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Stem borers of sorghum and their management options

Hayilu G
Ethiopian Institute of Agricultural Research,
Chiro National Sorghum Research and Training Center, Chiro, Ethiopia
Corresponding author: hayilugr@gmail.com

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ABSTRACT

Sorghum is crucial grain crop for subsistence farmers in Sub- Saharan Africa's economic and food security. However, the main factors limiting the crop's yield are biotic and abiotic stresses. Stem borers substantially reduce yields, which limits sorghum production. Additional, rising temperatures brought on by climate change have the potential to exacerbate yield losses by feeding the population of maize stem borers. Other pressures and the plant's low nutritional status exacerbate stem borer damage. In Africa, yield losses due to stem borer damage can range from 20% to 40% on average. The most harmful stage of the pest's growth is the larval stage. They are hidden inside the stem, feeding on the plants inside, which makes them extremelydifficult to control. Plant stems are severely damaged by stem borers, especially when the center leaves are destroyed. There are several ways to control the number of stem borers and the harm they do to cereal crops. These consist of the use of synthetic pesticides, biocontrol, host plant resistance, and cultural behaviors. Regarding its effects on the environment, human health, its financial costs, and its sustainability, each management approach has some benefits and drawbacks. The most crucial aspect of integrated insect pest management is host plant resistance. This is due to its low cost, compatibility with other integrated pest management (IPM) techniques, and safety for the environment. Through combining different insect-resistant genotypes in hybrids, millet crop stem borers, such as those of sorghum and maize, may be more effectively controlled. Numerous hybrids and inbred lines have been found as a result of worldwide research institutions like CIMMYT and regional research stations constantly screening vast genetic materials resistant to stem borers. But all of this was eclipsed by advances in molecular genetics and the introduction of genetically modified maize.

Keywords: Sorghum, Stem borer, host resistance, integrated insect management

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Introduction

Sorghum [Sorghum bicolor (L.) Moench] is classified as a C4 tropical crop (Zinzala*et al*., 2018), and it is a cereal crop that is widely grown as a staple food in the semi-arid tropical regions of Asia, Africa, and Central America. For more than 300 million people who reside in the semiarid tropics, it serves as their primary source of sustenance (Gierend&Swamikannu, 2016). The majority of sorghum grain produced is used for food, and it serves as a source of food security in some regions of Asia and Africa. Studies demonstrating the anti-inflammatory and cholesterol-lowering qualities of the grain and its byproducts (Althwab*et al*. 2015, Vanamala*et al*. 2018) have led to a rise in the usage of the crop as a food crop in high-income nations.

The United States (Poquette*et al*. 2014), Ethiopia (Mengistu*et al*. 2018), South Africa (Adeyanju et al 2019), and Kenya (De Groote *et al* 2020) are among the countries with the highest potential sorghum consumption in the future. Sorghum's popularity should result in more food being available in both rural and urban regions. Even in harsh environmental conditions, sorghum can generate large yields; nevertheless, damage by insect pests at different phases of the plant's development can lower its productivity, which has an effect on low-income farmers in developing nations. While producing high yields, sorghum is a very adaptable crop that can resist a range of soil fertility levels, drought, and temperatures; certain hybrids have even been shown to generate better yields after experiencing drought stress (Borrell*et al*. 2000).

Among biotic stressors, biotic insect pest are one of the most devastating constraints which are threatening regional and global food security crops including sorghum. They affect not only the productivity of crop, but also grain quality as well. According to Guo *et al*. (2011), there are over 150 insect species (in 29 families) that impact sorghum globally. These insects might be major, minor, or sporadic pests. Leaf-sucking species, leaf-feeding species, stalk or stem borers, pests of the panicle, and pests of the stored grain are all significant sorghum insect pests (Okosun *et al*., 2021). Shoot flies, midges, stem borers, and head bugs are severe insect pests in Africa, causing up to 85% damage in some cases (Overholt 2001, Kahate *et al*. 2014). According to the last decade review by Calatayud *et al.* (2014), the interactions of this insect pest with plants (Calatayud *et al*., 2008; Tekle, 2016), It's reproductive biology (Calatayud *et al*., 2011; Kruger *et al*., 2011&2014) and genetics (Sezonlin *et al*., 2006) have been well documented over the time. Recently, this insect has remained a serious barrier to sorghum and maize production in horn Africa, especially Ethiopia. As the report of Tekle (2016), the average grain yield loss of maize due to stalk borer borers in Ethiopia can be estimated between 20 - 50% (Boeke *et al*., 2004).As a result, this study review will provide current information on the economic relevance, distribution, life cycle, and genetics of the sorghum stem borer (Busseolafusca), as well as potential management methods for effective. Hence, the purpose of this article is to review the economic importance of sorghum stem borer andits control methods particularly focusing on pant host resistance.

