single trap was placed in each farm. The trap was mounted on an upright pole 1.5 m above the ground. Sticky floors and lures were replaced every month. The traps were visited weekly and the number of adult moths were recorded and removed.

6.2.2.3. Termination of diapauses *B. fusca* larvae

In both years, from November to May about 20 -30 healthy diapausing larvae, having similar size were collected from each farm and brought to Hawassa University College of Agriculture, Plant Protection Laboratory. Dried maize stalk having 15 cm length and 2.5-3.0 cm diameter were prepared. In each cut stem, a 12 cm depth hole was made on one side of the node using a cork borer. Then a single larva was introduced into the stalk piece and the hole was closed with pieces of maize stalk. Diapause larvae with the cut stems were packed in a bag and kept until June. Then the numbers of *B. fusca* pupae were recorded at 15-day intervals.

6.2.2.4. Effect of artificial wetting on survival, weight, and termination of diapauses larvae

At the end of December 2015, about 200 diapause larvae were collected from each district and brought to the laboratory. In the first week of January 2016, 160 healthy larvae were taken from each district and weighed. The 160 larvae were grouped in to two groups of 80 larvae. Then each larva was introduced into stalk pieces as described above. Stalks were labeled with the sample site, date, and weight. From preliminary studies, 20 ml of water adequately wetted 10 pieces of maize stalks. Therefore 80 diapause larvae within pieces of maize stalks from each site were wetted with 160 ml distilled water at five-day intervals using a hypodermic syringe for five months (until May). The remaining groups of 80 diapause larvae from each site were kept in dry stalks. At 15 days intervals, the body mass of all larvae, number of pupae and pupal case, alive and dead larvae were recorded and stalks were changed. Pupae and adult moths upon emergence were weighed.

6.2.3. Data analysis

Data on percent of pupation in study areas were subjected to statistical analysis. Analyses of variance between districts were carried out using SAS, 2004 software. The level of significance was set at $p = 0.05$ and the means were separated by student Newman-Keuls test. The effect of artificial wetting on pupation and mortality of *B. fusca* diapauses larvae was analyzed using t-test.

6.3. RESULTS

6.3.1. Population density, mortality and termination of *B. fusca* diapause larvae

Population density and number of dead diapause *B. fusca* larvae in the field varied between areas (Fig. 6.1). In both years, at the beginning of sampling (30 November), number of diapauses larvae was highest at Halaba and lowest at Hawassa Zuria (Fig. 6.1). Population density of diapause larvae was higher at the beginning of the study and declined with time because of mortality. Mortality of diapause larvae was lower (4 to 6 per 100 stalks) at the beginning of the samplings (from November to January), but sharply increased thereafter (Fig. 6.1). Termination period of *B. fusca* diapause larvae in the field varied between areas and seasons (Fig. 6.1). In both years, diapause *B. fusca* larvae from Hawassa started to pupate in early February whereas the diapause larvae from Halaba and Mareko started to pupate in March. Highest (54 to 80% and 51 to 72 %) terminated *B. fusca* diapauses larvae were observed in April during 2016 and 2017, respectively.

6.3.2. The flight period of adult *B. fusca* from diapause state

Flight period and population density of adult moths from diapause state varied between seasons (Fig. 6.2). The first moth flight was observed at the beginning and mid of April in Halaba; at mid and early of March in Hawassa and end of March and early April in Mareko in 2016 and 2017, respectively (Fig. 6.2). In both years, from January to March in Halaba, January to February in both Hawassa and Mareko adults of *B. fusca* were not recorded. In both years, at Hawassa and Mareko the moth flight peaked in April, whereas in Halaba the peak was in May (Fig. 6.2). In 2016, the peak moth flight observed in mid-May in Halaba and end of April in both Hawassa and Mareko. In 2017, the peak moth flight period was observed first May; mid-April and end of April in Halaba, Hawassa and Mareko, respectively.

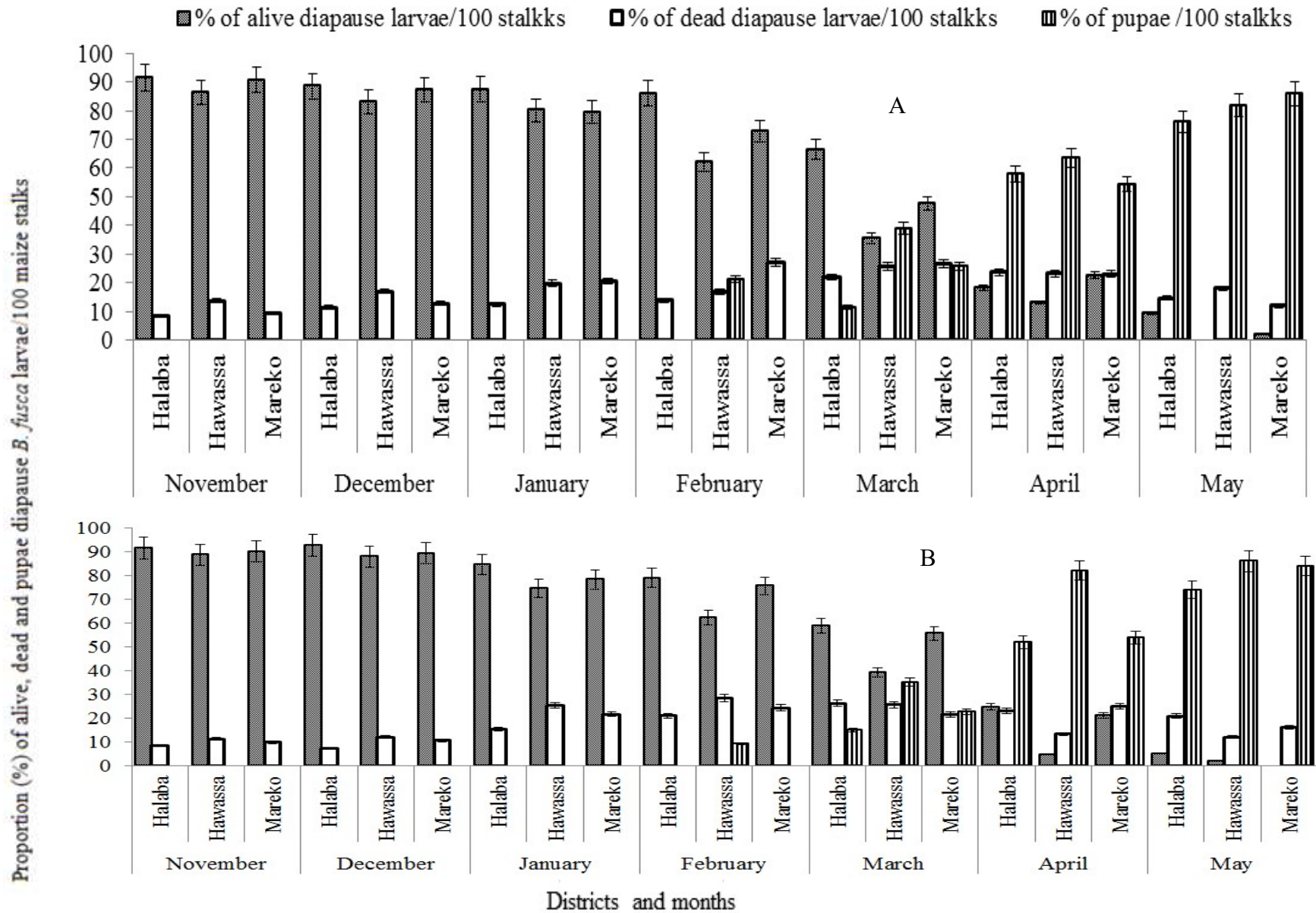


Figure 6.1. Proportion (%) of alive, dead and pupae diapause *B. fusca* larvae per 100 maize stalks in 2015/16 (A) and 2016/17 (B)

