STUDY ON THE BIOLOGY AND SOME ECOLOGICAL ASPECTS OF *CHILO PARTELLUS* (SWINHOE) (LEPIDOPTERA: CRAMBIDAE) IN RELATION TO ITS ALTITUDINAL EXPANSION

By

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A thesis submitted to the School of Graduate Studies of Addis Ababa University, in partial fulfillment of the requirements for the Degree of Master of Science in Biology (Insect Sciences)

June, 2005

Acknowledgements

I would like to express my heart felt gratitude and appreciation to my advisors Dr. Emana Getu and Dr. Tsedeke Abate of Ethiopian Agricultural Research Organization (EARO) and Dr. Bekele Jembere of Addis Ababa University for their professional assistance, advice and encouragement through out the study period. In addition to his supervision, Dr. Emana was very kind and helpful to me in various problems I faced during the study. I am thankful to him.

I am grateful to EARO, for giving me the opportunity for graduate studies and paying my salary during study period. I am also indebted to the International Center of Insect Physiology and Ecology (ICIPE) for their financial and material support for my study. I greatly acknowledge the support and cooperation by Mr. Difabachew Belay, coordinator of biological control of stemborer project. The assistance I received from Dr. Fassil Reda, Center Director of Melkassa Agricultural Research Center (MARC), is very much appreciated.

The technical support provided by Mr. Damtew Nigatu and Mr. Walelign Wondiyifraw during the field assessment and Mrs. Meseret Getachew and Mrs. Ayisha Abedella during my laboratory activity is highly appreciated. I am thankful to Mr. Yohannes Tilahun, for his assistance in analyzing data and Mr. Frew Kelemu and Mr. Abraham Gorfu for their help in mapping the study sites. I am indebted to Crop Protection, Food Science, Agronomy and Sorghum section staff of MARC for allowing their laboratory facilities such as growth chambers and incubators for my study.

I am very grateful for my father, mother and sisters and brothers for their prayer and support throughout my study period. I also extend my gratitude to all my classmates and colleagues for their encouragement, support and advice during my study.

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Abstract

Survey was carried out during 2004 main cropping season to investigate the abundance and distribution of stemborers, with emphasis on C. partellus *in central and eastern Ethiopia. Three species of stemborers,* Chilo partellus *(Swinhoe),* Busseola fusca *(Fuller) and* Sesamia calamistis *(Hampson) were recorded.* C. partellus *was dominant and widely distributed species recorded in 96 % of the surveyed sites. On the other hand,* B. fusca *was mainly recorded in highland areas while* S. calamistis *was found at all elevations but in small number. Though studies were not conducted so far on the increasing importance of* C. partellus, *the current survey revealed the expansion of the pest to high elevated areas as high as 2088 masl, where it was not recorded earlier in the country. Observations were also made during the survey on the effect of cropping system, wild host and weediness on percent infestation, stemborer composition and density. The result showed higher level of infestation on monocrops and on fields with wild hosts than intercrop and wild host free fields. Significant variation in level of infestation between crop types was observed. Chi square test revealed strong relationship between cropping systems, crop type, presence or absence of wild host and species composition at intermediate and highland. Borer density was highest at low altitude as compared to intermediate and high altitude.*

Laboratory study was conducted to observe the combined effect of relative humidity and temperature on the biological features of C. partellus. *Temperature levels tested were* 22^0C, 26^0C *and* 30^0C *while the relative humidity were 40 %, 60 %, and 80 %. The result obtained showed variation on potential and realized fecundity, the developmental time of immatures, and adult longevity due to differences in temperature levels, relative humidity and their interaction. Mean duration of* C. partellus *life cycle was 70.2 days at* 22^oC *and 80 % relative humidity whereas it took only 26.5 days to complete its life cycle at* $30\ ^oC$ *and 40 % relative humidity. Average life span adult* C. partellus *ranged 6.9-11.1 days at* $22\ ^oC$ *and 2.3 - 7.2 days at* $30\ ^oC$ *for the different levels of relative humidity tested.*

Although developmental period of immmatures and adult longevity was longest at lowest temperature level, C. partellus *successfully completed its life cycle suggesting reason for its expansion to high elevated areas.*

Key words: *Chilo partellus*, infestation, species composition, interactive effect, developmental time, longevity, fecundity

1. Introduction

Several insect pests attack maize and sorghum crops in Ethiopia and elsewhere in Africa. Lepidopterous stemborers are generally considered to be the most injurious (Ampofo, 1986; Seshu Reddy and Sum, 1992; Youdeowei, 1989). Several species of gramineous stemborers occur in Africa, although their importance varies by crop and region. Stemborers often occur as a complex of species with overlapping spatial and temporal distribution (Overholt *et al.*, 1997).

Maize (*Zea mays* L.) and sorghum (*Sorghum bicolor* Moech) are the main staple food crops in eastern and southern African countries (Minja, 1990). According to Central Statistics Authority (CSA) (2000) report, 29% of the cultivated land is devoted to maize and sorghum production in Ethiopia. Maize and sorghum rank first and second in terms of yield per hectare and total production, respectively. They account for about 41% of the total crop production of the country (CSA, 2000). Maize and sorghum grain are used for human consumption, while the stalks are used as animal feed, fuel, construction and mulching.

All stemborers occurring in Africa are thought to be indigenous, except *Chilo partellus* (Swinhoe). *C. partellus* invaded Africa from Asia in the early 20th century and was first found in Malawi (Tams, 1932). Since arriving in Africa, *C. partellus* has spread to nearly all countries in eastern and southern Africa and there is evidence that it is continuing to spread to western Africa (Nye, 1960; Van Hamburg, 1979; Kfir, 1998). The pest is known to be most damaging to maize and sorghum; however, it also attacks other crops such as pearl millet, finger millet, rice, wheat, sugar cane, foxtail and various wild grass species. In Ethiopia, *C. partellus* is one of the most important insect pests attacking maize and sorghum (Emana Getu *et al.*, 2001).

Elevation was thought to be an important factor in determining the distribution of the two most damaging cereal stemborers, *C. partellus* and *Busseola fusca* (Fuller), in eastern and

southern Africa (Nye, 1960; Seshu Reddy, 1983; Harris and Nwanze, 1992). *C. partellus* occurs below 1500 m, whereas *B. fusca* is found at elevation greater than 600 m (Overholt *et al.*, 1997). Nevertheless, Sithole (1987) challenged the hypothesis and indicated that temperature, rainfall and humidity are the most important climatic factors responsible for the distribution of the two stemborer species. Recently, Emana Getu *et al.* (2002) also indicated that the distribution of *C. partellus* is affected by rainfall and temperature. Moreover, evidence in some locations showed that the exotic stemborer, *C. partellus*, is gradually displacing the indigenous stemborer, *B. fusca* (Overholt *et al.*, 1994; Kfir, 1997). Comparative laboratory study conducted to examine the displacement of the indigenous stemborer *C. orichalcociliellus* in Kenya showed that *C. partellus* had higher fecundity than *C. orichalociliellus* at 25°C and 28 °C, but not at 31 °C (Ofamata *et al.*, 2000). In the recent survey conducted in Ethiopia *C. partellus* was recorded at an elevation of 1900 meters above sea level (masl) (Emana Getu, 2002). This shows that *C. partellus* has widened its adaptation zone and could be a potential pest at higher altitude by displacing the indigenous stemborer, *B. fusca*. In addition to its geographic expansion *C. partellus* has proven to be a very efficient colonizer and devastating pest wherever it occurs (Kfir, 1997; Emana Getu *et al.*, 2001).

The reason why this pest is climbing up the highland which is the potential area for maize production, its destructive nature and why it became a permanent pest in Ethiopia is not well understood. For the understanding of such this phenomenon, knowledge on the biology of the pest and its environmental requirements such as temperature and relative humidity is very crucial. Odum (1983) indicated temperature and relative humidity as the most important factors affecting the biology of a given insect. Fecundity, fertility, developmental period and longevity are the best measures of biology of a given insect (Southwood, 1978). In Ethiopia, no study has been carried out so far to investigate the biology and performance of *C. partellus* under different temperature and relative humidity regimes. Hence, this study was carried out to examine the biology of *C. partellus* at different temperatures and relative humidity regimes under laboratory condition. Surveys were also made at different ecological zones, namely, low,

intermediate and high lands in eastern and central Ethiopia, to assess *C. partellus* pest status at different ecological zones.

2. Objectives

2.1. General Objective

- ❖ To understand factors contributing to the altitudinal expansion and aggressiveness of *C. partellus*

2.2. Specific Objectives

1) To assess *C. partellus* pest status at different ecological zones

2) To investigate the effect of different levels temperatures and relative humidity on fecundity, developmental time and longevity of *C. partellus* under laboratory condition

3. Literature Review

3.1. Production and uses of sorghum and maize

Sorghum is the fourth most important crop in the world and is staple food in most parts of Africa. In Ethiopia, sorghum is one of the leading cereal crops comprising 15- 20 % of the total cereal production. It ranks second in yield per hectare and total production following maize. Sorghum occupies on average 6.75 million hectares of land annually and 7.74 million tones of production. Of which about 90% is used for human consumption. In addition to its uses as grain, sorghum stalk, crop residues and green plants are also used for animal feed, construction material and fuel (Brhane Gebrekidan and Yilma Kebede, 1979; CSA, 2001; CSA, 2004).

Maize, on the other hand, is the third most important cereal crop in the world exceeded only by wheat and rice. It serves as staple food in the tropics and is a major food crop for million of people in eastern Africa (Minja, 1990; Warui and Kuria, 1983). It also serves as raw material for many industrial products. In Ethiopia, it ranks first in yield per hectare and total grain production and second in area coverage exceeded only by teff (CSA, 2001). Maize is widely grown in western, central and eastern regions of the country. Production is possible in a wide range of altitude from 500 to 2300 masl. Around one to three million hectares of land is devoted to maize and over 28 million quintals produced annually (IAR/ CIMMYT, 1993).

Maize is eaten as '*injera*', porridge, bread and '*nifero*'. It can be eaten roasted or boiled as vegetables at green stage. Moreover, maize is used in making local drinks such as '*Tella*' and '*Arekie*'. The leaf and stalk are used for animal feed while dried stalk and cob are used for fuel. It also serves as industrial raw material for oil and glucose production. The most important producers of sorghum in Africa are Nigeria, Sudan and Ethiopia (Van Rensburg and Van Hamburg, 1975).

3.2. Factors limiting maize and sorghum production

Despite the diversity of uses and the wide range of environment in which the crops grow, yields are usually low in Ethiopia and elsewhere in east Africa. FAO (1991) yearbook depicted that yields range from 700 to 1800 $kgha^{-1}$ for maize and 455 to 1471$kgha^{-1}$ for sorghum in east Africa as compared to average yield of 7437 $kgha^{-1}$ and 3951$kgha^{-1}$ for maize and sorghum, respectively, in the USA. In Ethiopia national average yield is very low which is 1tone/ha for sorghum and 2 tones/ha for maize (IAR/ CIMMYT, 1993; CSA, 2000).

Several biotic and a biotic factors are responsible for low productivity of maize and sorghum. The major constraints for the low yield include poor soil fertility, low rainfall, weeds, disease and insect pests (CIMMYT and EARO, 1999). Among the insect pests lepidopterous stemborers take a big share in wreaking damage on both crops (Ampofo, 1986a, 1986b; Seshu Reddy, 1998).

3.3. Distribution of stemborers

A complex of stemborers, with overlapping spatial and temporal distribution occurs in Africa. Maes (1997) and Polazsek (1997) recoded more than 18 species of stemborers in the order Lepidoptera that cause damage to maize and sorghum in Africa. With the exception of *C. partellus*, other stemborers are known to be indigenous to Africa (Overholt *et al.*, 1996). In Ethiopia, three species of stemborers, namely *B. fusca, C. partellus*, and *Sesamia calamists* (Hampson) were reported to attack maize and sorghum (Assefa Gebre-Amlak, 1985; Emana Getu, 1997; and Emana Getu and Tsedeke Abate, 1999). In recent survey, Emana Getu *et al.* (2001) reported three more stemborer species attacking maize and sorghum. These were the lepidopterous *Sesamia nonagrioides botanephaga* Lefebvre and the Coleopterous *Rhynchaenus niger* (Horn) and *Pissodes dubius* (Strom).

The geographic distribution of the two most damaging stemborers of maize and sorghum, *B. fusca* and *C. partellus* is said to be elevation dependent (Ingram, 1958; Nye, 1960; Seshu Reddy, 1983; Harris and Nwanze, 1992). However, Sithole (1987) challenged the hypothesis by indicating the occurrence of *C. partellus* in warmer region while *B. fusca* in cooler area. He showed that the climatic factors, such as temperature, rainfall and humidity influence the distribution of the two stemborers, nevertheless temperature is the most important. Both generalizations may support each other as temperature and elevation are highly correlated. Emana Getu (2002) and Emana Getu *et al.* (2002) indicated that the distribution of *C. partellus* is affected by rainfall and temperature.

The distribution of *C. partellus* includes Afghanistan, Bangladeshi, Cambodia, India, Indonesia, Laos, Nepal, Pakistan, Sikkim, Sri Lanka, Thailand and Vietnam (Bleszynski, 1970; Harris, 1990) and this species is probably indigenous to Asia (Mohyuddin and Greathead, 1970; Harris, 1990). The pest was accidentally introduced to Africa before 1930 from Asia and was first recorded in Malawi (Tams, 1932).

Following its introduction, *C. partellus* has spread to all countries in eastern and southern Africa and there is evidence that it is continuing to spread to west. The African distribution of *C. partellus* now includes Ethiopia, Kenya, Malawi, Mozambique, Somalia, South Africa, Sudan, Tanzania, Uganda, Botswana, Swaziland, Zimbabwe, Burundi, Comoros, Djibouti, Rwanda, Cameroon and Togo (IAPSC, 1985; Harris, 1990; Sithole, 1990; Minija, 1990). In many areas, the exotic stemborer is now considered to be the most damaging to maize and sorghum, particularly at low to mid elevation (Seshu Reddy, 1985; Harris, 1990; Overholt *et al.*, 1994).

The recent study carried out in South Africa revealed that *C. partellus* is expanding its distribution into the high elevation of the eastern Highveld region of the country where *B. fusca* has been the only stemborer (Kfir, 1997). However, *C. partellus* rapidly increased its share of borer population year after year. According to the study, *C. partellus* accounted for 32% of the total borer population within 6 years and 59% within 7 years on maize and grain sorghum, respectively. The fastest population growth of *C. partellus* was

ones in Africa. Overholt (1998) described *S. calamistis* as the most economically important and widely distributed species. Bosque-Perez and Mareck (1990) also reported *S. calmistis* as a serious pest of cultivated cereals in West Africa. In Ethiopia, the pests occur sporadically regardless of elevation and temperature limits (Assefa Gebre-Amlak, 1985; Emana Getu and Tsedeke Abate, 1999).

3.4. Economic importance of stemborers

The lepidopterous stemborers that cause damage to maize and sorghum in Africa belong to three families: Crambidae, Noctuidae and Pyralidae (Maes, 1997). Their hosts are found in three main plant families: Cyperaceae, Gramineae (Poaceae) and Typhaceae (Emana Getu, 2002). Yield losses due to stemborers may vary from 10% to total loss (Matthee, 1974; van Rensburg and Bate, 1987). Among the existing stemborers the indigenous noctuids, *B. fusca* and *S. calamistis*, and the exotic Crambidae, *C. partellus* are the most economically important pests in maize and sorghum (Seshu Reddy, 1983; Assefa Gebre-Amlak, 1985, 1988; Harris and Nwanze, 1992; Overholt *et al.*, 1997; Van Den Berg *et al.*, 1997; Emana Getu and Tsedeke Abate, 1999; Emana Getu, 1997; Emana Getu *et al.*, 2001, 2002).

Damage symptoms produced by most stemborers are similar. The first instars feed initially by scraping in leaf whorls of the growing plants and result in window panning and pinholes. The older larvae bore into the stems and kill the central growing point producing 'deadhearts'. On maize the larvae also bore into the cobs and feed on the developing grain. Stem tunneling weakens the stem and interferes with the translocation of nutrients and metabolites in the plant resulting in malformed grains. In general, the damaged plants have poor growth, reduced yield and more susceptible to wind damage and secondary infection (Seshu Reddy, 1998).

Grain yield losses in maize and sorghum vary depending on cultivars, age of the crop at time of infestation and density of the borer population (Seshu Reddy and Walker, 1990; Warui and Kuria, 1983). In Uganda 56% grain yield loss was observed on sorghum

infested with *C. partellus* 20 days after emergence (Starks, 1969), while in Kenya losses ranged from 2 to 88% (Seshu Reddy, 1988). Moreover, Seshu Reddy *et al.* (1989), recorded 80% grain yield loss with eight *C. partellus* larvae per plant infested three weeks after emergence whereas the same density gave statistically insignificant losses when infested 60 days after emergence.

C. partellus is the most important stemborer in Mozambique and yield losses greater than 50% are common (Sithole, 1990). The same author reported sorghum yield losses ranging from 50-60% due to *C. partellus* in Zimbabwe. Kfir (2001) estimated more than 50% yield losses due to *C. partellus* in maize and sorghum in western Transvall and northwestern Orange Free State in South Africa. Ajayi (1987) reported a yield loss of 49% in sorghum crop in the northern Guinea where *B. fusca* predominates. In Burundi attacks by *B. fusca* occasionally caused yield reduction of 30-50% (Muyango, 1987 cited in Bosque- Perez and Shulthess, 1998).

In Ethiopia, Assefa Gebre-Amlak (1985) and Emana Getu and Tsedeke Abate (1999) recorded yield losses ranging from 10 to 100% due to stemborers. Among the stemborers recoded in Ethiopia, *B. fusca* and *C. partellus* are the most important stemborers ranking first and second, respectively, in abundance and distribution (Emana Getu *et al.* 2001). Observations indicated that *C. partellus* preferred sorghum to maize, while *B. fusca's* preference was the reverse (Emana Getu, 2002).

