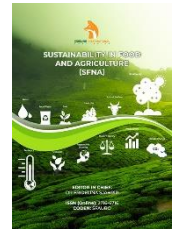


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RESEARCH ARTICLE

ECOLOGY AND DISTRIBUTION OF STEM BORERS IN NIGERIA

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ABSTRACT

There is a renewed interest in Nigeria to go back to Agriculture and see it as a profession. Maize is a major staple food for millions of people in the country. It is one of the most important cereal crops cultivated for food, feed and as industrial raw materials. In spite of the cultivation and uses of maize, production is seriously constrained by stem borers. Stem borers have been the most damaging group of insect pests in maize cultivation worldwide. Feeding by borer larvae on maize plants usually results in crop losses as a consequence of death of the growing point (dead heart), early leaf senescence, reduced translocation, lodging and direct damage to the ears. Yield loss due to stem borers in Africa vary from 0 - 100 % among ecological zones, regions and seasons. In sub Saharan Africa, particularly Nigeria, they can cause 20 - 40 % losses during cultivation and 30 - 90% losses postharvest and during storage. However, estimated yield losses may be higher than of 40 % are expected to occur at the smallholder level where suppression of the pest by chemicals is generally not practiced.

KEYWORDS

Stem borers, Pests Larvae, Species, Maize

1. INTRODUCTION

Maize (*Zea mays* L.) is a major staple food crop grown in diverse agro-ecological zones and is consumed by people with varying food preferences and socio-economic backgrounds in sub-Saharan Africa (SSA) (Olaniyan, 2015). Of the 22 countries in the world where maize forms the highest percentage of calorie intake in the national diet, 16 are in Africa (Nuss and Tanumihardjo, 2011). The top 20 countries, namely South Africa, Nigeria, Ethiopia, Egypt, Tanzania, Malawi, Kenya, Zambia, Uganda, Ghana, Mozambique, Cameroon, Mali, Burkina Faso, Benin, DRC, Angola, Zimbabwe, Togo, and Cote d'Ivoire. They account for 96 % of the total maize production in sub-Saharan Africa. Maize, which may be eaten as a vegetable or processed into various dishes, is regarded as a hunger breaker after a long dry period in developing countries. Additionally, maize is extensively traded as feed crop in livestock industries, and about 460 million (65 %) of total world maize production is used for this purpose (Olaniyan, 2015).

The major stem boring species associated with maize production in Nigeria are moths belonging to the families Noctuidae and Pyralidae, namely: the maize stalk borer (*Busseola fusca* Fuller), the pink stem borer (*Sesamia calamistis* Hampson), the millet stem borer (*Acigona ignefusalis* Hampson) and the African sugar cane borer (*Eldana saccharina* Walker); (Balogun and Tanimola 2001). In fact, stem borers have been the most damaging group of insect pests in maize cultivation worldwide (Tefera *et al.*, 2011). Nigeria is with nearly 8 million tonnes Africa's largest producer of maize (IITA, 2014) and stem borers cause 10-100% losses in maize grain yield (Sosan and Daramola 2001). However, Kakule *et al.* (1997) reported that within Africa, damage to maize varies with locations/regions, with sub-Saharan Africa recording the highest population of stem borers being directly correlated with damage and grain

yield. Crop losses and grain yield reduction may result from the damage caused to growing points leading to loss of stands (dead heart), damage to leaf (window pane) stem tunneling, hole (as portal of entry to secondary rot organisms), stem lodging, stem breakage, tassel and direct damage to ear shank and ear (Sosan and Daramola, 2001). However, the consequence on yield is variable and depends upon sowing, borer species composition and abundance as well as insecticide treatment (Ajala *et al.*, 2010; Okweche *et al.*, 2010). It has been observed that early-planted maize suffers less from borer attacks than late-planted maize in the Middle Belt of Nigeria (Okweche *et al.*, 2010). Heavy stem borer infestations have precluded second cropping of maize even in areas with potentials for two rain-fed crops (Ogunwolu, 1987).

1.1 World Maize Production

Maize is one of the major cereal crops and ranks third in production worldwide following wheat and rice. In more than 20 developing countries in the world, maize is the single largest source of calories and protein for the poor and is a primary weaning food for babies. In sub-Saharan Africa maize is one of the most important staple foods, providing food and income to over 300 million resource-poor smallholders (Romney *et al.*, 2003). Over 650 million people consume an average of 43 kg of maize per year (a 35 % increase since 1960), reaching 85-140 kg in Kenya, Lesotho, Malawi, South Africa, Zambia and Zimbabwe (Lumpkin and Armstrong, 2009). Its cultivation spans the entire continent and is the dominant cereal food crop in many countries, accounting for 56 % of total harvested area of annual food crops and 30-70 % of total caloric consumption.

1.2 Maize Production in Africa

Maize is a monoecious plant grown from latitude 58°N to 40°S, adaptable

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to a wide range of agro-ecological zones in Africa. Over 100 million people in Africa utilise maize as a staple food crop (Byerlee and Heisey, 1996), including as a constituent of livestock feed. Its acreage in tropical highlands (1800–2800 meters above sea level (masl)) is 1.7 million ha, in the subtropics and mid-altitude zones (1200–1800 masl) 8.1 million ha, and in lowland tropics (< 1200 masl) 12.3 million ha (Pingali, 2001). Biotic factors that reduce maize yields in Africa are stem borers, the parasitic weed *Striga* and Maize streak virus (MSV). For instance, Alegbejo *et al.* (2002) reported that Maize streak virus (MSV) alone causes yield losses that range from a trace to almost 100 %. The other diseases that affect maize include leaf blight, rusts, stalk and ear rots, and systemic foliar diseases (Alegbejo *et al.*, 2002).

2. YIELD DIMINISHING FACTORS

The yield potential for sub-Saharan Africa is 5 tonnes /ha in tropical highlands, 7.0 in subtropical and mid-altitude zones and 4.5 in tropical lowlands, compared to the current yields of 0.6, 2.5 and 0.7 tones /ha respectively (Pingali, 2001). This large yield gap is attributable to both abiotic and biotic constraints (Wambugu and Wafula, 2000). The major abiotic constraint is drought that causes an annual yield loss of about 15 % (Kamara *et al.*, 2003), while the second most important constraint is nitrogen. Other African streak viruses constraining maize production include *Panicum streak virus* (PanSV), *Sugarcane streak virus* (SSV), *Sugarcane streak Mauritius virus* (SSMV) and *Sugarcane streak Egypt virus* (SSEV) (Wilment *et al.*, 2001). Maize is susceptible to common species of Pythium and moderately susceptible to *Sclerotium rolfisii* and *Rhizoctonia* spp. Maize is also susceptible to stalk and cob rots caused by several Fusarium species but these do not normally affect vegetable crops.

3. STEM BORERS

Busseola fusca (Fuller), also known as the African stem borer, is a moth, indigenous to tropical Africa (Harris and Nwanze, 1992). Although indigenous, it was first recognised as a pest of maize in South Africa, and has become economically important in many of the maize growing countries on the African continent. *B. fusca* also co-exists with an alien invasive moth *Chilo partellus*, the spotted stem borer, particularly in the agro-ecological zones of Kenya. In some areas, such as the high elevations of the eastern Highveld region of South Africa, *Buseola fusca* has been reported to have been partially displaced by *C. partellus* (Kfir, 1997). The African maize stem borer, *Busseola fusca* (Fuller), is the most important insect pest of maize in South Africa. A generally accepted estimate of annual losses during the early part of the 20th century was 10 % of the national crop. South African maize production increased from less than one million tones (mt) in 1910 to 2.6 mt in 1950 and to 8.2 mt in 1972. This increase in production as well as the concomitant increase in area under maize production (4.7 million ha in 1972) significantly raised the economic status of the pest. Until the mid-1970s *B. fusca* received surprisingly little research attention over a period of half-a-century and control strategies of the time relied heavily on principles derived from the earlier research.