Geographical distribution of stem borer

According to Mally, B. fusca has been regarded a major pest of maize and sorghum in Sub-Saharan Africa since 1920. This pest was originally reported in Africa in the 1930s, in Malawi (Kfir 1997). It is prevalent throughout Sub-Saharan Africa, except in Zanzibar and Madagascar, according to kfir 2002; Le Ru *et al*., 2006). Eastern and southern African populations appear to be more adapted to their environment than West African populations. *Busseolafusca*is found in all agroecological zones of East Africa, from lowland semi-arid and arid savannahs to highland African wet mountain forests (Ong'amo *et al*., 2006; Le Ru *et al*., 2006; Ndemah *et al*., 2006; Kefle, 2016]. Despite its dominance in highland agroecologica zones, the stalk borer has expanded to most nations in eastern and southern Africa, according to a recent analysis in (Calatayud *et al*., 2014; Okosun *et al*., 2021). B. fusca is restricted to mid- and high elevations (>600m) in the eastern and southern regions of the continent, but in West Africa, the same species is present at all elevations but is more abundant in the savanna zone (Overholt *et al*., 2001; Tekle, 2016). Since then, a multitude of data on its distribution, pest status, and toxicity has been generated (Kfir, 2002; Calatayud *et al*., 2014). Currently, B. fusca is regarded as one of Africa's most damaging lepidopteran pests of maize and sorghum Van den Berg *et al* 1991. Within seven years, the expansion of this pest to high elevations is also found raised the infestation levels of stem borers in sorghum in the region to 59 percent.

Economic Losses in Sorghum from stem borers

The stem borer's significant damage, which directly affects grain yield variables including the density of fertile tillers and the number of productive panicles, is caused by its economic significance in Africa (Togola *et al*., 2020). However, because of sorghum and pearl millet plants generate viable tillers; they are less susceptible to stem borer damage than maize plants. Crop loss estimates varied significantly across different geographic and agro-ecological zones. Losses from B. fusca damage to maize fluctuate around 14% on average in Kenya alone (De Groote, 2002). While monocropped maize fields in Cameroon's humid forest zone frequently experience losses of over 40% (Chabi-Olaye *et al*., 2005). Sorghum production losses brought on by stem borers alone range from 11 to 49% in west Africa, 15 to 88% in east Africa, and 50 to 60% in southern Africa, according to Overholt (2001). Furthermore, stem borer has been linked to yield losses of between 10 and 100 percent in rice fields (Schulthess *et al*., 1991).

On the other hand Stem borer infestation, damage, and severity all significantly depend on the amount of rainfall, the type of crops grown, and the fertility of the soil, all of which have an impact on the plant's nutritional state (Tefera *et al*., 2011). Drought, other pressures, and the plant's poor nutritional state all exacerbate stem borer damage. Studies on various African stem borers revealed that higher pest loads and tunnel damage are correlated with higher nitrogen levels (Haile and Hofsvang, 2001). The plant's resistance to stem borer attack was also significantly influenced by soil nutrient levels, particularly nitrogen. Lower yield losses are a result of increased plant vigor, which is the cause of this (Jiang and Cheng, 2003).Favorable circumstances, including a 28°C temperature, long days (16 hours), and enough water end the larval diapause, allowing pupation to take place 9 days later (Kfir, 1993).The level of damage also relies on the species and density of the pest, the crop growth stage, and climatic and edaphic conditions. It attacks the plant at numerous phases of development, including seedlings, whorls, blooming structures, and fully developed grain. During the vegetative stage of the sorghum plant, C. partellus larvae are found beneath leaf sheaths and whorls, however during the reproductive stage, larvae are found in the stem. Infested plants are grouped together, and small "hot spots" with high shoot borer densities are present (Overholt*et al.* 1994). Infestations start as early as 15 days after seedling emergence and last till harvest because C. partellus larvae attack all sections of the host plant except the roots (Sharma 2003). Damage can cause plant stunting, which lowers grain and fodder output (Marulasiddesha *et al.* 2007, Singh *et al*. 2011).