3.5. Biology of *C. partellus* and *B. fusca*

Harris (1989, 1990) studied and reviewed the biology and ecology of *C. partellus.* According to the studies adult emerge from pupae late after noon and early evening and are active at night. During the day they rest on plants and plant debris and are seldom seen, unless disturbed. Mating usually takes place soon after the female emerge and lay egg on two to three subsequent nights. Batches of 10-80 overlapping eggs are laid on the underside of leaves mainly near the mid-ribs. Adults are usually short lived staying 2-5

days and do not fly long distance away from emergence sites. Eggs hatch 4-8 days after laying mostly early in the morning.

Early instars larvae start feeding in the leaf whorl. The older larvae leave the whorl and tunnel into stem and feed for 2-3 weeks. After completion of larval development pupation occurs in the stem for 5-12 day. Under favorable conditions, the life cycle is completed in 25-50 days and five or more successive generations may develop during a growing season. During cold and/or dry conditions, larvae may enter into a resting stage (diapause) in stem and stubbles where they may stay up to six months before pupating. With the onset of rainfall during the next growing season, the diapausing larvae pupate giving rise to the first generation moth.

After its first recognition by Fuller (Fuller, 1901 cited in Harris and Nwanze, 1992), several workers studied the biology and ecology of *B. fusca* (Unnithan, 1987; Van Rensburg *et al.*, 1987; Assefa, 1989a; Unnithan and Paye, 1990; Kfir and Bell, 1993). The studies showed local variation in life cycle depending mainly on climate. Harris and Nwanze (1992) summarized the basic pattern of life cycle as follows. Adults mostly emerge from pupae in the stem between sunset and midnight and are active at night. During the day, they rest on plants and plant debris and do not fly unless they are disturbed. Soon after emergence, the female release pheromones to attract males for mating. Once mating is completed, the female search for suitable host plants and oviposition take place. The female lay a total of 200 eggs during the 3-4 nights following emergence, where 30-100 batches of eggs are laid at a time. The eggs are hemispherical in shape measuring 1mm diameter and have about 70 crenulations (ridges) on egg shells.

Larvae hatch after a week and ascend to feed on young leaves before entering in to the leaf whorl. Later on, they bore into stem tissues and feed for 3-5 weeks resulting in extensive tunnels in stems and maize cobs. This stage of larval feeding in the stem will kill the central leaves and growing points producing 'deadhearts'. Sometimes the larvae leave the stem that it was feeding initially, especially if it has been severely damaged, and bore in to other stems. There are 6-7 larval instars and larval development generally takes

24-36 days before pupation. A fully grown larva is 40 mm long and usually has creamy white color often with distinctive gray tinge. The last instars larvae pupate in the tunnel after excavating emergence hole in a stem to facilitate exit of adult moth.

Adult emerge 9-14 days after pupation. The life cycle is completed in 7-8 weeks when the conditions are favorable. During unfavorable condition, i.e. dry and cold weather, larvae enter into a diapause for six months or more in stems stubbles and other plant residues before pupating during subsequent favorable season. Sharma (1993) noted that among three generations usually produced, the first generation is very damaging causing significant crop loss. The third generation larvae enter into diapause at the onset of dry season. Similar phenology was reported in Ethiopia by Assefa Gebre-Amlak (1988).

3.6. Stemborer control methods

There are several stemborer control methods. These include host plant resistance, cultural control, biological control and chemical control which can be used either singly or being integrated.

3.6.1. Host plant resistance

This is the most important and promising way to reduce damage and yield loss due to stemborers. The mechanism of host plant resistance could be either by resistance to initial attack, antibiosis once attacked or tolerance to attack (Seshu Reddy, 1998). Nwanze (1997) and Singh *et al.* (1983) indicated that host plant resistance is generally the most farmers' friendly pest control option. Use of resistant varieties was also suggested as one of the promising means of stemborer control (Bowden, 1976; Girling, 1980 and Van Resburg *et al.*, 1988). Hence, much effort has been made by scientists' worldwide to develop resistant maize and sorghum varieties against stemborers.

In response to efforts made to screen resistant genotypes against *S. calamistis* and *E. saccharina* at the International Institute of Tropical Agriculture (IITA), maize

populations with moderate resistance were identified (Bosque Perez *et al.*,1997). Burton *et al.* (1999) identified seven inbreed lines in Spain that are resistant to *S. nonagrioides*. In India two varieties (KE and CML 71) showed good level of resistance against stemborers (Yuma *et al.*, 2000). Ampofo *et al.* (1986 b) screened several local and exotic maize lines against *C. partellus* and identified Inbred A as susceptible, MP 702 moderately resistant and IC21-CM and MP 704 highly resistant.

In varietal screening more success has been achieved in sorghum than maize. Pradhan (1971), Jotwani (1978), Jotwani and Davies (1980) and Jotwani and Agarwal (1982) selected 26 lines as promising source of resistance after screening 6243 world sorghum germplasm collection. After evaluating 70 sorghum varieties against stemborers, Singh *et al.* (1983) reported significant variation in leaf feeding injury, number of hole and percent deadhearts and tunneling. Sirvastava (1985) in India identified a number of sorghum lines after screening under natural and artificial conditions. Seshu Reddy (1983, 1985) identified IS NOS. 1044, 1151, 3902, 4213, 4405, 5613, 10364, 10370, 10711, 12447, 18326, 18427, 18479, 18517, and 18676, S-178, Tx2780 and A & B Tx2756 as multiple source of resistance to stemborer complex in east Africa.

Several mechanisms are utilized by resistant maize and sorghum varieties/lines against the attack by *C. partellus* and *B. fusca*. These include non-preference for oviposition, reduced feeding, reduced tunneling, tolerance to leaf damage, dead heart and stem tunneling and antibiosis. In addition, morphological, physical, chemical and other plant characteristics and non-plant factors such as photo and geotactic stimuli were involved (Dabrowski and Kidavai, 1983, Saxena, 1985, 1990; Kumar and Saxena, 1992; Van Rensburg and Malan, 1982; Kumar, 1993).

As the result of the screening made to identify source of resistance against stemborers, more than 190 genotypes of sorghum with varying level of resistance to *C. partellus* and *B. fusca* were known between 1074 and 1989. However, most cultivars were not accepted by farmers due to some undesirable characteristics such as late maturity, panicle compactness, reduced crop height and poor vigor (Nwanze, 1997; Sharma, 1993). In

Ethiopia, Emana Getu (2005, in press) screened a number of maize and sorghum genotypes and come up with different level of resistance and especially he is advancing the promising sorghum genotypes by applying breeding techniques.

3.6.2. Cultural control

Several cultural practices serve sorghum and maize stemborer controls mainly by disrupting or slowing down the population build up. These include manipulation of planting time, tillage, mulching, spacing, fertilizer application, intercropping, crop rotation and crop residue management (Seshu Reddy, 1998).

Early sown sorghum is damaged more severely as compared to late sown one in northern Indian state (Seshu Reddy, 1985). Study in Tanzania also showed that the late sown maize largely escaped *B. fusca* attacks (Swaine, 1957). On the other hand, Warui and Kuria (1983) found lower number of *C. partellus* and *C. orichalcociliellus* per plant in early-planted maize. In Ethiopia, according to Assefa Gebre-Amlak (1988) early sown maize (in mid of April) was less affected by *B. fusca*. In more recent study in the southern part of the country Emana Getu and Tsedeke Abate (1999) found high infestation of *B. fusca* both in extra early and late planted maize.

Tillage reduces borer population by burying them deep in the soil and/or exposing to adverse weather and biotic factors (Seshu Reddy, 1998). In South Africa it was shown that plaughing and disking destroy 24% of the pest population in sorghum and 19% in maize (Kfir *et al.*, 1989; Kfir, 1990). In Uganda mulching new crops with untreated crop residue resulted in constant infestation by borers from the old stalks (Mohyuddin and Greathead, 1970). Emana Getu (1997) and Emana Getu and Tsedeke Abate (1999) observed 100% infestation by *C. partellus* in areas where untreated old stalks were used for soil conservation.

Spacing not only affects rate of plant development, but also affect pest population and ovipostion sites and food searching behavior of the pest (Lawani, 1982). Mathez (1972)

reported mortality rate as high as 100% during migration of first instar *C. partellus* larvae to the funnel of the plant or other plants in the vicinity.

Singh and Shekhawat (1964) reported an increase in the infestation of *C. partellus* and *Sesamia spp.* with increase in the level of nitrogen application on maize. They also found lowest infestation with no nitrogen. In Uganda sorghum plots fertilized with nitrogen and phosphorous had more *C. partellus* than unfertilized plots (Starks *et al.*, 1971). Siddiq (1972) found out that the application of nitrogenous fertilizer to sorghum in Sudan increased the infestation of *C. partellus.*

Alternating maize and/ or sorghum with crops from unrelated families like leguminous or root crops will enable to reduce stemborers population build-up. Seshu Reddy (1985) discouraged sequencing closely related crops such as maize and sorghum.

Intercropping is a traditional practice widely used by subsistence farmers in many tropical countries. The modifications of the microenvironment as the result of intercropping influence the plant infestation, development and movement of insect pests (Otieno, 1986; Omolo *et al.*, 1993). Intercropping maize and sorghum intensified *C. partellus* infestation as compared to their monocrops (Amoako- Atta *et al.*, 1983; Ogwaro, 1983). On the contrary, sorghum intercropped with non-host crops, such as cowpea (Omolo and Seshu Reddy, 1985) reduced *C. partellus* damage. Ampong- Nyarko *et al.* (1994) found reduced number of *C. partellus* in sorghum cowpea intercrop. Similarly, Skovgard and Pats (1996) recorded fewer larvae and pupae of *C. partellus* in maize intercropped with cowpea in Kenya. In Ethiopia, Emana (2005) reported that intercropping maize or sorghum with haricot bean at 2:1 ratio significantly reduced stem borer infestation.

Appropriate destruction and disposal of stubbles and stalks is essential as they serve as initial source of stemborers. Several workers recommended destruction of crop residues and stubble to reduce borer infestation (Ingram, 1958; Nye, 1960; Seshu Reddy, 1985a; Unnithan and Seshu Reddy, 1989). However, as the stalks are used for building, fencing,

animal feed and fuel other options have been suggested. Adesiyun and Ajayi (1980) suggested partial burning of sorghum stalks, which can kill 95% of *B. fusca* larvae without damaging the stalks. Taley and Thakare (1980) recommended the practice of chopping stalks to control *C. partellus*. To control *B. fusca* in Nigeria, Harris (1962) and Ajayi (1978) suggested spreading the stalks thinly in the field to expose the larvae to adverse weather conditions. Similarly, Assefa Gebre-Amlak (1988) recommended horizontal placement of the stalks in thin layers on the ground in Ethiopia.

3.6.3. Biological control

Natural enemies are usually not sufficiently abundant to keep stemborer population at low levels (Kfir, 1995). The impact of naturally occurring fungi, bacteria, protozoa, viruses and nematodes is often mitigated by the presence of long dry periods between cropping seasons and lack of physical contacts between stemborer larvae in the stem. The latter is also a serious constraint for the application of commercially produced microorganisms such as *B. thuringiensis*. Nematodes and microbial pathogens have been reported to infect all stages, but their impact is low under natural condition (Kfir, 1990; Overholt *et al.*, 1997). Combination of the different approaches of classical biological control, conservation of indigenous natural enemies, application of commercially produced microorganisms and redistribution of locally important natural enemies may provide a suitable management strategy for the sustainable control of *C. partellus* in Africa (Bonhof *et al.*, 1997).

Indigenous parasitoids of African stemborers have expanded their host ranges to include the exotic stemborer, but they do not appear to effectively regulate densities at acceptable levels (Oloo and Ogeda, 1990; Kfir, 1992). Because of the economic importance of *C. partellus*, and its status as an introduced pest, it has been the target of three classical biological control attempts in Africa. The Commonwealth Institute of Biological Control (CIBC) imported nine species of parasitoids of *C. partellus* from India and released these in Uganda, Tanzania, and Kenya from 1968-1972 (CIBC, 1968-72). In South Africa, 13

exotic parasitoids were introduced from 1977 to 1993 (Kfir, 1994). No establishments were reported in either of the programmes.

Another attempt to introduce exotic parasitoids for control of *C. partellus* was initiated in Kenya in 1991 by the International Centre of Insect Physiology and Ecology (ICIPE) (Overholt, 1993). *Cotesia flavipes* was selected as the first candidate for introduction because of its history of success outside of Africa, and its importance as a parasitoid of stemborers in its aboriginal home (Overholt *et al.*, 1994a). The first release was made in Kenya in 1993. Currently, the parasitoid is successfully established in Kenya, Tanzania, Uganda, Zambia and Ethiopia and gives tremendous suppression of stemborers which range from 10-40% (Omwega *et al.*, 1995; Overholt *et al.*, 1997, Emana Getu *et al.*, 2003).

3.6.4. Botanical control

Botanical extracts have been used traditionally by resource limited small-scale farmers in Africa to protect their crops from damage of pests. In Zambia, *Tephrosia volgelii*, leaf extracts were used as phagodeterrents and prevented ovipostion by *C. partellus* on maize. Studies showed that the percentage of damage by stemborers in control plots was almost three times higher than those sprayed with a 15% *T. vogellii* extracts. Investigations made at ICIPE on the use of neem seed (*Azadirachta indica*) revealed similar reduction in stemborer attack when compared to insecticide control (Seshu Reddy, 1998 cited in Polaszek, 1998).

In Tanzania *Tephrosia vogelii*, *Neurautanenia mitis* and *Cassia didymobotrya* plants gave promising results in controlling stemborers (Mallya, 1986; Marandu *et al.*, 1987). A preliminary field test in Ethiopia showed that application of extracts of fruits of chinaberry (*Phytolacca dodecandra* L.) and pepper tree (*Schinus molle* L.) significantly reduced the levels of leaf infestation and dead heart injury due to larvae of the maize stemborer, *B. fusca* (Assefa Gebre-Amlak and Ferdu Azerefegne, 1999). Moreover, application of extracts of neem berries (seed) and Pyrethrum flowers at 8% concentration

resulted in 90 and 100% mortality to first and second instars stemborer larvae respectively with three days under laboratory condition (EARO, 1999).

3.6.5. Chemical Control

In Africa, exclusive control of maize and sorghum stemborers by insecticides is uneconomical and not practical for resource limited small-scale farmers. Despite its limitation, chemical control has been used by large-scale and government farms for stemborer control (Seshu Reddy, 1998). Moreover, it was recommended as powerful tool in treating outbreaks (Bary and Andrew, 1971; Kishore and Jotwani, 1982; Kishore, 1989; Pal and Das, 1997).

Consideration of specific insect habitats, peak period of activity and vulnerable stage of the pest is essential for efficient and successful control (Kishore, 1989). Knowledge of economic thresholds (ETLs) for different stemborers is also important for cost effective application and minimum impact on environment (Pal and Das, 1997). In India, Pal and Das (1997) and Van Den Berg *et al.* (1997) recommended 10-25% deadhearts for sorghum seedling 20 days after emergence for the application of endosulfan 35% EC and carbofuran 3G. Several factor influence ETLs such as seasons, location, socioeconomic conditions, cost of inputs, value of the produce and productivity potential of the crop (Singh, 1997).

Several insecticides have been screened for the control of maize and sorghum stemborers in different regions in Africa. Insecticides that have been found effective as spray or dust treatments include carbofuran, carbaryl, deltamethrin, endosulfan and synthetic pyrethroids (Seshu Reddy, 1985; Ajayi, 1989; Minja, 1990; van Rensburg and van den Berg, 1992). Leaf whorl placement of granular or dust application of endosulfan, phenthoate, quinalphos, carbaryl, malathion, fenvalerate and endrin was also found to effectively control maize and sorghum stemborers (Thobbi *et al.*, 1968; Ahmed and Young, 1969; Kishore, 1989; Pal and Das, 1997). In Ethiopia, application of carbaryl

WP, endosulfan EC, cypermethrin G and cymbush EC was recommended for the control of *B. fusca* (Assefa Gebre-Amlak, 1982; Emana Getu, 1997).

3.6.6. Integrated stemborer management

Stemborers control using only one method has been proved to be difficult by many scientists working in the area (Minja, 1990; Brownbridge, 1991; ICIPE, 1995; Kfir, 1994; Skovgard and Pats, 1996). Relying on single control method like chemicals may also result in undesirable consequences such as pesticide resistance development, secondary pest out breaks, host plant resistance breakdown, environmental pollution and hazards (Chadwick and Marsh, 1993). Effective chemical control of stemborer has been hampered by high cost involved and inefficacy as the result of cryptic feeding behavior of the stemborer (Kfir, 1992; Overholt, 1998). Moreover, overlapping generation of stemborer, *C. partellus* in particular (Kfir, 1994; Kfir and Bell, 1993), rendered chemical control of the stemborers unsatisfactory.

The role of cultural practices such as intercropping in suppressing stemborers population may be limited (Oloo, 1989; Skovgard and Pats, 1996). Other cultural practices like crop residue destruction, tillage and fertilizer management haven't get wide acceptance due to multiple uses of crop residue, shortage of labor and lack of finance. Unavailability of the desirable agronomic characters such as crop height, plant vigor, panicle compactness, high yield limited use of host plant resistance (Nwanze, 1997; Sharma, 1993). Though botanical like neem gave promising results, it is not widely used (Mihm, 1994).

To address one or more problems arising from use of single control method and have sustainable control of stemborers integrating different control methods in compatible manner would be the best solution (Seshu Reddy, 1985; Minja, 1990; Overholt *et al.*, 1997 and Pal and Das, 1997). Betberder (1989) suggested to have directed effort towards an integrated approach particularly with one, which incorporates biological control in order to improve cereal production and insect pest management. Eman Getu *et al.* (2004) reported the significance of integrated stemborer management in Ethiopia and also pin

pointed compatible components that can be applied under Ethiopian low input farmers' condition.