Busseola fusca was first mentioned as *Sesamia fusca* in a report by Fuller in 1901 and described under the same name by Hampson in 1902. In 1953 African species of *Sesamia* and related genera were morpho-taxonomically revised and finally *S. fusca* was placed in the *Busseola* Thureau genus (Tams *et al.*, 1953). The first description of the oviposition site, eggs, larval behaviour and damage symptoms caused by *B. fusca* stemmed from South Africa. Since 1920, *B. fusca* has assumed as an important pest of maize and sorghum in sub-Saharan Africa, and first recommendations on how to control this pest were given in 1905. Since then, a plethora of information on its distribution, pest status and injuriousness were produced (Kfir *et al.*, 2002). *B. fusca* is considered to be the most destructive lepidopteran pests of maize (Kfir *et al.*, 2002) and sorghum (Van den Berg *et al.*, 1991) in Africa. Estimates of crop losses vary greatly in different regions and agro-ecological zones. In Kenya alone, losses due to *B. fusca* damage on maize fluctuate around 14 % on average (De Groote, 2002) while in the humid forest zone of Cameroon losses of around 40 % are common in monocropped maize fields (Chabi-Olaye *et al.*, 2005). Currently, this pest still presents a major constraint to the production of maize in areas where they are abundant.

Busseola fusca larvae feed on the aboveground parts of the grass hosts, causing economically important yield losses to crops such as maize. Feeding and tunneling by *B. fusca* larvae can result in the destruction of the growing point (resulting in “dead hearts”), early leaf senescence, interference with nutrient and metabolite translocation resulting in malformation of the grain, stem break-age, plant stunting, and direct damage to ears (Kfir *et al.* 2002). Tunnels in the plant stem may also predispose hosts to infection. Yield loss estimates may vary with region, *B.*

fusca infestation levels and plant developmental stage.

4. DISTRIBUTION OF MAIZE STEM BORERS IN AFRICA

Busseola fusca is currently known to occur in most countries South of the Sahara, and has not yet been reported anywhere outside of Africa (Haile and Hofsvang, 2002). The insect seems to display geographical differences in ecological preferences. In Eastern and Southern Africa *B. fusca* is a pest at higher altitudes (>1,500 m), while in West Africa it occurs from sea level to above 2,000 m. Haile and Hofsvang (2002) recorded *B. fusca* between 1,450 m and 2,350 m in Eritrea and in Cameroon (Central Africa) it is abundant from mid to high altitudes (700-1,000 m) (Ndemah *et al.*, 2001). Others have reported that it is unable to tolerate the warm temperatures occurring below 610 m. The distribution of *B. fusca* seems to be further influenced by moisture gradients. In West Africa, *B. fusca* is recorded as a pest in the dry savannah zone in lower altitudes (Kfir *et al.*, 2002) yet other studies recorded it being more abundant in the rainforest than the savanna (Sezonlin *et al.*, 2006). Three major population groups of *B. fusca* have been distinguished: a homogeneous and geographically isolated population from West Africa, and two populations from East and Central Africa with overlapping distributions (Sezonlin *et al.*, 2006).

Maize stem borer is a major pest in Africa, and occurs in contrasting climatic zones. A single species is able to complete 2-3 generations in the warmer West African countries such as Burkina Faso, southern Ghana, northern Nigeria (Harris 1962) and to also complete the same number of generations in the much cooler, higher altitude areas of Ethiopia and Lesotho (Ebenebe *et al.*, 2006). The annual heat sum in such different areas will clearly be very different. All the biological evidence supports the suggestion that there are different mitochondrial clades with overlapping distributions and different ecological characteristics (Sezonlin *et al.*, 2006; Felix *et al.*, 2009).

4.1 Distribution of Stem Borers Infesting Maize in Nigeria

The major species of stem borer associated with maize in Nigeria are the maize stalk borer, *Busseola fusca* Fuller (Noctuidae), the pink stalk borer, *Sesamia calamistis* Hampson (Noctuidae), the millet stem borer, *Acigona ignefusalis* Hampson (Pyralidae) and the Africa sugarcane borer, *Eldana saccharina* Walker (Pyralidae) (Balogun and Tanimola, 2001). Others of less importance are the spotted stalk borer (*Chilo partellus* Swinehoe, Pyralidae), *C. orichalcociliella*, *C. suppressalis*, and the ear borer (*Mussidia nigrivenella* Pyralidae) (Khan, *et al.*, 2000). Usua (1966) reported that *B. fusca* (Fuller) and *S. calamistis* (Hampson) were predominant in Northern and Southern Western Nigeria respectively. Polaszek, (1998) also reported that *Chilo partellus* (Lepidoptera; Pyralidae) is dominant at altitude below 1200 m while *B. fusca* (Lepidoptera: Nuctuidae) is dominant at higher altitudes. Usua (1997) observed that *S. calamistis* was more abundant than both *B. fusca* in Eastern and Southern States of Nigeria. Okweche *et al.* (2010) reported that *B. fusca* is the most predominant borer species in the guinea savanna agro-ecological zone of Nigeria followed by *S. calamistis*, *E. saccharina*, *A. ignefusalis* and *C. partellus* in early and late planted maize. Obhiokhenan *et al.* (2002) reported higher stem borer populations in the Mangrove zone followed by rain forest and derived savanna zones of Cross River State. The survey by Obhiokhenan *et al.* (2002) also showed that *S. calamistis* was more abundant than any other stem borers in all the vegetational zones of Cross River State followed by *Chilo* spp while *B. fusca* was absent.

4.2 General Stem Borer Damage and Larval Behaviour

Most stem borer species produce similar symptoms on maize and sorghum plants. Among cereals, maize is damaged more by stem borers because it has more of amino acids, sugars, than the other gramineous hosts (Krüger *et al.*, 2012). In addition, maize emits volatile compounds such as gas chromatography- electro-antennographic detector (GC-EAD analysis): Copaene, (Z)-3-hexenol, (E)-2-hexenol, 3-hexenyl acetate, (Z)-3-hexenyl acetate, linalool, 4,8-dimethyl, (E)- β -farnesene, (E)-nerolidol, (3E,7E)-4,8,12-trimethyl-1,3,7,11-tridecatetraene. Of these volatile compounds, those emitted by maize are more attractive to *B. fusca* than they are to *C. partellus*. Generally, soon after hatching, stem borer larvae crawl over the plant, congregate in the funnel and feed on the rolled leaves a few days before penetrating into the stem (Félix *et al.*, 2009). As the leaves grow away from the funnel, a characteristic pattern of holes and “window panes” can be seen, leaving transparent upper cuticle referred to as window panning (Chabi-Olaye *et al.*, 2005). Window panes refer to early larval feeding in which the larvae do not completely chew through the leaf but leave a thin layer of transparent leaf epidermis. Larvae can also feed on basal meristems of young maize plants resulting in the formation of dead heart. Dead heart is caused by the borers boring into the stalk at the soil level and tunneling upward. Dead hearts cause death of cereals such

as maize, while sorghum, millet and rice compensate by tillering. Older larvae make holes and tunnels in stems where they feed for 3 to 5 weeks, causing extensive tunnels. Larval tunneling within the stalk may also predispose plants and ears to infection by fungal pathogens, further compromising the long-term storability, and quality of food products.