Biology and Life cycle of stem borer(*Busseolafusca*)

Understanding how B. fusca interacts with plants requires a solid understanding of the species' biology. The majority of the material produced for B. fusca during the last century, which is the basis of our understanding of its biology and ecology (Okosun *et al*., 2020; Calatayud*et al*., 2014). Adult females lay hundreds of eggs in batches of 30 to 100 or more on the underside of leaves. However, according to a further assessment by Calatayud *et al*. 2014, female Busseolafusca oviposit a very varied quantity (from 100 to 800) of spherical and flattened eggs in batches (Kruger *et al*., 2012).

After hatching, larvae require 7 days to develop and begin feeding on the young blades in the leaf whorl (Unnithan 1987; Okosun *et al*., 2020). In most cases, stem borer damage is remarkably similar to fall arm worm damage. Larvae cause harm to the growth point in the whorl before burrowing into the stem. Larvae develop through 6-9 instars in 30-45 days before pupating in their feeding tube (Unnithan 1987). The pupal stage lasts between 10 and 20 days. The entire life cycle takes about 2 months, and up to four generations can occur every year (Unnithan 1987, Overholt *et al*. 2001; Okosun *et al*., 2020). Larvae of the previous generation enter compulsory diapause in sorghum stubble or wild grasses at the end of the wet season (Kfir 1991, Overholt *et al*. 2001; Calatayud *et al.*, 2014). During the dry season, diapausing larvae in dry stems can live for up to 6 months (Unnithan 1987, Kruger *et al*. 2012; Calatayud *et al*., 2014). They overwinter in the bottom and middle thirds of dry stalks and emerge from diapause over a three-week period from October to November.

Breeding progress for stalk borer control

Despite the heavy losses caused by stem borers and storage pests in Africa, only CIMMYT's Global Maize Program (GMP) includes breeding for resistance through the Insect Resistant Maize for Africa (IRMA) Project in collaboration with national partners (Mugo *et al.* 2008, CIMMYT 2011). This is attributed to the genetic and logistical challenges posed by screening and selecting for insect resistance. Pest resistance in maize is usually inherited in a polygenic or quantitative manner, with some influence of environmental factors; therefore, breeding for pest resistance is a time- and research-intensive endeavor. The recent identification of sources of resistance to important insect pests of maize and their incorporation into a limited number of adapted materials could be useful in setting up successful impact-oriented insect resistant breeding programs in eastern and southern Africa (CIMMYT, 2010).

Significant breeding efforts have been made at CIMMYT to incorporate the complex traits into elite maize varieties that are acceptable to African farmers. These efforts have most recently resulted in the development and release of open-pollinated varieties (OPVs) and hybrids in Kenya by the national partners (Mugo *et al*. 2001, Mugo *et al*. 2003, and Mugo *et al*. 2008, CIMMYT 2011). In 2006−2007, three maize OPVs and three maize hybrids with conventional stem borer resistance, and six post-harvest insect pest and stem borer resistant maize hybrids were released in Kenya. In addition, regional and international collaborators in China, Indonesia, 6 Mali, Nigeria, the Philippines, Peru, Thailand and Vietnam requested and received seeds, in 2006 and 2007, and collaborators in Ethiopia, Uganda, Tanzania, Malawi, Zambia, Zimbabwe and Mozambique are currently testing experimental stem borer and post-harvest insect-pests resistant maize germplasm for evaluation and use in their breeding programs (CIMMYT 2011). Vietnam in particular, identified CIMMYT insect resistant inbred MIRTC4AmF101 as combining well with Vietnamese commercial inbred (Vietnam Country Report, RETA No. 6208, 2007). Even though the germplasm does not show extreme resistance to stem borers, it significantly reduces borer damage.

Management of the maize stalk borers

Because nature of habitat of stem borers (internal shelter), their management requires some specific control measures and actions as reviewed in Togola *et al*. 2020. Various strategies exist for managing stem borers' population and damage in cereals crops. These include cultural practices, host plant resistance, biocontrol and use of synthetic pesticides. Each management method has some advantages and limitation regarding its impact on environment, human health and its economic costs and sustainability.