4. Material and Methods

4.1. Study sites

A field assessment was conducted on sorghum/ maize farms in central and eastern Ethiopia. The survey was made on subsistence farmers' fields during 2004 major cropping season at vegetative and maturity stages of the crop. The survey covered three altitude groups high (Chiro, Hirna), medium (Badessa, Assebot) and low (Wolenchiti, Meisso). Three representative locations were selected from each altitude groups for the surveys. The areas having altitudes (meters above sea level) below 1450m were classified as lowlands whereas areas between 1450m-1800m and above 1800 masl were classified as intermediate and highlands, respectively. The rainfall distribution pattern of the surveyed region is bimodal (Belay *et al.*, 1998). The area receives about 45% of annual rainfall during the long (major) rainy season that extends from July to October, whereas the short rainy season extends from April to June and receives about 25% of the annual rainfall.

4.2. Field assessment

From each location, three maize and/ or sorghum fields were selected randomly and percent infestation, species composition and stemborer density were recorded. The cropping system (monocrop and/or intercropping), weediness and presence of wild host were recorded for each sampled field. The levels of weediness were determined subjectively in to clean, some and a lot of weeds. The effects of cropping system, weediness, presence/ absence of wild host on percent infestation, stemborer species composition, stemborer density, severity and deadheart count were investigated for the three altitude groups. Temperature, relative humidity, altitude and longitude were also recorded. The current temperature and rainfall data were compared with the data collected over the past ten years for those locations whose meteorological data is available.

Percent infestation per field was determined at vegetative stage by randomly selecting five quadrates of '4 m x 4 m' each in an 'X' fashion. The total number of plants in the quadrates, plants with 'deadheart', leaf damage and tunneled stem were recorded. Percent infestation was calculated by dividing the number of infested plants to the total number of plants in the quadrates and multiplying by 100. Five heavily infested maize and/or sorghum plants were selected and cut at the ground level from each field at vegetative (before ear/ head formation) and maturity growth stages and dissected for species composition determination. Density per plant was determined by randomly removing 20 maize and/or sorghum plants per field and counting the number and type of stemborer per plant.

Investigation on wild host (presence or absence) was made in and around each field. Severity was recorded subjectively by the aid of reference sheets. Severity value ranged from 1-9 where 1 represents absence of infestation while 9 refers very high level of infestation and damage due to stemborers. Deadheart was determined by counting the number of individual sorghum and or maize plants whose central leaves and growing points were killed due to stemborer attack. Insect identification was done using field identification guide, microscope, comparing with voucher specimens and by assistance from experienced professionals. The coordinates of the survey sites were recorded using GPS (Global Positioning System). The survey sites were mapped using Arc View GIS software.

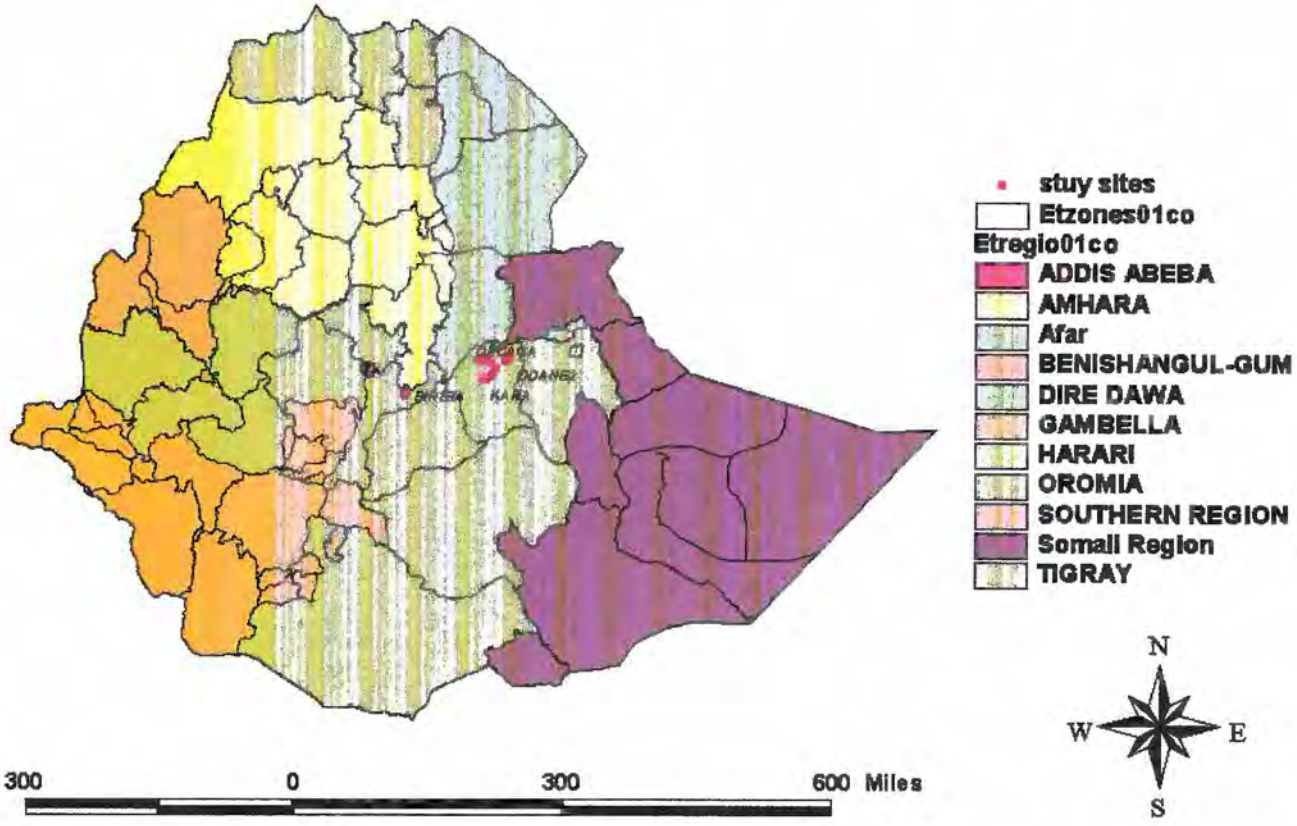

Fig. 1 Field assessment sites

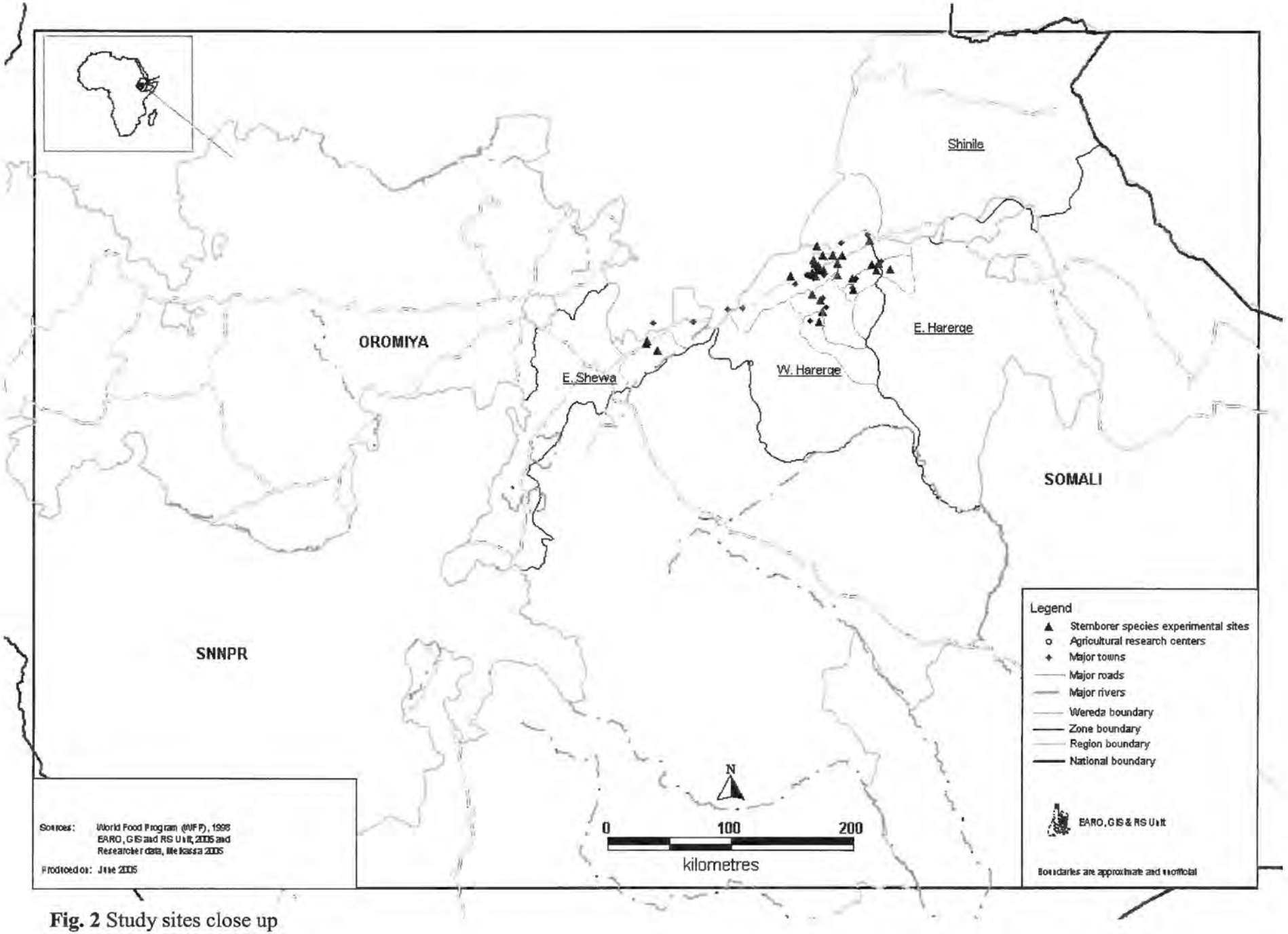

Fig. 2 Study sites close up

4.3. Laboratory Study

4.3.1. Insect collection and rearing

C. partellus larvae and pupae were collected from experimental fields of Melkassa Agricultural Research Center (MARC). MARC has an annual rainfall of 742.7 mm and average maximum and minimum temperature of 28°C and 14.4°C, respectively. The larvae/ pupae were collected by dissecting infested maize/sorghum. Collected larvae were given a fresh piece of maize stem and kept in plastic container (26 cm x 20 cm x 7 cm) covered with fine mesh screen and labeled and taken to MARC entomology laboratory. In the laboratory the collected larvae were transferred individually into 9cm diameter petri dish. In all experiments the maize variety Melakass-1 was used as food source for the larvae.

Once the larvae pupated, they were sexed and transferred to a clean (30 cm x 30 cm x 30 cm) Perspex sleeve cage before adult emergence. Soon after adult emergence, young maize shoots were placed in the cage as an oviposition substrate. Two cotton balls soaked with 20% sugar water solution were also placed in small vials (7 cm x 2.5 cm) at the corner of the cage to serve as food source for the emerging adult moths. Eggs laid were collected daily and used for different experiments.

4.3.2. Laboratory evaluation

Developmental time, adult longevity and potential fecundity of *C. partellus* were studied at three temperatures (22°C, 26°C & 30°C) and three relative humidity' (40 %, 60 % & 80 %). Temperatures and relative humidity were monitored by keeping '*in/out hygro-thermometer*' inside each incubator. Humidity's were inspected twice a day and necessary adjustments were made using cold water and fused calcium chloride ($CaCl_2$) whenever of deviation from required regimes were observed. Cold water was placed to raise the relative humidity while $CaCl_2$ was used to reduce the relative humidity. All studies were conducted at 12 L: 12 D photoperiod. The experiment was set up in completely

allowed mate and kept together until their death. The adults were provided with 20% sugar solution and maize shoot to serve as food source and oviposition substrate, respectively. The actual number of eggs the female laid during its life time was recorded for each temperature and relative humidity combinations.

4.4. Data Analysis

Field data were analyzed using the SPSS computer software. The influence of different agronomic practices on stemborer percent infestation, stemborer species composition and stemborer density was tested using ANOVA and independent T test, while the association of factors was tested using Chi square. Laboratory data were analyzed using SAS software in General Linear Model (GLM). Data were checked for normality before they were subjected to analysis. Data, which lacked normality, were transformed using different transformation (square root, logarithmic, reciprocal and arc sine). Significant means were separated using Tukey's Studentized Range (HSD) Test.

5. Results

5.1 Field assessment

The study sites and the distribution of stemborers in the sites were mapped using Arc View GIS software (Fig. 1, 2 & 3). The major stem borers, elevation at which they were found and the crops attacked are shown in Table 1 and Fig. 4. Three species of lepidopteran stem borers were recorded: *Busseola fusca* (Fuller), *Chilo partellus* (Swinhoe) and *Sesamia calamistis* (Hampson). They were found attacking maize and sorghum at elevations ranging from 1342 masl to 2088 masl. *C. partellus* was the most predominant and widely distributed in 96 % of the surveyed sites. *C. partellus* was most abundant species in mid and lowlands; however, it was recorded at an elevation of 2088 masl. *B. fusca* was mainly recorded at highland while *S. calamistis* was recorded at all elevations, but in small number.

The effects of cropping system, altitude, wild host and weediness on percent infestation, severity and deadheart count are given in Table 2. Percent infestation (P=0.048), severity (P=0.019) and deadheart count (P=0.002) were significantly higher in monocrop than in the intercrop. Farms with wild host have significantly higher percent infestation (P = 0.005) and severity (P = 0.009) as compared to wild host free fields. There was no significant difference in percent infestation (P = 0.187), severity (P = 0.499) and deadheart count (P = 0.366) among farms with different levels of weediness. Altitude didn't have influence on percent infestation (P = 0.181); however, significant difference in severity (P = 0.027) and deadheart count (P<0.001) were observed.

Damage due to stemborer on different crops and crop association is shown in Table 3. There was significant difference in percent infestation (P <0.0001), severity (P < 0.0001) and deadheart count (P <0.0001) on different crops. Sorghum intercropped with sesame had the highest percent infestation and deadheart count while maize intercropped with bean had the lowest. Sole sorghum had the highest severity, while maize intercropped with bean had the lowest. The highest deadheart number was recorded in sorghum

intercropped with sesame. In all cases, intercropping with beans reduced percent infestation, severity and deadheart count as compared to sorghum or maize monocrop.

Effect of cropping system, weediness, wild host and crop type on species composition of stemborers at different altitude groups is shown in Table 4 to 6. Chi square test revealed no significant association among cropping system, weediness, wild host with species composition at lowland both at vegetative and maturity stages (Table 4), while there was strong association among the factors at intermediate and higher altitudes (Table 5 & 6). Effect of different crops and crop association on species composition at different altitude groups is shown in Table 7. There was strong relationship between crop types and borer species composition at mid and highlands. The association was not significant at lowland and both at vegetative and maturity stages (Table 7). *C. partellus* was widely distributed and took the big share among the stem borer species available in most cases.

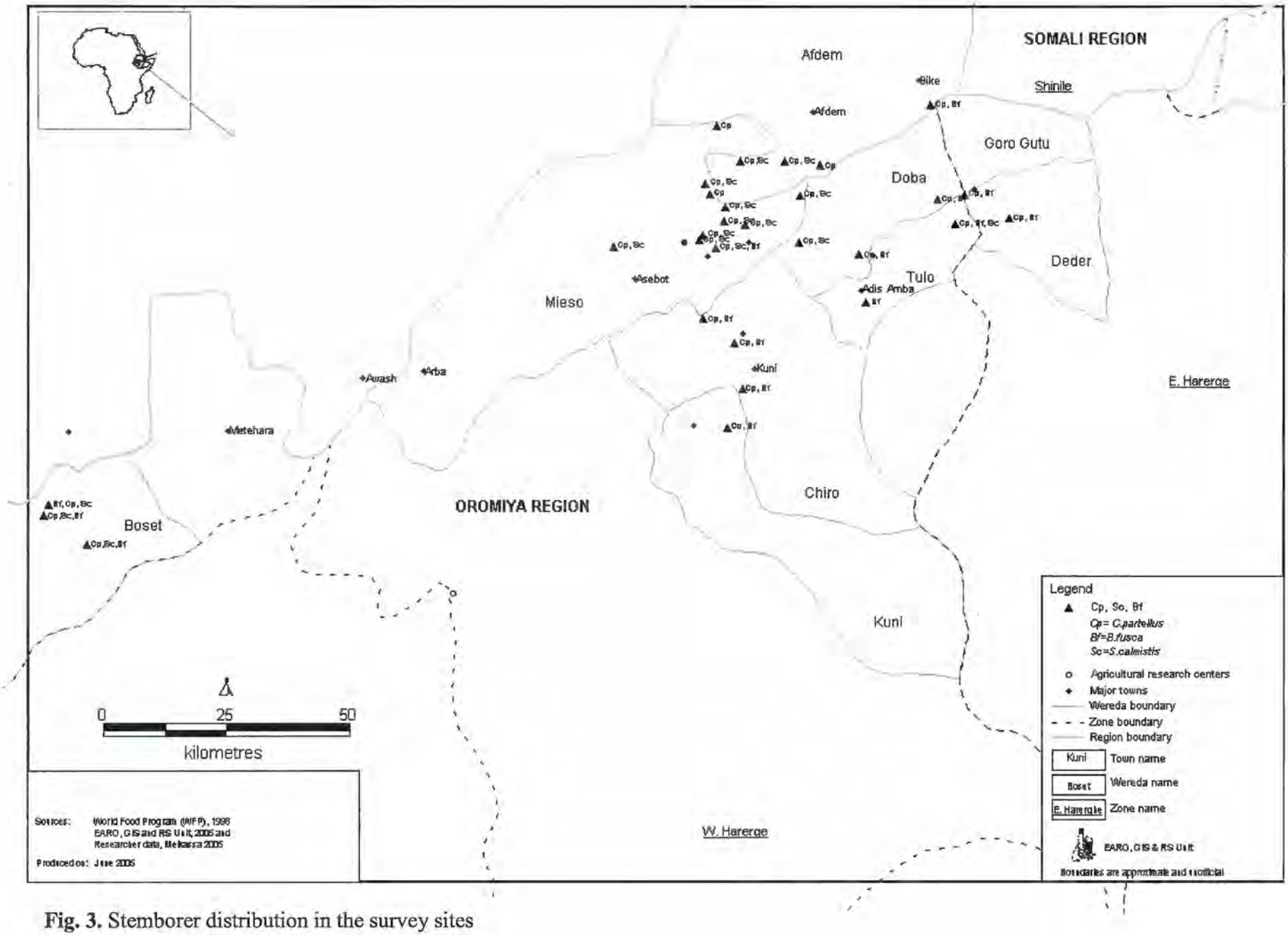

Fig. 3. Stemborer distribution in the survey sites

Table 1. Stem borers recorded in east and central Ethiopia (2004 main cropping season)

