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REVIEW ARTICLE

BIOLOGY, ECOLOGY AND MANAGEMENT OF CEREAL STEMBORERS IN AFRICA, WITH PARTICULAR REFERENCE TO ETHIOPIA.

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ABSTRACT: Grains of gramineous crops are of paramount importance in the world for feeding humans and livestock, and generating income. Moreover, the stalks of thick stemmed gramineous crops such as maize and sorghum are used for fuel, construction and livestock feed. The contribution of cereals like maize and sorghum towards food requirements of Ethiopian population is tremendous and these cereals rank first and second, respectively, in terms of yield per hectare and total production. However, their yields are affected by a large number of lepidopteran stemborers found in the families Pyralidae, Crambidae and Noctuidae and two species of Coleoptera in the family of Rhynchophoridae. Of the stemborer species attacking cereals, the spotted stemborer, *Chilo partellus* (Swinhoe) is an exotic species which has no co-evolved natural enemies to keep its population low. This species is very problematic in the dry lowland of eastern and southern African countries including Ethiopia. The other problematic species which is indigenous to Africa is maize stemborer, *Busseola fusca* (Fuller). This species can cause complete crop failure in most African countries in the wet-higher elevation. Other than these two species, the stemborers recorded in Africa are either minor or sporadic or pests of pocket areas. The yield losses due to these stemborers to cereals have been reported to vary from country to country and ranges from 20-80% depending on the pest density, type and variety of crops, species of stemborers involved in the infestation and phenological stage of the crop during infestation. To combat the complex species of stemborers involved in the infestation of important cereal crops, quite a large number of basic and applied researches have been conducted in Africa which include species composition, economic importance, distribution, biology, ecology and management. Hence, in this paper, critical review of stemborers' research outputs is presented. From the review, conclusions and recommendations are made to help cereal growers to make use of research results for the effective management of cereal stemborers which ultimately boost production and productivity.

Key words/phrases: Applied research; Basic research; Cereal stemborers; Cereal stemborers management; Review.

INTRODUCTION

Grains of gramineous crops are of paramount importance in the world for

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feeding humans and livestock, and providing income. Moreover, the stalks of thick stemmed gramineous crops such as maize and sorghum are used for fuel, construction and livestock feed (Emana Getu, 2002a). The contribution of cereals like maize and sorghum towards food requirements of African population is tremendous and these cereals rank first and second in Ethiopia, respectively, in terms of yield per hectare and total production. About 8.2 million hectares of land is under crop production in Ethiopia with more than 85% allotted to cereal production. Among the cereals, maize and sorghum are planted on about 29% of the cultivated land which accounts for 41% of the total crop production in the country (Emana Getu, 2002a). However, the yields of these useful crops are affected by a large number of lepidopteran stemborers found in the insect families of Pyralidae, Crambidae and Noctuidae and two species of Coleoptera in the family of Rhynchophoridae (Jepson, 1954; Nye, 1960; Bleszynski, 1970; Smith *et al*., 1993; Emana Getu, 2002a and b). Crops attacked by different species of stemborers include rice (*Oryza sativa*), maize (*Zea mays*), sorghum (*Sorghum* spp.), millet (*Pennisetum* spp.) and sugarcane (*Saccharum* spp.) (Bleszynski, 1970; Cheng, 1994). There are also a number of wild hosts from the families of Gramineae, Cyperaceae and Typhaceae which can serve as reservoirs of stemborers and natural enemies especially during the off-season when cultivated crops are not in the field (Polaszek, 1998). Emana Getu *et al*. (2007) reported over 62 plant species in Ethiopia which grow in the vicinity of maize and sorghum fields and serve as alternate hosts for stemborers.

In Africa, a complex of approximately 18 species of economically important lepidopteran cereal stemborers and two coleopteran species were recorded (Maes, 1998; Polaszek, 1998; Emana Getu, 2002a). In Ethiopia, seven species of stemborers from the orders Lepidoptera and Coleoptera were recorded on maize, sorghum, millet, rice and sugarcane (Emana Getu, 2002a; Emana Getu *et al*., 2001). The populations of these stemborers are naturally regulated by complex of natural enemies (parasitoids, predators and pathogens) which otherwise would have been resulted in a total devastation of the cultivated and wild hosts (Polaszek, 1998). Emana Getu (2002a) recorded 22 parasitoids, 14 predators and seven pathogens associated with cereal stemborers which can suppress the stemborers' population significantly in Ethiopia.

Yield losses caused by the stemborers to cereals have been reported to vary from country to country and regions within a country. However, 20-80% yield losses have been frequently reported from different African countries depending on the pest density, type and variety of crop, species of stemborers involved in the infestation and phenological stage of the crops during infestation (Ampofo, 1986; Seshu Reddy and Sum, 1992; Emana Getu and Tsedeke Abate, 1999; Emana Getu *et al*., 2007). In Zimbabwe, Sithole (1990) reported yield losses of 50-60% by *Chilo partellus* (Swinhoe) in sorghum. Asssefa Gebre-Amlak (1985), and Emana Getu and Tsedeke Abate (1999) reported from Ethiopia yield losses ranging from 10 to 100% in maize due to *Busseola fusca* (Fuller). Emana (2002a) estimated average yield losses of 65% and 83% to maize and sorghum, respectively, by either single species of stemborers such as *B. fusca* in the wet highland and *C. partellus* in the dry lowland or mixed species of stemborers in the transitional zones. To combat the complex species of stemborers involved in the infestation of important cereal crops in Africa, quite a large number of basic and applied research which included species composition, economic importance, distribution, biology, ecology and management have been conducted. However, the problems of stemborers have remained unsolved probably because of inaccessibility of research findings. Hence, the objective of this paper was to critically review available research findings on different aspects of stemborers which may be directly or indirectly utilized for the management of cereal stemborers in Africa in general, and Ethiopia in particular.

CEREAL STEMBOERS SPECIES COMPOSITION

More than 18 species of stemborers in the orders Lepidoptera cause damage to maize, sorghum, and other cultivated and wild hosts in Africa (Maes, 1998; Polaszek, 1998). These include the crambids *Chilo agamemnon* Bleszynski, *C. aleniellus* (Strand), *C. diffusiliness* (de Joannis), *C. orichalocociliellus* (Strand), *C. partellus* (Swinhoe), *C. zacconius* Bleszynski and *Coniesta ignefusalis* (Hampson); the noctuids *B. fusca*, *B. phaia* Bowden, *Manga basilinea* Bowden, *Sesamia calamistis* Hampson, *Sesamia albavena* Hampson, *S. cretica* Lederer, *S. nonagrioides* botanephaga Lefebvre, *S. penneseti* Tams and Bowden and *S. poephaga* Tams and Bowden, and the pyralid *Eldana saccharina* (walker). In addition to Lepidopteran stemborers, Emana Getu (2002a) reported two Coleopteran stemborers, namely *Rhynchaenus niger* (Horn) and *Pissodes dubius* (Strom) from Ethiopia. In Ethiopia, only seven species (five Lepidopterans and two Coleopterans) were recorded (Emana Getu, 2002a). These include *C. partellus*, *B. fusca*, *S. calamistis*, *S. nonagrioides* botanephaga, *E. saccharina*, *R. niger* and *P. dubius*. Details of these stemborers are given in Table 1.

Table 1. Stemborer species recorded in Africa.

Stemborer species	Hosts	Geographic distribution	Status	Reference (s)	Remark
Lepidoptera Noctudiae Sesamia *S. calamistis* Hampson	Maize, sorghum, finger millet, rice, sugar cane, *Andropogon* sp., *Cenchrus ciliaris*, *Coix lacryma-jobi*, *Echinochloa haploclada*, *Echinochloa pyramidalis*, *Hyparrhenia filipendula*, *Hyparrhenia rufa*, *Panicum maximum*, *Pennisetum purpureum*, *Phragmites sp.*, *Setaria sphacelata*, *sorghum arundinaceum*, *Sorghum versicolor*, *Sorghum vulgare var. sudanense*, *Tripsacum laxum*, *Cyperus distans*, *Cypersus immensis*, *Cyperus papyrus*, *Typha domingensis*	Most of tropical Africa (South Africa, Zimbabwe, Malawi, Uganda, Tanzania, Kenya, Zanzibar, Madagascar, Mauritius, Reunion, Angola, Nigeria, Cote d'vore, Cameron, Senegal, Gambia, Ghana, Mozambique, Ethiopia, Eritrea and Zambia	Major in West Africa and minor in other African countries	Harries, 1962; Polaszek, 1998; Tams and Bowden, 1953; Cugala et. Al, 1999; Gebere-Amlak, 1985;	Sporadic pest in Ethiopia on maize and sorghum
S. nonagrioides botanephaga Tams and Bowden	Rice, sorghum, sugar cane	Tropical and equatorial Africa	Major on rice in West Africa	Polaszek, 1998	Recorded in Ethiopia as minor pest of sorghum and sugar cane
S. n. penniseti Tams and Bowden	Rice	Nigeria	Major pest of rice in Nigeria	Polaszek, 1998	No record from Ethiopia
S. cretica Lederer	Sorghum, maize, rice, sugarcane, oats, wheat	Major on sorghum and sugarcane	Morocco, Egypt, Sudan, Somalia, Ethiopia, Kenya	Polaszek, 1998; Tams and Bowden, 1953; Nye, 1960	Recorded in Ethiopia as minor pest of sorghum
S. poephaga Tams and Bowden	Rice	Minor	West Africa	Polaszek, 1998	No record from Ethiopia
Busseola *B. fusca* (Fuller)	Sorghum, maize,wheat, barley,*Echinochloa pyramidalis*, *Hyparrhenia cymbaria*, *Hyparrhenia pilgerana*, *Hyparrhenia rufa*, *Panicum deustum*, *Panicum maximum*, *Pennisetum purpureum*, *Pennisetum trachphyllum*, *Rottboellia cochinensis*, *Setaria incrassate*, *Setaria sphacelata*, *Sorghum arundinaceum*, *Sorghum versicolor*, *Sorghum vulgare var. sudanense*, *Sporobolus marginatus*, *Sporobolus pyramidalis*, *Tripsacum laxum* and *Typha domingensis*	Sub-Saharan Africa (Angola, Benin, Botswana, Burkina Faso, Cameroon, Ethiopia, Ghana, Guinea, Cote d'Ivoire, Kenya, Lesotho, Malawi, Mali, Mozambique, Nigeria, Rwanda, Sierra Leone, Somalia, South Africa, Swaziland, Tanzania, Uganda, Zaire, Zambia, Zimbabwe	Major	Harris and Nwanze, 1992	Recorded in Ethiopia as major pests of maize and sorghum at higher elevations (>1600 meters above sea level)