Host-Plant Resistance

Host plant resistance is most important component of integrated insect pest's management. Plant resistance may limit pest population growth and enhance alance between pests and their natural antagonists. Sorghum resistance to insect pests is measured by antixenonis, antibiosis and tolerance. According to Okosun*et al.* 2020, antixenosis is a mechanism that has a negative impact on insect behavior and antibiosis also has a negative impact on insect life history and tolerance is plant's response to arthropod harm (Singh *et al*. 2011; Muturi *et al*. 2012 and Prasad *et al*. 2015). Combining diverse insect-resistance genotypes in sorghum hybrids can aid in control of major insect pests such as midges, mites, aphids, head caterpillars and stem borers (Marulasiddesha *et al*. 2007, Subbarayudu *et al.* 2011). For example, four genotypes were discovered to be resistant to shoot fly oviposition, shoot fly 'deadheart, stem: orer-induced 'deadheart,' and adult populations of shoot bug, Peregrinusmaidis (Ashmead) (Hemiptera: Delphacidae)(Subbarayudu *et al*. 2011). There are five resistant lines that have long-lasting resistance to A. soccata and C. partellus in terms of seedling vigor, leaf glossiness, deadhearts and number of stem borer exit holes (Prasad *et al*. 2015). Inbred lines of maize that are resistant to North American lepidopteran pests of maize were tested in South Africa, according to a recent review by Calatayud *et al.* (2014), and it was discovered that they are quite resistant to B. fusca. Later, it was discovered that some lines created by CIMMYT in Mexico have viable resistance to B. fusca.

Genetically Modified Maize (Bt-maize)

At the moment, cotton and corn are the most popular Btcrops.The proteins that produce the crystal, also known as Cry toxins, consolidate to form crystals during the sporulation of some Bt strains. Certain insect species belonging to the orders Lepidoptera, Coleoptera, Hymenoptera, Diptera, and Nematoda are poisonous to such cry poisons (Abbas, 2018).Bt maize/Bt corn is a maize variety that has been genetically modified to express one or more proteins from the Bacillus thuringiensis bacteria, including Delta endotoxins. Certain insect pests are poisoned by the protein. GM maize expressing insecticidal Cry proteins (Bt-maize) had been used successfully against B. fusca in South Africa until 2006, when the first occurrence of resistance was reported. Bt corn was first grown in the USA, Canada, and Europe (Spain) in 1997, and by 2009, it had been planted commercially in 11 nations. In the USA, 84% of corn was grown there, 83% in Argentina, 57% in South Africa, 36% in Brazil, 20% in Spain, and 19% in the Philippines during the time (James 2016). In 2016, there were 60.6 million ha of GM corn grown worldwide (in 16 countries), of which 6 million (10%) were Bt corn, 7 million (11.7%) were herbicide-tolerant corn, and 47.7 million (78.7%) were Bt and herbicide-tolerant corn varieties grown separately. Ostrinianubilalis, the European corn borer, was not allowed to infest the crop (James 2016).

Currently, there are 21 registered commercial varieties of maize with cry gene available. Additionally, maize has been genetically modified to exhibit multiple (stacked) traits; many of these varieties contain one or more herbicide tolerance genes as well as two or three cry genes.

In the first 13 years (1996–2008) following commercialization, planting Bt maize increased agricultural revenue by more than $8 billion, according to a recent research (Brookes and Barfoot, 2010). Two-thirds of the 1.5 million hectares of white maize farmed in South Africa in 2009 are now planted with Bt maize, which was introduced in 2001 (James, 2011). Before the transgenic maize was commercially introduced, estimations suggested that farmers may save $14 million to $69 million annually. The new commercialization of hybrid maize with multiple insect resistances may result in even greater cost savings.

Integrated pest management

The pest can damage crops substantially by attacking them at every stage of growth. The extent of stem borer infection mostly affected cultural practices, including time to sow, when to removal ofcrop residues, and alternate hosts. The goal of integrated pest management (IPM) is to successfully manage pests while reducing the usage of chemical pesticides by using a variety of pest control techniques (Kumar *et al*., 2023). Each control strategy has its limits, and none of them is frequently enough to effectively contain stem borer infestations. Therefore, it seems that the best course of action for controlling these pests is integrated pest management, or IPM.