Stem borers species	**Family**	**Elevation (masl)**	**Crop attacked**
C. partellus	Crambidae	1342-2088	Maize & sorghum
B. fusca	Noctuidae	1450-2088	Maize & sorghum
S. calamistis	Noctuidae	1342-2088	Maize & sorghum

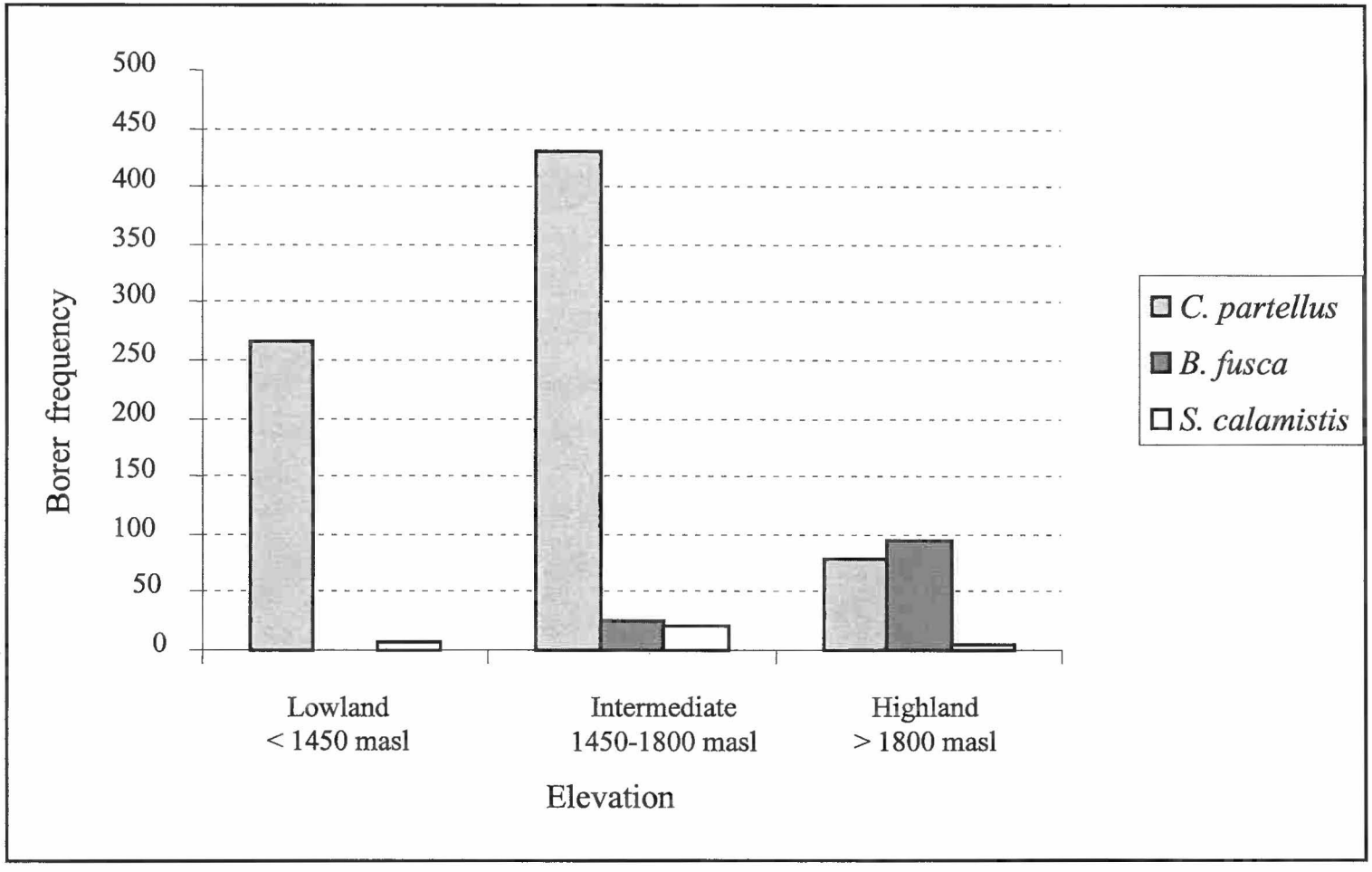

Fig 4. Stem borer distribution at different elevation

Table 2. Effect of altitude, cropping system, wild host, weediness on % infestation, severity and deadheart count by stemborers (mean ± SE)

Type of damage	Altitude			Cropping system		Wild host		Weediness		
	Lowland	**Intermediate**	**Highland**	**Monocrop**	**Intercrop**	**Present**	**Absent**	**Lots**	**Some**	**Clean**
% Infestation	73.2 ± 3.5	77.3 ± 3.8	83.9 ± 2.7	81.9 ± 3.2	73.6 ± 2.8	83.4 ± 2.9	71.5 ± 2.9	75.7 ± 3.9	81.1 ± 2.5	68.9 ± 6.1
Severity	5.5 ±0.2	6.1 ± 0.2	6.3 ± 0.2	6.3 ± 0.2	5.7 ± 0.2	6.3 ± 0.2	5.6 ± 0.2	5.8 ± 0.2	6.1 ± 0.2	5.9 ± 0.3
Deadheart	5.0 ± 0.6	4.2 ± 0.6	0.9 ± 0.2	4.8 ± 0.6	2.6 ± 0.4	3.9 ± 0.5	3.3 ± 0.5	3.1 ± 0.6	3.9 ± 0.5	4.5 ± 0.8

Table 3. Percent infestation, severity and deadheart count on different crops and crop association due to stemborers (mean ± SE)

Crops	% Infestation	Severity	Deadheart
Maize	33.5 ± 7.3	3.8 ± 0.3	0.6 ± 0.3
Sorghum	90.1 ± 2.1	6.7 ± 0.2	5.5 ± 0.6
Sorghum + Maize	65.7 ± 4.3	5.6 ± 0.3	2.9 ± 0.6
Sorghum + Sesame	94 ± 2.8	5.7 ± 0.4	7.7 ± 1.4
Sorghum + Maize + Sesame	81.8 ± 5.9	5.6 ± 0.2	2 ± 0.9
Sorghum + Beans	86.8 ± 4.5	6.3 ± 0.3	0.5 ± 0.2
Maize + Beans	25.8 ± 6.0	3.8 ± 0.6	0.0 ± 0.0
Sorghum + Maize + Beans	76.6 ± 3.6	5.9 ± 1.2	1.3 ± 0.5

Table 4. Effect of cropping system, weediness, wild host and crop type on species composition (%) at lowland

(i) Vegetative stage

Species Composition	Cropping system		Weediness			Wild host	
	Monocrop	Intercrop	Clean	Some	Lots	Present	Absent
C. partellus	94.4 (68)	98 (199)	98.6 (70)	96.8 (90)	96.4(107)	96.1(173)	98.9 (94)
B. fusca	0	0	0	0	0	0	0
S. calamistis	5.6 (4)	2.0 (4)	1.4 (1)	3.2 (3)	3.6 (4)	3.9 (7)	1.1 (1)
P value	0.12			0.67		0.18	

(ii) Maturity stage

Species Composition	Cropping system		Weediness			Wild host	
	Monocrop	Intercrop	Clean	Some	Lots	Present	Absent
C. partellus	100.0 (178)	99.7 (312)	100.0 (182)	100.0 (154)	99.4 (154)	100.0 (333)	99.4 (157)
B. fusca	0	0	0	0	0	0	0
S. calamistis	0.0 (0)	0.3 (1)	0.0 (0)	0.0 (0)	0.6 (1)	0.0 (0)	0.6 (1)
P value	0.45	0.45	0. 34	0.34	0.34	0.15	0.15

Numbers in parenthesis indicate the stemborer count while number outside show percent species composition

Table 5. Effect of cropping system, weediness, wild host and crop type on species composition (%) at intermediate

(i) Vegetative stage

Species Composition	Cropping system		Weediness		Wild host	
	Monocrop	**Intercrop**	**Some**	**Lots**	**Present**	**Absent**
C. partellus	87.4 (243)	94.4 (187)	91.8 (201)	89.1(229)	85..2 (167)	93..9 (263)
B. fusca	6.5 (18)	4.0 (8)	1.8 (4)	8.6 (22)	9.7 (19)	2.5 (7)
S. calamistis	6.1 (17)	1.5 (3)	6.4 (14)	2.3 (6)	5.1 (10)	3.6 (10)
P value	0.021		0.001		0.002	

(ii) Maturity stage

Species Composition	Cropping system		Weediness		Wild host	
	monocrop	**Intercrop**	**Some**	**Lots**	**Present**	**Absent**
C. partellus	93.2 (232)	90.8 (167)	100.0 (212)	84.6 (187)	89.7 (139)	93.5 (260)
B. fusca	6.8 (17)	9.2 (17)	0.0 (0)	15.4 (34)	10.3 (16)	6.5 (18)
S. calamistis	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)
P value	0.107		< 0.0001		0.15	

Numbers in parenthesis indicate the stemborer count while number outside show percent species composition

Table 6. Effect of cropping system, weediness, wild host and crop type on species composition at highland

(i) Vegetative stage

Species Composition	Cropping system		Weediness		Wild host	
	Monocrop	**Intercrop**	**Some**	**Lots**	**Present**	**Absent**
C. partellus	70.7 (41)	32.2 (37)	48.8 (63)	34.1 (15)	53.1(51)	35.1 (27)
B. fusca	27.6 (16)	67.8 (78)	51.2 (66)	63.6 (28)	45.8 (44)	64..9 (50)
S. calamistis	0.0 (0)	0.0 (0)	0.0 (0)	2.3 (1)	1.0(1)	0.0 (0)
P value	<0.0001		0.065		0.034	

(ii) Maturity stage

Species Composition	Cropping system		Weediness		Wild host	
	Monocrop	**Intercrop**	**Some**	**Lots**	**Present**	**Absent**
C. partellus	68.2 (88)	23..3 (27)	37.7 (57)	61.7 (58)	57.7 (101)	20.0 (14)
B. fusca	31.8 (41)	76.7 (89)	62..3 (94)	38.3 (36)	42.3 (74)	80.0 (56)
S. calamistis	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)
P value	< 0.0001		< 0.0001		< 0.0001	

Numbers in parenthesis indicate the stemborer count while number outside show percent species composition

Table 7. Effect of different crops and crop association on species composition (%) under different elevations

i) Vegetative stage

Crop	Lowland			Intermediate			Highland		
	Cp	***Bf***	***Sc***	***Cp***	***Bf***	***Sc***	***Cp***	***Bf***	***Sc***
Maize	-	-	-	83.3 (25)	10.0 (3)	6.7 (2)	-	-	-
Maize + beans	-	-	-	75.0 (12)	25.0 (4)	0.0 (0)	-	-	-
Maize + sorghum	100.0 (81)	0.0 (0)	0.0 (0)	98.5 (134)	1.5 (2)	0.0 (0)	-	-	-
Sorghum	94.4 (68)		5.6 (4)	88.1 (259)	5.8 (17)	6.1 (18)	70.7 (41)	27.6 (16)	1.7 (1)
Sorghum + beans	-		-	-	-	-	27.0 (20)	73.0 (54)	0.0 (0)
Sorghum + sesame	95.7 (67)	0.0 (0)	4.3 (3)	-	-	-	-	-	-
Sorghum + maize + sesame	98.1 (51)	0.0 (0)	1.9 (1)	-	-	-	-	-	-
Sorghum + Maize + beans	-	-	-	-	-	-	41.5 (17)	58.5 (24)	0.0 (0)
P value		0.182			< 0.0001			< 0.0001	

Numbers in parenthesis indicate the stemborer count while number outside show percent species composition

Key: - Cp = *Chilo partellus* Bf = *Busseola fusca* Sc = *Sesamia calamistis*

Table 7. ... continued

ii) Maturity stage

Crop	Lowland			Intermediate			Highland		
	Cp	***Bf***	***Sc***	***Cp***	***Bf***	***Sc***	***Cp***	***Bf***	***Sc***
Maize	-	-	-	100.0 (7)	-	-	-	-	
Maize + beans	-	-	-	37.5 (3)	62.5 (5)	-	-	-	-
Maize + sorghum	99.2 (127)	0.0 (0)	0.8 (0)	90.9 (120)	9.1 (12)	-	-	-	-
Sorghum	100.0 (178)	0.0 (0)	0.0 (0)				68.2 (88)	31.0 (40)	0.8 (1)
Sorghum + beans							13.8 (8)	86.2 (50)	0.0 (0)
Sorghum + sesame	100.0 (138)	0.0 (0)	0.0 (0)						
Sorghum + maize + sesame	100.0 (47)	0.0 (0)	0.0 (0)						
Sorghum + Maize + beans	-	-	-				25.9 (15)	60.3 (35)	13.8 (8)
P value		0.417			< 0.0001			< 0.0001	

Numbers in parenthesis indicate the stemborer count while number outside show percent species composition

Key: - *Cp = Chilo partellus* *Bf = Busseola fusca* *Sc = Sesamia calamistis*

Effect of cropping system, wild host and weediness on borer density per plant is shown in Table 8. There was no significant variation in borer density per plant due to cropping system and wild host. Even though there were variations in borer density per plant due to different levels of weediness, it was not statistically significant ($P < 0.24$) (Table 8). At maturity stage there was significant difference ($P = 0.028$) in borer density among the different elevations (Fig. 5.). Borer density was highest at low altitude as compared to mid and high altitudes. There was no significant difference among crops and crop association in stemborer density per plant (Table 9).

Comparison of the current (2004) meteorological data with the previous 8-10 years data showed no considerable variation in temperature and rainfall for survey sites where *C. partellus* was recorded. However, there was slight increase in minimum and maximum temperatures from September to October (appendix 14 and 18).

Table 8. Effect of cropping system and wild host on stemborer density per plant (mean ± SE)

	Cropping system		Wild host		Weediness		
	monocrop	**intercrop**	**present**	**absent**	**lots**	**some**	**clean**
I. Vegetative							
Borer density/ plant	3.5 ± 0.7	3.3 ± 0.5	3.3 ± 0.4	3.5 ± 0.7	3.6 ± 0.8	3.3 ± 0.4	2.6 ± 0.
P value	0.749		0.813		0.779		
II Maturity							
Borer density/ plant	5.4 ± 0.8	5.3 ± 0.9	5.36 ± 0.83	5.38 ± 0.85	6.2 ± 1.2	4.3 ± 1.2	6.7 ± 1.
P value	0.912		0.990		0.24		

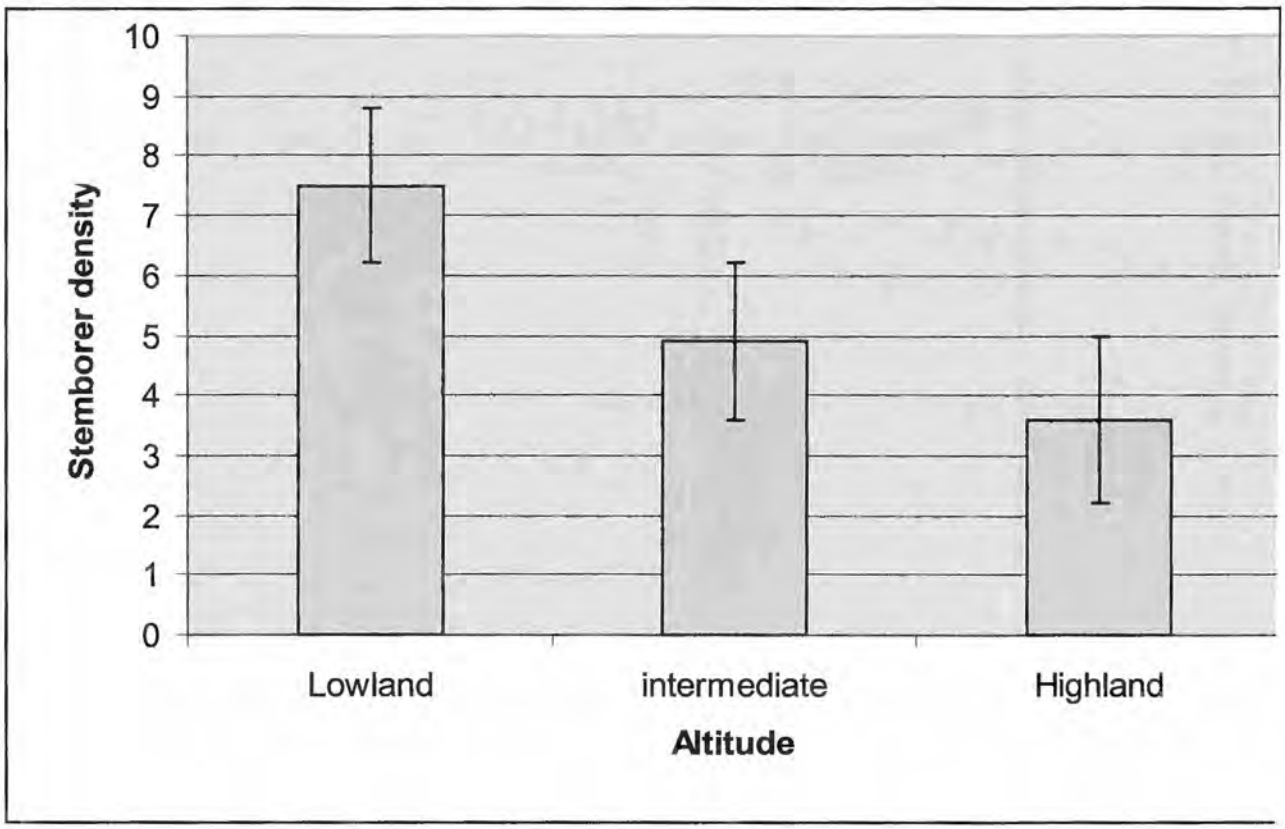

Fig. 5. Borer density per plant at different elevation

Table 9. Effect of different crops and crop association on stemborer density (mean ± SE)

Crop	**Vegetative stage**	**Maturity stage**
	Borers density/plant	***Borer density/plant***
Maize	0.85± 0.15	1.51± 1.01
Maize + beans	2.10 ± 0.00	1.15 ± 0.00
Maize + sorghum	3.57 ± 1.31	6.77 ± 1.57
Sorghum	4.04 ± 0.62	5.89 ± 0.72
Sorghum + beans	2.39 ± 0.28	2.97± 0.51
Sorghum + sesame	3.40 ± 0.75	7.45 ± 3.15
Sorghum + maize + sesame	3.30 ± 0. 00	9.47 ± 0.00
Sorghum + Maize + beans	3.48 ± 0.33	3.48 ± 0.23
P value	0.701	0.098

5.2. Laboratory Experiment

Analysis of variance for the main factors (temperature, and relative humidity) showed that there was significant interaction. Hence, proc sort analysis was used to separate the effect.