Table 1 continued

Stemborer species	Hosts	Geographic distribution	Status	Reference (s)	Remark
Crambidae ***Chilo*** *Chilo partellus* (Swinhoe)	Maize, sorghum, rice, sugarcane, Eleusine coracana, *Hyparrhenia rufa, Sorghum arundinaceum, Sorghum vulgare var. Sudanense, Pennisetum purpureum, Panicum maximum, Setaria incrassate, Rottboellia compressa, Sorghum verticilliflorum, Vossia cuspidate, Cenchrus ciliaris, Coix lacryma-jobi, Dactyloctenium bogdanii, Echinochloa haploclada, Echinochloa pyramidalis, Hyparrhenia filipendula, Hyparrhenia pilgerana, Panicum deustum, Pennisetum trachyphyllum, Phragmites sp., Rottboellia cochinchinensis, Sorghum arundinaceum, Sorghum vesicolor, Sporobolus marginatus,*	eastern and southern African countries (Ethiopia, Kenya, Malawi, Mozambique, Somalia, South Africa, Sudan, Tanzania, Uganada, Botswana, Swaziland, Zimbabwe, Comoro Islands, Madagascar, Lesotho, Eritrea, Zambia, Zanzibar, Somalia	Major	Bleszynski, 1970; Khan *et al*., 1997; Sithole, 1990; Delobel, 1975; Ebenebe *et al*., 1998	Recorded in Ethiopia within the elevation range of 2080 meters above sea level
Crambidae *Chilo zacconius* Blezynski	Rice, *Echinochloa crus-galli*, *Oryza barthii*, *Sorghum arundinaceum*, *Pennisetum* spp.	West Africa (Benin,Burkina Faso, Cameron, Ivory Coast, Mali, Niger, Nigeria, Senegal, Sierra Leone	Major pest of rice	Bleszynski, 1970	Not recorded from Ethiopia
Chilo diffusilineus	Rice	West Africa (Niger, Nigeria)	Major pest of lowland rice	Bordat and Pichot, 1978	Not recorded from Ethiopia
Chilo aleniellus	Rice	West Africa (Benin)	Minor pest of rice	Bordat and Pichot, 1978	Not recorded from Ethiopia
Chilo Agamemnon		East and North Africa (Uganda, Morocco)		Polaszek, 1998	Not recorded from Ethiopia
Chilo orichalcociliellus	Maize, Sorghum, *Eleusine coracana*, Sugarcane, *Panicum maximum*, *Pennisetum purpureum*, *Sorghum arundianceum*	Kenya, Tanzania, Malawi, Madagascar, South Africa, Zimbabwe, Demcratic Republic of Congo	Major pest of maize and sorghum	Bleszynski, 1970; Ofomata *et al*., 2000	Not recorded from Ethiopia; in Kenya its distribution is limited to the lowland coastal area

Table 1 continued

Stemborer species	Hosts	Geographic distribution	Status	Reference (s)	Remark
Chilo sacchariphagus (Bojer)	Sugar cane, maize, wild *Saccharum* spp, *Miscanthus* sp.	Mozambique	Major pest of sugar cane	Cheng, 1994; Kuniata, 1994; Williams, 1983; Goebel, 1999; Way and Turner, 1999	Introduced to Africa from Asian countries such as India, Thailand, Taiwan, Vietnam, Mainland China, Japan, Philippines, Malaysia, Sri Lanka. It is also present in the Indian Ocean Islands of Madagascar, Mauritius And Reunion
Pyralidae					
Eldana					
Eldana saccharina (Walker)	Sugarcane, maize, rice, sorghum, *Panicum maximum*, *Pennisetum purpureum*, *Phragmites* sp., *Rottboellia cochinchinensis*, *Sorghum arundinaceum*, *Sorghum vesicolor*, *Sorghum vulgare* var. sudanense, *Cyperus distans*, *Cyperus immensis*, *Cyperus maculates*, *Cyperus papyrus*	Sub-Saharan Africa (Burundi, Chad, Ghana, Kenya, Mozambique, Nigeria, Rwanda, Sierra Leone, Somalia, South Africa, Tanzania, Uganda, Zaire	Major pest of sugarcane	Khan *et al*., 1997; Maes, 1998; Atkinson, 1980; Bosque-Perez and Mareck, 1991; Emana Getu *et al*., 2007	Recorded in southern Ethiopia on sugarcane
Coleoptera					
Rhynchophoridae					
Rhynchaenus					
Rhynchaenus niger (Horn)	Sorghum	Ethiopia	Minor	Emana Getu *et al*., 2001; Emana Getu, 2002a	Recorded in Ethiopia in most sorghum producing areas
Pissodes					
Pissodes dubius (Strom)	Sorghum	Ethiopia	Minor	Emana Getu *et al*., 2001; Emana Getu, 2002a	Recorded in few sorghum producing areas

ECONOMIC IMPORTANCE OF CEREAL STEMBORERS

The stemborer species attacking cereals in Africa vary from country to country and regions within a country. Moreover, their status varies such that the species which is important in one country may not be important in another country. However, across the African countries, *B. fusca*, *C. partellus*, *S. calamistis* and *E. saccharina* are the most important species of stemborers causing economic losses to important cereals like maize, sorghum, rice, millet and sugarcane (Maes, 1998; Polsezek, 1998). Thus, the damage caused by these important species of stemborers is highlighted below.

B. fusca: This stemborer species is often the most serious stemborer of maize in the wet, mid and higher elevation areas of Africa. Yield losses have been estimated to be about 12% for every 10% of plants infested. In Burundi, *B. fusca* occasionally cause yield losses of 30-50%. In Zaire, losses of 8-9% in early-planted maize and 22-25% in late-planted maize have been reported. In Cameroon, weight losses of 4.6 g per borer in lowland fields and 8.7 g per borer in highland fields were reported (Harris and Nwanze, 1992; Cardwell *et al*., 1997; Seshu Reddy, 1988). Asssefa Gebre-Amlak (1985), and Emana Getu and Tsedeke Abate (1999) from Ethiopia reported yield losses ranging from 10 to 100% in maize due to *B. fusca*. Emana Getu (2002a) reported that over 60% of the stemborers' population attacking maize and sorghum in Ethiopia belongs to *B. fusca*.

C. partellus: *C. partellus* is considered to be the most important stemborer in most low to medium elevation areas of eastern and southern Africa including Ethiopia. Yield losses of 18% and 50% in maize were reported due to *C. partellus* in Kenya and Mozambique, respectively (Sithole, 1990). Recent evidence suggests that *C. partellus* is increasingly becoming a pest in higher elevation areas (greater than 1800 meters above sea level) as well in Africa (Kfir, 1997; Haile and Hofsvang, 2001; Emana Getu, 2002a; Emana Getu *et al*., 2003 and 2007; Amanuel Tamiru, 2005; Amanuel Tamiru *et al.*, 2007).

Sesamia calamistis: In eastern and southern Africa, *S. calamistis* is of only moderate importance. Although *S. calamistis* has a very wide distribution, densities are typically low in eastern and southern African countries. In contrast, *S. calamistis* is considered to be a very damaging borer in West Africa causing over 20% yield losses in maize (Bosque-Perez and Sculthes, 1998).

Eldana saccharina: In southern Africa, *E. saccharina* is considered to be a serious pest of sugarcane (Atkinson, 1980). In eastern Africa, *E. saccharina* attacks maize, but usually towards the end of the growing season, and is generally not considered a major pest. In West Africa, *E. saccharina* is a pest of maize and sugarcane. Boseque-Perez and Dabrowsky (1989) reported that even though *E. saccharina* attacks maize plants late in the growing season, the damage can be as high as 20%. In some sugar cane farms *E. saccharina* was recorded in Ethiopia, but the infestation level was very low (Emana Getu, unpublished data).

CEREAL STEMBOERS DISTRIBUTION

Geographic Information System (GIS) model clearly indicated that the distribution of cereal stemborers in Africa generally depends on rainfall, temperature, elevation, hosts and natural enemies (Emana Getu, 2002a). The distribution of *B. fusca* and *C. partellus* in Africa as mapped using GIS (Overholt *et al.*, 2001) (Figs. 1 and 2). The distribution of some of the stemborers is dramatically changing. For example, *C. partellus* is becoming a pest of highland areas as witnessed from surveys made in Ethiopia (Emana Getu, 2002a; Amanauel Tamiru *et al.*, 2007). Thus, there is a need for frequent updating of the distribution information of the major stemborers occurring in the continent. However, with the currently available information, the distribution of major stemborers occurring in African is highlighted below.