To keep pest populations below the point at which economic injury is caused (EIL), integrated pest management (IPM) calls for the integration of multiple complementary and compatible methods. Farmers can efficiently manage stem borers while reducing the environmental impact and guaranteeing sustainable practices by combining cultural methods, planting resistant cultivars, encouraging biological control, monitoring populations, and utilizing chemical control as last option. Many researches have documented how well IPM works to control stem borers in cereals (ICRISAT, 1987; Tefera *et al*., 2011, Togola *et al*. 2022). When sorghum varieties with tolerance or moderate resistance to stem borer are combined with need-based pesticide application, an improvement in yield can be achieved (Kalade*et al*., 1987). Pheromone bait traps, early planting, and crop residue destruction are among recommended strategies for effectively managing the millet stem borer C. ignefusalis. The International Institute for Semi-Arid Tropics concluded an international workshop that the main elements of the integrated management of cereal stem borers should be host plant resistance and cultural approaches (ICRISAT, 1987; Togola *et al*. 2022).

Conclusion

Among a group of insects that are economically significant to cereal crops in Africa, stem borersare most devastating factor to production and productivity of millet crops including sorghum. Despite complexity of their biology and the form of their attacks, their influence can be reduced by using an integrated pest management strategy. The integration of different tactics will determine how well the management solutions perform. Regarding to varietal resistance, additional investigation is required to find or create cultivars that are resistant to the attack of stem borers. More aggressive activity from the extension service is required in regards to deployment of chemical and biocontrol options in order to strengthen farmer capacity and enable them to take necessary measures to reduce yield losses in cereal and boost their earnings. Furthermore, to safeguard natural enemies at landscape level, an integrated strategy based on a mix of insect growth regulators and conservation techniques is advised. Additionally, regulations to prevent introduction of new pests are also necessary for long-term effective management.

References

Adeyanju AA, Kruger J, Taylor JR and Duodu KG (2019). Effects of different souring methods on the protein quality and iron and zinc bio accessibilities of non-alcoholic beverages from sorghum and amaranth. International journal of food science & technology, 54(3): 798-809.

Althwab S, Carr TP, Weller CL, Dweikat IM and Schlegel V (2015). Advances in grain sorghum and its co-products as a human health promoting dietary system. Food Research International, 77: 349-359.

Boeke SJ, Baumgart IR and Van loon JJA (2004). Toxicity and repellence of African plants traditionally used for the protection of stored cowpea against Callosobruchusmaculatus. J. Stored Prod. Res. 40: 423–438.

Brookes G and Barfoot P (2017). GM crops: global socio-economic and environmental impacts (1996–2015). Dorcester: PG Economics LTD. Online:

Calatayud PA, Ahuya PO, Wanjoya A, Le Rü B, Silvain JF and Frérot B (2008). Importance of plant physical cues in host acceptance for oviposition by Busseolafusca. *Entomologia experimental isetapplicata*, *126*(3): 233-243.

Calatayud PA, Gitau C, Calatayud S, Dupas S, Le Ru B and Silvain JF (2011). Variability in the reproductive biology and in resistance against Cotesiasesamiae among two Busseolafusca populations. Journal of Applied Entomology, 135(6): 423-429.

Calatayud PA, Le Ru BP, Van den Berg J and Schulthess F (2014). Ecology of the African maize stalk borer, Busseolafusca (Lepidoptera: Noctuidae) with special reference to insect-plant interactions. *Insects*, *5*(3): 539-563.

Calatayud PA, Le Ru BP, Van den Berg J and Schulthess F (2014). Ecology of the African maize stalk borer, Busseolafusca (Lepidoptera: Noctuidae) with special reference to insect-plant interactions. *Insects, 5(3):* 539-563.

Chabi-Olaye A, Nolte C, Schulthess F and Borgemeister C (2005). Relationships of intercropped maize, stem borer damage to maize yield and land-use efficiency in the humid forest of Cameroon. Bulletin of Entomological Research, 95(5):417-427.

CIMMYT (2010). Development of maize resistant to stem borers and maize resistant to maize weevil and to larger grain borer for eastern and southern Africa (IRMA-III Conventional). CIMMYT: Nairobi.

CIMMYT (2011). Developing Maize Resistant to Stem Borer and Storage Insect Pests for Eastern and Southern Africa - IRMA III Conventional (2009–2013). Progress report submitted to the Syngenta Foundation for Sustainable Agriculture. IRMA III CONV Document No. 5. Nairobi, Kenya:CIMMYT.

De Groote H (2002). Maize yield losses from stemborers in Kenya. Insect Sci. Appl. *22*: 89–96.

De Groote H, Mugalavai V, Ferruzzi M, Onkware A, Ayua E, Duodu KG, Ndegwa M and Hamaker BR (2020). Consumer acceptance and willingness to pay for instant cereal products with food-to-food fortification in Eldoret, Kenya. Food and nutrition bulletin, 41(2): 224-243.