5.2.1 Developmental time

Analyses of variance (ANOVA) for the developmental time are shown in (appendix 1-4). Egg laying to egg hatching time (egg period) was significantly affected by temperature ($P<0.0001$), relative humidity ($P < 0.0001$) and the interaction of temperature and relative humidity ($P< 0.0001$) (appendix 1.) Temperature ($P < 0.0001$), relative humidity ($P< 0.0001$) and their interaction ($P < 0.0001$) significantly affected larval developmental time (appendix 2.). Pupal period was significantly affected by temperature ($P < 0.0001$), relative humidity ($P< 0.0084$) and the interaction of temperature and relative humidity ($P<0.0001$) (appendix 3.). The egg to adult development time was significantly affected by temperature ($P < 0.0001$), relative humidity ($P = 0.00055$) and the interaction of temperature and relative humidity ($P <0.0001$) (appendix 4).

The combined effect of different levels of temperature and relative humidity on oviposition to egg hatching time of *C. partellus* is shown in Table 10. Egg period was significantly shorter at 30°C and 80 % relative humidity and longest at 22°C and 40 % relative humidity taking mean days of 3 and 8 respectively.

C. partellus larval period ranged from 17 days at 30°C and 40 % relative humidity to 51.8 days at 22°C and 80 % relative humidity. Significantly shorter larval periods were observed at 26°C and 30°C as compared to 22°C for all relative humidity levels. Successful larval development was observed at 22°C regardless of different relative humidity levels (Table 11).

The combined effect of different temperature and relative humidity levels on pupal period is show in Table 12. Pupal period ranged from 5.5 -12.3 days depending on temperature. Pupal period decreased with increased temperature regardless of the different relative humidity levels.

Despite the delay in pupal period, healthy and viable adults emerged from pupa kept at lower temperature (22^0C) at all levels of relative humidity.

Table 13 compares the effect of temperature on egg to adult emergence at each level of relative humidity. Developmental time from egg to adult emergence was short at higher temperatures and longer at lower temperature. For instance, at 30^0C and 40 % RH, egg to adult development was completed at 26.5 days whereas it took 70.2 day at 22°C and 80 % relative humidity.

The effect of relative humidity on the developmental time of *C. partellus* at different temperature level is shown in Table 14. The effect of relative humidity on developmental time of *C. partellus* was significant for egg period at 22°C and 26°C, for larval period at 30°C, for pupal period at 22°C and egg to adult period at 26°C and 30°C. There was no significant difference in larval period and egg to adult period at 22°C for 60 % and 40 % relative humidity. Egg period and pupal period didn't show significant differences at 30°C for 40 % and 60 % relative humidity. The effects of different levels of relative humidity were not significant for pupal period at 26°C

Results in Table 15 show the effect of temperature on the developmental time of *C. partellus* at different levels of relative humidity. At all relative humidity levels, temperature was inversely related to the different developmental stages of *C. partellus*. Higher temperatures resulted in shorter developmental time and lower temperature in longer temperature. The longest mean developmental time was 70.2 days at 22°C and 80 % relative humidity, while the shortest was 26.5 at 30°C and 40 % relative humidity.

Table 10. Combined effect of different levels of temperature and relative humidity on egg period (mean day ± SE) of *C. partellus*

Temp (°C)	Relative humidity (%)		
	40	60	80
22	8.0 ± 0.0 a	7.5± 0.0 b	7.0 ± 0.0 c
26	6.0 ± 0.0 d	5.0 ±1.0 e	4.0 ± 0.0 f
30	4.0 ± 0.0 f	4.0 ± 0.0 f	3.0 ± 0.0 g
P	<0.0001	<0.0001	<0.0001

Means with the same letter within column and rows are not significantly different at 5 % Tukey's Studentized Range (HSD) Test

Table 11. Combined effect of different levels of temperature and relative humidity on larval period (mean days + SE) of *C. partellus*

Temp (°C)	Relative Humidity (%)		
	40	60	80
22	40.3 ± 1.3d	40.9 ± 1.4d	51.8 ± 2.9 a
26	28.3 ± 0.5 c	23.1 ± 0.3 b	22.1 ± 0.3 b
30	17.0 ± 0.0 a	18.3 ± 0.2 a	21.1 ± 0.5 b
P	< 0.0001	<0.0001	<0.0001

Means with the same letter within columns and rows are not significantly different at 5% Tukey's Studentized Range (HSD) Test

Table 12. Combined effect of different levels of temperature and relative humidity on pupal period (mean days + SE) of *C. partellus*

Temp (°C)	Relative Humidity (%)		
	40	**60**	**80**
22	11.6 ± 0.2 ba	12.3 ± 0.2 a	11.4 ± 0.3 b
26	7.6 ± 0.1 c	7.3 ± 0.1 dc	7.5 ± 0.1 dc
30	5.5 ± 0.2 e	5.9 ± 0.1 e	6.9 ± 1.3 d
P	< 0.0001	<0.0001	<0.0001

Means with the same letter within columns and rows are not significantly different at 5% Tukey's Studentized Range (HSD) Test

Table 13. Combined effect of different levels of temperature and relative humidity on egg to adult emergence (mean days + SE) of *C. partellus*

Temp (°C)	Relative Humidity (%)		
	40	**60**	**80**
22	59.9 ± 1.3 b	60.7 ± 1.4 b	70.2 ± 2.9 a
26	41.9 ± 0.5 c	35.4 ± 0.3 d	33.6 ± 0.3 ed
30	26.5 ± 0.2 f	28.2 ± 0.3 f	30.9 ± 0.6 e
P	<0.0001	<0.0001	<0.0001

Means with the same letter within columns and rows are not significantly different at 5% Tukey's Studentized Range (HSD) Test

Table 14. The effect of relative humidity on the development time (mean days + SE) of *C. partellus* at different levels of temperatures

Temp. (°C)	RH (%)	Egg period	Larval period	Pupal period	Egg to adult
	40	8.0 ± 0.0 a	40.3 ± 1.3 a	11.6 ± 0.2 ba	59.9 ± 1.3 b
22	60	7.5 ± 0.0 b	40.9 ± 1.4 a	12.3 ± 0.2 a	60.7 ± 1.3 b
	80	7.0 ± 0.0 c	51.8 ± 2.9 b	11.4 ± 0.3 b	70.2 ± 2.9 a
	40	6.0 ± 0.0 a	28.3 ± 0.5 b	7.6 ± 0.1 a	41.9 ± 0.5 a
26	60	5.0 ± 0.0 b	23.1 ± 0.3 a	7.3 ± 0.1 a	35.4 ± 0.3 a
	80	4.0 ± 0.0 c	22.1 ± 0.3 a	7.5 ± 01 a	33.6 ± 0.3 c
	40	4.0 ± 0.0 a	17.0 ± 0.0 a	5.5 ± 0.2 b	26.5 ± 0.2 c
30	60	4.0 ± 0.0 a	18.3 ± 0.2 b	5.9 ± 0.1 b	28.2 ± 0.3 b
	80	3.0 ± 0.0 b	21.1 ± 0.5 c	6.9 ± 0.1 a	30.9 ± 0.6 a

Means followed by the same letter within column along each temperature are not significantly different from each other at 5% Tukey's Studentized Range (HSD) Test

Table 15. Effect of temperature on the development time (mean days ± SE.) of *C. partellus* under different levels of relative humidity

RH (%)	Temp (°C)	Egg Period	Larval period	Pupal period	Egg to adult
	22	8.0 ± 0.0 a	40.3 ± 1.3 c	11.6 ± 0.2 a	59.9 ± 1.3 a
40	26	6.0 ± 0.0 b	28.3 ± 0.5 b	7.6 ± 0.1 b	41.9 ± 0.5 b
	30	4.0 ± 0.0 c	17.0 ± 0.0 a	5.5 ± 0.2 c	26.5 ± 0.2 c
	22	7.5 ± 0.0 a	40.9 ± 1.4 c	12.3 ± 0.2 a	60.7 ± 1.4 a
60	26	5.0 ± 0.0 b	23.1 ± 0.3 b	7.3 ± 0.1 b	35.4 ± 0.3 b
	30	4.0 ± 0.0 c	18.3 ± 0.2 a	5.9 ± 0.1 c	28.2 ± 0.3 c
	22	7.0 ± 0.0 a	51.8 ± 2.9 b	11.4 ± 0.3 a	70.2 ± 2.9 a
80	26	4.0 ± 0.0 b	22.1 ± 0.3 a	7.5 ± 0.1 b	33.6 ± 0.3 b
	30	3.0 ± 0.0 c	21.1 ± 0.5 a	6.9 ± 0.1 c	30.9 ± 0.6 a

Means followed by the same letter within columns along each relative humidity are not significantly different from each other at 5% Tukey's Studentized Range (HSD) Test

5.2.2. Longevity

The longevity of adult male and female *C. partellus* was significantly ($P<0.005$) affected by temperature, relative humidity and their interaction except the interaction of relative humidity and sex (appendix 5).

Adult longevity of *C. partellus* was significantly affected by all interaction levels of temperature and relative humidity for both sexes (Table 16). *C. partellus* males lived longer at all relative humidity levels and 30°C. At 22°C, *C. partellus* female lived longer at 60 % and 80 % relative humidity. At 40 % relative humidity, the female lived longer than males at 26°C. In general, adult male and female *C. partellus* lived longer at lower temperature (22°C) regardless of the different levels of relative humidity when compared with 26°C and 30°C.

The effect of relative humidity on longevity of male and female *C. partellus* at different constant temperatures is shown in Table 17. There was no significant difference in adult longevity at all levels of relative humidity under 22°C. At 26°C, female lived longer than male except at 60 % relative humidity. There was no significant difference in male and female *C. partellus* longevity at different levels of relative humidity except for 80 % RH at 30°C.

The effect of temperature on adult longevity of *C. partellus* under different levels of relative humidity is shown in Table 18. The effect pf temperature was significant at all levels of relative humidity for both sexes. At 80 % relative humidity male longevity was longer than female at 22°C as compared to 26°C and 30°C. The longevity of adult *C. partellus* ranged from 2 days at 30°C to 19 days at 22°C.

Table 16. Adult longevity of C. partellus (mean days ± SE) at different levels of temperatures and relative humidity

Temp (°C)	Relative Humidity (%)					
	40		60		80	
	male	female	male	female	male	female
22	8.9 ± 0.5 bac	6..9 ± 0.4 edc	8.7 ± 0.3 bac	9.8 ± 0.4ba	9.7 ± 0.7 ba	11.1± 0.7 a
26	5.1 ± 0.7gf	6.7 ± 0.4 edc	4. 9 ± 0..2 edf	3..5 ± 0.1hg	3.2 ± 0.3 hi	4.4± 0.1gf
30	3.0± 0.2 hi	2.3 + 0.1 i	5.3 ± 0.3 edf	4.2 ± 0.3 hgf	7.2 ± 0.3 bdc	3.1 ± 0.4hi

Means followed by the same letter (s) under each column of relative humidity and across temperature levels are not significantly different from each other at 5 % Tukey's Studentized Range (HSD) Test

Table 17. Effect of relative humidity on adult longevity of *C. partellus* (mean days + SE) under different constant temperatures

Temp (°C)	RH (%)	Sex	
		Male	Female
22	40	8.9 ± 0.5 a	6.9 ± 0.4 b
	60	8.7 ± 0.3 a	9.8 ± 0.4 a
	80	9.7 ± 0.7 a	11.1 ± 0.7 a
26	40	5.1 ± 0.7 bc	6.7 ± 0.4 a
	60	4.9 ± 0.2 ba	3.5 ± 0.1 dc
	80	3.2 ± 0.3 d	4.4 ± 0.1 bc
30	40	3.1 ± 0.0 c	2.3 ± 0.1c
	60	5.3 ± 0.3 b	4.2 ± 0.3 b
	80	7.2 ± 0.3 a	3.1 ± 0.4c

Means followed by the same letter (S) across the row under sex column are not significantly different from each other at 5 % Tukey's Studentized Range (HSD) Test

Table 18. Effect of temperature on adult longevity of *C. partellus* (mean day s+ SE) at different levels of relative humidity

RH (%)	Temp (^{0}C)	Sex	
		Male	**Female**
40	22	8.9 ± 0.5 a	6.9 ± 0.4 a
	26	5.1 ± 0.7 b	6.7 ± 0.4 a
	30	3 ± 0.0 c	2.3 ± 0.1 c
60	22	8.7± 0.3 a	9.8 ± 0.4 a
	26	4.9 ± 0.2 cb	3.5 ± 0.1 d
	30	5.3 ± 0.3 b	4.2 ± 0.3 cd
80	22	9.7 ± 0.7 ba	11.1 ± 0.7 a
	26	3.2 ± 0.3 d	4.4 ± 0.1 c
	30	7.2 ± 0.3 b	3.1 ± 0.4 d

Means followed by the same letter (S) across the row under sex column are not significantly different from each other at 5 % Tukey's Studentized Range (HSD) Test

5.2.3. Potential and Realized Fecundity

The analysis of variance for potential fecundity of *C. partellus* is shown in appendix 6. Temperature (P=0.0096), relative humidity (P<0.0001) and the interaction of temperature and relative humidity (P<0.0001) significantly affected the potential fecundity. The analysis of variance for realized fecundity of *C. partellus* is given in appendix 7. The numbers of eggs laid by female *C. partellus* were significantly affected by temperature (P=0.0006), relative humidity (P<0.0001) and the interaction of temperature and relative humidity (P<0.0001).

The effect of relative humidity on potential and realized fecundity of *C. partellus* at different temperatures is shown in Table 19. Relative humidity significantly (P< 0.05) affected potential and realized fecundity of *C. partellus* at different temperatures. For the three temperature regimes, higher potential and realized fecundity were obtained at 60 % and 80 % relative humidity.

Temperature significantly affected the potential and realized fecundity of *C. partellus* at different levels of relative humidity. In most cases, higher egg load and realized fecundity were obtained at higher temperatures (30°C). At lower temperatures the number of eggs laid and the egg loads were lower. There was no significant difference in potential and realized fecundity at 22°C and 26°C under 40 % and 60 % relative humidity (Table 20).

Table 19. Effect of relative humidity on potential and realized fecundity of C. partellus at different temperatures

Temp (^{0}C)	RH (%)	Fecundity	
		Potential	**Realized**
22	40	591.3 ± 22.9 cd	251.4 ± 8.3 de
	60	692.0 ± 25.3 bc	309.9 ± 11.7dc
	80	650.5 ± 32.6 bcd	341.8 ± 13.7 bc
26	40	542.5 ± 28.5 d	204.4 ± 15.1e
	60	751.0 ± 31.4 ba	349.5 ± 27.9 bc
	80	861.13 ± 27.2 d	414.4 ± 22.8 ba
30	40	753.3 ± 25.3 ba	341.0 ± 27.5 bc
	60	573.4 ± 26.2 cd	232.6 ± 22.2 de
	80	835.6 ± 24.0 a	476.2 ± 16.0 a

Means followed by the same letter (s) within a column along each temperature are not significantly different from each other at 5 % Tukey's Studentized Range (HSD) Test

Table 20. Effect of temperature on potential and realized fecundity of *C. partellus* (mean days ± SE) at different levels of relative humidity

RH (%)	Temp (^{0}C)	Fecundity	
		Potential	**Realized**
40	22	591.3 ± 22.9 b	251.4 ± 8.3 b
	26	542.5 ± 28.5 b	204.4 ± 15.1 b
	30	753.3 ± 25.3 a	341.0 ± 27.5 a
60	22	692.0± 25.3 a	309.9 ± 11.7 a
	26	751.0 ± 31.4 a	349.5 ± 27.9 a
	30	573.4 ± 26.2 b	232.6 ± 22.2 b
80	22	650.5 ± 32.6 b	341.8 ± 13.7 c
	26	861.1 ± 27.2 a	414.7 ± 22.8 b
	30	835.6 ± 24.0 a	476.2 ± 16.0 a

Means followed by the same letter (s) within a column along each relative humidity are not significantly different from each other at 5 % Tukey's Studentized Range (HSD) Test

6. Discussion

Three species of stemborers, *C. partellus*, *B. fusca*, and *S. calamists* were recorded in central and eastern Ethiopia during 2004 main cropping season survey. Similar records were reported in Ethiopia previously (Assefa Gebre-Amlak, 1985; Emana Getu, 1997; Kassahun Yitaferu and Walker, 1997; Emana Getu and Tsedeke Abate, 1999; Mulugetta, 2001) and other parts of Africa (Seshu Reddy, 1983; Van Rensburg *et al.*, 1987; Minja, 1990; Kalule *et al.*, 1997). *C. partellus* was recorded at all elevations, though it was particularly abundant at lowland and intermediate ranges. *B. fusca* was mainly dominant in highlands and cooler areas while *S. calamistis* was recorded at all elevations.