There is an evidence of variation in the lengths of stem tunneling associated with the different stem borer species. *B. fusca* larvae produce the largest stem tunneling, followed by *C. partellus*. Mostly, the holes are prepared for pupation. The feeding habit reduces the flow of water and nutrients throughout the plant, and can reduce grain weight, kernel number, thereby reducing yields (Ratnadass *et al.*, 2001). The extensive tunneling of stem borers inside the stems weakens the plants, causing breakage and lodging (Ebenebe *et al.*, 2000). Lodged plants are likely to yield lower and make harvesting more difficult. For instance, Ndemah *et al.* (2006) reported that yield losses as high as 40 % could result from lodging. Damage to the stem can lead to the infection by Fusarium stalk rot (Félix *et al.*, 2009). Other plant parts such as tassels and ears are prone to stem borer damage. Extensive damage can result in complete death of the plant. After killing the plant, larvae usually migrate to new plants and enter by boring into the stem near the base. Plants damaged by stem borers are often stunted and may die. Infested plants if they survive may or may not produce harvestable ears. If they do, they are usually smaller than normal plants making them less marketable especially if they are sold as green mealies. In addition, those plants that do not produce ears compete with plants for water, nutrients and sunlight. The magnitude of the damage is influenced by soil fertility (Muyekho *et al.*, 2005), farming systems (Waladde *et al.*, 2002; Alata ud *et al.*, 2008) and maize moths fly at night and lay eggs on maize plants between the leaf sheath and the stem on the youngest fully unfolded leaf. Eggs hatch into caterpillars, which move into the growing points, where they start to feed.

5. YIELD LOSSES DUE TO MAIZE STEM BORERS IN AFRICA

Yield loss due to stem borers in Africa vary from 0-100 % among ecological zones, regions and seasons. In Sub Saharan Africa, they can cause 20-40 % losses during cultivation and 30-90 % losses postharvest and during storage (Van Rensburg *et al.*, 1997). The severity and nature of stem borer damage depends upon the borer species, the plant growth stage, the number of larvae feeding on the plant and the plant's reaction to the borer feeding. Feeding by borer larvae on maize plants usually results in crop losses as a consequence of death of the growing point (dead heart), early leaf senescence, reduced translocation, lodging and direct damage to the ears. Estimated yield losses of 10-43 % are expected to occur at the smallholder level where suppression of the pest by chemicals is generally not practiced. Yield losses of 12 % for every 10 % plants infested were reported in Tanzania and Kenya (Malusi and Okuku, 2013). Yield losses depend on the age of the plant at infestation. In Ghana, yield loss as high as 40 % has been attributed to *B. fusca* infestations. In Democratic Republic of Congo (DRC) *B. fusca* occasionally caused yield losses of 8-9 % in early planted maize, and 22-25 % in late planted maize (Félix, 2008). In Kenya, *B. fusca* accounted for 82 % of all maize losses (Sezonlin *et al.*, 2006). *C. partellus* is the most damaging pest in Eastern and Southern Africa and causes significant grain yield losses. Its control has been a challenge among smallholder farmers (Félix *et al.*, 2013). *B. fusca* can feed on maize kernels at maturity (Félix *et al.*, 2009). *B. fusca* larva produces higher effect on grain weight reduction as compared to *C. partellus*. In Ethiopia, *B. fusca* and *C. partellus* are considered to be the most damaging insect pests, with reported yield losses of 0 to 100, 39 to 100, 10 to 19 and 2 to 27 % from South, North, East and Western Ethiopia, respectively (Unnithan and Paye, 1990).

Maximum grain yield reduction and stalk damage in maize was reported due to *C. partellus* on 20-day-old crop, while there was insignificant larval effect on yields for 60-day-old crop. The economic injury levels (EIL) of *C. partellus* in maize are 3 and 4 larvae per plant in maize 20 and 40 days after plant emergence, respectively. Generally, the amounts of yield loss vary greatly, depending upon the country, season, maize variety, fertilization, severity damage, stem tunneling and generation of stem borers involved. The first and second generations causes more yield losses than the third generation (Sezonlin *et al.*, 2006).

6. BIOLOGY OF MAIZE STEM BORERS

A good knowledge of the biology of *B. fusca* is a prerequisite for understanding how this species interacts with plants. Most of the information produced for *B. fusca* during the last century, which forms the basis of the knowledge of the biology and ecology of this pest, stemmed from South Africa. However, since the majority of the studies in South Africa addressed *B. fusca* at high altitudes and in commercial farming systems, some aspects regarding its biology and interactions with the

environment may differ from those in other agro ecological zones.

B. fusca exhibits complete metamorphosis, including egg, larval, pupal, and adult stages. *B. fusca* has 2-3 distinct generations in most locations. However, in areas that are warm and humid, some *B. fusca* larvae may give rise to a fourth adult generation (Harris and Nwanze, 1992). Another factor that plays a role in the biology of *B. fusca* is larval diapause. Much work has been conducted on the diapause strategies of *B. fusca*, and it appears that larvae diapause in most locations during cold, dry periods (Harris and Nwanze 1992). The state of host plant maturity is thought to be a critical factor in the induction of diapause while soil moisture is imperative for its termination (Kfir *et al.*, 2002). Temperature and photoperiod appear not to influence diapause. It has been suggested that diapause in *B. fusca* is obligatory, but this is unconfirmed. Between 9 and 14 days after pupation, the adults emerge from emergence windows bored by the larvae prior to pupation (Harris and Nwanze, 1992). Plants most attractive for oviposition are those that germinated 3-5 weeks prior to eclosion. Female *B. fusca* prefer the underside of the youngest fully unfolded leaf as oviposition sites (Harris and Nwanze, 1992). Eggs generally hatch about a week later, while larvae take 3-5 weeks to develop. *Busseola fusca* eggs are hemispherical, with crenulations, and are laid in clusters (Harris and Nwanze, 1992). Reports of total fecundity vary from 30-100 eggs (Harris and Nwanze, 1992) to 723 eggs. Upon hatching, larvae disperse and then enter the leaf whorls, boring into the stems, producing extensive tunnels in the stem and cob (Harris and Nwanze, 1992). Larvae of *B. fusca* look similar to those of *C. partellus* in many ways. *Busseola fusca* larvae are 40 mm long when fully grown, normally a creamy white colour with a distinctive grey tinge. Sometimes *B. fusca* larvae have a pink colour similar to *C. partellus*. Both borers have a brown head capsule, but *B. fusca* can be distinguished from *C. partellus* by the hooks on the prolegs (Harris and Nwanze, 1992). Hooks on the prolegs of *B. fusca* are arranged in a semicircle, while those in *C. partellus* are arranged in a full circle (Harris and Nwanze, 1992).

6.1 Eggs of *B. fusca*

Busseola fusca females oviposita highly variable number (from 100 up to 800) of round and flattened eggs in batches (Kruger *et al.*, 2012). The batches are laid behind the vertical edges of leaf sheaths of pre-tasseling plants and also, but rarely, underneath the outer husk leaves of ears (Mally, 1920). Van Rensburg *et al.*, 1987 recorded eggs on 12 to 16 week old plants, but only when these were planted very late in the season. It appears that the position at which the eggs are found correlates with the developmental stage of the plant and with increasing plant age, egg batches are increasingly found higher up on the plant (Van Rensburg *et al.*, 1987). Studies have also shown that leaf sheaths fitted more loosely around stems as plants gets older, and that females preferred the sheaths of youngest unfolded leaves for oviposition. Although it is rare to find more than one *B. fusca* egg batch per plant cases of between 2 and 4 egg batches per plant have been observed. This could be attributed to extremely high population pressure at late planting dates.

In South Africa, with its unimodal rainfall pattern allowing for one crop per annum, it was also observed that egg batches of spring moth generation were smaller than those of summer moths (Kruger *et al.*, 2012). A possible explanation is that body reserves of spring moths are smaller than those of the summer moth since the former would have utilized reserves during diapause. Similarly, Usua (1967) in Nigeria reported that spring moths laid approximately 65 % fewer eggs than summer moth. Field studies during which more than a thousand egg batches were collected in South Africa, showed that the average size of an egg batch of 1st and 2nd generation females were 22 and 33 eggs respectively (Van Rensburg *et al.*, 1987). Results from van Rensburg and colleagues indicate that a single moth lays 7-8 egg batches.

