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Review

Status and management strategies of major insect pests and fungal diseases of maize in Africa: A review

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The escalating populations in Africa contribute to the already existing challenge of food insecurity, which is further exacerbated by the emergence and resurgence of pests and diseases, resulting in substantial annual yield losses. Maize, a vital staple crop in sub-Saharan Africa, serves as crucial food source, animal fodder, and raw material for industries. Nonetheless, its vulnerability to pests and diseases puts significant pressure on the crop. Consequently, the extensive losses experienced during pre and post-harvest stages due to insect pests and fungal diseases constitute grave menace to food security. Managing these destructive pests and diseases in a sustainable manner is a complex task that necessitates collaboration at regional and global levels. Notable examples of highly damaging insect pests and fungal diseases of maize include the spotted stem borer, black maize beetle, African stalk borer, fall armyworm, maize ear rot, and grey leaf spot. Thus, this review examines the economic implications and management practices used in SSA. It offers recommendations for the enhancement, coordination, and adoption of integrated pest and disease management approaches on a regional scale. The study's findings aim to support ongoing research efforts focused on maize crops, benefiting Agricultural entomologists, plant pathologists, breeders, and other stakeholders worldwide.

Key words: Maize, food insecurity, insect pests, fungal diseases, sustainable management.

INTRODUCTION

Maize (*Zea mays* L.) plays a significant role in world-wide agricultural production. Africa alone utilized 30.0% of the world's maize, with Sub-Saharan Africa (SSA) accounting for 21.0 of the consumption (Okon et al., 2022). Smallholder farmers cultivate an estimated 35-40 million hectares of maize in SSA (Boddupalli et al., 2020). This crop is essential for providing energy and protein to over 300 million impoverished and malnourished Africans, as well as weaned infants (Dey et al., 2015; Semagn et al., 2015). Additionally, maize is a crucial unprocessed

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material for livestock feed production and serves as a fundamental ingredient in various food and industrial products such as confectionery, starch, oil, beverages, fuels, and plastics (Badu-Apraku et al., 2017; Kaul et al., 2019; Naz et al., 2019; Gamage et al., 2022). The demand for maize in SSA is projected to triple by 2050, highlighting its potential to enhance food security and uplift farming communities out of poverty (Cock et al., 2017; Kumela et al., 2019; Acevedo-Siaca and Goldsmith, 2020). However, several challenges including unproductive soil, drought, scarcity of improved seeds and inputs, virulent pests and diseases outbreaks contribute to lower average maize yields in SSA compared to the world-wide average (Badu-Apraku et al., 2017; Boddupalli et al., 2020). Insect pests and fungal diseases pose significant threats to maize production in SSA due to their destructive nature and ability to cause substantial yield losses, especially under favorable environmental conditions (Midega et al., 2016a). Notable *Lepidopterous* insects affecting maize include *Busseola fusca, Eldana saccharina, Sesamia calamistis, Mussidia nigrivenella, Chilo partellus, and Spodoptera frugiperda* (Ong'amo et al., 2006; Goergen et al., 2016). Maize ear rot, capable of producing mycotoxins and grey leaf spot are common and problematic diseases in SSA (Bandyopadhyay et al., 2016; Badu-Apraku et al., 2017). The economic impact of major insect species like *C. partellus*, *B. fusca*, and *S. frugiperda* in sub-Saharan Africa ranged from $18.2-80 billion since 1970 (Diagne et al., 2021; Ratto et al., 2022).

According to Day et al. (2017) and Prasanna et al. (2018) the impact of fall armyworm has resulted in anticipated reductions in crop yields across various regions. Specifically, in West Africa, the predicted yield losses range from 22% to 67%, while in East Africa, it is estimated to be around 32%. The entire continent has experienced yield losses ranging from 21% to 53%.