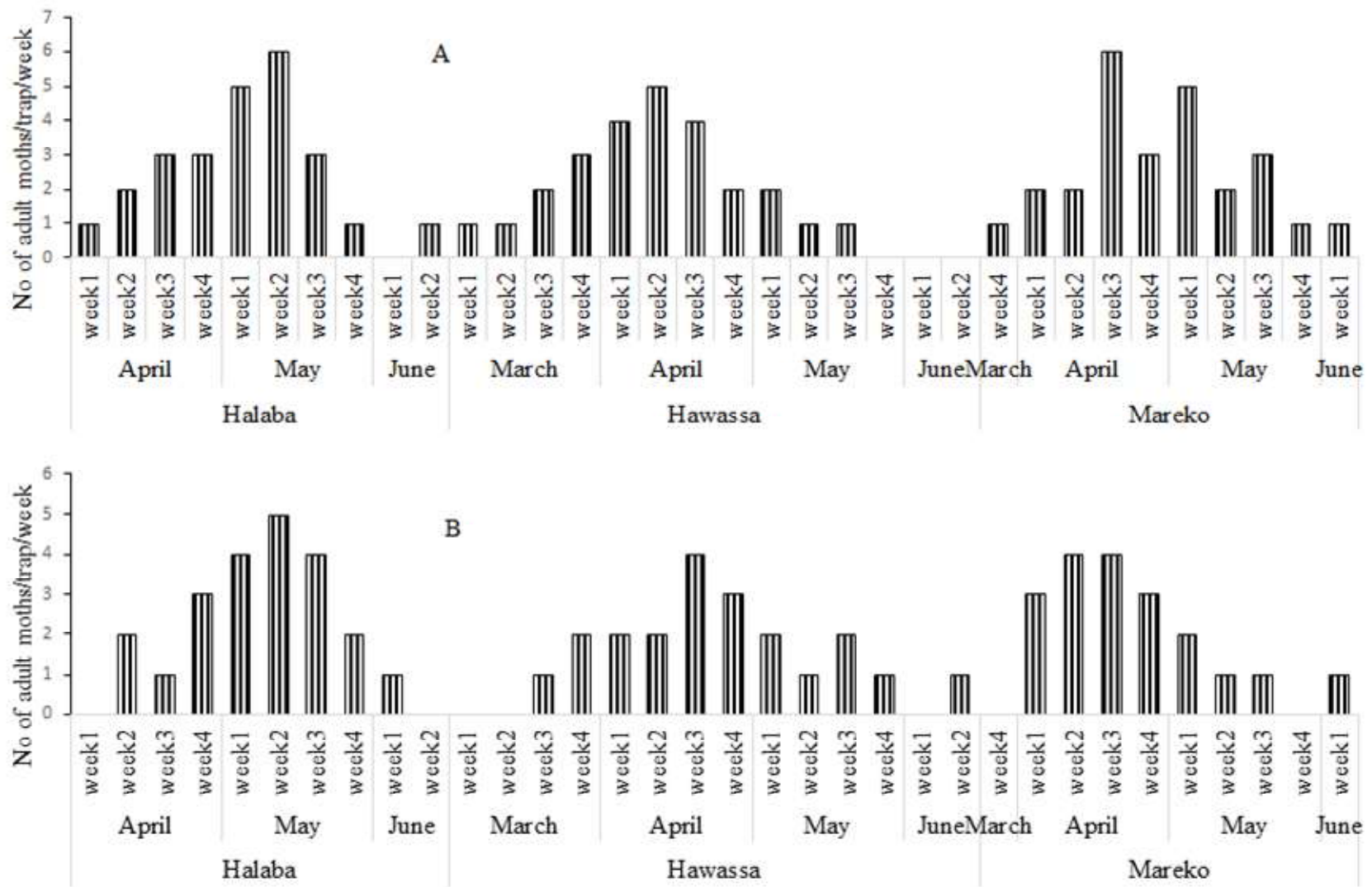


Figure 6.2. Number of adult *B. fusca* moths per trap per week in Halaba, Hawassa and Mareko during 2016(A) and 2017(B).

6.3.3. Termination of diapause *B. fusca* larvae

The time to termination of diapause in *B. fusca* larvae as indicated by pupation significantly varied between study areas and seasons (Table 6.1 and 6.2). In both years, diapause *B. fusca* larvae collected from Hawassa pupated earlier followed by Mareko compared to Halaba. Diapause larvae from Hawassa and Mareko started to pupate in March, and those from Halaba in April. In both years, diapause larvae those collected in the end of November and kept in the laboratory, only 0 to 23 % and 0 to 18% of them were pupated in the end of March, 2016 and 2017, respectively (Table 6.1 and 6.2), whereas when collection was made in end of February, 25 to 45% and 5 to 33% of them were pupated in the end of March, 2016 and 2017, respectively. Generally, larvae collected late from the field pupated earlier than larvae collected early.

Table 6. 1. Percent pupation of diapauses *B. fusca* larvae collected between November and May in 2015/16 under laboratory

District	Collection		Pupation (%)							
	date	March		April		May		June		
		15	30	15	30	15	30	15	30	
Halaba	November	0.0b	0.0c	11.7c	28.4b	30.0c	42.0b	68.7a	73.4a	
Hawassa	30	15.5a	23.3a	43.4a	46.7a	58.3a	63.3a	66.7a	75.0a	
Mareko		0.0b	6.7b	23.3b	35.0b	41.7b	56.7a	61.7a	66.5b	
Halaba	December	0.0c	0.0b	23.4c	30.0c	36.7b	48.4b	71.7a	72.4b	
Hawassa	30	21.7a	35.0a	45.0a	56.7a	60.0a	66.7a	76.7a	80.0a	
Mareko		5.0b	33.0a	35.0b	36.7b	45.0b	56.7b	73.3a	78.0a	
Halaba	January	1.7b	10.0b	34.2b	36.7c	43.4c	51.6c	61.7b	76.7b	
Hawassa	30	25.0a	36.7a	46.7a	65.0a	66.7a	76.7a	76.7a	85.0a	
Mareko		23.4a	36.7a	36.7b	48.4b	53.3b	63.7b	65.0b	76.7b	
Halaba	February	16.7c	25.0b	33.3b	36.7b	42.4b	60.0b	65.7b	80.0a	
Hawassa	30	40.0a	45.3a	48.7a	60.2a	65.0a	73.3a	81.7a	83.4a	
Mareko		25.0b	40.0a	40.0ab	53.4a	58.3a	66.7b	71.7b	77.5a	
Halaba	March			35.0c	50.0b	55.0b	66.7b	80.0b	83.4a	
Hawassa	30			56.7a	73.3a	78.3a	81.7a	87.5a	87.5a	
Mareko				46.7b	58.3b	60.7b	65.0b	73.3c	80.0a	
Halaba	April					66.7b	71.7b	71.7b	86.7a	
Hawassa	30					78.4a	83.7a	83.7a	91.6a	
Mareko						60.4b	70.0b	80.0a	85.0a	
Halaba	May							75.0b	83.4b	
Hawassa	30							88.4a	88.4a	
Mareko								76.7b	88.4a	

Means within a column followed by the same letter(s) are not significantly different at $P < 0.05$ using Student Newman-Keuls test

Table 6.2. Percent pupation of diapauses *B. fusca* larvae collected between November and May in 2016/17 under laboratory

District	Collection date	Observation months (dates) and percent(%) of pupation							
		March		April		May		June	
		15	30	15	30	15	30	15	30
Halaba	November	0.0b	0.0c	10.3b	20.0b	35.0b	40.0b	55.0c	77.5b
Hawassa	30	8.3a	18.3a	28.3a	38.3a	45.0a	58.3a	61.7b	85.0a
Mareko		1.7b	13.3b	23.4a	33.3a	46.7a	53.3a	70.0a	76.7b
Halaba	December	0.0b	0.0c	13.3c	21.7b	40.0b	45.0c	54.7b	77.7a
Hawassa	30	13.9a	20.0a	34.0a	45.0a	53.0a	73.3a	76.7a	80.8a
Mareko		3.3b	13.4b	25.0b	41.7a	48.3a	56.7b	71.7a	76.7a
Halaba	January	0.0c	0.0b	18.3b	36.7b	46.7b	56.7b	76.0a	85.9a
Hawassa	30	11.7a	26.7a	36.7a	53.3a	60.0a	73.3a	76.7a	81.0a
Mareko		6.7b	20.4a	33.0a	43.3ab	50.0b	66.7ab	73.3a	78.0a
Halaba	February	0.0c	5.0c	23.3b	38.3b	48.7b	58.3b	75.0a	80.0a
Hawassa	30	20.0a	33.3a	38.3a	53.3a	63.3a	73.3a	71.8a	86.7a
Mareko		6.7b	25.0b	36.7a	50.0a	53.3b	63.3b	68.4a	83.0a
Halaba	March			28.3c	43.3b	48.3b	58.3b	73.3a	83.4a
Hawassa	30			45.0a	58.3a	66.7a	71.7a	78.3a	86.4a
Mareko				38.3b	53.3a	61.7a	67.8a	71.7a	78.3a
Halaba	April					50.0b	65.0b	70.0b	80.0b
Hawassa	30					65.0a	73.3a	80.0a	90.0a
Mareko						61.7a	66.7b	73.0b	86.7ab
Halaba	May							86.7a	86.7a
Hawassa	30							83.3a	88.4a
Mareko								80.0a	90.0a

Means within a column followed by the same letter(s) are not significantly different at $P < 0.05$ using Student Newman-Keuls test

6.3.4. Effect of artificial wetting on the weight of diapause larvae

Busseola fusca larvae, pupae and adults from the wet condition were heavier than those from the dry condition (Table 6.3). Diapause larvae kept in dry condition for five months lost 33 to 40 % of their initial body weight before pupation but they lost only 14 to 16% when kept in wet condition. Similarly, emerged pupae from diapause larvae lost about 44 to 49 % and 25 to 27% of the initial body weight of diapause larvae when kept in dry and wet conditions, respectively. The resulting adult moths of *B. fusca* retained about 66 to 68% and 41 to 44 % of the initial body weight at the start of diapause when they were kept in wet and dry conditions, respectively.

Table 6.3. Weight loss of diapause *B. fusca* larvae, pupae and adult stages under wet and dry conditions

Site	Stage	Weight Dry condition (mg)	Weight loss (%)	Weight Wet condition (mg)	Weight loss (%)
Halaba	Larva at collection	319.5±32.9	-	306.8±24.5	-
	Larvae before pupation	212.8±21.5	33.39	262.6±23.9	14.40
	Pupae	184.3±17.6	44.18	229.9±18.4	25.06
	Adult	141.4±15.8	58.20	206.3±14.3	32.77
Hawassa					
Zuria	Larva at collection	308.9±31.4	-	302.5±25.6	-
	Larvae before pupation	184.0±18.6	40.81	251.6±21.3	16.83
	Pupae	156.8±15.0	49.70	219.5±18.0	27.12
	Adult	125.4±11.3	59.96	197.7±12.4	34.24
Mareko					
Mareko	Larva at collection	305.3±29.2	-	308.6±23.7	-
	Larvae before pupation	193.6±20.6	36.50	263.5±21.9	14.73
	Pupae	164.2±16.7	46.11	230.6±17.8	25.49
	Adult	131.9±13.7	56.66	206.9±15.9	33.23

6.3.5. Effect of artificial wetting on termination and survival of diapause of *B. fusca* larvae

There were no marked differences in percent and time of pupation between diapaused *B. fusca* larva kept either in wet or in dry conditions (Table 6.4). *Busseola fusca* larvae under diapause collected from Hawassa and Mareko and kept in both conditions started to pupate by mid and end of March, respectively. Similarly those larvae collected from Halaba started to pupate in mid-April. It was also observed that diapause *B. fusca* larvae kept in dry conditions survived more than those kept in wet conditions (Table 6.4). Mortality of larvae increased in later periods in both conditions.