6.2 Larvae of *B. fusca*

Eggs hatch after about one week and larvae migrate first to the whorl where they feed on young and tender leaves deep inside the whorl. In contrast to stem borer species from the *Sesamia* and *Chilo* genera, young *B. fusca* larvae do not consume any leaf tissue outside of the whorls of plants. Larvae can remain in the whorls of especially older plants (6-8 weeks old) up to the 4th

instar. From the 3rd instar onwards, larvae migrate to the lower parts of the plant where they penetrate into the stem. Some larvae do however migrate away from natal plants with approximately 4 % of larvae leaving the natal plant immediately after hatching. The larval stage lasts between 31 and 50 days (Kruger *et al.*, 2012) and consists of 7-8 instars with a minimum of 6 (Unnithan, 1987). More recently, continuous observations of larvae on an artificial diet indicated that, under optimum environmental

conditions (25 °C and 50%–60% r.h.). The larval stage consisted of 5 stages and was completed during approximately 35 days. Additional instars were observed when the conditions were suboptimal or when larvae went into diapauses (Malusi and Okuku, 2013). It is well known that *B. fusca* undergoes a facultative diapause consisting mostly of a larval quiescence.

6.3 Larval migration patterns

Busseola fusca larvae migrate throughout all larval stages (Van Rensburg *et al.*, 1987). This migration commences immediately after egg hatch and ceases during the last instar when larvae prepare pupa cells in which they become pupae, or go into diapause. Clear patterns in the intra-seasonal progression of larval infestations have been described by many researchers (Van Rensburg *et al.*, 1987). Although a small proportion of larvae migrate off plants immediately after hatching, the great majority (81 %) of larvae up to the 4th instar remain in the whorl (Van den Berg and Van Rensburg, 1996). The low degree of damage caused by stem borer larvae to whorl leaves of wild hosts indicates that they do not feed in whorls for extended periods of time. In late-infested maize and sorghum, 1st instar larvae may commence feeding on silk of ears, panicles or in young emerging panicles for some time before migrating and commencing feeding inside ears or stems.

Migration does not cease after the larvae leave plant whorls to feed inside maize stems. Larvae migrate until the 6th instar, a behaviour that is clearly density dependent. Migration of late-instar larvae between plants also increases the likelihood of parasitism and predation. Studies have shown that large numbers of 5th and 6th instar larvae of *B. fusca*, parasitized by *C. sesamiae*, are often observed inside the last whorl leaves of plants, when maize plants commence anthesis and flowers emerge. In areas where *B. fusca* goes into facultative diapause for a period of at least 5 months, only one 6th instar larvae occurs per stem base, a few cm below soil level (Van Rensburg *et al.*, 1987). In warmer areas that *B. fusca* goes into diapause in the lower part of the stem, 25–60 cm above soil surface.

Up to 70 % of larvae may migrate to adjacent rows over a 5-week period, and that the incidence of plants remaining with a single larva at this time may be as high as 67 % (Van Rensburg *et al.*, 1987). This extent of occurrences of a single larva per stem in spite of the pseudo-aggregated oviposition behaviour illustrates the high migration potential of *B. fusca*. It also explains the patchy infestation pattern of *B. fusca* in the field and the increased percentage of plants damaged by larvae over time.

6.4 Adults of *B. fusca*

The mean sex ratio of *B. fusca* is 1:1 (male: female) (Kruger *et al.*, 2012). The adults emerge about 13–14 days after pupation and they emerge mostly between sunset and midnight (Calatayud *et al.*, 2007). Most male insects emerge before onset of the scotophase, while most females do so one hour later. The average life span of moths ranges between 8 and 10 days (Ratnadass *et al.*, 2001; Calatayud *et al.*, 2007).

7. ADULTS BEHAVIOUR AND PREFERENCES

7.1 Moth flight patterns

Light and pheromone traps have been used extensively to study the flight patterns of *B. fusca* (Van Rensburg *et al.*, 1997). Generally, in areas where only one rainy season occurs, distinct flight patterns are observed. Moth numbers in pheromone and light traps show less discernible patterns in areas where maize is cultivated throughout the year. It has been known since early 1970s that more than one generation of moths occurred in a season and that early infestations in a given season were derived from late infestations of the preceding season. Infestation patterns also vary between localities and are associated with the rainfall and temperature gradient existing from east to west in the greater production area. For instance, in South Africa, the first flight commences during early spring after the first good rains. The first and second flights are separated by a distinct period in December during which no moths occur. In an attempt to assist producers in identifying potentially hazardous on-farm flight levels, a pheromone trapping system was developed during the 1980s (Revington *et al.*, 1984). The system was, however, shown to be unreliable during periods of pronounced moth activity due to poor competition of the synthetic pheromone with the natural product (Van Rensburg, 1992).

7.2 African Pink Stem Borer (*Sesamia calamistis*, Hampson, 1910)

This species is found in sub-Saharan Africa and some of the islands in the Indian Ocean. It commonly occurs in wetter localities at all altitudes. The main crops affected are maize, sorghum, pearl millet, wheat, rice and sugarcane. The larvae (caterpillars) Larvae can tunnel into the stem which

can result in broken stems or drying and eventual death of the growing point of the maize. The common names are: African pink stem borer, pink stalk borer, pink stalk borer of sugarcane, African pink borer of sugarcane, Mauritius pink borer of sugarcane, southern pink borer of sugarcane. Synonyms are *Sesamia mediastriga* Bethune-Baker, 1911 The purple stem borer (*Sesamia inferens*) (Lepidoptera: Noctuidae) which attacks maize, sorghum, pearl millet, finger millet, wheat, rice, oats, barley, sugarcane and some wild grasses (Kruger *et al.*, 2012).

7.3 Eggs and larvae of *S. calamistis*

Eggs are inserted between the lower leaf sheaths and the stem in batches of 10-40 and arranged in two to four contiguous rows. On average, each female lays around 300 eggs in a period of five days. Egg laying occurs from the time plants are two weeks old until flowering. The most serious damage, however, occurs at early plant stages (Van Rensburg *et al.*, 1987).

Most larvae penetrate the stem shortly after they emerge from their eggs. Larval feeding might result in dead hearts and the tunneling and girdling activity of the larvae often results in stalk breakage. During the ear filling period, the majority of the larvae occur in the ears. Development of the larvae takes four to six weeks. Most larvae pupate within the stem or cobs. The African pink stalk borer breeds throughout the year and has no period of suspended development (diapause). However, it is less abundant during the dry season when it is limited to mature grasses - elephant grass (*Pennisetum purpureum*), *Setaria* species and itch grass (*Rottboellia exaltata*) among others, as a food source (Kruger *et al.*, 2012). Eggs are hemispherical, about 1 mm in diameter and slightly flattened with radial ridges (crenulations). They are creamy-white when laid but darken as they develop. The larva of the African pink stalk borer looks smooth and shiny and lack obvious hairs or markings. Their colour is variable but they are usually creamy-white with a distinctive pink suffusion (hence the common name). The head and prothoracic shield (a plate on the dorsal surface of the thorax) are brown; the dorsal part of the last abdominal segment bearing the anus (the suranal plate) is yellow-brown. Setae (bristles) are present on small, inconspicuous pinacula (hardened - sclerotized - areas that indicate points of muscle attachment) and the spiracles (breathing holes found along the side of the body) are elongate-oval with black surrounds. The crochets (hooks) of the larval abdominal prolegs are arranged in lines as is the case for noctuid stem borers. This contrasts with pyralid borers whose crochets are arranged in circles. Mature larvae are between 30-40 mm long, pink with buff and pink dorsal markings and a brown head (Ratnadass *et al.*, 2001).