EFFECT OF MAJOR INSECT PESTS OF MAIZE

The rapid and destructive spread of pests and diseases affecting maize during pre- and post-harvest stages is deeply concerning. Particularly, significant attention is given to the primary insect pests before the harvest.

Spotted stem borer

It is responsible for 15 to 60% crop losses globally, significantly lowers maize production as revealed. Substantial losses of between 24 and 75% in Africa's key maize-belt countries are devastated singly by the pest. In Kenya, study disclosed that stem borers were found to cause (10-100%) losses (Ong'amo et al., 2006). Also, in 1999 and 2000, losses recorded by stem borers in Kenya were estimated to have cost 25-59.8 million USD (De Groote et al., 2002). Following the recorded yield losses of 23.5% in Uganda (Wamatsembe et al., 2017), the destructive insects have been observed to have expanded their invasion into previously unaffected regions. The grain is preferably vulnerable to mycotoxins and storage insect pest contamination prior harvest as a result of stem borer damage to maize ears (Opoku et al., 2019; Njeru et al., 2020). Stem borer maize ears destruction predisposed sizeable grain to mycotoxins and storage insect pest infestations prior harvest (Njeru et al., 2020). *C. partellus*, commonly known as maize borer, has the highest impact on grain yield, leading to significant impairment of maize stalks (80%) when infestations occur at 20 days old. However, when identical infestations happen at later stages of crop development, minimal damage is observed (Van den berg, 2009). The research conducted by Ouma et al. (2003) reveals that the maize borer is responsible for causing approximately 14% (equivalent to 0.44 million tons) of total maize losses in Kenya, resulting in an estimated economic loss ranging from 25 to 60 million USD.

African stalk borer (*Busseola fusca*)

Notable losses have been reported in various countries: Kenya (14%; De Groote, 2002), Lesotho (0.4-36%; Ebenebe et al., 1999), Cameroon (0.4-41%; Chabi-Olaye et al., 2005a; Chabi-Olaye et al., 2005b), South Africa (10-100%), and Zimbabwe (17%; Chabi-Olaye et al., 2005b). A report by Ndjomatchoua et al. (2020) highlighted yield losses in smallholder farms ranging from 56.85 to 133.48 kg/ha, particularly due to mean cob mass depletion. Additionally, in the lowland and highland regions of Eastern Africa, *B. fusca* and *C. partellus* feed on the inner parts of maize plants, leading to significant damage. Consequently, smallholder farmers experience annual grain losses valued at approximately $450 million due to these two pests (Ndjomatchoua et al., 2020).

Fall armyworm (*Spodoptera frugiperda*)

The fall armyworm (FAW) has caused varying degrees of crop damage in several countries. The impact of FAW invasion on resource-poor farmers in sub-Saharan Africa (SSA) has worsened (Wightman, 2018). A report revealed that in the absence of proper management measures, FAW significantly reduced yields by 21 to 53 percent annually in twelve maize- producing countries in Africa (Abrahams et al., 2017). The estimated economic impact of these losses was projected to be between USD 2.48 and 6.19 million, according to Abrahams et al. (2017) and Day et al. (2017).

In Kenya and Ethiopia, FAW infestation resulted in yield losses of 0.77 to 1.0 t ha^{-1}, with farmers reporting that approximately 32% (Ethiopia) and 47.3% (Kenya) of their fields were infested during the season, and they anticipated a continued rise in invasions in the future (Kumela et al., 2018). In Mozambique, FAW was responsible for crop losses of 65% in certain regions (CABI, 2018). Moreover, *S. frugiperda*, the fall armyworm, has the ability to consume maize grain partially or completely, leading to reduced quality and quantity (Harrison et al., 2019). A report by Baudron et al. (2019) indicated that FAW attacks in Zimbabwe's Chipinge and Makoni areas resulted in yield reductions of 11.57% and 16.39%, respectively. De Groote et al. (2020) estimated yield losses of 32–34% in Kenya due to FAW. In Ghana, the predicted yield losses caused by FAW were estimated to reach 67% (Day et al., 2017), while in Zambia, the losses were up to 35% (Rwomushana et al., 2018). In Ethiopia, when the infestation occurred during the late whorl growth stage, specifically stage 1.5 of maize growth, it led to a 30% reduction in yield (Assefa and Ayalew, 2019).