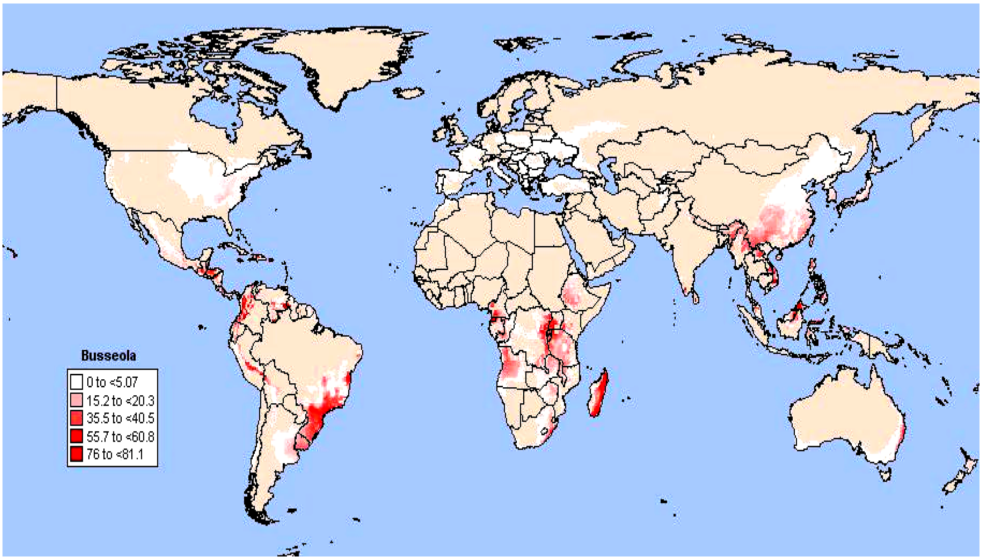

Fig. 1. Distribution of *Busseola fusca* (numbers indicated in the keys show density of *B. fusca* per 20 maize plants).

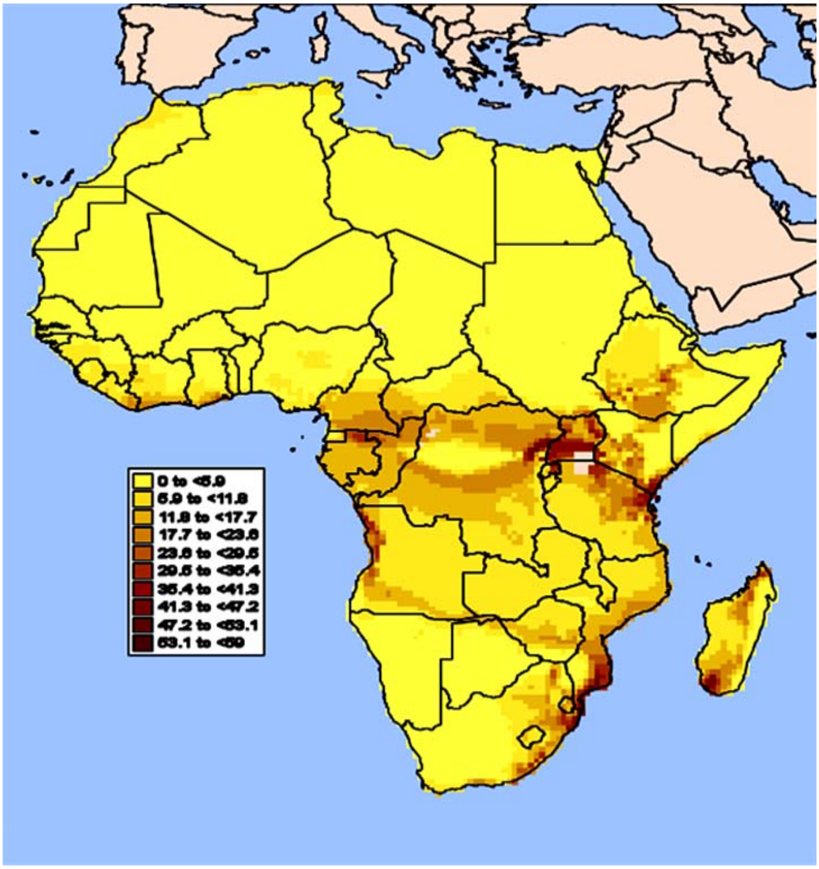

Fig. 2. Distribution of *Chilo partellus* (numbers indicated in the key show the density of *C. partellus* per 20 maize plants).

B. fusca: *B. fusca* is distributed widely throughout the sub-Saharan Africa. Populations in eastern and southern Africa appear to be adapted to different environments from those in West Africa. In the eastern and southern parts of the continent, *B. fusca* is restricted to mid and high elevation areas (>600 m), whereas in West Africa, the same species is found at all elevations, but is most abundant in the drier savanna zone. Country records included Angola, Benin, Botswana, Burkina Faso, Cameroon, Ethiopia, Ghana, Guinea, Cote d'Ivoire, Kenya, Lesotho, Malawi, Mali, Mozambique, Nigeria, Rwanda, Sierra Leone, Somalia, South Africa, Swaziland, Tanzania, Uganda, Zaire, Zambia and Zimbabwe (Harris and Nwanze, 1992; Assefa Gebre-Amlak, 1985; Emana Getu, 2002a; Emana Getu *et al*., 2001 and 2007).

C. partellus: *C. partellus* is native to Asia where it is considered to be a pest of maize and sorghum. It was first reported in Africa in 1930 in Malawi, and has since spread to most countries in eastern and southern Africa, including Ethiopia, Kenya, Malawi, Mozambique, Somalia, South Africa, Sudan, Tanzania, Uganda, Botswana, Swaziland, Zimbabwe, Comoro Islands, Madagascar, Lesotho, Eritrea, Zambia, Zanzibar and Somalia (Polsezek, 1998; Sithole, 1990; Bleszynski, 1970; Delobel, 1975; Emana Getu, 2002a and b; Emana Getu *et al*., 2001 and 2007). *C. partellus* was considered to be a low land pest of maize and sorghum both in Asia and Africa below 1600 meters above sea level (m.a.s.l), but survey reports since early 2000 indicated that the pest has become important up to an elevation of 2200 m.a.s.l., which could be due to either climatic change or change of behavior in certain populations (Emana Getu, 2002a and b; Emana Getu *et al*., 2001, 2002 and 2003).

S. calamistis: *S. calamistis* occurs throughout most of the tropical African countries. Country records include South Africa, Zimbabwe, Malawi, Uganda, Tanzania, Kenya, Zanzibar, Madagascar, Mauritius, Reunion, Angola, Nigeria, Coted'Ivoire, Cameroon, Sengegal, Gambia, Ghana, Mozambique, Ethiopia, Eritrea and Zambia (Tams and Bowden, 1953; Cugala *et al*., 1999; Assefa Gebre-Amlak, 1985; Emana Getu, 2002a; Emana Getu *et al*., 2001 and 2007).

E. saccharina: *E. saccharina* had wide distribution in sub-Saharan Africa including Burundi, Chad, Ghana, Kenya, Mozambique, Nigeria, Rwanda, Sierra Leone, Somalia, South Africa, Tanzania, Uganda, Ethiopia and Zaire (Maes, 1998; Emana Getu, unpublished data).

CEREAL STEMBORERS' DAMAGE SYMPTOM

Most stemborer species produce similar symptoms of damage in maize and sorghum (Ampofo, 1986; Seshu Reddy, 1988; Seshu Reddy and Sum, 1992; Sithole, 1990). Damage symptoms caused by stemborers' larvae feeding vary according to the stages of the crops and type of crops. The adult moths lay batches of eggs on leaves or behind in the leaf sheaths. Newly hatched larvae climb from the oviposition site to the whorl and enter the stem, except *S. calamistis*, which directly bore. The stemborers feed initially by scraping the epidermis of the young and tender leaves near the base of the whorl. The feeding activity is later visible as elongated scars on the expanded leaves with characteristic "pin-holes" and "window panning". Later, the larvae feed and tunnel inside the stems and may kill the central leaves and growing point producing "dead hearts" in young plants, resulting in no yield. Prior to pupation, larvae cut exit holes through which adult moths emerge. Thin membranes of stem tissue cover these exit holes. Stem tunneling weakens the stem, interferes with the translocation of metabolites and nutrients within the plant, resulting in malformation of the grains. Affected plants have stunted growth, reduced yield and are more susceptible to wind damage and secondary infections. Stem or peduncle breakage is associated with the borer damage in maize and sorghum. In maize, in addition to stem breakage, the larvae bore into the maize cobs and feed on the developing grains. In sorghum, they also cause chaffy heads by feeding on developed grains.

CEREAL STEMBORERS BIOLOGY

Like the symptoms there are some similarities of biology of different stemborers' species which can be summarized below (Bosque-Perez and Schulthess, 1998; Overholt, *et al*., 2001).

B.fusca: The female lays several hundred eggs in batches of 30-50, inserted between the sheath and the stem (Fig. 3). Incubation lasts about one week. After hatching the larvae feed on the young blades of the leaf whorl and then, suspended from silk strands, spread to neighboring plants (Overholt, *et al*., 2001). They penetrate the stems by boring through the whorl base. Generally, they destroy the growing point and tunnel downward. After passing through six to eight stages (instars) in 30-45 days, they chew an outlet for the adult and pupate in the tunnel. Pupation lasts 10-20 days. Up to four generations are produced per year. At the end of the rainy season, larvae of the last generation enter diapause in maize and sorghum stubble or in wild grasses. They pupate a few months later, just before the start of the following rainy season (Overholt, *et al*., 2001; Assefa Gebre-Amlak, 1989a and b). The fecundity of the female moths which come from diapause larvae are significantly lower when compared to the moths which come from non-diapause larvae. Emana Getu (2002a) reported that *B. fusca* female moth which comes from non-diapause larvae lays over 300 eggs in her life time, while a female moth which comes from diapause larvae can only lay up to 150 eggs in her life time. Although there is some confusion, it is said that diapause in *B. fusca* is obligate i.e when food and moisture get scarce, the last instar larva goes into diapause for approximately 3-5 months until favorable conditions return such as emergence of crop seedling and onset of rainfall.

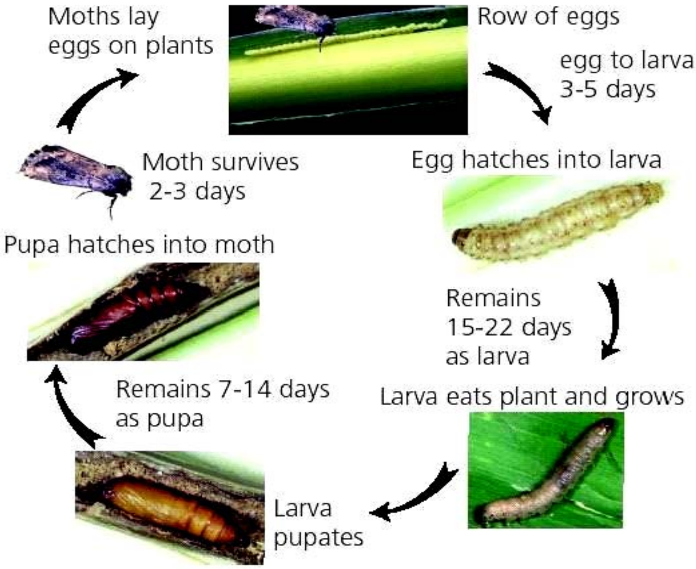

Fig.3. Life cycle (egg batch, larva, pupa and adult) of *Buseola fusca*.