Table 6.4. The effect of artificial wetting on pupation and mortality of diapause *B. fusca* larvae

Districts	Conditions	Pupation (%)						Mortality (%)				
		March		April		May		January	February	March	April	May
Halaba		15	30	15	30	15	30	30	30	30	30	30
	Wet	-	-	21.2±6.8	34.0±8.5	44.9±7.0	58.3±6.8	8.8±1.8	15.3±2	20.0±1	26.4±2	28.2±6
	Dry	-	-	16.7±4.2	31.1±8.1	45.3±7.3	52.4±7.1	7.5±2.6	8.8±1	13.7±2	20.0±2	23.7±4
	t-value P-value	-	-	1.95 0.07	0.24 0.81	-0.045 0.96	0.48 0.63	1.42 0.16	2.45 0.03	2.41 0.03	0.49 0.02	2.02 0.11
Hawassa	Wet	0.54±0.2	8.3±1.6	19.4±2	38.6±8.1	50.4±6.7	61.4±5.5	9.8±2	13.4±1.7a	16.7±1.5	22.7±1.6	25.7±3
	Dry	2.6±0.5	16.0±2.3	22.3±2	33.2±6.9	48.3±5.9	57.2±5.3	6.7±2	6.5±1.5b	12.4±1.9	16.7±2.3	18.6±2
	t-value P-value	4.81 0.00	3.89 0.01	1.10 0.31	0.49 0.63	0.23 0.81	0.54 0.59	2.13 0.09	2.56 0.02	1.57 0.13	1.95 0.07	-2.29 0.08
Mareko	Wet	-	6.5±1.2	21.4±5	32.8±8.8	54.9±7.6	64.3±3.8	11.7±3a	15.2±4a	18.7±2.2	21.7±2.1	23.8±2
	Dry	-	11.6±2	23.3±5	35.2±8.9	47.4±8.3	70.4±5.7	5.5±2b	8.2±3b	12.6±1.4	18.8±1.6	20.5±2
	t-value p-value	-	1.79 0.09	0.95 0.43	-0.20 0.83	0.81 0.17	1.33 0.20	2.97 0.04	2.12 0.02	1.72 0.11	1.10 0.31	1.46 0.21

Means within a column alone in each district having $p \geq 0.05$ are not significant different

6.4. DISCUSSION

Busseola fusca survives in crop residues (maize stalks) during the dry season as diapause larvae. Yitaferu and Gebre-Amlak (1994) indicated that a large number of sorghum stacks are left in the field for long periods, which serves as a reservoir of carry-over populations of *B. fusca* in eastern Ethiopia. In Uganda, crop residues are often used to mulch, under these conditions borers from the old stalks constantly infested the newly planted crops (Mohyuddin and Greathead, 1970). In Africa, farmers normally stack dry stalks in the field where they are kept until the commencement of rains before being taken to villages, thus creating a reservoir for the infestation in the following season (Van den Berg and Nur, 1998). In the current study, the highest incidence of diapause *B. fusca* larvae was recorded in Halaba followed by Mareko as compared with Hawassa. Two factors could be responsible for the local variation in the incidence of diapause; weather conditions and local variation in the genetic constitution of the populations (Masaki, 1980). Mortality of diapause larvae was lower at the beginning of sampling but increased sharply over time.

As a time advanced, population densities of alive diapause larvae per 100 stalks were decreased where as mortality increased. Gebre-Amlak (1988) reported that horizontal placement of stalks influences the number of surviving larvae and exposure for 4 weeks resulted in 97 % mortality of *B. fusca* larvae in maize at Hawassa, South Ethiopia. Dejenet al. (2010) observed that horizontal placement of sorghum stalks for 6–8 weeks causes larval mortality of 72–94 %, and the practice could be used as a part of an integrated stalks borer management strategy for northwestern Ethiopia farmers. Adesiyum and Ajayi (1980) reported that horizontal spread of stalks in an open field at different exposure periods caused 95% mortality of diapausing *B. fusca* larvae.

In both years, in Hawassa pupation of *B. fusca* occurred earlier (February to May) than the period reported by Gebre - Amlak, 1989 (April to May). The development time of diapause *B. fusca* larvae varied between locations. Diapause larvae collected in November, started to pupate in March in both Hawassa and Mareko, whereas in Halaba it started in April. Duration of the diapause maintenance period is highly variable among species (and biotype) and environmental conditions before or during diapause (Tauber and Tauber, 1976). The adult flight period of *B. fusca* also varied between study areas and seasons. These results agree with Annecke and Moran (1982) and van Rensburg *et al.* (1985) who indicated that moth flights occur during specific periods within each season and varied between localities as well as between seasons for each locality.

Highest body weight losses were observed in *B. fusca* larvae maintained in dry conditions, over those kept in the wet conditions. The result agrees with Tippawan *et al.* (1999) who reported that, larval body weight in bamboo borer, *Omphisa fuscidentalis* decreased to about half of the initial weight over nine months. The moths from diapause larvae kept under dry condition lost much of the initial body weight compared to those provided with moisture. A similar result was obtained by Kostal *et al.* (1998) who reported that, Mediterranean tiger moth (*Cymbalophora pudica*) in diapause lost up to 50% of their body. During diapause, not only the physiological (suppression of metabolic activity) but several morphological (weight, size, body color) and behavioral changes may also be encountered in insects (Dhillon and Hasan, 2017).

Artificial wetting did not hasten diapause termination but caused higher larval mortality. Similarly, Gebre-Amlak (1989) reported that *B. fusca* larvae given access to water between December and February early in diapause did not pupate but rather increased natural mortality. Okuda (1990) reported that when diapause *B. fusca* were provided with water by means of a

pipet no pupation was recorded. Diapause *B. fusca* was probably genetically controlled and the influence of food and water was less apparent (USUA, 1968).

6.5. SUMMARY AND CONCLUSION

Population density, time of pupation and flight activities of *B. fusca* from diapause state varied between areas and seasons. In both years, higher diapause *B. fusca* larvae were recorded in Halaba followed by Mareko. Early pupation of diapause *B. fusca* larvae were recorded in Hawassa followed by Mareko. Watering of diapause larvae under laboratory was not found important for terminating the diapauses state. The emerging moths from diapause larvae kept in wet condition were heavier in weight than larvae kept in dry condition. Heavier female moths are known to lay more number of eggs (Maksimovic, 1958). Diapause *B. fusca* larvae those kept in dry conditions were more likely to survive than kept in wet conditions.

Timing management practice largely depends on the population density of the pest, the severity of damage and the stage of the plant at infestation. Levels of infestations could vary in different seasons and localities. The knowledge on the period of termination of diapause and moth flight will help in making decisions and timing of management practices. It is essential to monitor the survival of the diapausing larvae and population of moth and flight period. Crop residues are important for carrying over stem borer larval populations from one growingseason to the next. A considerable proportion of *B. fusca* larvae survive in the maize stubble. The first generation of adult population of maize stalk borers, *B. fusca* should be reduced by destroying the larvae in oldstalks. More studies from different agro ecologies for longer periods, including years of unusual weather are recommended in order to have better understanding on the diapause of larva, survival, population density of moths and the subsequent levels of infestation.

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7. CROP INJURY AND YIELD LOSSES IN MAIZE BY THE AFRICAN MAIZE STALK BORER, *Busseola fusca* (Fuller) (LEPIDOPTERA: NOCTUIDAE) IN SOUTHERN ETHIOPIA

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ABSTRACT

African maize stalk borer, Busseola fusca is an important pest of maize in sub-Saharan Africa. This study investigated the relationship between B. fusca population density and yield losses in maize and the effect of weather factors, temperature and rainfall. Twenty - four maize farms were visited in 12 localities of southern Ethiopia at three growth stages of maize during 2015 and 2016. Data were collected on percent of infestation, number of larvae and pupae, crop injury variables (borer exit holes, injured internodes, tunnel length) and grain yield per plant from insecticide protected and not-protected plots. In both years, Busseola fusca was present in damaging levels in all the study areas. Infestation, population density and crop injury variables significantly varied between years, growth stage of maize and locations. Percent infestation at mid-whorl stage of maize ranged from 13.6 % to 25.9% and 19.5% to 41.4% in 2015 and 2016, respectively. The level of infestation increased through time and at maturity stage reached to ranges of 36.8% to 68.8% in 2015 and 65.5% to 80.7% in 2016. As altitude increase, levels of infestation, population density and crop injury increased. Population density of B. fusca was higher at mid-whorl than silking and maturity stages of maize. Precipitation had a positive effect on the population density of B. fusca. A single stem borer, B. fusca per plant reduced grain yield by 9.2 g/plant. Similarly, one cm tunnel length and one hole per plant reduced grain yield by 1.3 and 4.8 g/plant, respectively. Crop injury and maize grain yield losses significantly lower in protected plot than unprotected. To reduce crop injury and yield losses in maize due to stem borer, farmers especially in higher elevations need to monitor their crop and use effective intervention methods.