7.4 Adults of *S. calamistis*

Pupae are up to about 18 mm long, brown to yellowish-brown with a wrinkled (creased) frontal region of the head and a terminal "tail" (cremaster) with four large and two small spines. The wingspan in females of the African pink stalk borer is 20-30 mm and in males a little less. The forewings are pale-brownish, with variable but generally inconspicuous darker markings along the margin and an overall silky appearance (Ratnadass *et al.*, 2001). Hind wings are white.

7.5 Millet Stem Borer, *Coniesta ignefusalis*

The millet stem borer, *Coniesta ignefusalis* (Hampson), was first named and described by Hampson (1919) in the genus *Diatraea*. Since then, although its status as a good species has never been in doubt, its correct generic placing has still not been determined. Taxonomists have assigned it to such different genera as *Haimbachia*, *Eoreuma*, and *Donacoscaptes*. It was most recently assigned to *Acigona*, but as the genus is now known to be a noctuid and not a pyralid, it has been recommended that the species should remain in *Coniesta* until a thorough taxonomic revision can be undertaken (Khan *et al.*, 2000).

7.6 Eggs and larvae of *C. ignefusalis*

Eggs are about 1-mm long and are laid in batches of 20-25 between leaf sheaths and stems. They are yellowish-white and elliptical and are partially flattened by the pressure of growing stems against the leaf sheaths. Larvae grow to a length of about 20 mm and have a prominent, reddish-brown head. During the growing season, the white body of active larvae is conspicuously marked with black spots. During the dry season, they enter into diapause and lose these black markings. The pyralid larvae are easily distinguished from those of the noctuid stem borer by the circular series of crotchets on the ventral abdominal prolegs. Pupae are up to 15 mm long, yellowish to reddish brown and with thorn-like spikes on the abdominal segments. Hatched larvae remain clustered for approximately 24 hrs, then tunnel into the leaf sheaths dead heart caused by *Coniesta ignefusalis* larvae on pearl millet and eventually enter the stalk. During feeding and development, the stem borer causes different types of

damage depending on the stage of millet growth and the generation of infesting larvae. First-generation larvae cause dead hearts and a consequent loss of crop stand. Second-generation larvae cause lodging, disrupt the plant vascular system and prevent or limit grain formation. Larvae can migrate between plants, moving a maximum of 1.2 m in the insectary and 1.8 m in the field (Harris, 1962). Larval survival during the growing season is high probably because larvae enter leaf sheaths or stems within 24 h after hatching. During the wet season, larvae complete development in approximately 30 to 40 days (mean 34 days). There are usually six, but sometimes seven instars. Male pupae develop in 7-12 days (9.3 average), and female 7-13 days (9.7 average).

The life history of the millet stem borer was described by Bako (1977). Adults are active mostly during scotophase, but remain on the lower leaf surface or along stems, with head turned towards the ground during the day. In Nigeria, the sex ratio from light traps or by rearing adults from field-collected eggs, larvae, and pupae showed significantly more females than males (Harris, 1962). In Niger a sex ratio of 1:1 was reported based on a sample of 1087 pupae, suggesting that the ratio imbalance from light trap catches could be due to differential responses of males and females to light (ICRISAT, 1988). Mating in the laboratory occurs late during the night of adult emergence or early the following night. Oviposition begins the first night after mating and peaks on the third night after emergence. It can continue through the sixth night after mating. In the field, adult females place their eggs in batches, averaging 20 to 50 eggs between the leaf sheath and the stem, or on lower leaf blades (Harris, 1962). Youm (1990) reported that *C. ignefusalis* oviposition is mostly associated with leaf sheath and rarely occurs on leaves. Each female may lay over 200 eggs in total. Newly deposited eggs are creamy white to yellow, turning dark after 8 to 11 days, and hatch 24 h after darkening. Two or three generations occur during each millet-growing season.

8. GEOGRAPHICAL DISTRIBUTION OF *C. IGNEFUSALIS*

C. ignefusalis is restricted to mainland Africa, south of the Sahara and has been most frequently recorded in West Africa (Senegal, Mali, Gambia, Guinea Bissau, Benin, Burkina Faso, Chad, Mauritania, Ghana, Niger, and Nigeria). It has also been recorded in Sudan, Ethiopia, and Angola and is probably more widely distributed in tropical Africa than published records indicate. In Nigeria, it occurs at altitudes up to about 1000 m (Youm *et al.*, 1993a).

9. ADULT EMERGENCE, MATING, AND DISPERSAL

During the dry season, larvae remain in diapause until the onset of the next season rains and then pupate. Emerging adults infest the new millet plants. Nothing is known about adult movements and migratory habits. However, like most pyralids, the millet stem borer is unlikely to be a migratory pest. Mating is mediated by the female, sex pheromone which attracts males. *Coniesta ignefusalis* sex pheromone consists of a three component blend: (Z)-7-dodecen-1-ol, (Z)-5-decen-1-ol, and (Z)-7-dodecen-1-ol (Youm *et al.*, 1993a). Youm *et al.* (1993b) reported that female attractiveness was affected by age: males were more attracted to 1-day old females than 4-day old ones probably because older females produce less pheromone. However, this needs to be further investigated.

10. SUGARCANE STEM BORER, *ELDANA SACCHARINA*

E. saccharina is indigenous to Africa. The African sugarcane stalk borer is widely distributed in sub-Saharan Africa including Burundi, the Democratic Republic of Congo, Kenya, Rwanda, Tanzania and Uganda. Sugarcane is the main crop host of the African sugarcane stalk borer but it will also attack maize (where it is a relatively minor pest), sorghum and rice. It attacks maize plants late in their development when it can affect grain filling which results in yield loss. Sugarcane stalk borer, African sugarcane stem borer, *Eldana* borer *Eldana conipyga* Strand, 1912 (Youm *et al.*, 1993a)

11. EGGS AND LARVAE OF *E. SACCHARINA*

The eggs of the African sugarcane stalk borer are yellow, oval and laid in batches, usually on dry dead maize leaves. They become pink just before emergence. The African sugarcane stalk borer larvae are light-brown to dark-grey coloured with brown pinacula (hardened – sclerotized – areas that indicate points of muscle attachment), covered with very small dark coloured spots and have a distinct brown prothoracic shield (a plate on the dorsal surface of the thorax). The head is reddish-brown to dark-brown. Larvae may be distinguished from other stem borer larvae by the circular arrangement of crochets (hooks) on the prolegs, pinacula and tubercles (small rounded projections) along the body. Eggs are laid in batches of 50 - 100 eggs in folds of dead leaves, behind the leaf sheath or on dry leaves

at the bases of plants or on plant debris on soil. Females may lay 400-600 eggs in their lifetime. Eggs hatch within five-six days. Young larvae feed externally on the green surface of the plant and later tunnel into the stems where they eat out tunnels within which they pupate. Larvae can develop in 21 days but development may last up to three months. The larvae do not go into a state of suspended development (diapause). Adults emerge in 7-14 days after the onset of pupation and only live for a few days (ICRISAT, 1988).

12. ADULTS OF *E. SACCHARINA*

The adult African sugarcane stalk borer is small with a wingspan of 35 mm. The forewings are pale brown with two dark spots in the Centre and elongate with a rounded front edge. The hind wings are whitish with a short fringe and brown longitudinal veins. At rest the wings are folded over the abdomen in such a manner that their outer edges are parallel to each other, and they cover the lighter coloured hind wings which are hidden from view. Both the adult or larval stages are unlikely to be confused with any other stem borers present in Africa. Sugarcane is the main crop host of the African sugarcane stalk borer but it will also attack maize, sorghum and rice (Ratnadass *et al.*, 2001). In the wild its hosts are wild grasses (Poaceae) such as Guinea grass (*Panicum maximum*), wetland sedges (Cyperaceae) such as papyrus (*Cyperus papyrus*), rushes (Juncaceae) and typha (Typhaceae).