C. partellus: *C. partellus* moths emerge in the late afternoon and early evening. Mating occurs soon after emergence and on the two to three subsequent nights (Berger, 1989). Egg batches of 10-80 overlapping eggs are laid on the underside (Päts and Ekbom, 1994) or upper sides (Mathez, 1972) of leaves, often near midribs (Fig. 4). The fecundity of *C. partellus* is reported to be approximately 434 eggs per female (Berger, 1989; Overholt *et al*., 2001). Adults live for approximately two to seven days (Alghali, 1988) and normally do not disperse far from emergence sites. Eggs hatch in the early morning (6.00 to 8.00 h), four to eight days after being oviposited (Berger, 1989; Delobel, 1975). Young larvae ascend plants to enter the leaf whorls, where they start to feed. Older larvae tunnel into stem tissue and pupate after feeding for 2 to 3 weeks, unless they go into quiescence. Moths eclose from the pupae after 4 to 8 days. The life cycle is completed in 25 to 50 days when conditions are favorable (Harris, 1990). During the growing season, three or more successive generations may develop. Although the life cycle may be continuous when favorable conditions for host plant growth exist, it is usually interrupted by a cold or dry season. To overcome this period, the mature larvae enter diapause inside old stems or stubble (Scheltes, 1978) and pupate on the return of favorable conditions. Unlike *B. fusca* diapause in *C. partellus* is facultative as the diapuse larva in a dry stalk and active larva on irrigated crops were frequently found during the dry season of the year.

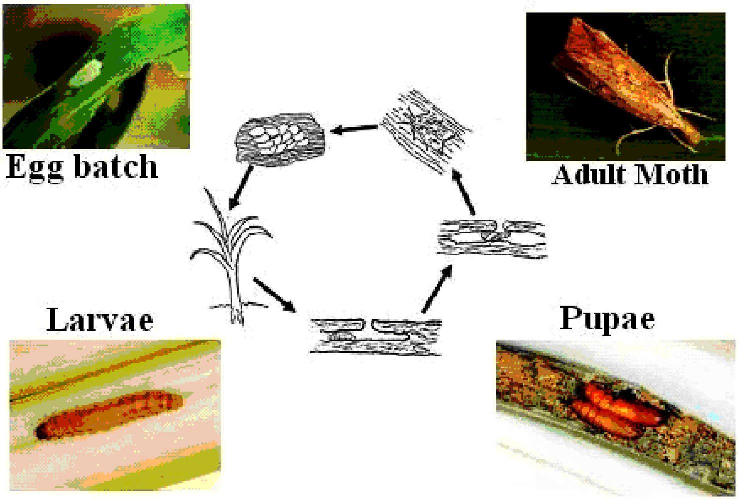

Fig.4. Life cycle (egg batch, larva, pupa and adult) of *Chilo partellus.*

***S. calamistis*:** Female adults of *S. calamistsis* lay approximately 300 eggs in a lifespan of five to six days. The spherical eggs are laid in batches of 10 to 40 eggs (Bosque-Perez and Dabrowski, 1989), usually in two to four adjoining rows between the lower leaf sheaths and stems (Mathez, 1972). Under field conditions, eggs hatch in five to six days. Shortly after hatching, larvae penetrate the stems directly or start feeding on the leaf sheath first (Holloway, 1998). *S. calamistsis* larvae are also highly attracted to cobs. During the larval stage, which lasts for 30 to 60 days and usually involves five to six moults, larvae may successively attack a number of young stems. Pupation generally takes place in the stem or cobs (Bosque-Perez and Schulthess, 1998) and the pupal period lasts for 10 to 12 days. In contrast to many other stemborers, *S. calamistis* breeds throughout the year and has no resting stage (Holloway, 1998). In the dry season, it can be found in mature grasses or in maize or sorghum growing in small areas near water (Harris, 1962; Emana Getu, 2002a). In areas where *S. calamistis* is forced to feed on wild grasses to bridge the cropping season, larval survival and adult fecundity will be greatly reduced and as a result, stemborer densities will be low (Bosque-Perez and Schulthess, 1998). The combined effect of fewer adults and reduced fecundity may explain the low incidence of *S. calamistis* in maize or sorghum early in the season.

E. saccharina: Females lay batches of 50-100 eggs on dry leaves at the bases of plants, which may partly explain the tendency of *E. saccharina* to infest mature crops. Eggs hatch after about 6 days and the young larvae feed externally on epidermal tissue before penetrating the stems. The length of larval development is variable and may take up to 2 months. Larvae pupate within the stems. Up to six generations may develop in a year and there is no diapause in *E. saccharina* (Overholt, *et al*., 2001).

ECOLOGY OF CEREAL STEMBORERS

The most important ecological aspects of stemborers are the hosts (cultivated and wild), the natural enemies (parasitoids, predators and pathogens) and the physical factors such as temperature, relative humidity, rainfall and elevation (Assefa Gebre-Amlak, 1985; Emana Getu, 2002a; Emana Getu, 2004a and b; Emana Getu, 2007; Emana Getu *et al*., 2001, 2003 and 2004). The interactions of stemborers with these factors affect the distribution and abundance of the stemborers.

Plants recorded as hosts of stemborers are maize, sorghum, rice, sugarcane, *Eleusine coracana*, *Hyparrhenia rufa*, *Panicum maximum*, *Pennisetum purpureum*, *Rottboellia compressa*, *Sorghum verticilliflorum*, *Vossia cuspidate*, *Cenchrus ciliaris*, *Coix lacryma-jobi*, *Dactyloctenium bogdanii*, *Echinochloa haploclada*, *Echinochloa pyramidalis*, *Hyparrhenia filipendula*, *Hyparrhenia pilgerana*, *Panicum deustum*, *Pennisetum trachyphyllum*, *Phragmites* spp., *Rottboellia cochinchinensis*, *Setaria incrassate*, *Sorghum arundinaceum*, *Sorghum vesicolor*, *Sorghum vulgare* var. sudanense and *Sporobolus marginatus* (Bleszynski, 1970; Khan *et al*., 1997; Emana Getu, 2002a). The presence of these hosts within the crop field and/or near by the crop fields highly influence the infestation of stemborers by directly affecting the borers density and indirectly affecting their natural enemies (Emana Getu, 2002a; Emana Getu *et al*., 2007). Some of the wild hosts are perennial in nature and serve stemborers as hosts throughout the year. These stemborers have both negative and positive ecological values. The negative ecological value is that these stemborers will shift to crop fields when crops are planted and cause heavy damage to crops. The positive ecological value is that these stemborers could serve as food sources for the natural enemies when crops are out of season, so that the natural enemies conserved on the wild hosts will move to the crop field when the crops are planted and suppress the population density of the stemborer and thereby minimize losses due to stemborers on crops (Emana Getu, 2002a; Emana Getu *et al*., 2007).

A large number of natural enemies from parasitoids, predators and pathogens groups were recorded on different species of stemborers in Africa (Bonhof *et al*., 1997; Mohyuddin and Greathead, 1970; Walker, 1994; Odindo *et al*., 1989; Otieno, 1986; Maes, 1998; Polaszek, 1998; Emana Getu, 2002a). Some of the parasitoids recorded in Africa from the orders Hymenoptera and Diptera on larvae, pupae and eggs of stemborers include *Cotesia flavipes* (Cameron), *Cotesia sesamiae* (Cameron), *Bracon sesamiae* (Cameron), *Dolichogenidae fuscivora* Walker, *Dolichogenidae* polaszeki Walker, *Glyptapanteles africanus* (Cameron), *Dentichasmias busseolae* Heinrich, *Xanthopimpla citrina* (Holmgren), *Xanthopimpla stemmator* Thunberg, *Sturmiopsis parasitica* (Curran), *Stenobracon rufus* (Szepligeti), *Pediobius furvus* (Gahan), *Telenomus busseolae* (Gahan), *T. thestor* Nixon and *Trichgrammatoidea* sp. (Bonhof *et al*., 1997).

Predators of cereal stemborers recorded in Africa from the order Coleoptera, Dermaptera, Hedmiptera and Hymenoptera include *Cheilomenes sulphurea* Olivier, *C. propinqus* Mulsant, *Diaperasticus erythrocephala* Olivier, *Forficula auricularia* Linnaeus, *Orius* sp., *Chrysopa* sp., *Camponotus* sp., *Camponotus rufoglaucus* (Jerdon), *C. sericeus* (Fabricius), *Carciocondyla schuckardi* Arnold, *C. emeryi* Forel, *Dorylus* sp., *Dorylus helvolus* (Linnaeus), *Pheidole* sp., *Pheidole megacephala* Fabricus and *P. guineense* Fabricius (Bonhof *et al*., 1997).

Bonhof *et al*. (1997) also reported pathogens from fungi, virues, bacteria, protozoa and nematodes groups on stemborers in Africa. These include *Aspergillus* sp., *Beauveria bassiana*, *Cordyceps* sp., *Metarhizium* sp., *Metarhizium anisopliae*, *Rhizopus* sp., *Baculoviridae*, *Polyhedral* inclusion bodies, *Bacillus thuringiensis* Berliner, *Monococcus* sp., *Streptococcus* sp., *Microsporidia*, *Gregarine*, *Nosema* sp., *Nosema marcucae* Odindo and Jura, *Hexamermis* sp. and *Panagrolaimus* sp.