Black maize beetle (*Heteronychus arator*)

The black maize beetle, a highly destructive pest with a broad range of hosts that includes maize, various cereals (such as wheat and barley), and sugarcane, is primarily found in West Africa but is native to Southern, Eastern, and Central Africa (Musikavanhu, 1996). Given that maize constitutes 70% of the staple crops in sub-Saharan Africa (SSA), *H. arator* poses a significant threat to both the region's food security and monocultures. Reports frequently indicate losses of around 35% in maize crops in Tanzania and Zambia. The most damage to maize is caused by the adult and larval stages of the beetle (Bulinski and Matthiessen, 2002). Because of its exceptional ability to move, the adult beetle has the capability to sever juvenile maize stems located just beneath the soil surface. This action results in the drying out of the stalk and ultimately causes the plant to die (Bruce and Picket, 2011). According to Ahad and Bhagat's study (2012), significant damage can be caused by as few as five beetles per square meter. The establishment and spread of *H. arator* are influenced by environmental factors such as temperature, moisture content, and soil organic matter (Mansfield et al., 2016). It thrives and reproduces best in environments with soil and ambient temperatures above 15°C, as stated by Bruce and Picket (2011). Conversely, low temperatures make it challenging for larvae to survive, offering potential opportunities for cultural control methods.

Maize weevil (*Sitophilus zeamais*) and Larger grain borer (*Prostephanus truncatus*)

The maize weevil, known as a destructive pest that affects maize grains from the field to storage, is a global concern (Adedire et al., 2011). The significant impact of post-harvest losses caused by *S. zeamais* on Africa's food security has been widely recognized (Abebe et al., 2009; Tefera et al., 2011). The maize weevil, the primary insect pest in maize storage, poses a significant threat to stored maize grains (Nwosu, 2018b; Ileke et al., 2020). Demissie et al. (2008) reported that the weevil begins its infestation in the field and the majority of the harm takes place during the storage period. The maize weevil and larger grain borer the primary pests found in stored maize, significantly affect food security for small-scale farmers in sub-Saharan Africa (Vowotor et al., 2005; Derera et al., 2014). Studies conducted by Nwosu et al. (2018a) and Lwanga et al. (2018) indicate that *S. zeamais* is a significant pest of stored maize grains in tropical and subtropical regions, resulting in measurable yield losses of 15-30%. Boxall (2002) reported post-harvest weight losses in maize grains in Kenya due to maize weevil infestation ranging from 20% to 30% during three months of on-farm storage. A report revealed that the maize weevil can cause both qualitative and quantitative damage, leading to grain weight losses of 20-90% in control-treated stored maize in Cameroon (Muzemu et al., 2013). The weevil significantly reduces maize grain weight and nutritional value by 60% within 3-6 months of storage, directly affecting Nigeria's ability to provide food for its population (Adesina, 2012; Ileke et al., 2016). These damages, as highlighted by Tefera et al. (2011) and Napoleão et al. (2013) often result in decreased grain weight and nutritional content, reduced seed germination, and ultimately lower marketability.

According to a study by Lale and Ofuya (2001), *S. zeamais* has the ability to perforate and invade grain kernels, leading to a decrease in their nutritional and seed value and ultimately rendering them aesthetically unattractive in both domestic and international markets. Additionally, *S. zeamais* infestation causes maize seeds to lose viability for planting and reduces their nutritional benefits.