C. partellus was said to be lowland pest occurring below 1500 m (Warui and Kuria, 1983; Overholt *et al.*, 1997; Haile and Hofsvang, 2001). In Ethiopia, Assefa Gebre-Amlak (1985) recorded *C. partellus* at an elevation up to 1700 masl. Moreover, recently Emana Getu (2002) reported the pest at an elevation of 1900 masl. In the current study, *C. partellus* was recorded at an elevation of 2088 masl suggesting that the pest is gradually expanding its ecological niche. The result concur with Bate *et al.* (1991), who reported that *C. partellus* is gaining importance by expanding its geographic distribution to the high elevations of the western Highveld region of South Africa. The current finding is in contrary with Ingram (1958), Nye (1960), Seshu Reddy (1983), Harris and Nwanze (1992) who reported that *C. partellus* is a low elevation stemborer species.

The current survey revealed that *C. partellus* was the predominant species with wide distribution from lowland to highland. In some areas mixed borer population consisted about 94 % *C. partellus*, 4 % *B. fusca* and 1.5 % *S. calmistis* were recorded. This may contradict the country wide survey by Emana Getu (2002) who reported that *B. fusca* is the most important and widely distributed stemborer species in Ethiopia. The shift in abundance of the two pests seems that the exotic *C. partellus* is overtaking the position of the indigenous *B. fusca*. An increase in temperature noted at high elevation might also have contributed for the occurrence of the pest at higher altitudes. No report was available in Ethiopia concerning interspecific association of the two stemborers and competitive displacement of *B. fusca*. However, studies from Kenya

indicated that the indigenous stemborer species, *B. fusca* and *C. orichalcociliellus* are being gradually displaced by the exotic stemborer, *C. partellus* (Overholt *et al.,* 1994; Ofomata *et al.*, 1999).

In the current study, it was observed that species composition, varied with cropping system, weediness, wild host and crop type at mid and higher altitudes. *C. partellus* was abundant in monocrop than intercrop. In most cases, higher proportion of *C. partellus* was recorded from farms with wild hosts as compared to those with out wild hosts. There was high *C. partellus* proportion in sorghum than maize sole cropping. For both crops intercropping with beans reduced density per plant of *C. partellus*. Emana Getu (2002) also reported similar facts on effect of cropping system, crop type, presence/ absence of wild host and soil fertility on species composition. Analysis of these factors is said to be essential for implementing appropriate pest management options (Emana Getu, 2002).

Additionally, cropping system and presence or absence of wild host had significant effect on percent infestation, severity and deadheart number. Higher stemborer percent infestation, severity and deadheart count were observed in monocrop than intercrop. The result agrees with previous reports which indicated that intercropping lowers infestation of pest (Root, 1973; Risch *et al.,* 1983; Andow, 1991; Pats and Ekbom, 1994; Skovagard and Pats, 1996; Emana, 2002, Emana Getu, 2005). Roots (1973) explained the increased pest population in monoculture is due to higher concentration of the host plants in time and space, while Risch *et al.* (1983) and Andow (1991) suggested that the reduction in pest number in multiple cropping arise from herbivore impediments in colonization and movement. Presence of wild host also increased the infestation by stemborers and severity of damage. This could be due the role of wild hosts in supporting carrying over population to the next season and as the result influencing status of stemborers in subsequent crops.

Laboratory investigation showed that temperature, relative humidity and interaction of temperature and relative humidity significantly affected the developmental time of *C. partellus*. The significance of the interaction between relative humidity and temperature verify variation in the developmental time of *C. partellus* is controlled by the interaction of temperature and relative

humidity. Though there was no previous information in the interactive effect of temperature and relative humidity on *C. partellus* development in Ethiopia, several workers reported the significance of temperature and relative humidity on development of other insects (Wilson *et al.,* 1982; Rahim *et al.,* 1991; Guglielomone, 1992; Ouedraogo *et al.,* 1996; Emana Getu, 2002; Emana Getu *et al.,* 2003; Emana Getu *et al.*, 2004).

In this study, significant differences in the developmental time of *C. partellus* were observed due to temperature, relative humidity and their interaction. The difference in life history processes of *C. partellus* under different levels of temperature and relative humidity suggests that these factors may influence the spread and establishment of the pest. Sithole (1987) stated temperature, rainfall and humidity are responsible for geographic distribution of *C. partellus* and *B. fusca,* temperature being the most important.

Egg hatching took 3-8 days depending on temperature and relative humidity. Egg period was inversely related to temperature and relative humidity. Egg period took longer time (8 days) at 22°C .and 40 % relative humidity whereas was shortest day was recorded at 30°C and 80 % relative humidity. Despite the significant delay, egg hatching took place at lower temperature (22°C) at all relative humidity.

Larval period was significantly longer at lower temperature (22°C) when compared to the higher temperatures (26°C and 30°C) at all levels of relative humidity. However, successful larval development was observed at 22°C regardless of relative humidity regimes indicating *C. partellus* ability to under go larval development at lower temperature and higher relative humidity

Pupal period was shorter at higher temperature and longer at lower temperature . Despite the longer time taken, healthy and viable adults were obtained from pupae kept at 22°C. This suggests *C. partellus* pupae complete pupal developmental stage and can produce viable adults at lower temperature.

Even though successful development from egg to adult was possible at all levels of temperatures tested, significant variation in number of days was observed among the temperature regimes. Egg to adult developmental time was inversely related to temperature. Mbapila *et al.*, (2002) reported similar results in *C. partellus*. Though development took relatively longer time at 22°C, *C. partellus* was able to complete its development from egg to adult at all levels of relative humidity. This confirmed that *C. partellus* can survive and complete its life cycle at lower temperature and higher relative humidity.

Comparison result showed variation in developmental time of *C. partellus* due to relative humidity at different temperature levels. Egg to adult development was different for the three levels of relative humidity at 30°C. Egg hatching varied due to relative humidity at 22°C and 26°C. At all temperature levels egg period was significantly reduced due to higher relative humidity. This concurs with ICIPE report which indicated the importance of high relative humidity in favoring normal embryonic development and hatching (http://nbo.icipe.org). The effect of 80 % relative humidity on *C. partellus* developmental time is different from 40 % and 60 % relative humidity at all temperature levels except for larval and pupal period at 26°C. These results, in general, show that relative humidity contributes its share for variation in development time of *C. partellus*.

Temperature caused marked variation in developmental time of *C. partellus* at different levels of relative humidity. An increase in temperature resulted in a significant decrease in egg period, larval period and pupal period regardless of relative humidity levels. Mean duration of *C. partellus* life cycle was reduced from 59.9 days at 22°C to 26.5 days at 30 °C at 40% relative humidity. More or less similar reduction in duration of *C. partellus* life cycle was observed due to an increase in temperature at 60 % and 80 % relative humidity. The significant variation in developmental time due to temperature signifies the crucial role temperature plays in determining development of *C. partellus*. Several workers reported similar results in other insects (Yadav and Chaudhary, 1987; Muegge and Lambdin, 1989; Rahim *et al.*, 1991).

Temperature and relative humidity and their interaction significantly influenced male and female longevity of *C. partellus*. This fact suggests that these factors play an important role in

determining the life span of adult *C. partellus*. All relative humidity showed variation for male and female adult longevity at 26°C. Adult male and female *C. partellus* lived longer at lower temperature and the longevity was reduced at higher temperature. Average life span of adult *C. partellus* was 6.9-11.1 days at 22°C while it was only 2.3-7.2 days at 30°C. Male or female *C. partellus* may live longer depending on temperature, relative humidity and their interaction. In this study adult longevity was not significantly affected by the interaction of relative humidity and sex. This result agrees with Mbapila *et al.* (2002) who reported that adult life stage of *C. partellus* is inversely related to temperature. Different workers have also demonstrated the effect of temperature, relative humidity and food on adult longevity of other insects (Potting, 1996; Mbapila, 1997).

Temperature, relative humidity and their interaction significantly affected the potential and realized fecundity of *C. partellus*. The significance of interaction indicates the variation in actual number of eggs laid with temperature and relative humidity. In the current study the average potential fecundity observed was 542.5-861.13 eggs whereas the actual was 204.4 -476.2 eggs. Higher potential and realized fecundity were observed at higher relative humidity (60 %, 80 %) at different levels of temperature. In most cases, higher egg load and realized fecundity were obtained at 30° C. Despite the lower number of eggs laid *C. partellus*, was able to produce viable eggs even at lower temperature.

7. Conclusion and Recommendation

7.1. Conclusion

From this work it can be concluded that *C. partellus*, *B. fusca* and *S. calamistis* were the major stem borer species recorded in central and eastern Ethiopia. *C. partellus* was the dominant species with wide distribution. *C. partellus* was known to be low land pest however, in the current survey the pest was recorded at an elevation of 2088 masl. This indicates the adopting behavior of *C. partellus* to higher ecological niches at higher altitudes. An increasing importance of the pest in abundance and distribution suggest that it may be displacing the indigenous stemborer, *B. fusca* or competing with it.

C. partellus was highly abundant in monocrop than inter crop. Higher percentage of *C. partellus* was recorded from fields with wild hosts in and around than wild host free fields. Sorghum fields had higher *C. partellus* infestation than maize under monocropping. Percent infestation and severity of the pest was high in fields with wild hosts and monoculture. Comparison results also revealed a small increase in temperature in highland areas where *C. paretellus* was currently recorded which might have contributed to the occurrence of the pest. These facts suggest that some ecological factors may influence species composition and *C. partellus* abundance.

There was significant variation in life history processes of *C. partellus* due to temperature, relative humidity and their interaction. These factors have played significant role in increasing altitudinal expansion of the niche, successful establishment and spread of the pest. The current study showed *C. partellus* ability to reproduce, survive and complete its life cycle at lower temperature and higher relative humidity. This could be one reason which enabled *C. partellus* to invade higher elevations characterized by having low temperatures and high relative humidity.

7.2. Recommendation

- More survey should be carried out in other parts of the country to substantiate the current finding that *C. partellus* is expanding its ecological niche.
- More biological and ecological studies should be carried out to substantiate the information on the factors that helped *C. partellus* expand its niche.
- Investigation should be carried out to know whether *C. partellus* is displacing the indigenous stemborers, mainly *B. fusca.*
- As the current status of *C. partellus* is alarming IPM option for its management should be worked out.

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9. Appendices

Appendix 1. Analysis of variance for egg period of *C. partellus*

Source	DF	Type III SS	MS	F valve	P
Temp	2	28.59	14.29	Infty	< 0.0001
RH	2	3.78	1.89	Infty	< 0.0001
Temp x RH	4	0.69	0.17	Infty	< 0.0001

Appendix 2. Analysis of variance larval developmental time *C. partellus*

Source	DF	Type III SS	MS	F valve	P
Temp	2	67.98	33.99	689.43	< 0.0001
RH	2	0.91	0,45	9.20	< 0.0001
Temp x RH	4	4.45	1.11	22.55	< 0.0001

Appendix 3. Analysis of variance for pupal period of *C. partellus*

Source	DF	Type III SS	MS	F valve	P
Temp	2	41.69	20.85	802.11	< 0.0001
RH	2	0.25	0.13	4.87	0.0084
Temp x RH	4	1.26	0.31	12.10	< 0.0001

Appendix 4. Analysis of variance for egg to adult emergence of *C. partellus*

Source	DF	Type III SS	MS	F valve	P
Temp	2	5.49	2.75	1170.31	< 0.0001
RH	2	0.02	0.01	5.30	0.0055
Temp x RH	4	0.26	0.06	27.41	< 0.0001

Appendix 5. Analysis of variance table (GLM Procedure) for longevity of female and male adults of *C. partellus* at different levels of constant temperatures and relative humidity.

Source	DF	Type III SS	MS	F-value	P
Temp	2	9.48	4.74	271.71	<0.0001
RH	2	0.34	0.17	9.77	<0.0001
Sex	1	0.21	0.21	12.14	0.0006
Temp * Sex	2	1.13	0.56	32.34	<0.0001
RH * Sex	3	0.03	0.01	0.78	0.4587
Temp * RH	4	2.05	0.51	29.31	<0.0001
Temp * RH * Sex	4	1.29	0.32	18.53	<0.0001

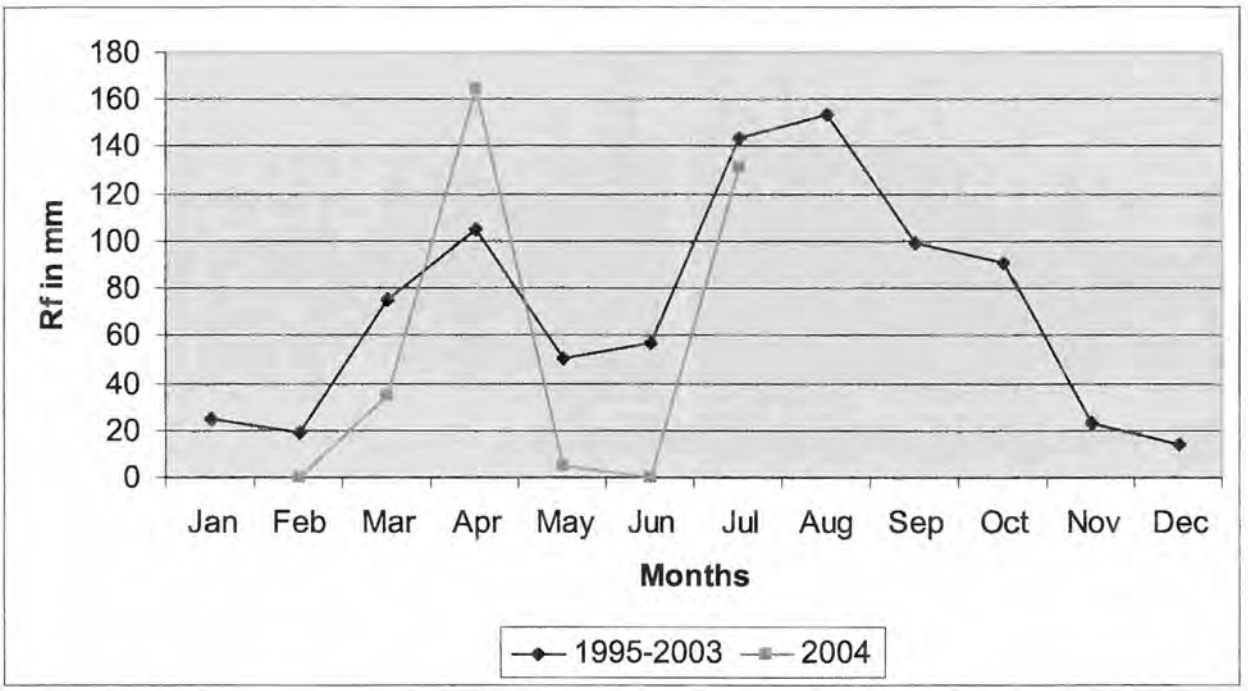
Appendix 6. Analysis of variance for potential fecundity of *C. partellus* at different temperature and relative humidity.

Source	**DF**	**Type III SS**	**MS**	**F valve**	**P**
Temp	2	336894.489	168447.244	7.57	< 0.0006
RH	2	1126437.222	563218.611	25.31	< 0.0001
Temp x RH	4	1678127.022	419531.756	18.85	< 0.0001

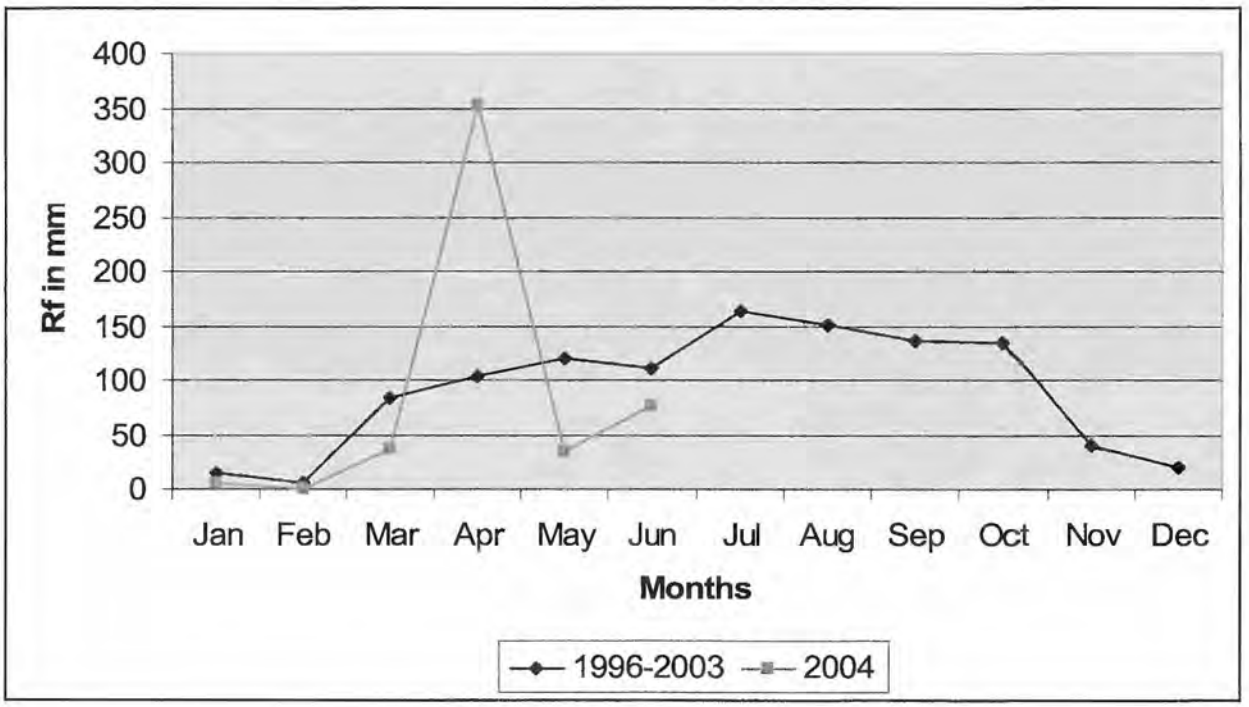
Appendix 7. Analysis of variance for realized fecundity of *C. partellus* at different temperature and relative humidity.