In the surveys made between 1999 and 2000 in Ethiopia, Emana Getu (2002a) reported 21 parasitoids, 14 predators and seven pathogens on stemborers (Tables 2, 3 and 4). The natural enemies were recorded on eggs, larvae and pupae stages of stemborers. Some of the natural enemies such as *C. flavipes* resulted in over 70% parasitism in areas where *C. partellus* dominated the stemborer species (Emana Getu *et al*., 2007). *C. flavipes* is Asian origin endo larval parasitoids of stemborers introduced into Africa for classical biological control of *C. partellus* in eastern and southern African counties. The parasitoid was not released in Ethiopia, but invaded the country probably from the earlier releases of the neighboring countries like Somalia and Kenya and for the first time was recorded in Ethiopia in 1999 (Emana Getu, 2002a; Emana Getu *et al*., 2001 and 2003). The parasitoid is expected to greatly impact cereal stemborers in as it has established new association with *S. calamistis* and *B. fusca* in addition to its almost 100% parasitism of *C. partellus*. The origin of *C. flavipes* in Ethiopia was not known, but preliminary molecular analysis indicated that it is similar to the parent populations (Indian and Pakistani populations) and populations established in other African countries such as Kenya, Uganda and Tanzania (Emana Getu, 2008).

Temperature, relative humidity, rainfall and elevation are the most important physical factors affecting the distribution, abundance and species composition of stemborers (Overholt *et al*., 2001; Kfir, 1997; Emana Getu, 2002a). Emana Getu (2002a), Emana Getu *et al*. (2002, 2003 and 2004) indicated that *C. partellus* is abundant in dry, hot and lowland areas, while *B. fusca* is dominant in cool, wet and highland areas.

Table 2. Primary parasitoids of stemborers recorded in Africa.

Parasitoid	Host species	Host stage	Distribution	Reference (s)
HYMENOPTERA				
Braconidae				
Cotesia sesamiae (Cameron)	Cp, Co, Sc, Bf, Es	L	Afro tropical including Madagascar, Mauritius and Reunion, Ethiopia	Walker, 1994; Polaszek, 1998; Assefa Gebre-Amlak, 1985; Emana Getu, 2002a
Cotesia ruficrus (Haliday)	Ms, Cz, Pg, Sn, Sc, Ml, CC, Ai	L	Cameron, Ivory coast, Madagascar, Nigeria, Senegal, Somalia, South Africa, Sudan, Uganda and Zimbabwe, Ethiopia	Walker, 1994; Bonhof, 1997; Polaszek, 1998; Emana Getu, 2002a
Cotesia flavipes Cameron	Cp, Sc, Bf	L	South and south east Asia, Kenya, Uganda, Tanzania, Madagascar, Mauritius and parts of neotropics, Ethiopia	Walker, 1994; Potting, 1996; Polszek, 1998; Emaana, 2002a
Dolichegenidea polaszeki Walker	Bf, Sc, Sb, Cp, ES	L	Benin, Ghana, Kenya, Malawi, Nigeria, Uganda, Zambia, Ethiopia	Walker, 1994; Polaszek, 1998; Emana Getu, 2002a
Dolichogenidea oryzae Walker	Cd, Cz	L	Ivory coast, Niger, Senegal	Walker, 1994; Polaszek, 1998
Dolichogenidea fuscivora Walker	Cp, Bf	L	Ethiopia	Walker, 1994; Polaszek, 1998; Emana Getu, 2002a
Dolichogenidea aethopica (Wilkinson)	Cz	L	Ivory coast, Kenya, Sierra Leone, Somalia, South Africa, Sudan, Tanzania, Uganda	Walker, 1994; Polaszek, 1998
Dolichogenidea cameroonensis Walker	Unknown	L	Cameroon	Polaszek, 1998
Bracon sesamiae Cameron	Bf, Sc, Cp	L	Cameron, Ethiopia, Senegal, South Africa, Tanzania, Uganda	Polaszek, 1998; Assefa Gebre-Amlak, 1985; Emana Getu, 2002a
Bracon hebetor Say	Bf, Sc, Cp, Es	L	Cosmopolitan	Plosazek, 1998; Assefa Gebre-Amlak, 1985
Stenobracon rufus (Szépligeti)	Bf, Sc, Cp, Es	P	Afro tropical including Madagascar, Ethiopia	Polaszek, 1998; Emana Getu, 2002a
Chelonus curvimaculatus Cameron	Bf, Sc, Cp, Cz	P	Congo, Kenya, Madagascar, Mauritius, Senegal, Somalia, South Africa, Sudan, Tanzania, Uganda, Zambia, Zimbabwe, Ethiopia	Polaszek, 1998; Emana Getu, 2002a
Glyptapanteles maculitarsis (Cameron)	Bf	L	Kenya, Nigeria, Sierra Leone, South Africa, Tanzania, Uganda, Ethiopia	Polszek, 1998; Emana Getu, 2002a
Chalcidoidea				
Psilochalcis soundanensis (Steffan)	Bf, Ci, Cp, Cz, Es, Ms	L-P	Cameron, Ghana, Kenya, mali, Mozambique, Niger, Nigeria, Senegal, Sudan, Uganda, Asia (India, Pakistan), Ethiopia	Polaszek, 1998; Emana Getu, 2002a
Eulophidae				
Pediobius furvus Gahan	Bf, Cp, Sc	L-P	Ethiopia	Polaszek, 1998; Emana Getu, 2002a

Table 2 continued

Parasitoid	Host species	Host stage	Distribution	Reference (s)
Eurytomidae				
Eurytoma oryzivora Delvare	Cp, Ms	L	Cameroon, Senegal, Sierra Leone, Tanzania, Ethiopia	Polaszek, 1998; Emana Getu, 2002a
Trichogrammatoidea				
Lathromeris ovicida (Risbec)	Bf, Sc, Cz, , Ms	Egg	Benin, Cameron, Ghana, Ivory coast, Nigeria, Uganda	Polaszek, 1998
Ichneumonidae				
Dentichasmias busseolae Heinrich	Cp	P	Burkina Faso, Cameroon, Kenya, Malawi, Ethiopia Mozambique, Nigeria, Sierra Leone, South Africa, Uganda	Polaszek, 1998; Emana Getu, 2002a
Ichneumon rubriornatus Cameron	Bf, Sc	P	Ethiopia, Niger, South Africa	Polaszek, 1998
Procerochasmias nigromaculatus (Cameron)	Bf, Cp, Es, Sc	P	Cameroon, Ethiopia, Kenya, Mozambique, South Africa, Tanzania, Uganda, Zimbabwe	Polaszek, 1998; Emana Getu, 2002a
Xanthopimpla stemmator (Thunberg)	Cs, Sc	P	Mauritius, Madagascar, Ethiopia	Polaszek, 1998; Emana Getu, Observ.
Xanthopimpla citrina (Holmgren)	Bf, Ca, Cp, Cs, Sc	P	Ivory coast, Kenya, Madagascar, Mauritius, Mozambique, Nigeria, Tanzania	Polaszek, 1998
Scelionidae				
Telenomus busseolae Gahan	Bf, Sb, Si, Scr, Sn, Ci	E	Cameron, Egypt, Ghana, Kenya, Mauritius, Niger, Nigeria, Reunion, Senegal, South Africa, Uganda, Ethiopia	Polaszek, 1998; Emana Getu, 2002a
DIPTERA				
Tachinidae				
Sturmiopsis parasitica (Curran)	Bf, Es, Sc, Sn, Cp	L	East, West and southern Africa, Ethiopia	Polaszek, 1998; Emana Getu, 2002a
Siphona murina (Mesnil)	Bf	L	Uganda, Kenya, northern Tanzania, Ethiopia	Polaszek, 1998; Emana Getu, 2002a

Cp = *C. partellus*
Co = *C. orichalcociliellus*
Sc = *S. calamistis*
Bf = *B. fusca*
Es = *E. saccharina*
Ms = *Maliarpha separtella*
Sb = *S. botanephaga*
Cd = *C. diffusilineus*
Ci = *C. infuscatellus*
Ca = *C. aleniellus*
Cs = *C. sacchariphagus*
Si = *S. inferens* (Walker)
Scr = *S. cretica*

Cz = *C. zacconius*
Pg = *Pectinophora gossypiella*
Sn = *S. nonagrioides*
Ml = *Mythimna loreyi* (Duponche)
Cc = *Chrysodeixis chalcites* (Esper)
Ai = *Agrotis ipsilon* (Hufanagel)
E = Egg
L = Larva
P = Pupa
L-P = Larval-Pupal

Table 3. Predators recorded on African cereal stemborers

Predators	Host species	Host stage	Distribution	Reference (s)
COLEOPTERA				
Coccinellidae				
Cheilomenes sulphurea Olivier	Cp	E	Kenya, Ethiopia	Bonhof; 1997 and 2000; Emana Getu, 2002a
C. propinqus Mulsant	Cp	E	Kenya, Ethiopia	Bonhof, 1997 and 2000; Polaszek, 1998; Emana Getu, 2002a
DERMAPTERA				
Forficulidae				
Diaperasticus erythrocephala Olivier	Cp	E/L	Kenya, Ethiopia	Bonhof, 1997 and 2000; Polaszek, 1998 ; Emana Getu, 2002a
Forficula auricularia Linnaeus	Cp	E/L	Kenya, Ethiopia	Bonhof, 1997 and 2000; Polaszek, 1998; Emana Getu, 2002a
HETEROPTERA				
Anthocoridae				
Orius sp.	Cp	E	Kenya	Bonhof, 1997 and 2000; Polaszek, 1998
Chrysopidae				
Chyrysopa sp.	Bf	E/L	Kenya, Ethiopia	Bonhof, 1997 and 2000; Polazek, 1998; Emana Getu, 2002a
HYMENOPTERA				
Formicidae				
Pheidole megacephala Fabricius	Cp, Bf	E/L	Uganda, Ethiopia	Bonhof, 1997; Polaszek, 1998; Emana Getu, 2002a
Pheidole guineense Fabricius	Bf	E/L	Uganda, Ethiopia	Bonhof, 1997; Emana Getu, 2002a
Dorylus helvolus (Linnaeus)	Bf	L	Uganda	Bonhof, 1997; Emana Getu, 2002a
Camponotus rufoglaucus (Jerdon)	?	?	Kenya, Ethiopia	Bonhof, 1997; Emana Getu, 2002a
C. sericeus (Fabricius)	ES	E	Uganda, Ethiopia	Bonhof, 1997; Emana Getu, 2002a
Carciocondyla schuckardi Arnold	Bf	E/L	Kenya	Bonhof, 1997