13. HOST PLANTS OF MAIZE STEM BORERS

The main crop hosts for *B. fusca* are maize and sorghum as well as pearl millet (*Pennisetum glaucum*), finger millet (*Eleusine coracana* L.), and sugarcane (*Saccharum officinarum*), but to a much lesser extent (Calatayud *et al.*, 2006). Although the host plant on which *B. fusca* originally evolved is unknown, indigenous African grasses have been recorded as hosts, specifically *Sorghum verticilliflorum* (Steud.) *Pennisetum purpureum* Schum., *Panicum maximum* Jacq., *Hyparrhenia rufa* Nees (Stapf), *Rottboellia exaltata* (L.), and *Phragmites* sp. (Harris and Nwanze, 1992).

14. BEHAVIOURAL BASIS OF HOST PLANT SELECTION

The different behavioural steps leading to host selection and oviposition have been well described in *B. fusca* (Calatayud *et al.*, 2008). Similar to other noctuids, the behavioural steps leading to oviposition by a gravid moth follow a sequential pattern involving searching, orientation, encounter, landing, surface evaluation, and acceptance. Before landing, plant volatiles influence the female orientation, indicating from a distance the suitability of the plant species; the female antennae bear numerous multiporous trichoid sensilla able to collect volatiles (Calatayud *et al.*, 2006). Thereafter, the visual cues are also involved in the female's orientation and landing (Calatayud *et al.*, 2008). It is after landing that the final decision for oviposition takes place. The female typically sweeps her ovipositor on the plant surface as if evaluating the suitability of the plant, simultaneously touching it with the tips of her antennae, and then, if the plant is accepted, oviposition takes place. The tip of each antenna bears several uniporous sensilla able to taste the plant's surface (Calatayud *et al.*, 2006). In addition, the ovipositor bears about nine uniporous chemosensory sensilla (i.e., taste receptors) located within the inner border of the ventral surface of each lobe of this organ (Calatayud *et al.*, 2006). Combinations of tactile and gustatory stimuli from the plant are received during the ovipositor sweep behaviour.

During this behavioural step, the claws at the distal part of the ovipositor leave small injuries on the plant surface, which are deep enough to liberate inner plant cuticular compounds, which differ between plant species (e.g., between host and non-host plants) (Juma, 2005). These compounds are perceived by the taste receptors on the ovipositor, which then activate the appropriate behaviour (acceptance or rejection) depending on the nature/composition of these cuticular chemicals. Like all noctuid borer species, *B. fusca* females oviposit egg batches between the leaf sheath and the stem (Kaufmann, 1983). *Busseola fusca* prefers to oviposit inside leaf sheaths of the youngest fully unfolded leaves (Van Rensburg *et al.*, 1987). In choice tests, *B. fusca* moths show preference for maize to sorghum plants of similar sizes (Rebe *et al.*, 2004). It can therefore be concluded that the physical properties of the leaf sheath and stem play a crucial role in plant acceptance for oviposition. In fact, *B. fusca* prefers to oviposit on waxy plant species (Haile and Hofsvang, 2002) and do not oviposit at all on *Melinis minutiflora*, a species with glandular trichomes (Khan *et al.*, 2000). It was also shown that 3-6 weeks old maize plants are most attractive for oviposition. Thus, *B. fusca* prefers pre-tasseling plants; oviposition rarely occurs on older maize plants (Van Rensburg *et al.*, 1987), but if so, the insect lays batches on the upper part of the plants where the leaf sheaths are young and soft. Oviposition on maize plants in

the post anthesis period has been reported by van Rensburg and colleagues (Van Rensburg *et al.*, 1987) but, when provided with a choice, moths prefer plants during the vegetative stages of development. A significance correlation exists between stalk circumference and *B. fusca* egg number in maize (Alata *et al.*, 2008).

All these reports and observations suggest that plant physical cues, such as surface texture (e.g., pubescence), plant size (e.g., stem diameter), and leaf sheath rigidity, strongly influence the acceptability by *B. fusca* of a host species or plant part. Alata *et al.* (2008) reported that *B. fusca* does not prefer to oviposit on plants with very small stem diameter and prefers to oviposit on plants with non-pubescent or smooth surfaces, over pubescent or rough surfaces. Pubescence and rough surfaces significantly affect the behavioural steps leading to oviposition since it interferes with the ovipositor sweep process necessary to find a suitable oviposition site. In addition, the rigidity of the support that the leaf sheath provides influences the proper insertion of the ovipositor for egg deposition. It can be concluded that oviposition acceptance in *B. fusca* is very likely caused by evolved mechanisms of oviposition site selection; that is, suitable oviposition sites are restricted to the gaps between the leaf sheath and the stem, and, hence, rigidity and pubescence of the stem or leaf sheath will affect oviposition (Alata *et al.*, 2008). Oviposition patterns, host selection and to a lesser extent larval distribution on plants seem to be closely related to crop phenology. In field studies on grain sorghum, oviposition on both main stems and tillers reached a maximum at six to eight weeks after plant emergence. This differs from the known pattern in maize of three to five weeks, and could be ascribed to the difference in growth rates of the two crops. Elongation of grain sorghum stems is slower, while stalks of maize are generally thicker and thus favour oviposition at earlier crop growth stages. The period of oviposition is extended in grain sorghum, possibly due to tillering, which provided leaf sheaths of suitable tightness over a longer period of crop development than in maize.

Host selection in phytophagous insects is generally determined by the adults. However, in many Lepidoptera species the larvae can engage in host plant selection (Erdegu, 1998). After hatching underneath the leaf sheath, *B. fusca* neonate larvae ascend to the whorl, where they either feed on the leaves or disperse via ballooning-off (Kaufmann, 1983). This dispersal phenomenon is generally density dependent and might be influenced by host plant quality. After feeding in the leaf whorl, 3rd to 4th instar larvae descend and bore into the plant stem. Generally, lepidopteran larvae display food preferences via a phenomenon driven by chemoreceptors located on the mouthparts (Schoonhoven and Vanloon, 2002). Like other Lepidoptera species, *B. fusca* larvae possess sensory structures able to detect plant compounds, including volatiles (Juma *et al.*, 2008). Although the antennae of the larvae are short and simple, they bear three multiporous cone-shaped basiconic sensilla able to detect volatiles. In fact, the 3rd instar larvae are able to recognize the odours of their host plant at a distance.

The larvae possess also on their maxillary galeae two uniporous styloconic sensilla, which are contact chemoreceptors. They have also maxillary palps having eight small basiconic sensilla at the tip, which were also found to be gustatory (Juma *et al.*, 2008). Plant sugars are often considered as primary feeding stimuli, involved among the compounds that induce the host plant acceptance by herbivorous insects (Schoonhoven *et al.*, 2005). It was recently shown that sucrose is a feeding stimulant and positively influences food choice by *B. fusca* larvae, whereas turanose (an isomer of sucrose), as a ago deterrent, negatively contributes to larval food choice (Juma *et al.*, 2013). The uniporous styloconic sensilla of the maxillary galeae are able to detect both sugars but the lateral styloconic appears more sensitive to sucrose at low concentrations whereas the medial styloconic is more sensitive to turanose. These findings indicate that the balance in concentrations of these sugars somehow influences the overall host plant choice made by the larvae.

Among the most important factors determining larval choice of host plant might be differences in silicon (Si) content. In higher plants, silicon levels range between 0.1-10 % on a dry weight basis and they are generally higher in grasses than in dicotyledonous plants (Epstein, 1999). Plant resistance to insects, pathogens or abiotic factors has been shown to be related to the level of accumulation and polymerization of Si in tissues (Reynolds *et al.*, 2009). For *B. fusca*, it has been observed that Si in plant epidermal cells appears to provide a physical barrier by increasing leaf abrasion, which subsequently increases wearing off of the mandibles of *B. fusca* larvae, which physically deter larval feeding (Juma, 2010). Consequently, *B. fusca* larvae prefer to feed on grasses that have low levels of Si.