Source	**DF**	**Type III SS**	**MS**	**F valve**	**P**
Temp	2	28.59	14.29	Infty	< 0.0001
RH	2	3.78	1.89	Infty	< 0.0001
Temp x RH	4	0.69	0.17	Infty	< 0.0001

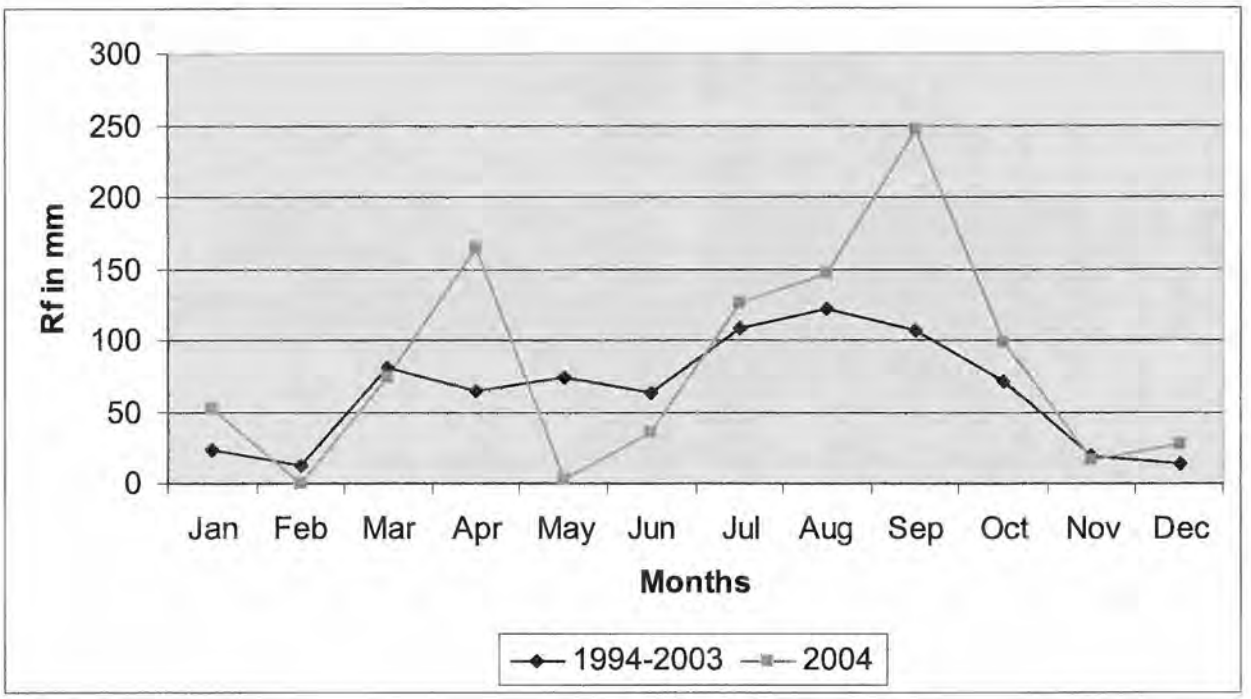
Appendix 8. Rainfall at Assebot



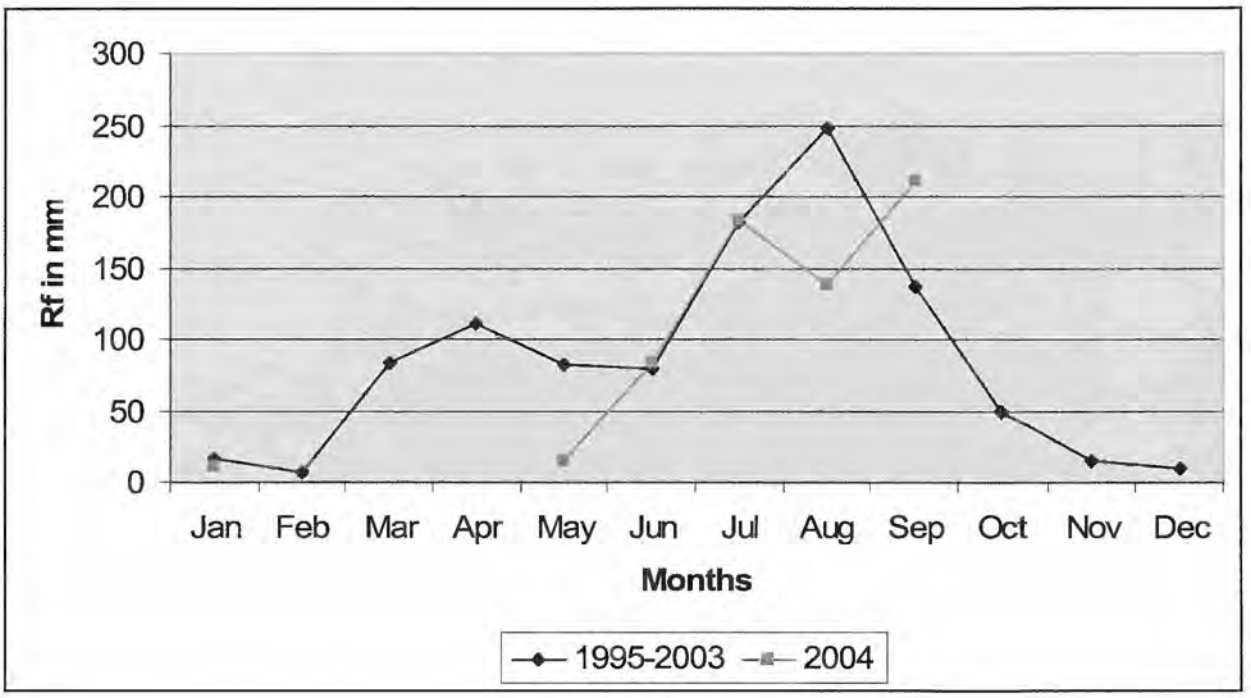
Appendix 9. Rainfall at Bedessa



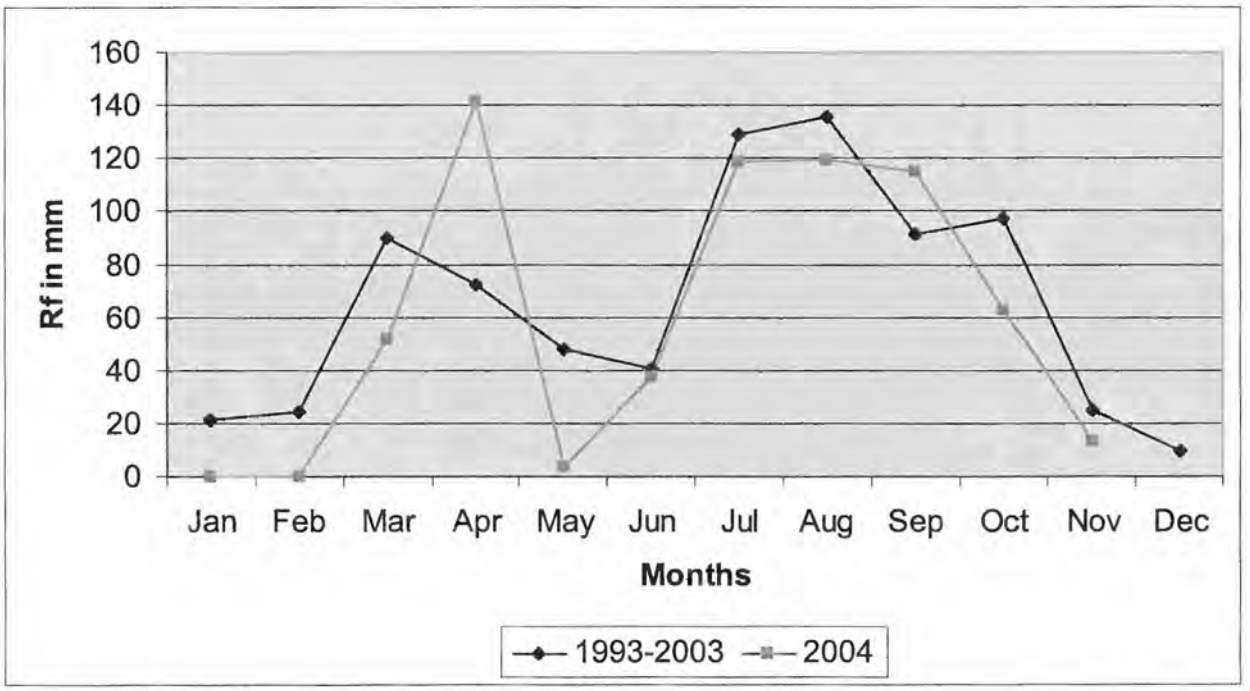
Appendix 10. Rainfall at Asebe Teferi



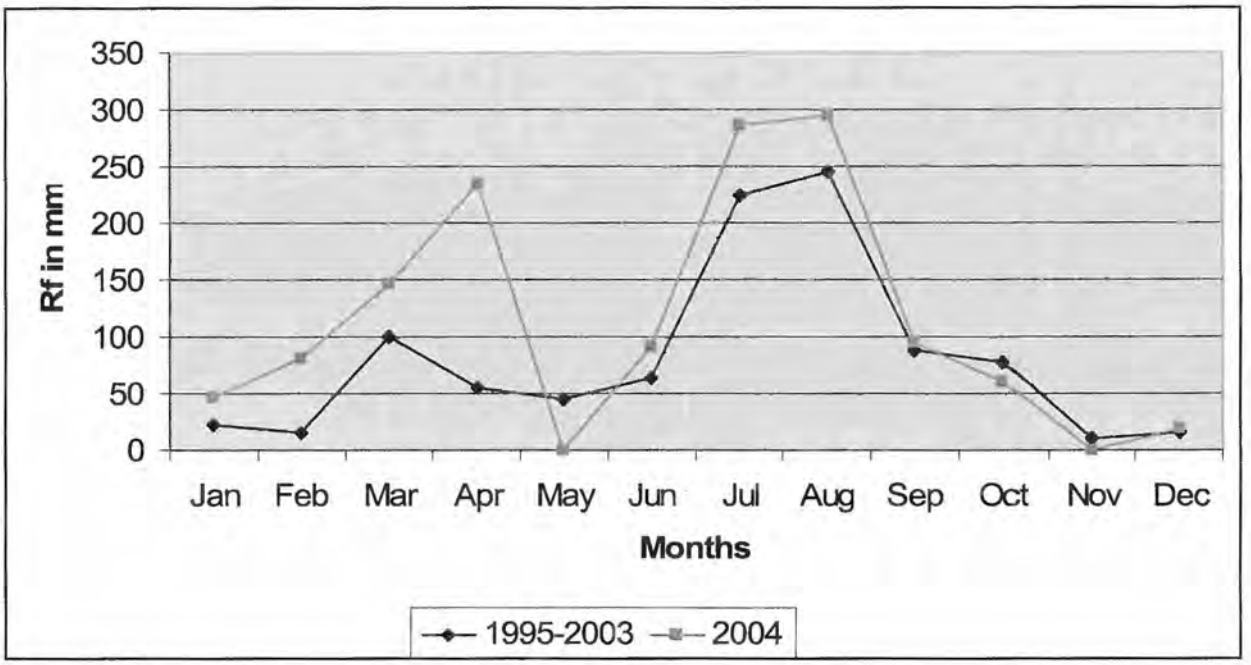
Appendix 11.Rainfall at Hirna



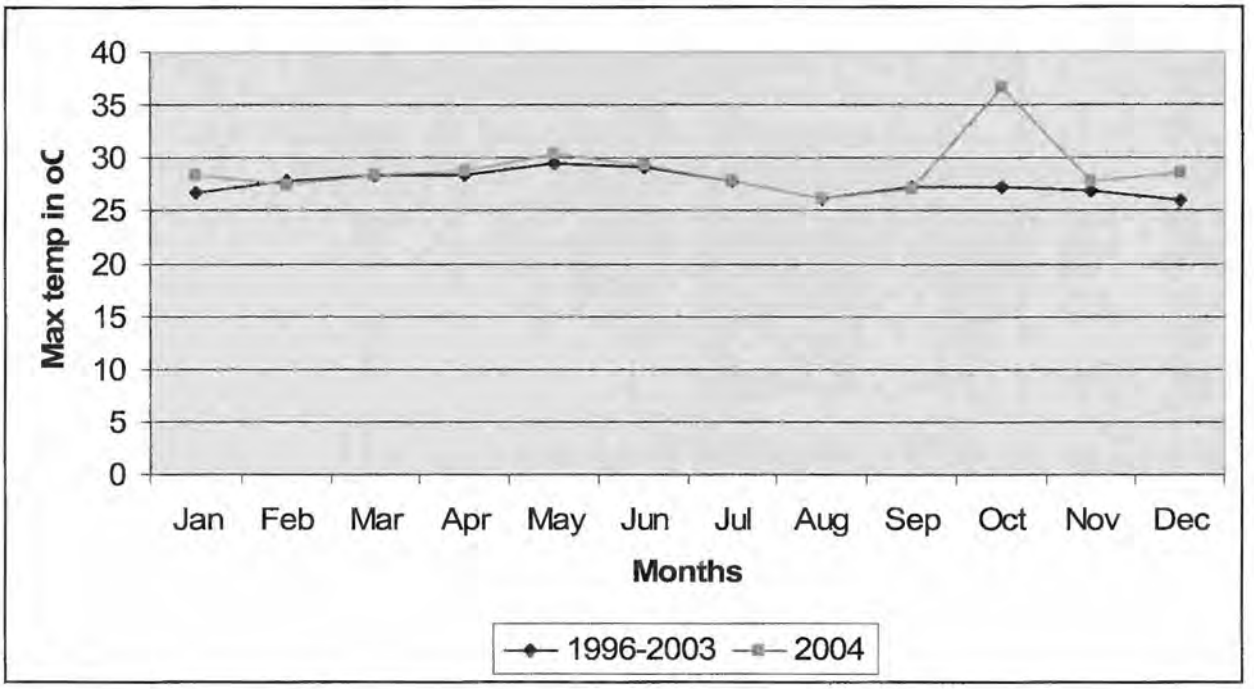
Appendix 12. Rainfall at Meisso



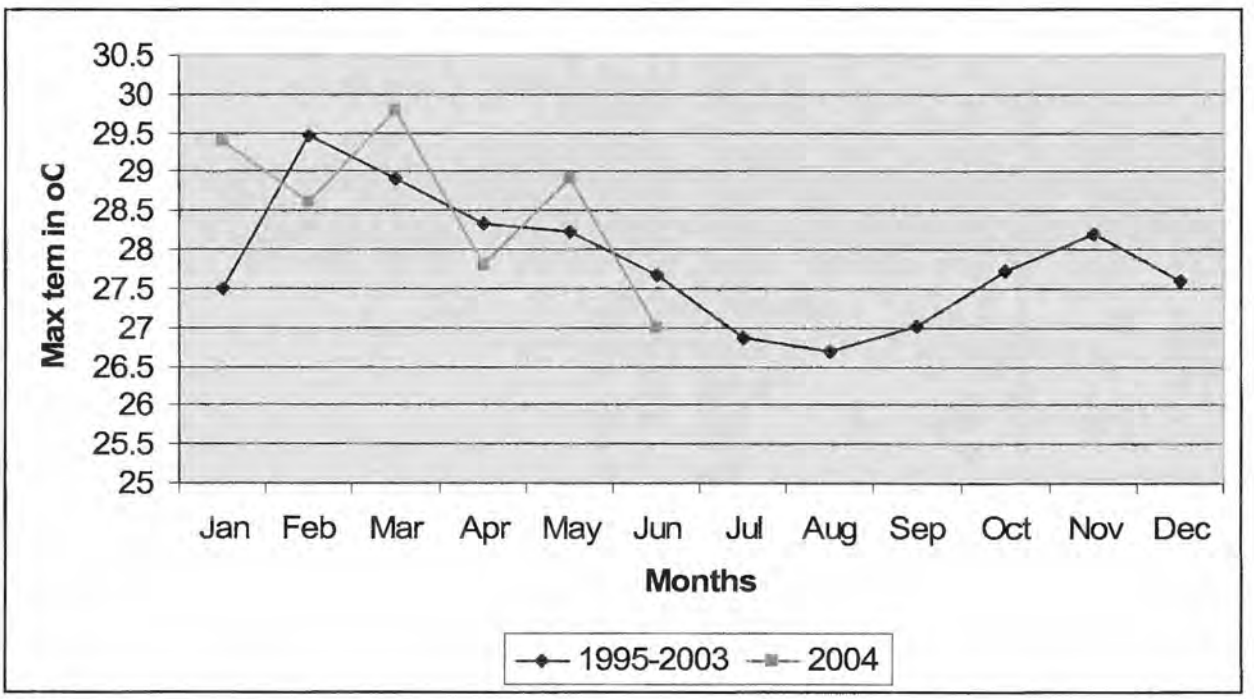
Appendix 13. Rainfall at Wolenchiti



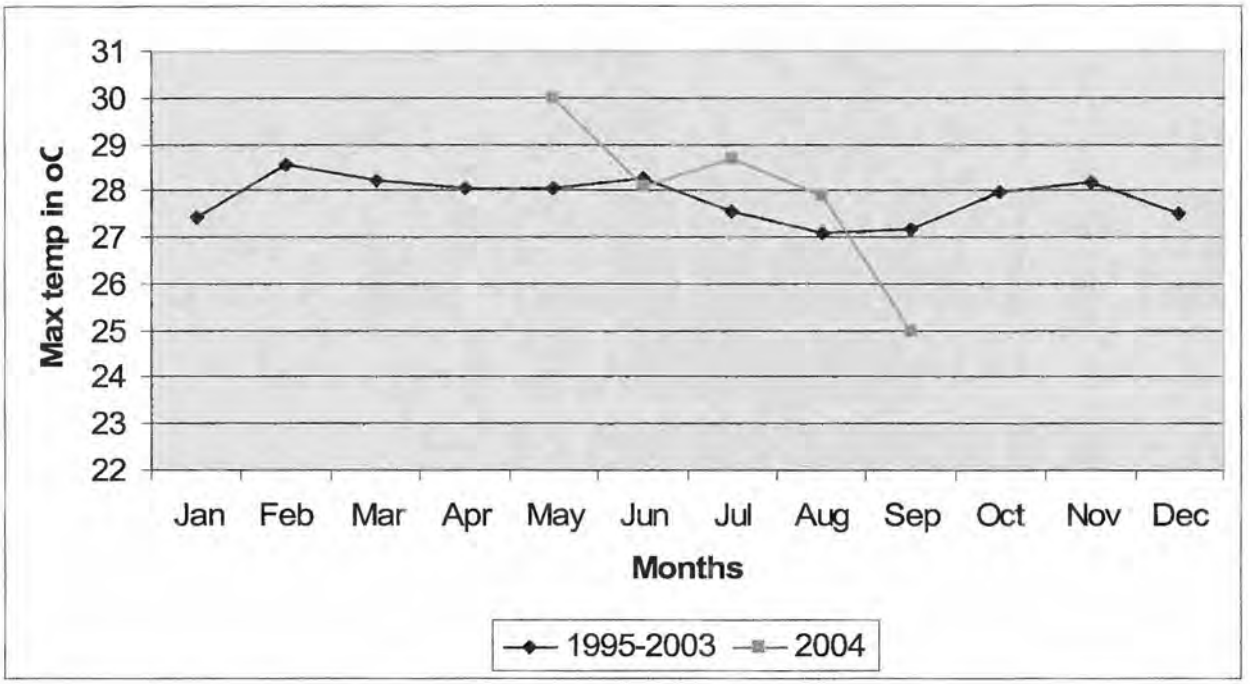
Appendix 14. Maximum Temperature at Asebe Teferi



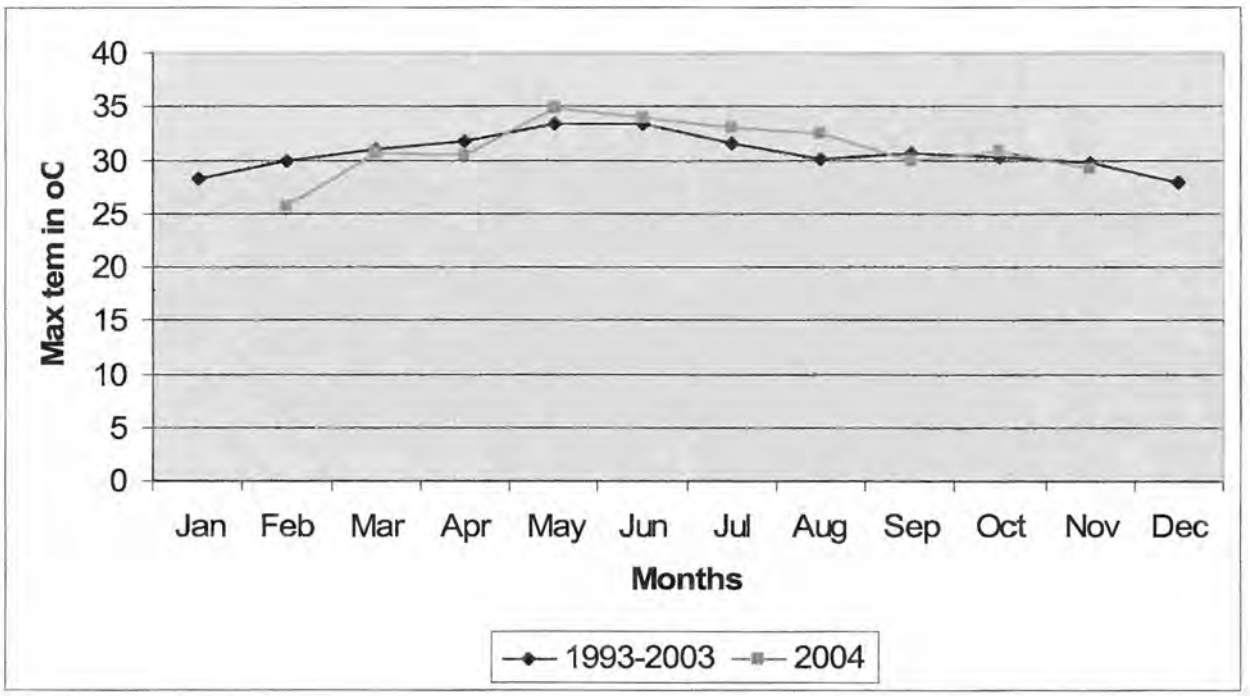
Appendix 15. Maximum temperature at Bedessa



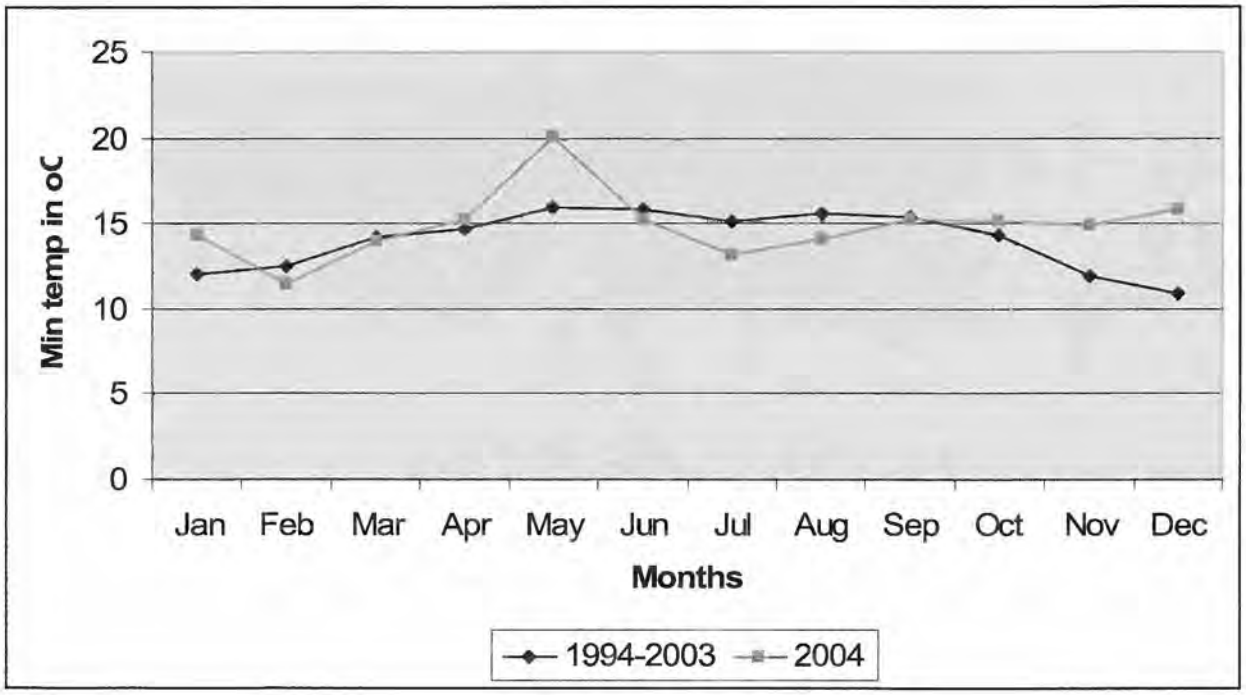