E = Egg Es = *E. saccharina*
L = Larva E/L = egg or larva
Cp = C. Partellus Bf = *B. fusca*

Table 4. Pathogens of cereal stemborers in Africa

Pathogens	Host species	Host stage	Distribution	Référence (s)
Fungi				
Aspergillus sp.	Cp	L	Kenya, Ethiopia	Bonhof, 1997; Emana Getu, 2002a ; Polaszek, 1998
Beauveria bassina Vuillemin	Cp	E	Kenya, Ethiopia	Bonholf, 1997; Polaszek, 1998 ; Emana Getu, 2002a
Metharhizium anisopliae var. anisopliae	Cp	E/YL	Kenya, Ethiopia	Maniania, 1991; Bonhof, 1997; Emana Getu, 2002a
Paecilomyces fumosoroseus (Wize) Brown and Smith	Cp	E	Kenya, Ethiopia	Maniania, 1991; Bonhof, 1997
Bacteria				
Bacillus thuringiensis Berliner	Bf, Cp	L	Kenya, Ethiopia	Assefa, 1985; Bonhof, 1997; Emana Getu *et al*., 2007
Monococcus sp.	?	L	Kenya	Odindo *et al*., 1989 ; Bonhof, 1997
Streptococcus sp.	?	L	Kenya	Odindo *et al*., 1989 ; Bonhof, 1997
Viruses				
Baculoviridae (granulosis virus)	Bf, Cp	L	Kenya	Odindo *et al*., 1989; Bonhof, 1997
Polyhedral inclusion bodies	Bf, Cp, Co	L	Kenya	Odindo *et al*., 1989; Bonhof, 1997
Protozoa				
Nosema marucae Odindo and Jua	?	L	Kenya	Odindo *et al*., 1989; Bonhof, 1997
Nematodes				
Hexamermis sp.	Bf, Cp, Es	L	Kenya, Uganda, Tanzania, Ethiopia	Mohyuddin and Greathead, 1970; Bonhof, 1997; Emana Getu, 2002a
Panagrolamis sp.	?	?	Kenya	Otieno, 1985; Bonhof, 1997

E/YL = Egg or young larva Es = *E. saccharina*
E = Egg Bf = *B. fusca*
L = Larva E/L = egg or larva
Cp = C. partellus

MANAGEMENT OF CEREAL STEMBORERS

A number of stemborer management practices are under utilization in Africa in different countries including Ethiopia against different species of stemborers (Emana Getu *et al*., 2007; Assefa Gebre-Amlak, 1990a and b, 1991). These practices include cultural, use of resistant varieties, biological control, botanical control, chemical control and integrated borer management. A brief aspect of each category is discussed below.

Stemborers' cultural control methods

A number of stemborer control options were developed under this category which includes sowing date, habitat management, intercropping, adjusting fertilizer use and type, stalk/stubble management, crop rotation, tillage and mulching, and wild host management (Assefa Gebre-Amlak, 1989a; Emana Getu, 2002a; Emana Getu *et al*., 2007).

Sowing date

Controversial ideas were published concerning stemborer infestation and sowing dates. However, over 98% of the published literature demonstrated that early sowing immediately at the onset of rainfall significantly reduced the infestation of stemborers (Chinwada *et al*., 2001; Assefa Gebre-Amlak *et al*., 1989b; Emana Getu and Tsedeke Abate, 1999; Emana Getu, 1998a; Emana Getu *et al*., 2007). In Ethiopia, a number of sowing date experiments were conducted against stemborers. Sowing date experiments conducted at Awassa, Areka, Arsi Negele, Gambela, Ziway, Sirinka, Meiso and Melkassa indicated that early-planted maize and sorghum suffered less from the attack of stemborers (Assefa Gebre-Amlak, 1989a and b; Assefa Gebre-Amlak *et al*., 1989; Assefa Gebre-Amlak and Ferdu Azerefeghne, 1996 and 1999; Emana Getu, 1999; Emana Getu and Tsedeke Abate, 1999; Tsedeke Abate and Elias Worku, 1997). For the early sowing to be used as stemborers management options, mass planting of the crops is essential. The main reason why early sowing has less stemborers infestation is that the critical growth stage (seedling) of the crop coincides with low populations of stemborers which come from the less fecund female moth which come from diapause larvae. If this planting is followed, the heavy population of stemborers occurs at the time the crops can tolerate the infestation and give reasonable yield. In general, early planted cereal (maize/sorghum) can escape the infestation of stemborers. The term early is a relative term as it is linked to the onset of rainfall. For example, early sowing for Awassa and Arsi-Negele is mid to end of April, while early sowing for Ziway, Melkassa and Meiso is mid to end of June. Therefore, it is necessary to know the time of the onset of rainfall at a particular location before recommending sowing date as stemborers' management option. Hence, it is very logical to have a different sowing date recommendation for different locations based on the onset of rainfall. It is also logical that a different sowing date recommendation for the management of stemborers should be made with the progressively changing of the onset of rainfall due to climate change. Sowing date recommendation is mainly applicable for areas largely infested by *B. fusca*.

Habitat management

Khan *et al* (1997) developed an intercropping and trap crop system using a push-pull strategy for the control of stemborers in small scale maize farming system. The push-pull strategy involves trapping stemborers on highly susceptible trap plants (pull) and driving them away from the crop using repellent intercrops (push). Napier grass (*Pennisetum purpureum* Schumach) and Sudan grass (*Sorghum vulgare* sudanense Stapf.) are used as trap plants, whereas molasses grass (*Melinis minutiflora* Beauv.) and two species of *Desmodium* (*Desmodium intortum* Urb.) repel ovipositing stemborers moths. The integrated push-pull strategies were shown to increase parasitism of stemborers through attraction of parasitoids to one of the intercrops, molasses grass. The leguminous intercrop, silver leaf desmodium, drastically reduced damage to maize by the parasitic weed, striga. Kenyan farmers have managed to control stemborers and striga using habitat management and boost the yield of maize and sorghum (Khan *et al*., 1997). These pull and push plants also highly contributed to livestock production as they serve nutritive feed to the livestock (Khan *et al*., 1997).

Emana Getu (2002a) recorded 17 species of wild hosts of stemborers in Ethiopia. Some of these wild hosts have been tested for their potential of habitat management of stemborers in Ethiopia and elsewhere. For example, Delenasaw Yewalaw (2004) tested *Pennisetum purpurum* (Scumach), *Sorghum vulgare* var. Sudanese (Pers.), *Panicum maximum* Jacq., *Sorghum arundinaceum* Stapf and *Hyperrhania rufa* (Nees). The results of the studies showed that maize plots surrounded by all the tested wild hosts significantly ($P<0.05$) had lower mean percent foliar infestation and stemborer density than maize monocrop. Moreover, the highest mean percent parasitism (67%) of *C. partellus* by the major parasitoid, *C. flavipes* (Cameron), was recorded in maize plots surrounded by the wild hosts. This technology is very much accepted in Africa, particularly eastern and southern Africa where stemborers, striga and shortage of animal feed are major constraints. In

Ethiopia, this technology is extremely useful in eastern and north-eastern Ethiopia where *C. partellus* and striga are the major bottlenecks of maize and sorghum production. In Harereghe, farmers keep one or two livestock as supplement to crop production. These farmers use border rows of crops to feed their animals which otherwise can be used for their own food. If such farmers are advised to grow napier at the border of maize and sorghum, they can satisfy the feed need of their animals. Hence, it is timely to adopt this technology with little modification to fit to each country's condition.

Intercropping

In Ethiopia, about 70% of the farmers grow maize and sorghum as an intercrop and 30% as a monocrop (Emana Getu, 2002a; Emana Getu *et al*., 2002). The major companion crops are legumes, cereals, pumpkin, groundnut, sesame, potato and sweet potato which vary by region. Intercropping has many advantages over monocropping, including pest control. Much of the published work indicates that intercropping lowers the infestation of pests and increases the abundance of natural enemies which is explained by resource concentration and natural enemy hypotheses (Emana Getu, 2002a). Emana Getu *et al*. (2007) reported lower stemborer density per plant in intercropping than monocropping. Moreover, they reported more parasitism in intercropping than in monocropping. The intercropping experiment conducted in eastern Ethiopia indicated that the mean number of stemborer larvae per maize stem was found significantly lower under chat-maize intecropping than maize monocropping. Moreover, more number of parasitoid cocoons was recorded on the intercropped plot than a monocropped plot (Daniel Tekle, 2002). Hadush Tsehaye *et al*. (2007) reported that stemborer abundance and damage on sorghum were usually lower in the sorghum-cowpea intercropping than in the sorghum monocropping in Tigray. A number of predators (ants, spiders and ladybird beetles) were relatively high in the intercrop than in the monocrop. Emana Getu *et al*. (2007) studied the effect of cropping systems in Northern Ethiopia and recommended that maize-mustard intercropping significantly reduced borer density and damage caused by *B. fusca*, especially at the vegetative stage.

Adjusting fertilizer use and type

Emana Getu (2002a) reported that stemborer infestation was high in the soil where total Nitrogen was high. A field experiment was also conducted to see the effects of NPK fertilizers on the infestation of stemborers and the preliminary result indicated that high level of Nitrogen favored stemborer infestation (Emana Getu, unpublished data). Melakau Wale *et al*. (2006) reported similar result from Northern Ethiopia where they indicated that in the cool-wet western Amhara Region, increasing levels of N fertilizer tended to increase pest density, plant growth and damage variables. As the nutrient content of the soil vary from place to place, experiments should be conducted to adjust the fertilizer need of maize/sorghum which predispose the crop to less infestation of stemborers.