Keywords: Stalk borer, injury variables, population density, yield loss, maize, highlands, Ethiopia

7.1. INTRODUCTION

Maize (*Zea mays* L.) is one of the most important staple food crops in sub-Saharan Africa (Shiferaw et al., 2011). Among cereal crops, maize has the highest average yield per ha and ranks third after wheat and rice in total area and production in the world (FAO, 2018). Ethiopia

is the fourth largest maize producing country in Africa, and first in the East African region (FAO, 2018). Among all cereals, maize is second to teff (*Eragrostis tef*) in area coverage but first in productivity and total production in Ethiopia (CSA, 2017/18). In Ethiopia, smallholder farmers across all the regions cultivate maize (CSA, 2017/18). Together, the regions of Oromia, Amhara, Southern Nations, Nationalities, and Peoples' Region (SNNPR) and Tigray account for 97.3% of maize production in Ethiopia (CSA, 2017/18). The yield of maize in SNNPR was estimated at 3.8 t/ha and the national average yield at 3.9 t/ha (CSA, 2017/18) which is below the global average of 5.8 t/ha (USDA, 2018). The low productivity of maize is attributed to a multitude of abiotic and biotic factors (Tilahun et al., 2012). Among biotic factors, diseases (grey leaf spot, leaf blight, common leaf rust etc.), parasitic weeds (mainly *Striga hermontica*), and insect pests (maize stem borer, fall armyworm etc.) are the main maize yield limiting factors (Keno et al. 2018). Stem borers are generally considered the major constraint to maize production in Africa (Kfir et al., 2002). Stem borers are generally considered the major constraint to maize production in Africa (Kfir et al., 2002).

Of the known stem borer species causing economic yield losses in sub-Saharan Africa, the indigenous noctuids *Busseola fusca* (Fuller) and *Sesamia calamistis* Hampson and the exotic crambid *Chilo partellus* (Swinhoe) are the most important in Ethiopia (Demissie et al., 2012; Dejen et al., 2014). *Chilo partellus* is the most damaging in the lowland areas while *Busseola fusca* is restricted to mid and high-altitude zones (Getu et al., 2001; Wale et al., 2006). Studies by Dejen et al. (2014) have indicated that *C. partellus* has begun to expand its distribution into mid and high elevation areas by displacing the native borer species, *B. fusca*. *Sesamia calamistis* is sporadic and distributed in the intermediate altitude, 1200 m to 1750 m (Gebre-Amlak et al., 1989; Tasdesse et al., 1993).

Maize plants are less tolerant to stem borer attack when compared to those of sorghum (*Sorghum bicolor*) and pearl millet (*Pennisetum glaucum*), and hence losses of maize grain yields are greater (Ongamo et al., 2016). In Africa, yield losses due to stem borers vary widely by country, season, crop type and management (Khan et al., 2007). Stem borers cause 20-50% maize yield losses at the smallholder level in several African countries (De Groote, 2002). In South Africa, *B. fusca* infestation resulted in yield losses of 10 - 100 % (Ongamo et al., 2016). In Mozambique, yield losses due to stem borer attacks are often more than 50% (Cugala and Omwega, 2001). In Kenya, more than 10% of potential maize maturity is lost due to infestation by *B. fusca* (Ongamo et al. 2016). In Ethiopia, the average yield loss of maize caused by cereal stem borers was estimated to be between 10 and 50 % (Getu, 2001; Goftishu et al., 2017).

Routine and appropriate farm management practices can potentially alter the infestation level of the stem borers (Ebenebe et al., 2001). Cultural practices, such as crop residue management (Dejen, 2004), intercropping (Tsehaye et al., 2007; Wale et al., 2007; Belay et al., 2009) and modification of planting dates (Dejen, 2004), have been recommended for reducing the damage caused by cereal stem borers in Ethiopia. Host-plant resistance has potential to provide effective control of *B. fusca* (Van Rensburg, 1993). However, maize varieties resistant to this pest are still not available in Africa (Kfir et al., 2002). On the other hand, synthetic insecticides (Chinwada et al., 2001), natural insecticides (Dejen et al., 2011; Tilahun and Azerefegne, 2013; Wondimu and Dejen, 2014) have also been recommended for the control of stem borers.

Integrated pest management of stem borers combines cultural Biological, host plant resistance and chemical control methods to manage them (Bosque-Perez, 1995). Chemical control of insect pests will continue to be a major component of integrated pest management

(Jotwani, 1983). When the stem borer population build-up to levels that threaten to cause economic losses, chemical control remains the only method by which immediate losses can be averted (Kalule and Masud, 1998). Chemical Control of stem borers with contact insecticides must be carefully timed to coincide with the limited period when early instars stem borer larvae are exposed on the leaves before boring into the stem (Jotwani, 1983; Segeren et al., 1991). However, systemic insecticides are effective even after the larvae penetrate the stem (Bosquepérez, 1995). Several systemic and contact insecticides formulated either as granules or spray applications are registered for stem borer control in African countries (Chinwada et al., 2001).

Busseola fusca is considered to be the most destructive lepidopteran pests of maize (Kfir et al., 2002) and sorghum (Van den et al., 1991) in Africa. Estimates of crop losses vary greatly in different regions and agro-ecological zones (Calatayud et al., 2014). Stem borer infestation is severe in Southern Ethiopia, where maize production is further limited by declining soil fertility (Corral-Nunez et al., 2014) and unpredictable rainfall (Muluneh et al., 2015). Recent information on incidence, crop injury variables, population density and yield loss due to stem borers is required for appropriate agronomic intervention/s (Kihara et al., 2015). Moreover, governments require yield loss data to plan for food and crop production in the process of resource allocation for research, extension and allied operations (Walker, 1987). Knowledge of pest incidence, injury and yield loss levels in the different agro-ecologies would facilitate strategic decisions about selection of management practices. Yield losses could vary across seasons, ecological zones, the age of crop at the time of infestation, crop varietal resistance to larval feeding, stem borer species/density and agronomic practices (Polaszek, 1998). This study assessed infestation, population density, crop injury variables and yield losses in maize due to maize stalk borer in southern Ethiopia, a region which extensively produces maize.

7.2. MATERIALS AND METHODS

7.2.1. Study areas

A field survey was carried out in twenty-four maize farms received similar input and management practices in southern Ethiopia during 2015 and 2016 of the main cropping seasons of May to October. The number of study areas (zones and districts), the number of sampled farms, sampling plots and sampled plants were described in Table 4.1. The elevation of each farm was recorded using a handheld Global Positioning System (GPS) brand name (GPS 60, Germany). Weather data such as rainfall and temperature of the study areas during study periods were obtained from the Ethiopian metrological agency.

7.2.2. Sampling methods

7.2.2.1. Infestation, population density and crop injury variables

Sampling was done at three different growth stages of maize; mid-whorl (8-10 leaves), silking and maturity/maturity. The sampled farms grew the varieties BH 540 and shone. In each farm, five sampling plots (Table 4.1) of 9 m², four in the corner two meters inside the border and one in the center were taken. In each sample plot, the total and infested number of plants was recorded. Plants with typical characteristics of stem borer damage (dead heart, scarified leaves, and larval entry and exit holes in stems, presence of frass) were considered as infested. In addition, in each plot ten randomly selected plants were dissected, and the number of larvae and pupae were recorded. Similarly, at maturity, data on numbers of larvae and pupae and crop injury variables (borer exit holes per plant, injured internodes, tunnel length,) and grain yield per plant were recorded. Larvae retrieved during dissections were brought to the laboratory and fed on fresh maize in Petri-dish until pupation. The pupae were kept separately until the adults emerge.

Adults were killed with Ethyl acetate and identified with reference keys provided by Polaszek (1994).

7.2.2.2. Yield loss assessment

During 2016 rainy season, a single maize farm which planted the maize variety “Shone” was selected from each of the six districts. Within the selected farms, two adjacent plots of 1000m² each were staked out, of which one half was protected from stem borer infestation by spraying with insecticide and the other half was not protected and used as a control treatment. The protected plots were sprayed with lambda-cyhalothrin (Karate ®5 EC) at a rate of 300 ml/ha applied two times. The first application was made 20-30 days after planting when 5 -10 % of infestations by stem borer were observed and the second application made ten days after the first spray. There was two meters gap between protected and unprotected plots. At maturity stage, fifty plants were randomly sampled from the treated and untreated plots. The plants were dissected and the number of *B. fusca* larvae, pupae and crop injury variables (tunnel length, number of holes, bored internodes per plant) were recorded on each plant. Cobs from each maize plant were bagged separately and the grains were shelled and weighed after drying. The moisture content of the grain was adjusted to 13.5% moisture level.

7.2.3. Data analysis

Data on infestation, population density and injury variables between study areas were subjected to statistical analysis of variance. The analyses were done separately for each cropping season. The level of significance was set at $p = 0.05$ and the means were separated by student Newman-Keuls test (SNKT). Comparison between cropping years, varieties, chemical treated and untreated were analyzed using t - test. Before analysis, count and percentage data were transformed using square roots and arcsine, respectively. Untransformed mean values were used

in the tables. Stepwise multiple regression was used to find which *B. fusca* population density and injury variables had significant effect on grain yield; to check the effect of weather data (temperature and rainfall) on population density of *B. fusca*. All statistical analyses were performed using SAS, 2004 software.