Haile H and Hofsvang T (2001). Effect of sowing dates and fertilizer on the severity of stem borer (Busseolafusca Fuller, Lepidoptera: Noctuidae) on sorghum in Eritrea. International Journal of Pest Management 47: 259-264.

Holst-Jensen A (2007). Sampling, detection, identification and quantification of genetically modified organisms (GMOs). In *Food Toxicants Analysis* (pp. 231-268).Elsevier.

ICRISAT (International Crops Research Institute for Semi-Arid Tropics) (1987). International workshop on sorghum stem borers, 17-20 Nov, 1987, ICRISAT Center, India Patancheru. 1989. AP. 502324 India: ICRISAT.

James C (2016). Global status of commercialized Biotech/GM crops: ISAAA Brief No 52.

Kalode MB, Bentur JS and Srinivasan TE (1987). Screening and breeding rice for stem borer resistance. In: Proceedings of the International Workshop on Sorghum Stem Borers. 1987, November. pp. 17-20.

Kfir R, Overholt WA, Khan ZR and Polaszek A (2002). Biology and management of economically important lepidopteran cereal stem borers in Africa. Annu. Rev. Entomol., 47: 701–731.

Kfir R (1997). Competitive displacement of Busseolafusca (Lepidoptera: Noctuidae) by Chilopartellus (Lepidoptera: Pyralidae). Annu.Entomol. Soc. Am. 90: 619–624.

Kruger M, Van den Berg J and Van Rensburg JBJ (2012). Reproductive biology of Bt-resistant and susceptible field-collected larvae of the maize stem borer, Busseolafusca (Lepidoptera: Noctuidae). African Entomology, 20(1): 35-43.

Kruger M, Van Rensburg JBJ and Van den Berg J (2014). No fitness costs associated with resistance of Busseolafusca (Lepidoptera: Noctuidae) to genetically modified Bt maize. Crop Protection, 55: 1-6.

Kumar A, Birah A, Tanwar RK, Khokhar MK and Singh SP (2023). Large-scale IPM validation in whitefly (Bemisiatabaci)-prone cotton (Gossypium spp.) fields adjoining kinnow orchards. The Indian Journal of Agricultural Sciences, 93(3): 296-301.

Kumar S, Kumar A, Bankar DR, Chauhan AS and Kumar S (2023). Integrated Management of Rice Yellow Stem Borer, Scirpophagaincertulas (Walker) in Paddy Ecosystem.

Le Ru BP, Ong'amo GO, Moyal P, Ngala L, Musyoka B, Abdullah Z, Cugala D, Defabachew B, Haile TA, Matama TK and Lada VY (2006). Diversity of lepidopteran stem borers on monocotyledonous plants in eastern Africa and the islands of Madagascar and Zanzibar revisited. Bulletin of Entomological Research, 96(6): 555-563.

Mally CW (1920). The Maize Stalk Borer, *BusseolaFusca*, Fuller. In *Bulletin*; Department of Agriculture of Union of South Africa: Pretoria, South Africa, 1920; p. 3.

Marulasiddesha KN, Sankar M and Gouda GR (2007). Screening of sorghum genotypes for resistance to damage caused by the stem borer Chilopartellus (Swinhoe). Spanish J. Agric. Res. 1: 79–81.

Mengistu G, Shimelis H, Laing M and Lule D (2018). Breeding for anthracnose ('Colletotrichumsublineolum'Henn.) resistance in sorghum: Challenges and opportunities. Australian Journal of Crop Science, *12*(12): 1911-1920.

Moglia A and Portis E (2016). Genetically modified foods.In *Encyclopedia of Food and Health* (Vol. 1, pp. 196-203). Academic Press-Elsevier.

Mugo S, Bergvinson DJ and Hoisington D (2001). Options in Developing Stem borer-Resistant Maize: CIMMYT Approaches and Experiences. Insect Sci Applic 21(4): 409-415.

Mugo S, Mulaa M, Likhayo P, Wangalachi A and Gichuki S (2008). Insect Resistant Maize for Africa (IRMA) Project. IRMA Project Document No. 30. CIMMYT: Nairobi.

Mugo S, Poland D, Mulaa M, Odhiambo B and Hoisington D (2003). Insect Resistant Maize for Africa (IRMA) Project. IRMA Project Document No. 15. CIMMYT: Nairobi.