Stalk/stubble management

Farmers store sorghum stalks vertically either in the field or around their homestead. The diapause larvae over season inside the stalk up to the next rainy season. Hence, designing methods by which stalks are kept safe and diapause larvae killed are essential. Towards this end, several experiments were conducted (Assefa Gebre-Amlak, 1988; Emana Getu, 2002a). All of the experiments recommended 4 to 8 weeks of horizontal placement of maize or sorghum which substantially (90-98%) reduced the carryover diapausing larvae in the next season and thereby reduced stemborer infestation on the next crop. This should be done with great care as maize/sorghum stalk at some time have better value for farmers as it can be used for construction, animal feed, firewood and soil conservation, among others.

Crop rotation

Crop rotation is a classical cultural practice, which denies access of the pest to its host. A sequence of closely related crops such as maize and sorghum should be avoided (Seshu Reddy, 1985). Instead the plots should be rotated with crops like pulses and oil crops. Emana Getu (2002a and b) reported 100% stem borer infestation and 80% crop losses on the plot that sorghum was grown continuously year after year, whereas less than 10% infestation and insignificant yield losses was reported on the plot where sorghum was alternated with either pulses or oil crops.

Tillage and mulching

During the off-season, tillage destroys stubble and volunteer hosts that may harbor the stemborers (Seshu Reddy, 1985). Mohyuddin and Greathead (1970) in Uganda observed high levels of stemborers infestations when untreated crop residues were used to mulch the next crop. In Ethiopia, the infestation of *C. partellus* was 100% in areas where farmers used old stalks as mulch for soil conservation (Emana Getu, 1997; Emana Getu and Tesedeke Abate, 1999).

Use of resistant varieties

It is generally accepted that host plant resistance (HPR) is the most farmer-friendly pest control option. When combined with timely sowing, an HPR-based IPM strategy can readily capitalize on high-yielding, moderately resistant/tolerant crop varieties. Sharma (1993) has provided detailed up-to-date information on the use of resistant sorghum cultivars in IPM in different ecosytems worldwide. Over 190 genotypes with varying degrees of resistance to *Chilo* and *Busseola* spp. were reported between 1974 and 1989. Recently, a number of maize and sorghum varieties have been identified as resistant to different species of stemborers by different organizations in Africa and Asia (Emana Getu, 2002a). The resistant level obtained was spectacular for certain crop varieties as some of the varieties were immune to certain species of stemborers. However, the problem with most of these varieties is that they are agronomically poor, especially in yield. It is possible to transfer these important genes into high yielding crop (s) varieties and create a variety with stemborer resistant gene (s) and also give high yield. For example, from the large number of sorghum germplasm tested against stemborers SODF 103, 90 MW 5353, ICSV 680 and ICSV 708 were found to be resistant (Emana Getu *et al*., 2007). Emana Getu (2005a) reported considerable variability among sorghum genotypes with respect to stemborers, particularly to *C. partellus.* Some of the released varieties such as Gobeye and T76#23 were found to be relatively resistant to *C. partellus*. Sefedin Beredin (2006) and Zerubabael Kibret (2007) cited in Emana Getu *et al*. (2007) screened a large number of maize and sorghum genotypes against *C. partellus* at Melkassa, respectively. The results obtained demonstrated considerable variations in terms of infestation among the tested genotypes of both crops. To obtain stemborers resistant sorghum genotype can be obtained, some of the following measures should be taken: 1. Advanced research work which can go up to the commercial release of stemborers resistant variety (ies). 2. Clear understanding of the mechanism of resistance. 3. If it is antibiosis, the chemicals which are responsible should be known.

Natural and Biological controls

There are three modalities of biological control. These include introduction/classical, augmentation and conservation. Individual modality uses either parasitoids or predators or pathogens.

Parasitoids

Though a large number of parasitoids are associated to stemborers in the new and old worlds, few of them have been considered in the biological control of stemborers (Emana Getu, 2002a and b; Overholt *et al*., 1997). For example, in Africa two parasitoids, *C. flavipes* and *X.* *stemator* were considered for biological control of stemborers. *C. flavipes* was released since 1993 in eastern and southern African countries where the exotic stemborer, *C. partellus* is a menace in maize and sorghum production. The parasitoid at the moment significantly suppressed the stemborer population in Africa including Ethiopia where the mean percent parasitism reach as high as 70% (Emana Getu, unpublished data). *C. flavipes* was mass reared in the laboratory and released at Wolenchiti, Meiso and Melkassa in 2004. The recovery/establishment survey was conducted in 2005 and parasitism in all the three areas ranged between 75 and 87% which is over 50% increment when compared to the pre augmentation release of 2003 parasitism (Emana Getu, 2005a). This parasitoid was not released in Ethiopia, but for the first time recorded in Ethiopia in 1999 (Emana Getu, 2002b; Emana Getu, 2005b; Emana Getu *et al*., 2001; Emana Getu *et al*., 2003).

A pupal parasitoid of stemborers, *X. stemator,* was released in some African countries like Kenya, Ethiopia and Zimbabwe. In Ethiopia, the release was made in some parts of the country where stemborers are important pests in maize and sorghum production. With the 2006 season survey, there was evidence of establishment of the parasitoid as few recoveries were made (Emana Getu, Personal observation). The use of parasitoids on eggs, larvae and pupae stages seems to be one of the best stemborers control options.

Predators

There is no biological control attempt made so far for the control of stemborers. However, there are potential predators as can be seen from the surveys taken in Ethiopia (Emana Getu, 2002a) and Kenya (Bonholf, 2000). Farmers should be advised to conserve the natural enemies such as earwigs, ladybird beetles, ants and spider mites which were recorded preying on the eggs and early instars of stemborers.

Microbial control

The cryptic feeding habit of stemborers makes the use of microbial control less effective against them (Maniania, 1991). However, some studies indicate the effectiveness of some microbial organisms. For example, biological control studies were conducted with isolates of entomopathogenic fungi such as *Beauveria bassiana* and *Metarrhizium anisopliae* from Ethiopia against *C. partellus* (Tadele Tefera, 2004; Tadele Tefera and Pringle, 2007). The results obtained indicate that *B. bassiana* (BB-01) and *M. anisopliae* (PPRC-4, PPRC-19, PPRC-61 and EE-01) were found to be highly pathogenic to the larvae inducing 90 to 100% mortality seven days after treatment. Second and sixth instar larvae were more vulnerable to these isolates than third, fourth and fifth instar larvae. The use of *Bacillus thuringiensis* Berliner in the control of stemborer was reported by Emana Getu *et al*. (2001). Two bacterial preparations, *Bitoxi bacillin* and *Dendero bacillin* 10% were applied on the third instar larvae of maize stemborer and caused 80-90% mortality following 10 days after application in the laboratory. Four bacteria and one fungus collected from the maize stemborer larvae during a survey in Ambo area were purified and tested on the first instar larvae and the bacteria were found to be pathogenic to *B. fusca*.

Botanical control

A large number of plants have insecticidal values against stemborers. These include *Azadirachta indica*, *Melia azedarach*, *Phytolacca dodecandra, Hagenia abyssinica*, *Allium sativaum*, *Chrysanthemem sp*., *Capsicum annuum*, *Croton macrostachyus*, *Milletia ferruginea*, *Girardinia diversifolia, Catha edulis* and *Culpurinia sp*. were some of the botanical plants found to be effective against stemborers (Daniel Tekle, 2002; Assefa Gebre-Amlak and Ferdu Azerefeghne, 1999; Emana Getu, 2005a; Habte Tekei, 1999). Different parts of the plants (seed, flower, leaves, roots and fruits) at different formulations (oil, powder, water and extract) with different level of efficacy were used for the control of stemborers. For example, oils from *A. indica*, *H. abyssinica* and *M. furregemia* gave 100% mortality of stemborers at 5% concentration. Extracts of *A. indica* seeds and Chrysanthemem flowers caused the highest borer mortality (85-100%), garlic bulb caused 49.9% to 55% mortality at 6 % concentration, 54.9-55% mortality at 8% concentration. Extracts of *M. furegemia* seeds gave 59.9 % mortality. Extracts of endod (*Phytolacca dodecandra* L.) and all other remaining plant materials caused 50% mortality of stemborers. Chat (*Khatha edulis*) leaf extracts inhibited the larval feeding activity and caused larval mortality in stemborers (Daniel Tekle, 2002). Extracts of fruits of chinaberry (*Melia azedarach* L.), endod (*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*, and resulted in increases in crop yield (Assefa Gebre-Amlak and Ferdu Azerefeghne, 1999). Extracts of both leaves and fruits of chinaberry (either fresh or dried) were effective in reducing the number of larvae. All the rates (2, 10 and 20 kg/ha for fresh leaves; 1, 2 and 10 kg/ha for dried leaves; 10, 20 and 30 kg/ha for fresh fruits, and 2, 10 and 20 kg/ha for dried leaves) used significantly reduced the number of larvae compared to the untreated control. Fresh leaves and fruits of endod were also effective against *B. fusca*. Fruits of pepper tree were superior to leaves (Emana Getu *et al*., 2007). Almost all studies conducted on botanicals in Africa including Ethiopia are based on crude product such as seed/fruit, leaf, stem and root powders which require large quantity for effective control of the stemborers which makes the use of botanicals difficult or impossible on large plot of land. To solve this problem there is some study progress with neem to isolate the active ingredient from the plant and different products and formulations were produced at the processing plant. To date, there are a number of neem products that are commercially available in any pesticide shop like synthetic pesticide in the world. Hence, such attempts should be done for the rest of the botanicals.

Use of Transgenic plants

Transgenic plants expressing *Baccillus thuringiensis* ð-endotoxin are now being used commercially in several crop species. These toxins have demonstrated good control of temperate (*Ostinia nubilalis* (Hubner)) and tropical (*Diatraea grandiosella* Dyar and *D. saccharalis*) stemborers in maize (Bergvinson *et al*., 1997). Resistance to *B. thuringiensis* toxins has been reported in over 11 species in both field and laboratory studies (Melaku Wale *et al*., 2006), demonstrating the need for resistance management strategies to prolong the efficacy of this valuable pest management tool within an integrated control programme. Resistance involves reduced binding of toxins to midgut epithelia cells and is generally considered to be a recessive trait. Resistance management will require the use of spatial and temporal refugia which may require unique schemes for each pest complex. Information is presented on the mode of action of cry toxins, resistance mechanisms, interaction of transgenic plants and bio-control agents, and management/deployment strategies for transgenic maize in tropical ecologies (Emana Getu 2002a). The application of this technology is questionable in Ethiopia at the moment because the parasitism rate is tremendously increasing from 5% in 1999 to over 80% in 2008.