7.3. RESULTS

7.3.1. Infestation of *B. fusca*

Busseola fusca was present and cause significant injuries to maize plant in all the study areas during both years. However, the infestation levels significantly varied between locations, growth stage of the crop and years (Table 7. 1 and 7.5). In 2015, highest infestation (23.7 and 28.1 %) at mid-whorl and (67.9 and 69.7%) at maturity stages was recorded in Gurage zone. Wolaita zone also sustained high infestation (20.1 to 22.8 %) at mid-whorl and (57.0 and 64.5%) at maturity whereas Sidama zone had the lowest infestation (8.8 and 18.4 %) at mid-whorl and (31.2 to 42.3%) at maturity (Table 7.1). Similar trends of infestation were observed in 2016; the highest in Gurage zone followed by Wolaita zone and the lowest in Sidama zone (Table 7.1). Percent infestation increased across the growth stages of maize.

Table 7.1. Mean (\pm SE) percent of infestation of *B. fusca* on three growth maize in southern Ethiopia during 2015 and 2016.

Zone	Districts	Percent (%) of infested maize plant by <i>B. fusca</i>					
		Mid- whorl		Silking stage		Maturity stage	
		2015	2016	2015	2016	2015	2016
Gurage	Mareko	28.1 \pm 1.9 ^a	43.4 \pm 3.8 ^a	38.2 \pm 3.4 ^a	67.7 \pm 3.6 ^a	67.9 \pm 2.6 ^a	79.6 \pm 2.5 ^a
	Meskan	23.7 \pm 1.8 ^{ab}	39.4 \pm 2.4 ^a	46.3 \pm 3.7 ^a	66.9 \pm 2.9 ^a	69.7 \pm 2.9 ^a	81.7 \pm 3.4 ^a
Wolaita	Damot Gale	22.8 \pm 1.4 ^{ab}	30.7 \pm 2.2 ^b	53.3 \pm 1.6 ^a	64.6 \pm 3.2 ^a	64.5 \pm 3.5 ^a	76.3 \pm 3.9 ^a
	Boloso Sore	20.1 \pm 2.2 ^{ab}	33.3 \pm 3.3 ^b	36.6 \pm 1.2 ^a	57.0 \pm 2.4 ^b	57.0 \pm 2.2 ^b	69.0 \pm 3.3 ^a
Sidama	Wendo Genet	18.4 \pm 1.1 ^b	25.2 \pm 2.3 ^c	19.6 \pm 1.6 ^b	34.4 \pm 1.7 ^c	42.3 \pm 2.1 ^c	74.6 \pm 3.2 ^a
	Hawassa Zuria	8.8 \pm 1.3 ^c	13.7 \pm 1.4 ^d	22.9 \pm 2.2 ^b	31.6 \pm 2.2 ^c	31.2 \pm 3.2 ^d	56.4 \pm 2.4 ^b
	F-Value	38.04	56.80	10.49	76.53	76.72	13.55
	P- Value	0.00	0.00	0.00	0.00	0.00	0.01

Means within a column followed by the same letter (s) are not significantly different at $P < 0.05$

using Student Newman-Keuls test

7.3.2. The population density of *B. fusca*

The density of larvae and pupae varied ($P < 0.05$) across the locations, maize stages and years (Table 7.2 and 7.5). In 2015 and 2016 Gurage zone harbored a higher number of larvae, especially during the mid-whorl stage. While lower mean number of larvae per plant was recorded in Hawassa Zuria of Sidama zone (Table 7.2). Generally, higher numbers of *B. fusca* larvae per plant were recorded at the mid-whorl stage of maize than the silking and maturity.

Table 7.2. Mean (\pm SE) number of *B. fusca* larvae and pupae per plant at three growth stages of maize in Southern Ethiopia during 2015 and 2016.

2015		Maize growth stage				
Zone	District	Mid - whorl	Silking stage		Maturity stage	
		Larvae/plant	Larvae/plant	pupae/plant	Larvae/plant	pupae/plant
Gurage	Mareko	6.0 \pm 0.34 ^a	3.6 \pm 0.27 ^a	1.1 \pm 0.09 ^{ab}	1.3 \pm 0.12 ^a	0.6 \pm 0.10 ^b
	Meskan	5.6 \pm 0.33 ^{ab}	2.4 \pm 0.19 ^b	1.3 \pm 0.10 ^a	1.0 \pm 0.10 ^{ab}	0.5 \pm 0.09 ^b
Wolaita	Damot Gale	4.9 \pm 0.25 ^b	2.9 \pm 0.56 ^{ab}	1.2 \pm 0.10 ^a	1.3 \pm 0.11 ^a	1.0 \pm 0.10 ^a
	Boloso Sore	4.4 \pm 0.22 ^c	3.0 \pm 0.26 ^{ab}	1.3 \pm 0.9 ^a	1.3 \pm 0.11 ^a	0.8 \pm 0.09 ^{ab}
Sidama	Wendo Genet	4.6 \pm 0.34 ^{bc}	2.5 \pm 0.21 ^b	1.1 \pm 0.10 ^{ab}	0.8 \pm 0.09 ^b	0.5 \pm 0.08 ^b
	Hawassa Zuria	3.7 \pm 0.25 ^d	2.4 \pm 0.27 ^b	0.8 \pm 0.09 ^b	0.9 \pm 0.09 ^{ab}	0.5 \pm 0.08 ^b
	F-Value	8.6	3.4	3.9	3.9	4.2
	P- Value	0.00	0.01	0.00	0.00	0.00
2016						
Gurage	Mareko	7.8 \pm 0.19 ^a	2.6 \pm 0.09 ^a	1.5 \pm 0.07 ^{ab}	1.1 \pm 0.14 ^{ab}	0.8 \pm 0.11 ^a
	Meskan	7.6 \pm 0.17 ^a	2.8 \pm 0.09 ^a	1.6 ^a \pm 0.08 ^b	1.4 \pm 0.14 ^{ab}	0.6 \pm 0.09 ^a
Wolaita	Damot Gale	6.1 \pm 0.22 ^b	2.6 \pm 0.15 ^a	2.0 \pm 0.09 ^a	1.6 \pm 0.19 ^a	0.7 \pm 0.10 ^a
	Boloso Sore	5.8 \pm 0.24 ^b	1.9 \pm 0.26 ^b	1.1 \pm 0.09 ^b	1.3 \pm 0.15 ^{ab}	0.9 \pm 0.10 ^a
Sidama	Wendo Genet	4.4 \pm 0.29 ^c	2.9 \pm 0.08 ^a	1.9 \pm 0.08 ^a	1.0 \pm 0.13 ^{ab}	0.9 \pm 0.12 ^a
	Hawassa Zuria	3.7 \pm 0.25 ^c	1.6 \pm 0.09 ^b	0.8 \pm 0.07 ^b	0.8 \pm 0.09 ^b	0.6 \pm 0.08 ^a
	F-Value	8.6	6.6	6.9	3.3	1.6
	P-value	0.00	0.00	0.00	0.01	0.20

Means within a column followed by the same letter (s) are not significantly different at $P < 0.05$ using Student Newman-Keuls test

7.3.3. Infestation and population density of *B. fusca* on two maize varieties

In both years, *B. fusca* was injurious on two varieties of maize grown in the study localities.

Within the same location infestation level, number of larvae and pupae per plant did not vary significantly between both varieties (Table 7.3)

Table 7.3. Mean (\pm SE) infestation and population density of *B. fusca* on two maize varieties in southern Ethiopia during 2015 and 2016.

Zone	Year	Maize Variety	Mid - whorl stage		Silking stage		Maturity stage	
			Infestation (%)	Larvae /plant	Larvae /plant	Pupae /plant	Larvae /plant	Pupae /plant
Gurage	2015	BH540	28.7 \pm 3.1	5.73 \pm 0.04	2.6 \pm 0.3	1.1 \pm 0.10	1.12 \pm 0.1	0.64 \pm 0.1
		Shone	31.1 \pm 2.9	5.82 \pm 0.30	3.4 \pm 0.2	0.9 \pm 0.09	1.08 \pm 0.1	0.40 \pm 0.1
		t-value	0.12	-1.4	1.62	0.60	0.30	1.85
		P-value	0.91	0.88	0.05	0.72	0.76	0.07
Sidama		BH540	13.7 \pm 2.7	3.5 \pm 0.3	2.7 \pm 0.3	0.9 \pm 0.1	1.4 \pm 0.1	1.2 \pm 0.08
		Shone	18.4 \pm 1.9	4.5 \pm 0.4	2.5 \pm 0.2	1.1 \pm 0.1	1.3 \pm 0.1	1.3 \pm 0.10
		t-value	-1.98	-1.18	0.65	0.43	-0.24	0.42
		P-value	0.06	0.24	0.90	0.72	0.81	0.63
Wolaita		BH540	23.6 \pm 1.7	4.6 \pm 0.23	2.8 \pm 0.3	1.3 \pm 0.1	0.8 \pm 0.1	0.6 \pm 0.1
		Shone	27.2 \pm 1.6	4.9 \pm 0.34	2.9 \pm 0.2	1.3 \pm 0.1	0.9 \pm 0.1	0.5 \pm 0.1
		t-value	0.71	-0.32	0.33	1.44	0.89	0.42
		P-value	0.49	0.75	0.74	0.15	0.37	0.67
Gurage	2016	BH540	31.2 \pm 2.6	7.8 \pm 0.2	1.2 \pm 0.1	2.8 \pm 0.03	0.4 \pm 0.1	0.21 \pm 0.1
		Shone	34.1 \pm 2.4	7.6 \pm 0.2	1.2 \pm 0.1	2.9 \pm 0.04	0.4 \pm 0.1	0.23 \pm 0.1
		t-value	-0.14	-0.02	0.09	-0.37	-0.81	-0.33
		P-value	0.86	0.98	0.93	0.70	0.41	0.76
Sidama		BH540	24.5 \pm 1.8	3.6 \pm 0.3	1.3 \pm 0.1	1.7 \pm 0.1	1.3 \pm 0.1	0.3 \pm 0.1
		Shone	25.2 \pm 2.3	3.7 \pm 0.3	1.4 \pm 0.1	1.8 \pm 0.1	1.1 \pm 0.1	0.5 \pm 0.1
		t-value	0.27	-0.26	0.63	0.53	-1.21	-1.09
		P-value	0.78	0.79	0.92	0.70	0.19	0.08
Wolaita		BH540	28.0 \pm 1.8	6.1 \pm 0.2	1.6 \pm 0.2	0.6 \pm 0.1	1.2 \pm 0.1	1.1 \pm 0.1
		Shone	29.3 \pm 2.4	6.3 \pm 0.3	1.7 \pm 0.2	0.7 \pm 0.1	0.8 \pm 0.1	1.0 \pm 0.1
		t-value	0.72	0.08	-0.81	-0.33	-0.14	1.43
		P-value	0.42	0.93	0.41	0.76	0.18	0.15