Appendix 16. Maximum temperature at Hirna .



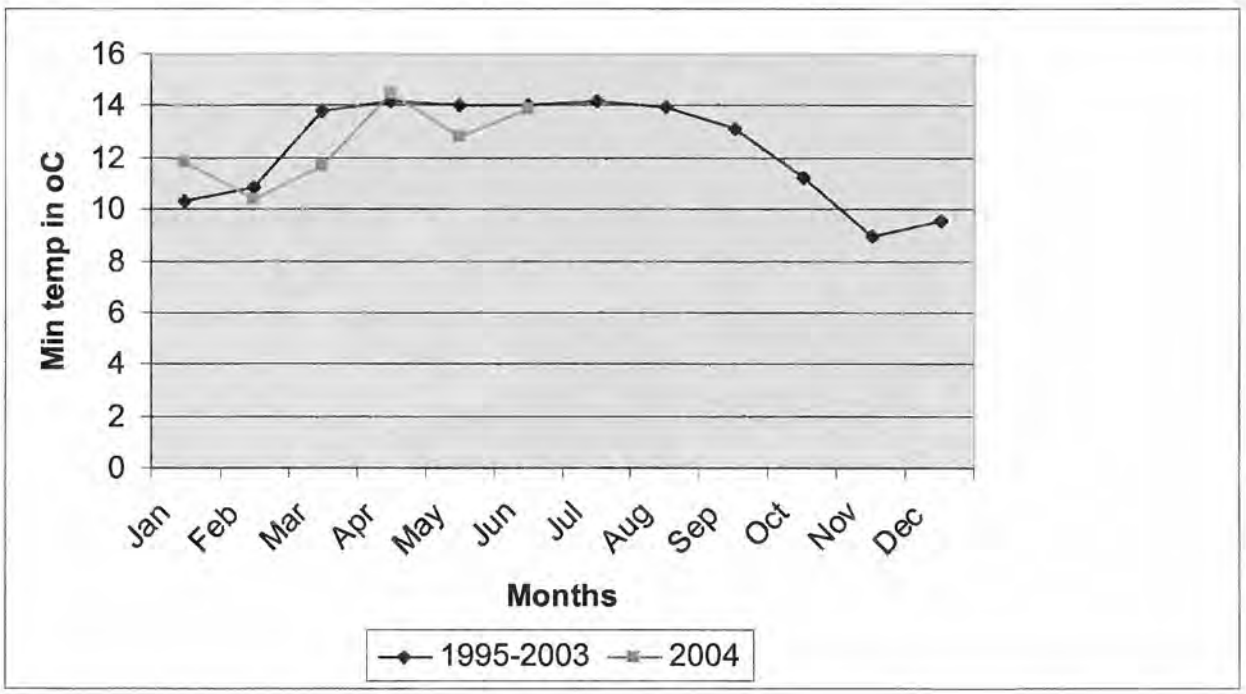
Appendix 17. Maximum Temperature at Meisso



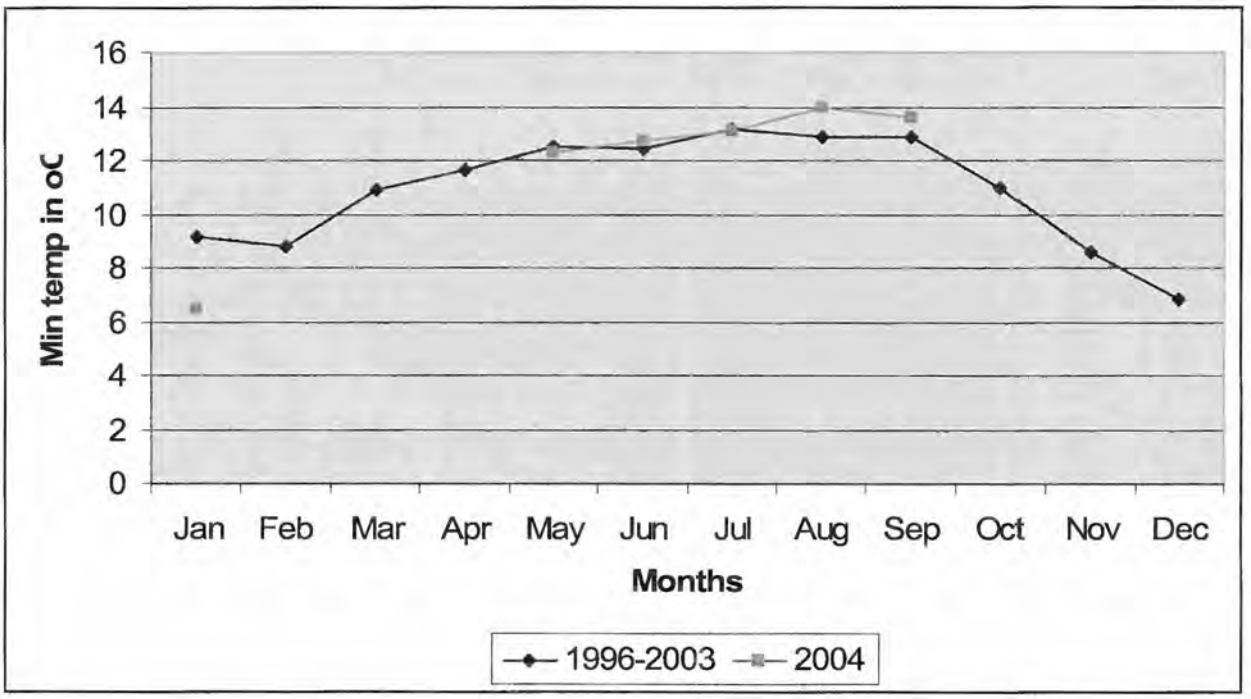
Appendix 18. Minimum Temperature of Asebe Teferi



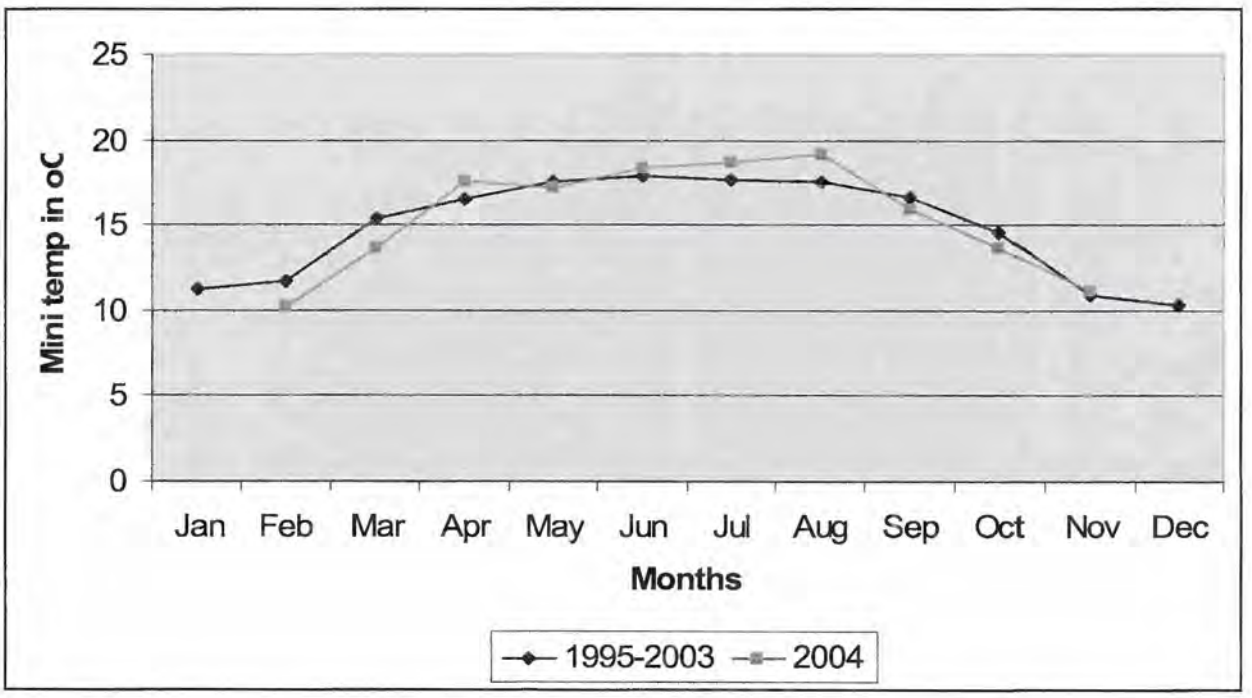
Appendix 19. Minimum Temperature at Bedessa



Appendix 20. Minimum Temperature at Hirna



Appendix 21. Minimum Temperature at Meisso



STUDY ON THE BIOLOGY AND SOME ECOLOGICAL ASPECTS OF *CHILO PARTELLUS* (SWINEHOE) (LEPIDOPTERA: CRAMBIDAE) IN RELATION TO ITS GEOGRAPHIC EXPANSION

By

Amanuel Tamiru Abamo

This thesis is my original work and has not been presented for a degree in any other University and that all sources of materials used for the thesis have been duly acknowledged.

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