Ndemah R, Schulthess F and Nolte C (2006). The effect of grassy field margins and fertilizer on soil water, plant nutrient levels, stem borer attacks and yield of maize in the humid forest zone of Cameroon. In *Annales de la Sociétéentomologique de France* (Vol. 42, No. 3-4, pp. 461-470).

Okosun OO, Allen KC, Glover JP and Reddy GV (2021). Biology, ecology, and management of key sorghum insect pests. Journal of Integrated Pest Management, 12(1): 4.

Ong'amo GO, Le Rü BP, Dupas S, Moyal P, Calatayud PA and Silvain JF (2006). Distribution, pest status and agro-climatic preferences of lepidopteran stem borers of maize in Kenya. In *Annales de la Sociétéentomologique de France*, 42(2): 171-177.

Ong'amo GO, Rü BPL, Dupas S, Moyal P, Muchugu E, Calatayud PA and Silvain JF (2006). The role of wild host plants in the abundance of lepidopteran stem borers along altitudinal gradient in Kenya. In *Annales de la Sociétéentomologique de France*, 42(3-4): 363-370).

Overholt WA, Maes KVN and Goebel FR (2001). Field guide to stemborer larvae of maize and Sorghum.ICIPE Science press.(Nairobi, Kenya) 31 pp.

Overholt WA, Ogedah K and Lammers PM (1994). Distribution and sampling of Chilopartellus (Lepidoptera: Pyralidae) in maize and sorghum on the Kenya coast. Bull. Entomol. Res. 84: 367–378.

Poquette NM, Gu X and Lee SO (2014). Grain sorghum muffin reduces glucose and insulin responses in men. Food & function, 5(5): 894-899.

Schulthess F, Bosque-Pérez NA and Gounou S (1991). Sampling lepidopterous pests on maize in West Africa. Bulletin of entomological Research, 81(3): 297-301.

Sezonlin M, Dupas S, Le Rü B, Le Gall P, Moyal P, Calatayud PA, Giffard I, Faure N and Silvain JF (2006). Phylogeography and population genetics of the maize stalk borer Busseolafusca (Lepidoptera, Noctuidae) in sub-Saharan Africa. Molecular Ecology, 15(2): 407-420.

Sharma HC (2003). Effect of spotted stem borer damage on fodder quality in sorghum, pp. 38-39.

Singh BU, Rao KV and Sharma HC (2011). Comparison of selection indices to identify sorghum genotypes resistant to the spotted stemborer, Chilopartellus (Lepidoptera: Noctuidae). Int. J. Trop. Insect Sci., 31: 38–51.

Tefera TM, Mugo SN, Tende R and Likhayo P (2011). *Methods of screening maize for resistance to stem borers and post-harvest insect pests*.CIMMYT.

Tekle AT (2016). Assessment on distribution, biology and management of maize stem borer (Busseolafusca Fuller) in Ethiopia. Assessment, *6*(5).

Togola A, Boukar O, Tamo M and Chamarthi S (2020). Stem borers of cereal crops in

Africa and their management. *Pests Control and Acarology*, p.59.

Togola A, Boukar O, Tamo M and Chamarthi S (2020). Stem borers of cereal crops in Africa and their management. In Pests Control and Acarology (p. 59). *Intech Open*.

Unnithan GC and Paye SO (1990). Factors involved in mating, longevity, fecundity and egg fertility in the maize stemborer, Busseolafusca (Fuller) (Lep., Noctuidae). J. Appl. Entomol., 109: 295–301.

Van den Berg J, van Rensburg JBJ and Pringle KL (1991). Comparative injuriousness of *Busseolafusca* (Lepidoptera: Noctuidae) and *Chilopartellus* (Lepidoptera: Pyralidae) on grain sorghum. Bull. Entomol. Res., 82: 137–143.

Vanamala JK, Massey AR, Pinnamaneni SR, Reddivari L and Reardon KF (2018). Grain and sweet sorghum (Sorghum bicolor L. Moench) serves as a novel source of bioactive compounds for human health. Critical Reviews in Food Science and Nutrition, 58(17): 2867-2881.

Zinzala S, Davda BK, Modha KG, Patel RK and Baldaniya V (2018). Genetic Diversity Analysis of Sorghum (Sorghum Bicolor L. Moench) Genotypes Using Rapd Markers. Biosciences Biotechnology Research Asia, 15(4): 833-839.

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