Means within a column alone in each zone having $p \geq 0.05$ are not significant different

7.3.4. Infestation and injury variables of *B. fusca* at maize maturity

Infested plants, bored internodes, number of exit holes and tunnel length per plant varied ($P < 0.05$) across the study areas are shown (Table 7.4). In both years the infestation and injury variables were higher in Gurage followed by Wolaita and Sidama zones

Table 7.4. Mean (\pm SE) infestation and injury variables of *B. fusca* at maturity stage of maize in southern Ethiopia

Zone/Districts	Localities	(% of infested plants)		Hole /plant		% of bored internodes		% of tunneled length	
		2015	2016	2015	2016	2015	2016	2015	2016
Gurage									
Mareko	Dida Halibo	66.4 \pm 2.7 ^a	77.4 \pm 2.7 ^{abc}	8.2 \pm 0.80 ^a	9.4 \pm 0.7 ^b	20.9 \pm 2.1 ^{ab}	38.2 \pm 1.6 ^a	11.6 \pm 0.93 ^a	10.1 \pm 0.8 ^{ab}
	Dida midore	69.6 \pm 2.4 ^a	82.4 \pm 2.2 ^a	7.1 \pm 0.83 ^{ab}	9.2 \pm 0.8 ^b	22.6 \pm 2.8 ^a	33.5 \pm 2.1 ^b	10.7 \pm 0.94 ^a	12.9 \pm 0.8 ^a
Meskan	Dida	68.0 \pm 3.0 ^a	83.3 \pm 3.8 ^a	8.1 \pm 0.79 ^a	11.2 \pm 0.8 ^a	19.5 \pm 1.8 ^{ab}	38.3 \pm 1.6 ^a	10.4 \pm 0.97 ^a	11.2 \pm 0.8 ^{ab}
	Ocha Genemae	69.9 \pm 2.8 ^a	80.1 \pm 3.0 ^{ab}	8.2 \pm 0.76 ^a	8.8 \pm 0.6 ^b	19.6 \pm 1.9 ^{ab}	30.6 \pm 2.1 ^b	10.7 \pm 0.98 ^a	12.0 \pm 0.5 ^{ab}
Sidama									
Hawassa Zuria	Jara Kerera	34.1 \pm 2.0 ^d	47.8 \pm 2.8 ^d	1.8 \pm 0.30 ^c	5.5 \pm 0.5 ^c	5.4 \pm 0.6 ^c	26.8 \pm 2.2 ^b	3.1 \pm 0.34 ^{bc}	3.4 \pm 0.5 ^d
	Jara Demuwa	28.3 \pm 2.0 ^d	65.0 \pm 3.4 ^c	1.0 \pm 0.15 ^c	4.6 \pm 0.4 ^c	5.9 \pm 0.57 ^c	24.8 \pm 2.0 ^b	2.6 \pm 0.22 ^c	6.8 \pm 0.5 ^c
Wondo Genet	Aruma	46.9 \pm 4.7 ^c	75.1 \pm 2.2 ^{abc}	2.3 \pm 0.38 ^c	5.4 \pm 0.5 ^c	3.7 \pm 0.42 ^c	29.8 \pm 2.2 ^b	3.2 \pm 0.40 ^{bc}	6.6 \pm 0.5 ^c
	Yuwo	37.8 \pm 2.4 ^d	74.1 \pm 2.0 ^{abc}	1.6 \pm 0.27 ^c	5.0 \pm 0.0 ^c	3.6 \pm 0.35 ^c	26.9 \pm 1.9 ^b	2.5 \pm 0.36 ^c	10.3 \pm 0.7 ^{ab}
Wolaita									
Boloso Sore	Wormuma	60.0 \pm 4.1 ^b	67.6 \pm 4.0 ^{bc}	5.6 \pm 0.58 ^b	6.4 \pm 0.5 ^c	11.9 \pm 1.1 ^b	28.3 \pm 1.6 ^b	6.0 \pm 0.55 ^{ab}	9.5 \pm 0.8 ^b
	Dola	54.0 \pm 2.8 ^{bc}	77.4 \pm 3.8 ^{abc}	6.6 \pm 0.84 ^{ab}	5.6 \pm 0.4 ^c	10.1 \pm 0.8 ^b	24.4 \pm 1.5 ^b	5.6 \pm 0.33 ^{ab}	11.5 \pm 0.4 ^{ab}
Damot Gale	Bugae	63.3 \pm 4.5 ^{ab}	73.3 \pm 3.8 ^{abc}	5.4 \pm 0.83 ^b	6.5 \pm 0.6 ^c	15.5 \pm 1.4 ^{ab}	26.7 \pm 1.7 ^b	4.9 \pm 0.49 ^{ab}	11.3 \pm 0.6 ^{ab}
	Shasha Gale	65.8 \pm 3.3 ^a	79.3 \pm 3.3 ^b	3.3 \pm 0.55 ^c	5.7 \pm 0.5 ^c	16.2 \pm 1.6 ^{ab}	30.1 \pm 1.9 ^b	4.1 \pm 0.31 ^{ab}	10.8 \pm 0.6 ^{ab}
F-Value		31.0	25.0	18.9	12.4	26.3	5.5	37.2	16.9
P- Value		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Means within a column followed by the same letter (s) are not significantly different at $P < 0.05$ using Student Newman-Keuls test

7.3.5. Effect of cropping years on infestation, population density and injury variables of *B. fusca* on maize

Cropping seasons significantly ($P < 0.05$) influenced the infestation, population density and injury variables of *B. fusca* on maize (Table 7.5). Percent of infestation, population density and injury variables of *B. fusca* were higher during 2016 than 2015.

Table 7.5. Effect of cropping years on infestation, population density and injury variables of *B. fusca* on maize

Zone	Year	Maize growth stage										
		Mid - whorl		Silking			Maturity					
		Infestation %	Larvae/plant	Infestation %	Larvae/plant	Pupae/plant	Infestation %	Larvae/plant	Pupa/plant	Hole/plant	% bored internode	% tunnel length
Gurage	2015	25.88	5.8	42.10	3.0	1.14	68.8	1.15	0.55	7.91	20.52	10.85
	2016	41.40	7.7	67.27	2.7	1.55	80.7	1.25	0.70	9.65	35.15	11.55
	t-value	-6.54	-7.50	-6.74	12.31	-11.50	-10.21	-0.81	-1.97	-2.94	-17.7	-5.61
	P-value	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.02	0.00	0.05
Wolaita	2015	21.88	4.65	35.95	2.95	1.27	60.77	1.09	0.55	5.23	13.43	5.15
	2016	32.12	5.95	61.48	2.25	1.55	72.65	1.75	0.80	6.05	27.38	10.78
	t-value	-5.16	-7.41	-12.02	3.31	4.30	-4.51	-3.73	-2.55	-1.13	-7.88	-18.17
	P-value	0.00	0.00	0.00	0.00	0.00	0.001	0.00	0.01	0.30	0.00	0.00
Sidama	2015	13.65	4.14	21.20	2.45	0.96	36.75	0.85	0.51	1.68	4.65	2.85
	2016	19.42	4.05	32.98	2.25	1.35	65.45	0.91	0.75	5.13	27.08	6.78
	t-value	-2.63	1.83	-7.78	5.70	1.56	-5.20	-0.46	-2.47	-10.62	-37.87	-10.14
	P-value	0.01	0.06	0.00	0.00	0.00	0.00	0.03	0.01	0.00	0.00	0.00

Means within a column alone in each zone having $p \geq 0.05$ are not significant different

7.3.6. Effect of altitude on infestation, population density and injury variables of *B. fusca* on maize

Busseola fusca occurred at elevations from 1600 up to 2216 MASL of the surveyed areas in southern Ethiopia. Higher levels of infestations, population density and crop injury variables were encountered in higher elevations than lower areas (Figure 7.1).