EFFECT OF FUNGI DISEASES OF MAIZE

Grey leaf spot (*Cercospora zeae-maydis*)

Grey leaf spot (GLS) disease, caused by *Cercospora zeae-maydis*, is a significant disease affecting maize worldwide (Zhang et al., 2012; Savary et al., 2019). It was observed in Sub- Saharan Africa (SSA) and can cause yield losses of 20 to 60%, particularly in susceptible maize cultivars (Korsman et al., 2012; Nsibo et al., 2019). Severe defoliation of leaves and stalks can lead to yield losses as high as 90% (Sibiya et al., 2012). In Eastern Africa, estimated yield losses of 70% have been reported (Kibe et al., 2020). *C. zeae-maydis* has had a significant negative impact on maize farmers in Ethiopia, with high incidence rates reported in major maize-growing districts

(Nega et al., 2016). Similar incidences have been observed in South-west Ethiopia with (70%) yield losses (Gemechu et al., 2018). In countries of Southern Africa, losses in maize yield as a result of *C. zeae-maydis* reached 60%, resulting in damage to leaves, stems, and roots (Dhau et al., 2017). The fungus constitutes stellar threat to maize production in the African continent due to its ability to rapidly destroy foliage as the crop approaches maturity (Alemu Nega, 2016).

Maize ear rot

Fungal species such as *Aspergillus* species and *Fusarium* species are responsible for causing ear rot disease in maize. The global presence of the pathogens is greatly influenced by favorable environmental conditions such as abundant rainfall and high temperatures. These fungi species produce mycotoxins, such as aflatoxins and fumonisins, which contaminate maize grains before harvest (Wagacha and Muthomi, 2008; Mukanga et al., 2010; Buszewska-Forajta, 2020). Infection by *Aspergillus* species can occur during both pre-harvest and post-harvest stages, including storage and processing (Atehnkeng et al., 2014; Bandyopadhyay et al., 2016). Maize kernels are contaminated via the silk, providing a pathway for the fungi to approach the enclosed kernels (Falade et al., 2019). Inoculum sources include but not limited to soil, crop debris, insects, and air, allowing the pathogen to travel long distances (Mehl and Cotty, 2010). The high levels of my cotoxins, especially fumonisins and aflatoxins, found in grains in Sub-Saharan Africa have negative impacts on human health and animal productivity. Stunting in children, liver cancer, and even loss of human lives are ascribed to consuming food contaminated with high mycotoxin levels (Mukanga et al., 2010; Bhat et al., 2010). Mycotoxin contamination also has economic consequences, as grains may be rejected in international markets or receives poor pricing as a result of deplorable condition (Mukanga et al., 2010). Maximal levels of mycotoxins were noticed in maize samples in countries such as Zambia and Tanzania, indicating a risk to the well-being of the population (Mukanga et al., 2010; Degraeve et al., 2016). Aflatoxin poisoning has been reported in Kenya, causing severe health problems and deaths (Mahuku et al., 2019). Maize yield losses ranging from 10% to 40% due to fumonisins have been reported across maize fields in Sub- Saharan Africa (Chilaka et al., 2017).

MANAGEMENT STRATEGIES

Preventive and curative strategies are schemes harnessed by farmers to checkmate pre and post-harvest insect pests and fungal diseases of maize in field and storage. The primary methods employed for managing wild pests encompass a variety of strategies, including cultural practices, biological controls, chemical interventions, host plant resistance, and the use of plant-based pesticides, among others.