15. PHEROMONES AND MATING

Only the females emit pheromones. Males and females exhibit simple and

rapid courtship behaviour without any particular characteristic events (Frérot, 2006). The sex pheromone of *B. fusca* females was first identified as a mixture of Z -11-tetradecen-1-yl acetate Z11-14: Ac), E -11-tetradecen-1-yl acetate E11-14: Ac), and Z-9-tetradecen-1-yl acetate Z9-14: Ac). More recently, an additional pheromone component, (Z)-11-hexadecen-1-yl acetate was identified and when added to the aforementioned three-component synthetic blend resulted in improved attraction of males (Félix, 2009).

The females start calling a few hours after emergence, indicating absence of a sexual maturation time (Calatayud, *et al.*, 2007). The calling behaviour generally commences during the fourth hour after the onset of the scotophase but it is slightly delayed for young females having emerged the same night as compared to older females (Calatayud *et al.*, 2007). Mating starts within a few hours after moth emergence. Moreover, mating occurs generally during the first six hours of the night, and the males can mate several times but only once per night (Unnithan, 1990). A single spermatophore is generally sufficient to fertilize all eggs of a female throughout her life span

(Unnithan, 1990), indicating that polyandry is not obligatory and not necessary. Laboratory studies also showed that female calling behaviour and male attraction was not influenced by the presence of plants, irrespective if it was a host or non-host (Félix, 2009). The oviposition period lasts for 3-4 nights (Unnithan, 1987). It commences during the first night after mating, peaks during the second and then gradually decreases until the fifth night (Calatayud *et al.*, 2007).

16. MANAGEMENT OF STEM BORERS

Most stem borer attacks on cereal crops result from infestation by more than one species and, since there are important differences in biology and ecology that limit the effectiveness of some techniques, integrated pest management programmes must be devised to meet local conditions. Many different chemical and non-chemical control measures have been developed and applied since 1920, when Mally reviewed early work in South Africa, and these have been summarized, with bibliographies, by Harris and Nwanze (1992). The main elements available for inclusion in modern IPM programs are noted.

17. CULTURAL CONTROL

Cultural methods and practices that can be used to control stem borers include appropriate crop residue disposal, planting date manipulation, host resistance, destruction of volunteer and alternative host plants, tillage practices, crop rotation and intercropping (Kaufmann, 1983). These control measures do not guarantee 100 % control, but help to reduce infestation and enable sustainable maize production (Unnithan, 1990). Cultural control is useful because it combines effectiveness with minimal extra labour and cost (Félix, 2009). Appropriate disposal of crop residues after harvest can reduce carry over populations of diapause larvae of stem borers and so limit initial establishment of the following season's crop. Later sowing of maize is less affected by stem borer larvae than earlier sowings as it disrupts their seasonal cycle (Unnithan, 1990). It is thought that at the start of the rainy season, borer populations arising from diapausing-generation larvae will still be building up, so fewer moths will oviposit on early planted crops. In a study, the infestation of late-sown maize, attacked by the second generation of *B. fusca* was higher (22-100) than early-sown maize attacked by the first generation (0-22 %) (Unnithan, 1987).

Host resistance to insect is the genetic property that enables a plant to avoid, minimize, tolerate or recover from injury caused by the pests. These plants have genetic traits which manifest as antibiosis, in which the biology of the pest is adversely affected after feeding on the plant. Furthermore, they can have genetic traits which manifest as antixenosis (non-preference) where the plant is not desirable as a host and the pest seeks alternative hosts. They can also be tolerant and able to withstand or recover from the pest damage (Frérot, 2006). Destruction of volunteer and alternative host plants reduces overwintering and hibernation of stem borer species. Stubble is probably the main source of initial stem borers' infestation in subsequent seasons (Malusi and Okuku, 2013). Deep ploughing is effective as it brings the larvae and pupae to the soil surface (Félix, 2009). The larvae will be then exposed to the heat from the sun and predators like cattle egret (*Bubulcus ibis*). Deep ploughing also controls stem borers because by burying, pupae and stem borer moths do not emerge from great depths. However, zero tillage provides insect pests with shelter from plant materials. This may lead to an increase in the number of pests and must be avoided if stem borer numbers are to be reduced (Félix, 2009).

Appropriate disposal of crop residues after harvest can reduce carry-over populations of diapause larvae and so limit initial establishment of the pest on the following season's crops. Burning or burying by deep ploughing are effective but in areas where stems of cereals are used as building and fencing materials it may be better to devise means of destroying diapausing larvae without destroying the stems. Adesiyun and Ajayi (1980) showed that partial burning of sorghum stalks kills 95 % of *B. fusca* larvae within them and also improves the quality of the stems as building material. Alternatively, simply leaving stems lying on the ground exposed to the full heat of the sun for a month or so after harvest has been shown to reduce populations of diapausing larvae. Using crop residues for fodder and silage has also been recommended. Cultivation by disking and ploughing may also be effective, and, when preceded by slashing, can reduce larval populations by almost 100 %. Intercropping maize and/or sorghum with cowpeas may reduce damage caused by *B. fusca*.

18. HOST-PLANT RESISTANCE

Screening maize and sorghum genotypes for resistance to *B. fusca* has until recently been limited by the lack of effective techniques, especially the inability to rear *B. fusca* on artificial diets. Much screening has therefore been against field infestations, often against complexes of different borer species. In Ethiopia, barely 1 % of nearly 6000 indigenous sorghum genotypes showed promising levels of tolerance but in South Africa several lines of maize have intermediate levels of tolerance to whorl feeding by first-instar larvae (Barrow, 1993). Mechanisms of resistance are not well understood but effects of preferential oviposition have been reported by van Rensburg *et al.* (1989). Barrow (1993) suggested that three factors related to resistance are present in maize, the first killing early instar larvae, the second repelling larvae and the third retarding larval development.

19. BIOLOGICAL CONTROL

Natural enemies play an important role in the control of lepidopterous borers in Africa. Biological control is the use of parasitoids, predators, nematodes and/or pathogens to maintain density of a species at a lower level than would occur in their absence. The main attraction of this control is that it lowers the need for using chemicals and there is limited environmental pollution, which may affect non-targeted flora and fauna (Félix, 2009). It usually offers a lasting solution of stemborer control from one introduction hence beneficial to both smallholder and commercial farmers. Some parasitoids attack eggs, some attack larvae, while some attack pupae. Trichogramma spp. (Hymenoptera: Trichogrammatidae) and Platytelenomus busseola (Hymenoptera) are egg parasitoids, that contribute to natural mortality of stem borers. Hymenopteran parasitoids like *Cotesia* spp. have highly specialized ovipositors for stinging and depositing eggs in the host. The sting causes permanent paralysis in the host body. Trichogramma spp. parasitise eggs of stem borers while *Cotesia* spp. parasitize their larvae (Chabi-Olaye, 2004). Egg parasitism offers good control in that it stops the emergence of the damaging larval stage (Félix, 2009). *Dentichasmias busseolae* (Heinrich) (Hymenoptera: Ichneumonidae), *Pediobius furvus* (Gahan) (Hymenoptera: Eulophidae) and *Lepidoscelio* spp. *Xanthopimpla stemmator* (Thunberg) (Hymenoptera: Ichneumonidae) are parasitoids of stem borers.