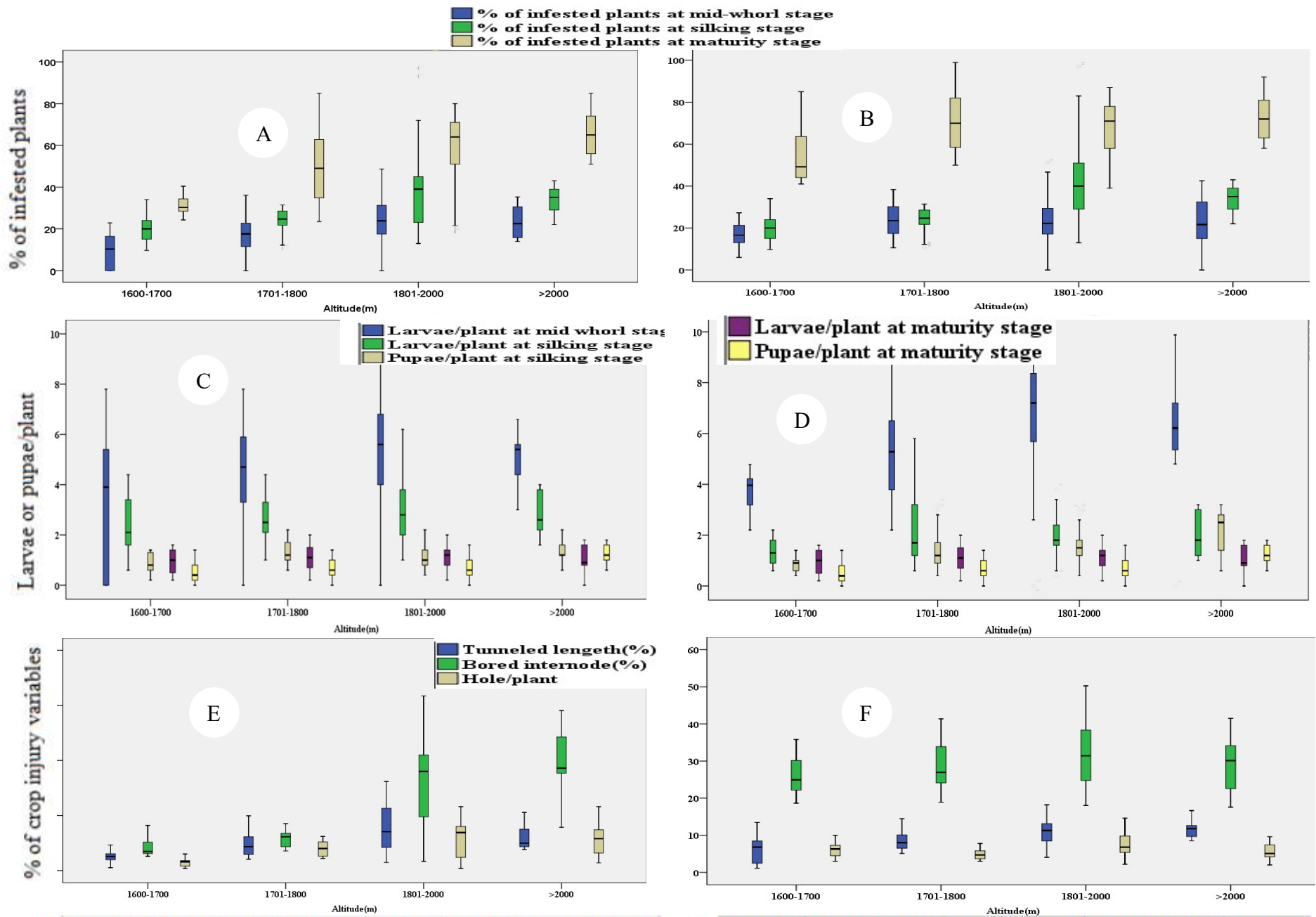


Figure 7.1. Percent of infested plants (A and B), population density (C and D) and crop injury variables (E and F) of *B. fusca* on maize in four altitude groups in 2015 (left side) and 2016 (right side)

7.3.7. Comparison of crop injury variables and yield due to *B. fusca* on maize

Crop injury variables (number of holes per plant, tunnel length, and bored internodes) and grain yield loss by *B. fusca* on maize significantly varied between chemical treated and unprotected plots in all districts. Crop injury variables and grain yield losses were significantly ($p < 0.05$) higher in chemically treated maize plots as compared to the treated plots (Table 7. 6).

Table 7.6. Comparison of crop injury variables and grain yield of maize for chemically treated and untreated plot

Parameter	Treatment	Districts					
		Mareko	Meskan	Wondo genet	Hawassa zuria	Damot gale	Boloso sore
No of holes/ plant	Treated	1.2±0.29	1.6±0.29	1.7±0.27	2.5±0.27	1.6±0.32	2.5±0.47
	Untreated	9.4±0.74	6.5±0.52	5.2±0.52	6.5±0.57	4.9±0.41	5.7±0.52
	t-value	-9.31	-8.18	-6.12	-6.31	-6.14	-4.59
	p-value	0.00	0.00	0.00	0.00	0.00	0.00
Tunnel(cm)/plant	Treated	5.6±0.79	4.6±0.74	6.2±0.75	10.6±0.86	4.46±0.76	4.3±0.84
	Untreated	22.1±0.95	21.3±1.05	11.4±0.55	18.2±0.66	19.9±1.0	15.8±0.66
	t-value	-11.28	-10.55	-5.74	-6.74	-10.17	-10.34
	p-value	0.00	0.00	0.00	0.00	0.00	0.00
No of bored internodes/plant	Treated	1.2±0.18	1.1±0.20	1.0±0.17	1.9±0.23	0.9±0.18	1.1±0.14
	Untreated	3.9±0.18	3.9±0.17	3.7±0.16	4.9±0.14	3.5±0.16	3.2±0.16
	t-value	-9.95	-9.81	-10.13	-12.28	-9.93	-8.21
	p-value	0.00	0.00	0.00	0.00	0.00	0.00
Grain yield (g/plant)	Treated	186.1±5.53	179.1±5.85	178.7±6.83	161.1±5.78	160.7±5.35	173.6±6.17
	Untreated	147.6±3.42	149.5±4.59	157.0±3.84	149.8±4.31	135.7±4.39	153.1±4.16
	t-value	6.17	3.84	2.99	1.53	3.44	2.81
	p-value	0.00	0.00	0.00	0.12	0.00	0.00
Grain yield (t/ha)	Treated	6.85±0.28	6.96±0.23	7.09±0.22	6.46±0.21	6.61±0.22	6.84±0.25
	Untreated	5.11±0.08	5.47±0.16	5.96±0.16	5.83±0.19	4.88±0.18	5.44±0.18
	t-value	7.64	5.28	3.99	1.99	5.59	5.42
	p-value	0.00	0.00	0.00	0.05	0.00	0.00

Means within a column alone in each district having $p \geq 0.05$ are not significant different

7.3.8. Relationship between weather factors and population density of *B. fusca*

The population density of *B. fusca* was positively related with precipitation (Table 7.7).

Whereas, air temperature negatively affected population density of *B. fusca*.

Table 7.7. Stepwise regression analysis of seasonal precipitation (mm) and temperature (°c) on population density of *B. fusca*

Year	Model	Dependent variable	Independent variable	Intercept	Coefficient (slope)	t-value	P-value	R ²	
2015	1	Larvae	Precipitation	243.5	0.13	3.5	0.04	85	
			Temperature		-17.96	-2.1	0.013		
	2		Precipitation	74.8	0.14	2.7	0.05	65	
	2016	1	Pupae	Precipitation	88.7	0.05	1.5	0.23	58
				Temperature		-3.31	-1.10	0.41	
2			Precipitation	18.2	0.07	1.60	0.19	39	
2016	1	Larvae	Precipitation	150.9	0.14	3.1	0.05	81	
			Temperature		-6.12	-0.80	0.32		
	2		Precipitation	17.2	0.16	3.6	0.02	72	
	1	Pupae	Precipitation	158.0	0.1	0.9	0.4	65	
			Temperature		-5.8	-2.1	0.12		
2		Precipitation	172.30	0.40	2.50	0.06	62		

7.3.9. The relation between population density, crop injury variables and yield of maize

The regression analysis showed that larvae, pupae, tunnel length and hole per plant were major maize yield affecting factors (Table 7.8). Tunnel length per plant alone is highly related to yield loss and explained about 39% of the variation in yield of maize. The regression analysis also indicated that the presence of each individual of *B. fusca* (larvae or pupae) reduced yield by 9.2 g / plant (Table 7.8). Similarly, one cm tunneled length and one hole per plant reduced grain yield by 1.3 and 4.8 g/plant, respectively.

Table 7.8. Stepwise regression analysis of maize grain yield (g/plant) during 2016 on *B. fusca* population density and damage variables

Model	Independent variable	Intercept	Coefficient (slope)	t-value	P-value	R ²
1	Tunnel(cm)/plant	174.42	-1.5	-7.7	<0.001	39.2
2	Tunnel (cm) / plant	208.12	-1.4	-7.5	<0.001	52.4
	Stem borer / plant		-9.2	-4.9	<0.001	
3	Tunnel (cm) / plant	217.61	-1.3	-6.3	<0.001	63.7
	Stem borer/plant		-9.2	-4.8	<0.001	
	Hole/plant		-4.8	-2.4	<0.001	

7.4. DISCUSSION

Infestation of *B. fusca* was prevalent across all the studied areas of southern Ethiopia with variations observed in number of insect per plant, percentage of infested plants and injury levels from seedling to maturity. Percent of infested plants increased through time while the number of larvae decreased. The increase in the number of infested plants towards the end of the growing season could be attributed to multiple ovipositions per plant by two or more generations during a particular season (Ebenebe et al., 2000) and inter-plant larval migration across the plants. *Busseola fusca* lays its eggs in batches and the early instar feed in softer tissues thereafter moves to other parts and neighboring plants. Calatayud et al. (2014) indicated that *B. fusca* is known to migrate to neighboring plants throughout the larval stage. Within five weeks after hatch, up to 70% of *B. fusca* larvae tend to migrate to other plants and after this migration of larvae up to 67% of them occur as single individuals per plant (Van Rensburg et al., 1987). The number of infested plants increases rapidly towards the end of the season as larvae migrate to neighboring not infested plants to find shelter as diapause larvae (Walters et al., 1976).