Cultural control

In a bid to surmount food security, and combat losses due to threatening pests and diseases, smallholder farmers in SSA substantially harnessed diverse cultural practices. These practices are regarded as conventional approaches to pest control. Cultural practices are considered as traditional forms of pest management. Techniques are based on the modification of cropping systems to ensure pest and disease evasion or avoidance during the most susceptible crop growth stage or pest population peak. Cultural strategies also strive to enrich the crop-growing environment to promote crop immunity and also create a discouraging environment that retards the proliferation of destructive organisms (pests and diseases). The merits of cultural applications lie in their manageability, minimal cost, and suitability for economically stressed smallholder farmers (Haouas and Hufnagel, 2020). Cultural control presents the first line of defense towards the prevention of in-field incidence and infestation in maize. Among the most effective cultural practices are avoidance planting and harvesting, intercropping, break cropping, precision fertilizer application, and efficient weed management. Field hygiene and appropriate soil fertilization boost plant immunity and promote plant vigor. Studies by Sarwar, (2011a) and Sarwar, (2012b) confirmed the effect of zinc and potassium availability in reducing stem borer incidence and increasing paddy yield in rice. The destruction of crop residue through burning, ploughing, or disking is an effectual scheme for interrupting the number of insect pests in cereals (Kfir, 1995a).

Considerable management of *B. fusca* through intercropping cassava and cowpea with silver leaf (*Desmodium uncinatum*) (Jacq.) DC.) (Fabales: Fabaceae) was reported by Akol et al. (2011a). Also, meagre-income farmers in Malawi utilized fish soup mixed with sugar solution as a pull strategy that attracted *S. frugiperda*'s natural enemies under field conditions (Harrison et al., 2019). Efficacy of the sugar solution against FAW population growth and leaf damage in maize fields was also reported by Canas and O'Neil (1998). In addition, *Bracharia* cv. Mulato II had been utilized as an attractant border crop to reduce FAW populations in maize in East African (Midega et al., 2018b).

Additionally, mycotoxin incidence and proliferation can be lowered by practicing rotational farming and the general elimination of other abiotic and biotic stress factors (Hell et al., 2011; Omotayo et al., 2019). Kang'Ethe et al., (2017) further confirmed that rotational farming assists in minimizing soil-nutrient deficiencies, and pre-harvest mycotoxins contamination in Kenya. Livestock waste is utilized as a cultural approach to control diseases. The utilization of manures from livestock (for instance, ruminant/non-ruminants) in the management of grey leaf spot disease of maize was reported in Tanzania (Lyimo et al., 2012). Additionally, in Nigeria, soil organic amendments disclosed maximal reduction in maize stalk rot caused by *Fusarium* species (Olajumoke et al., 2022). Interestingly, the combined utilization of poultry waste and sawdust biochar effectively reduced maize ear rot disease severity caused by fusarium in maize in Nigeria (Akanmu et al., 2020). Major cardinal drawbacks of this practice is that they must be consistent and collaborative effort from field to crop harvest.

Biological control

The objective of biological control is to employ and manage natural enemies to ensure that pest populations remain below the threshold at which economic damage occurs (known as the economic injury level or EIL). Macro and microorganisms present potential biocontrol agents (Haouas and Hufnagel, 2020). The introduction of larval parasitoids such as *Cotesia sesamiae* (Cameron) (Hymenoptera: Braconidae) and *Bracon sesamiae* (Cameron) (Hymenoptera: Braconidae) have proven to be effective toward the control of *B. fusca* (Kfir, 1997b).

Other fundamental parasitic organisms of *B. fusca* include Tetrastich atriclavus (Waterston) (Hymenoptera: Eulophidae), Apanteles sesamiae (Cameron) (Hymenoptera: Braconidae), and *Pediobius furvus* (Gahan) (Hymenoptera: Eulophidae) (Haouas and Hufnagel, 2020). The predation of the spotted stem borer *C. partellus* by *Cotesia flavipes* (Cameron) (Hymenoptera: Braconidae) and *Xanthopimpla stemmator* (Thunberg) (Hymenoptera; Ichneumonidae) was also reported (Akol, 2011b). Maize crop which produce the Bt toxin have been observed to effect lethality to *B. fusca* and *C. partellus* (Mukanga et al., 2010; Tefera et al., 2016b).