In South Africa, *Procerochasmias nigromaculatus* Cameron (Hymenoptera: Ichneumonidae) was recorded with up to 100 % pupal parasitism on *B. fusca*. In addition, in South Africa, *Dentichasmias busseolae* caused up to 100 % pupal parasitism of *C. partellus*. Furthermore, in South Africa the parasitoid *Cotesia sesamiae* (Cameron) (Hymenoptera: Braconidae) accounted for up to 90 % of parasitized *B. fusca* larvae, but have not yet been able to maintain populations below economic threshold levels (Malusi and Okuku, 2013). Parasitoids of hosts which feed in exposed situations usually pupate in protective silken cocoons produced by the larvae themselves. Some parasitoids can pupate within the eaten out body of the host (Félix, 2009). In Ghana, exotic species of *Trichogramma* showed high fecundity and helped to control stem borers, including *B. fusca*. In Southern Benin, *Telenomus busseola* (Ghana) (Hymenoptera: Scionidae) and *Telenomus isis* (Polaszek) (Hymenoptera: Scionidae) are the most important natural control factors of stem borers, including *B. fusca* on maize. In Ethiopia the Braconid, *Dolichogenidea fuscivora* was found to be the major larval parasitoids of *B. fusca* with parasitism as high as 71 % in the dry season and 18 % in the wet season. *Cotesia sesamiae* (Cameron) (Hymenoptera: Braconidae) is the most important larval parasitoid of *B. fusca* with 20 to 25% parasitization in Ethiopia (Kruger, 2012). It is also a gregarious larval endoparasitoid of *S. calamistis*. *Pediobius furvus* Gahan is a gregarious primary pupal parasitoid of *B. fusca* in maize and sorghum in Ethiopia. According to Kruger (2012), *Stenobracon rufus* is a solitary pupal parasitoid of *B. fusca* attacking maize and sorghum in Ethiopia with 14 % parasitization.

In Zimbabwe, many natural enemies associated with maize stem borers have been recorded on the high yield region and outside the Highveld. These include parasitoids such as the *Bracon sesamiae* Cameron (Hymenoptera: Braconidae), which attacks larvae of *B. fusca*, *Chelonus curvamaculatus* Cameron (Hymenoptera: Braconidae), on larvae of *B. fusca* and *C. partellus*. Others are *Cotesia sesamiae* Cameron (Hymenoptera: Braconidae), which attacks larvae of *B. fusca*, *C. partellus* and *S. calamistis*, *Dolichogenidea palaszeki* Walker (Hymenoptera: Braconidae), which attacks the larvae of *B. fusca*. Similarly, *Dentichasmias busseolae* Heinrich (Hymenoptera: Ichneumonidae) attacks pupae of *C. partellus* and *Procerochasmias nigromaculatus* (Cameron) (Hymenoptera: Ichneumonidae), on pupae of *B. fusca*. *Pediobius furvus* Gahan (Hymenoptera: Eulophidae), also attacks the larvae of *C. partellus*. *Sturmiopsis parasitica* (Curran) (Diptera: Tachinidae), attacks larvae and pupae of *B. fusca* (Kaufmann, 1983). Kaufmann (1983) also noted that opal parasitoids such as *Procerochasmias nigromaculatus* (Cameron) and *Dentichasmias busseola* Heinrich were frequently observed in the field. However, owing to the low numbers of pupae collected, the actual field parasitism rates could not be determined.

Generally, the levels of stem borers parasitism by indigenous natural enemies are not satisfactory. *Cotesia flavipes* (Hymenoptera: Braconidae) was imported and released due to low background of low parasitism by native parasitoid species in Zimbabwe between 1999 and 2002. Parasitoids locate borers by laying eggs into them while feeding inside the plant stems. Predators are valuable components of Integrated Pest Management (IPM). Ants (Hymenoptera: Formicidae) are the most important predators of stem borers in maize fields (Van den Berg, 1991). They attack all stages of stem borers, and are among the few predators preying on stem borer larvae and pupae. According to Félix (2009), *Componotus* spp. (Formicidae) and *Pheidole* spp. (Formicidae) appear to be the most important and common species in Zimbabwe. Ants of the genus *Lepisiota* were reported preying on eggs and larvae of stem borers (Van den Berg, 1991). In Ethiopia, Earwigs (Dermaptera) and ants were commonly seen preying on *B. fusca*. Entomopathogenic viruses, bacteria and fungi can be used as pathogens to control insect pests. *Bacillus thuringiensis* (Bt) lowered stem borer larvae in Kenya with a consequent increase in the yield. *Beauveria bassiana* is known to control *C. partellus* by infecting insect hosts through the skin penetration. This makes them readily able to kill piercing and sucking pests which may not be killed by stomach poisons. High humidity is needed in this case for *Beauveria bassiana* germination (Félix, 2009).

Potentials for biological control are currently being investigated, especially in East and South Africa. Classical biological control by introduction of parasitoids from Asia and/or the Americas has been attempted on a number of occasions but with little success so far. The general situation in Africa has been reviewed by a number of authors over the past 30 years (Harris and Nwanze, 1992) and implementation programmes are now in progress in East and South Africa. Geographic differences in host acceptance and suitability do exist and were studied in Zimbabwe. (Chinwada *et al.*, 2001) reported 18 species of parasitoid developing on *B. fusca* in South Africa, of which the indigenous species *Cotesia sesamiae* and *Bracon sesamiae* were most abundant, and discussed proposals for further introductions of exotic species into South Africa. This could involve transfers within Africa of *B. fusca* parasitoids not known to occur in South Africa and/or introductions from outside Africa of stem borer parasitoids from other parts of the world.

20. CHEMICAL CONTROL

In addition to cultural control measures aimed at the destruction of stubble to destroy overwintering populations of larvae, early chemical control involved whorl applications of lead arsenate as soon as visible symptoms of infestation became apparent. DDT, the first synthetic insecticide, replaced lead arsenate during the 1950s. During the early 1960s it became common practice in some areas to apply DDT preventatively 28 to 35 days after planting. This inevitably led to some applications being given too early, whereas others were not economically justified in view of the pronounced spatial and temporal variability of infestation levels. DDT was withdrawn from the agricultural market in 1976. This immediately led to the evaluation and registration of a number of new generation insecticides, including organophosphate and carbamate compounds, later followed by the synthetic pyrethroids (Kruger *et al.*, 2012). Most of these were considerably more expensive and some less persistent than DDT. At the same time, a steep increase in production costs without a concomitant increase in producer prices of maize placed the spotlight on the economics of stem borer control. Start looking for signs of damage when plants are 2 to 4 weeks old, depending on the area. If you find damage holes in the leaves then use any of the following chemicals:

- Thiodan 3% G - a pinch into the funnel of each plant (3- 4 kg/ha).
- Diptorex 2.5% G - a pinch into the funnel of each plant (3 - 4 kg/ha).
- Bulldock 0.05% G - one shake in the funnel of each plant (7.5 - 10 kg/ha).
- Ambush 0.05%G - one shake per plant in the funnel (7.5 - 10 kg/ha).
- Pymac (the residue from pyrethrum processing) - a spoonful of Pymac should be applied into the funnel of each plant.

20.1 Integrated management

Since stem borers is an important pest of maize in sub-Saharan Africa, a wide range of methods have been researched, tested and implemented to manage this pest. These include among others control by pesticides, cultural practices, host plant resistance as well as biological control agents (Kfir *et al.*, 2002). Cultural control is a long-established method of modifying the habitat to make the environment unfavourable for the survival and reproduction of pests. Moreover, it is the most relevant and economic method of stem borer control available for resource-poor farmers in Africa. This management strategy, considered the first line of defense against pests and among the oldest traditional practices, includes techniques such as destruction of crop residues, intercropping, crop rotation, manipulation of planting dates, tillage methods and improvement of soil fertility. In addition, the aim of these control techniques is to reduce rather than eradicate pest populations and it can be used in conjunction with other methods. Diagnostic work in West Africa indicated that increased plant diversity in (mixed cropping) and around (wild habitats) maize fields, or improvement of soil fertility via integration of grain legumes or cover crops as short fallow, or provision of nitrogen fertilizer or silicon (Si) could influence stem borers infestation levels (Ndemah *et al.*, 2003). In addition to cultural control, host plant resistance, genetically modified Bt maize and chemical control offer potential options for pest management.

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