Pheromone Technology

The use of pheromone traps in population monitoring and forecasting of lepidopterous pests is an important component in integrated pest management. This is true for other crops and for other insect species. For example, the pheromone trap network for *Helicoverpa armigera* (Hubner) is well developed and constitutes an integral part in the management of this pest at many locations across India (Srivastava *et al*., 1992). There are few cases where this element has been successfully used in the direct reduction of pest populations and crop damage. As demonstrated by Nwanze (1997) pheromones can be used as a component of stemborers control if used as mating disruption on crops like maize and sorghum.

Chemical control

Arrays of chemicals (insecticides) were recommended for the control of stemborers which include selecron E.C, cypermethrin 1% G, cypermethrin 5% EC, primiphos methyl 50% EC, cyhalothrin 5% EC, sumicomb 30% EC, sumicombi 1.8% D, Fenom 100% EC, Fenitrothion 50% EC, Fenithrothion 5% D, Ethiosulfan 35% EC, Diazinon 60% EC, Ethiosulfan 5% EC, Thionex 25% EC, Actellic % EC, Decitab and cypermethrin G, chloropyriphos 2G, endosulfan, carbofuran, diazinon and trichlorfon G (Assefa Gebre-Amlak, and Ferdu Azerefegne, 1999; Emana Getu, 1998b and c; Emana Getu *et al*., 2007). However, their time of application and frequency of application highly determine the effectiveness of the insecticides, apart from other limitations such as availability, cost, non-target effect and resistance development among others.

Integrated Pest Management

There are different opinions on Integrated Pest Management (IPM). Brader (1979) defines integrated pest control as a pest management system that in the context of the associated environment and the population dynamics of the pest species, utilises all suitable techniques and methods, cultural practices, host plant resistance, chemical insecticides, biological control and legislation, in as compatible a manner as possible and maintains the pest population at levels below those causing economic injury. This definition is the concept of the early years of IPM. Basically, it was only a concept, not a product or a technology. The emphasis was not on the target group or end-user. A recent definition by Wightman (1993) described IPM as "management activities that are carried out by farmers…" Both definitions merit consideration in that they describe both ends of a continuum in Research and Development (R and D). In essence, the former emphasizes the process of developing IPM strategies and the latter, that of its implementation. However, Brader's definition, like the early years of IPM, was only a concept in which all possible control options were implied and single-option-based IPM strategies were not accommodated within IPM framework. Today, IPM is synonymous with environmental safety and sustainability and therefore, any non-chemical control option can readily find a place in this framework (Nwanze, 1997).

As far as stemborers' management technologies are concerned, a number of recommendations are available, but the efforts done to analyze the combinations (integration) of the technologies for better management of stemborers are very few and were started very recently (Emana Getu, 1999; Emana Getu, 2002a; Emana Getu, 2004 b; Emana Getu, 2005a; Emana Getu *et al*., 2003; Assefa Gebre-Amlak and Ferdu Azerefeghne, 1996). For example, integration of sowing date and botanical application for the control of stemborer conducted at Areka using neem seed powder showed that the earliest sown maize treated with neem seed powder 30 days after emergence resulted in the lowest cob damage and highest yield. In another experiment at Melkassa and Meiso the combination of resistant sorghum variety, intercropping beans within the sorghum rows at the ratio of 2:1 (sorghum: bean), use of napier grass as a trap plant and application of neem seed powder gave over 97% of *C. partellus* control (Emana Getu, 1998a; Emana Getu, 1999; Emana Getu *et al*., 2003; Emana Getu *et al*., 2007; Emana Getu, unpublished). Integrated management of stem borers on sorghum using chemicals, sowing date x variety gave good control of stemborers at Ziway (Emana Getu *et al*., 2007). The management options to be considered in the integration should be compatible, environmentally friendly and economically feasible in addition to efficacy in controlling stemborers.

CONCLUSIONS AND RECOMMENDATIONS

Though a number of stemborer species are recorded in Africa, *C. partellus*, *B. fusca*, *S. calamistis* and *E. saccharina* have wide distribution and have great economic values. The rest of the stemborer species recorded in Africa have either pocket distribution or are economically important locally. Hence, this review concentrated on the four species which have wide geographic coverage in Africa and also that highly affect the production of major cereals grown in Africa such as maize, sorghum, millets, sugar cane and rice. More or less the biology of the stemborer species are the same, with little differences, in that all of them resume cryptic feeding habit after the 1^{st} or 2^{nd} larval instar, which make their control difficult. Thus, management of stemborers should either focus on preventive method and/or arrange the control option (s) before the borers enter inside the stem especially when insecticides are used as a control option which requires detail knowledge on the biology of the stemborers. Highly diversified control options are available on the management of cereal stemborers which ranges from the cheapest and traditional cultural control methods to the use of insecticides. Maybe what is lacking is developing sound integrated pest management from the existing control options which need evaluation of these control options by mixing them to find out the best mix which can be used for the integrated management of cereal stemborers.

The old philosophy of biological control indicates that biological control does not work under annual crops condition mainly because of non-stability which affects the efficiency of biological control agents. However, this philosophy has been disproved in the case of cereal stemborers which have rich guilds of natural enemies both in old and new associations which can be included in one of the three biological control approach (conservation, augmentation and classical biological control). In stemborer biological control, three of the approaches are successfully applied and gave effective control of stemborers. The classical biological control which targeted *C. partellus* by importing the old association natural enemy from Asia into Africa highly suppressed the population of *C. partellus* and some indigenous stemborers such as *B. fusca* and *Sesamia calamistis*. In Ethiopia, the mean percent parasitism by *C. flavipes* reached 70% according to the data recorded in 2006 (Emana Getu, unpublished data). Therefore, from both diversity and efficiency points of view, it can be concluded that biological control is a central part of cereal stemborers management.

The use of push-pull strategy (habitat management) in the control of stemborers is an ecologically and economically sound stemborer management in that the grasses used for the purpose can also be used as livestock feed in addition to enriching the soil by fixing nitrogen and adding organic matter to the soil. Moreover, the grasses attract the natural enemies to the system. This option of stemborers control is also a solution to striga, a pest highly limiting the production of sorghum in East Africa including Ethiopia. To adopt such practice is very simple in African countries where crops-livestock type of mixed agriculture is common.

Horizontal lying of stalks to expose diapause larvae to the sun heat and kill them is a very useful method of stemborer management as the stalks can be used for the intended purpose such as construction, fire wood and livestock feed. Hence, the use of this method should be encouraged.

The century old intercropping system practiced by African farmers happens to be one of the best options of stemborers control in addition to its other advantages such as restoring soil fertility, insurance against crop failures, diversifying food needs among others. Intercropping of cereals with the non host crops to stemborers such as beans should be encouraged as the land use efficiency is also high if planted in the proportion of 1:2 ratio (intercrop: cereals).

Some of the effective botanicals against stemborers such as neem have reached the level of replacing synthetic insecticides. This may have adverse effect on the natural enemies as there are processing plants which utilize botanical plants like neem for producing plant based bio-pesticides such as nembicidine. There are also local plants having insecticidal properties. Hence, the use of effective, safe and available botanical plants for the control of stemborers should be encouraged.

Some crops such as sorghum and millet have genes responsible for resistance of stemborers as was practically witnessed by experiments conducted in Ethiopia by a number of scientists. Hence, activities towards utilization of these genes for the management of stemborers deserve special attention. Moreover, varietal response of crops like rice should be studied.

From the review of cereal stemborers the following recommendations can be made:

1. The biology of cereal stemborers makes their control difficult because of the complex biology of the insects, mainly the cryptic feeding nature of the damaging stage (larval stage) of the pests. Understanding the biology of stemborers is a must for effective control of stemborers particularly when insecticides are used as a control option.

2. Understanding the ecology of stemborers such as cultivated/wild hosts, status of natural enemies and physical environmental factors is highly useful for the environmentally sound management of cereal stemborers.

3. Some of the stemborer species such as *C. partellus* are expanding in their geographical distribution; hence, there is a need for updating the distribution map of cereal stemborers periodically.

4. Some of the natural enemies associated to stemborers such as *C. flavipes* should be utilized for the biological control of stemborers by applying conservation and/or augmentative mechanisms as need arises.

5. Programs towards developing highly resistant crop varieties against stemborers should be launched through coordinated efforts of entomologists and breeders.
6. Quite a large number of technologies are available for the management of cereal stemborers, but information on their integration to get high level of stemborer control is scanty. Thus, applied research in this area is very crucial. However, some control options such as sowing date, intercropping, habitat management, stalk management, biological control, resistant variety, use of botanical plants and reduced use of insecticide can be recommended for the control of cereal stemborers.
7. Extension mechanisms should be devised to disseminate the existing cereal stemborer management technologies such as production of use friendly booklets to be used as manual by the extension workers and farmers. Towards this end, a booklet prepared by the author of this manuscript was sent to press some months ago and will be out very soon and distributed to stakeholders. The conversion of this version (English) to local language (s) is vital but requires fund.
8. Research on emerging technologies such as the use of Bt maize for the control of stemborers should be considered after understanding the environmental impact such as the non-target effect.
9. Research on stemborers should continue as there could be status change with stemborers maybe due to climate change. For example, the coleopteran stemborers recorded are progressing very fast in terms of both expanding their geographical distribution and pest status. Others such as *C. partellus* are very quickly expanding their niche to the highland as the current highest elevation where *C. partellus* recorded is 2200 meters above sea level. Hence, to cope with any kind of change, continuous research is needed.
10. We have to make sure that the rich natural enemies in maize/sorghum agro-ecosystem existing in Africa in general and Ethiopia in particular are maintained year-in and year-out.

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