In Kenya and Tanzania, the most common parasitoids viz Charopsater and *Coccygidium luteum* (Brullé) (Hymenoptera: Braconidae), with parasitism of up to 12% and 8.3% respectively (CABI, 2018). Biocontrol agents exhibiting larval toxicity, and impeding reproductive ability in FAW have been reported by FAO, (2018). In SSA, diverse FAW control biological agents include but not limited to *Doru luteipes* (Scudder) (Dermaptera: Forfuculidae), *Orius insidiosus* (Say) (Hemiptera: Anthorcoridae), *Telenomus remus* (Nixon) (Hymenoptera: Platygastridae), and *Trichogramma chilonis* (Ishi) (Hymenoptera: Trichogrammatidae) have been utilized (Tefera et al., 2019; Souza et al., 2020). Reports by (Kenis et al., 2019; Tefera et al., 2019) showed that *T. chilonis* and *T. remus* can elicit (45%) predatoriness against eggs and larvae FAW and in Benin, Cote d'Ivoire, Ghana, Kenya, Nigeria and South Africa. Whilst, Benin and Ghana, *Chelonus bifoveolatus* (Szepligeti) (Hymenoptera: Braconidae) and *C. luteum* significantly efficacious on egg and larval parasitoids (Agboyi et al., 2020). Sisay et al., (2018) also reported the efficiency of *Cotesia icipe* (Fernández-Triana and Fiaboe) (Hymenoptera: Braconidae), as a new FAW parasitoid in East Africa. Figueroa-López et al., (2016) reported the potential of utilizing biological control techniques to treat of maize ear rot disease. This control alternative hinges on toxicity-dependent competitive exclusion of toxin producing members of *Aspergillus* section *flavi* (Medina et al., 2017, Guimarães et al., 2020). Figueroa-López et al. (2016) explained the efficacy of *Bacillus subtilis* (Ehrenberg) (Bacillales: Bacillaceae) in fusarium ear rot control in the tropics. Significant progress has been made in reducing mycotoxin contamination in maize in sub-Saharan Africa through the implementation of biological strategies.

Interestingly, the use of non-toxigenic strains belonging to the *Aspergillus* section *flavi* had been employed as a method to mitigate aflatoxin contamination in maize before harvest. Mauro et al. (2015) conducted a study highlighting this approach. Additionally, Bandyopadhyay et al. (2016) study demonstrated the effectiveness of Aflasafe, a bio-pesticide, in reducing aflatoxin levels in maize fields. The study reported (67-95%) aflatoxins in treated maize fields across various countries including Burkina Faso, Burundi, Gambia, Ghana, Kenya, Malawi, Mozambique, Nigeria, Rwanda, Senegal, Tanzania, Uganda, and Zambia. Furthermore, Weaver et al. (2017) study showed that *Ostrinia mubilalis*, a species of moth, was efficacious in suppressing the presence of mycotoxins in maize.

Chemical control

Chemical approach presents a major and integral component of pest management. Globally, synthetic pesticides are consistently utilized in controlling pests and diseases, with varying levels of attainment. For instance, effective management of the larger grain borer has relied intensely on the application of organophosphates that include pirimiphos-methyl, fenitrothion, permethrin, and bromophos dilute dust (Kimenju and De Groote, 2010). Industrial insecticides had been universally harnessed over decades to reduce the menace of *S. zeamais* and associated storage pests on a commercial level (Gbaye and Holloway, 2011). Control of *H. arator* had been substantially relied on insecticides viz chlopyriphos, fensulfothion and isazophos over time (Bruce and Picket, 2011). In SSA, FAW control included Dimethoate 40%, carbaryl, chlorantraniliprole, lambda-cyhalothrin, lindane, malathion 50% EC, methomyl, methyl parathion, spinetoram, and spinosad (Bateman et al., 2018; Sissay et al., 2019). The insecticides had varying degrees of efficacy across various production regions in SSA (Bateman et al., 2018; Sissay et al., 2019). In Ethiopia and Kenya, 48% of maize farmers utilized synthetic insecticides toward FAW control in 2018 (Kumela et al., 2018). Further, Dimethoate 40%, Lambda-cyhalothrin 5 EC, Chlorantraniliprole 20 SC, and Spinetoram 120 SC, significantly alleviated *S. frugiperda* leaf damage, while heightening larval mortality and biomass in maize in Ethiopia (Sisay et al., 2018). Also, leaf spot diseases have been effectively controlled using synthetic fungicide mixtures of prothiaconazole, fluxapyroxad and pyralostrobin (Anco, et al., 2020). In Ghana, thiophanate methyl is known to minimize the severity of foliar groundnut fungal diseases (Nutsugah et al., 2007; Kankam et al., 2022). Masiello et al., (2019) reported the efficiency of man-made fungicides in mitigating mycotoxins in corn. Additionally, fungicides such as propiconazole, azoxystrobin, and benzimidazole had been effective against grey leaf spot disease (Zhang et al., 2012; Dhami et al., 2015). Prothioconazole and boscalid were effective minimizing the population of *A. flavus* with (75 and 56%) contamination in maize fields, while prothioconazole and thiophanate- methyl successfully suppressed *fusarium* species contamination up to 52% and 48% respectively (Limay-Rios and Schaafsma, 2018).