In the current study, *B. fusca* was the only lepidopterous species infesting maize in the study areas of southern Ethiopia with an elevation of 1600 to 2176 MASL. Depending on the altitude stem borers may occur as single species or communities of mixed species attacking maize plants in the same field (Tefera, 2004; Ong'amo et al., 2006). However, the level of infestation, injury and population density varied across the study areas. In Eritrea, Haile and Hofsvang (2002) reported that infestation and population density of *B. fusca* was variable between locations and seasons. The population density of *B. fusca* was higher at higher elevations. This result is in agreement with Dejen et al. (2014) who found that the distribution of *B. fusca* had a positive relationship with elevation. The population dynamics of *B. fusca* and *C. partellus* are influenced by several factors specifically: host availability, location, suitability, mate location, the success of oviposition, larval survival and establishment, temperature and altitude (Mailafiyaet al., 2011; Ongamo et al., 2012).

The study indicates that the densities of *B. fusca* populations are very variable across the years and locations. The level of infestation, population density and crop injury were higher in 2016 than 2015 in all studied areas. Dejen et al. (2014) reported that the distribution of *B. fusca* had a positive relationship with rainfall and an inverse relationship with temperature. Borer populations are strongly influenced by the amount and distribution of rainfall (Ndemah et al. 2000; Ndemah and Schulthess, 2002). Variations in maize stem borer population could be due to the extent of the carryover populations of diapause larvae and suitability of the weather condition especially the rainfall which influences the availability of host plants (Ndemah et al. 2000; Ndemah and Schulthess, 2002).

During the study periods, early and the highest percent of infestation of maize by *B. fusca*, were observed in Gurage zone. In this zone, maize stubbles are stacked for animal feed and

construction purposes more frequently than in the other zones. The residues harbor diapausing larvae during the off-season and, thus, are a major source of infestation (Van den Berg et al., 1998; Gebre-Amlak, 1988). Stubble and old stems of sorghum and maize left in the field were shown to contain large numbers of live larvae and constituted an important reservoir for new infestations of lepidopterous stem borers (Pats, 1996; Gebre-Amlak, 1988; Ebenebe et al., 2001). There were no differences between the long cycled variety Shone (162 days) and medium cycled BH 540 (145 days) (MOA, Crop Variety Register, 1998-2012) for infestation level, and larvae and pupae population density. Even though the data came from two varieties, results of this study agree with those reported by Kfir et al. (2002) who did not find maize varieties resistant to *B. fusca* in Africa.

During the study period, crop injury variables and grain yield loss by *B. fusca* on maize significantly ($p < 0.05$) varied between maize plots protected with insecticide and unprotected in all study areas. Lower crop injury and higher maize grain yield were recorded from protected plots as compared with unprotected plots. Use of systemic insecticides can reduce *B. fusca* populations, damage and the yield and advantage due to the use of insecticides varied from 16.3 to 29.5 q/ha over the untreated control (Haile, 2015). Maize yield losses could vary with seasons, ecological zones, the age of crop at the time of infestation, crop varietal resistance to larval feeding, stem borer species/density, agronomic practices (Polaszek, 1998). Reddy et al. (2004) reported that, maize protected with insecticides against *B. fusca* resulted in yield increase of 39.4% to 42.7% over the control. Yield loss due to *B. fusca* on maize crop varied between the studied areas. Yield losses could vary with seasons, ecological zones, the age of crop at the time of infestation, crop varietal resistance to larval feeding, stem borer species/density, agronomic practices (Polaszek 1998).

Busseola fusca population, tunnel length and exit holes per plant had a negatively effect on grain yield of maize. This result agree with (McFarlane, 1990) who reported that, increaments in the tunnel length, hole number, bored internode and stem borer population density had a negative effect on grain yield of maize. Higher stem borer densities resulted in significantly higher plant damage, which negatively affected yields (Cugala et al., 2006). Van Rensburg et al. (1988) also stated that yield is inversely correlated with the level of internal plant damage by *B. fusca* larvae in maize, with a decrease in ear mass as the number of damaged zones per plant increases. One cm tunnel length reduced grain yield by 1.3 g/plant. Songa et al. (2001) observed that stem borers injury greatly reduced maize yield with tunnel lengths greater than 20 cm causing 40 % potential yield loss. Odiyi (2007) and Singh et al. (2011) observed that the direct effect of stem tunneling on maize grain yield loss was greater than the effect of leaf feeding. USUA (1968) reported that presence of one or two larvae of *B. fusca* per plant reduced the yield by as much as 25%. Our result enlighten that the level of plant infestation, crop injury and maize grain yield losses by *B. fusca* were severe in southern Ethiopia. Maize producers in southern Ethiopia need to continuously monitor the level of *B. fusca*, infestation and adopt management practices that reduce pest population, damage and yield loss.

7.5. REFERENCE

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8. GENERAL SUMMARY AND RECOMMENDATION

The maize stalk borer, *B. fusca* is a major constraint for the production of maize in southern Ethiopia. Distribution pattern infestation, larvae and pupae of *B. fusca* varied between growth stages of maize. For 10% infestation, which is considered as action threshold level for stem borers management on maize, 22 sampling units (660 plants) per hectare at the precision of 20% are required. *Busseola fusca* has three generations in southern Ethiopia. Higher number of egg batches and eggs per week were recorded in the second generation than both first and third generations. Earlier fighting *B. fusca* moth observed in Hawassa Zuria than in Wolaita Sodo. The patterns and periods of *B. fusca* moth flight of the different generation are clear and predictable and can be used in adjusting planting time of maize or making management decisions.

Access to water did not enhance pupation during the diapause. Larvae, pupae and adults emerged from wet condition were heavier than the dry condition. Population density of *B. fusca* larvae, pupae and moth flighting period varied among years, locations. Levels of infestations, population density of *B. fusca* larvae and pupae varied across the locations, maize stages and years. Increase in altitude positively affected the population density of *B. fusca* and the resultant infestation and yield loss. Crop injury variables were higher and grain yield was lower in unprotected maize plots compared to the chemically protected.

A better understanding of the ecology of maize stem is both important not only for assessing the rate of spread but also for predicting the impact of agricultural practices on the dynamics of stem borer populations. It essential to monitor the survival of diapausing larvae, flight period of moths, ovipostion and larvae population. More studies from different agro ecologies for longer periods, including years of unusual weather are recommended in order to

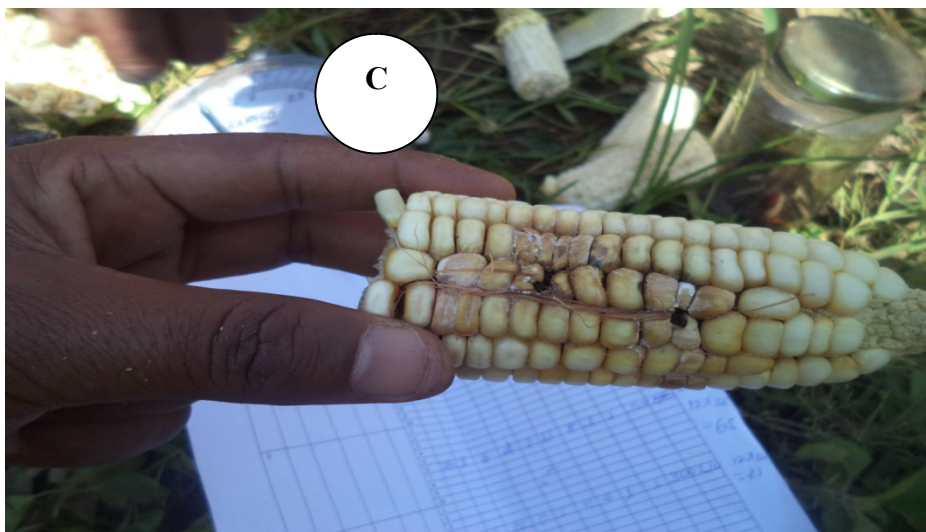
have better understanding on the diapause of larva, survival, population density of moths and the subsequent levels of infestation.

Moreover, there is a need to create awareness among farmers about the yield loss and management methods to minimize the damage caused by stem borers. Cultural practice such as crop diversification; disposal of crop residues after maturity can reduce initial establishment of stem borer infestation. Planting of maize at the beginning of April and May in Hawassa Zuria and Wolaita Sodo, respectively may encounter infestation by the first generation, but could be no longer suitable for oviposition and consumption by second-generation *B. fusca* larvae. The second generation, therefore, could be regarded as low in economic importance on early planted maize.

Appendix 1: Photos of developmental stages of the maize stalk borer, *Busseola fusca*: eggs (A), larvae (B), pupae (C) and adults (D).



Appendix 2: Injury of the stalk borer *Busseola fusca* on leaves (A), in the stem (B) and on the cob of maize (C and D).



BIOGRAPHY

The author, Abrham Taddele was born in Amhara region, East Gojam Zone, Gozamin woreda, Yebo Kebele on April 5, 1986. He attended his elementary school education in dilbetgil and secondary education in Debre Markos Senior Secondary Comprehensive School. He joined Haromaya University in 2006 and graduated with a Bachelor of Science Degree in Crop production and protection in 2008. After graduation, he joined Hawassa University in February 2009 to pursue his study for Master of Science degree in crop protection and graduated in June 2011. After completion of MSc degree, he employed in Wolaita Sodo University as lecturer and he served for two years. Then, he joined School of Graduate Studies in Hawassa University in October 2014 to pursue his PhD study in Agricultural Entomology