However, due to associated risks (of synthetic chemicals) to human health and environmental damage, and emergence of new resistant races of pests/ pathogens, the sustainable and continued use of chemical control methods becomes questionable.

Host plant resistance

Host plant resistance refers to the inherited genetic characteristic of plants that enables them to withstand attacks from pests and diseases, as well as recover from the damage caused by such attacks (Togola et al., 2017). When combined with cultural or biological measures, the scheme is by far the most farmer-friendly pest management option and significantly reduces both pre and post-harvest damage. In the case of maize, host plant resistance has been effectively utilized for disease control. Tefera et al., (2011) highlighted the utilization of vigorous and productive maize varieties resistant to *P. truncatus* and *S. zeamais* as a potential method to lessen post-harvest losses. Numerous genes associated with quantitative trait loci (QTLs) have been identified to modulate maize's resilience to stalk injury caused by larvae of various *Lepidoptera* species (Smith, 2009). For instance, the International Institute of Tropical Agriculture (IITA) developed, pioneer and released a stem borer-resistant maize variety in South Eastern Nigeria (Ajala et al., 2001). Similarly, up until 2010, ten (10) improved maize lines with high resilience to conventional stem borer were released in Kenya (Tefera et al., 2011; CIMMYT, 2011). In South Africa, 42 maize lines with high resistance to stem borer were released in 2004 after extensive resistance screening and cultivar development (Van Rensburg and Klopper, 2004b). Various studies have reported quantitative trait loci (QTLs) associated with resistance to fall armyworm (FAW) damage in maize (Womack et al., 2018a; Womack et al., 2020), and CIMMYT collections of maize cultivars are currently assessed against FAW resistance in Kenya (Prasanna et al., 2018).

Maize accessions Mp708 and FAW7050 were found to exhibit resistance to FAW due to enhance defense proteins, elevated amounts of amino acids and glucose, and the presence of jasmonic acid (Chen et al., 2009). Additionally, accessions, Mp708 and FAW7061 had shown resistance to FAW infestation (Ni et al., 2011). Another study demonstrated that FAW resistance in a maize line of Mp708 is attributed to the terpenoid (E)-β-caryophyllene (Smith et al., 2012). Resistant maize cultivars had proven to be reliable, cost-effective, and ecologically sustainable approach to managing GLS disease (Zhang et al., 2012). In Ethiopia, inbred lines BH546, BH547, and BH661 were identified to possess genes resistant to foliar diseases, including grey leaf spot disease (Keno et al., 2018). Similarly, four maize genetically similar maize lines were discovered as potential sources of resistance to grey leaf spot disease in Ethiopia, which could be beneficial to farmers and breeding programs (Bekeko et al., 2018). Durable resistance and genomic selection such as marker-assisted selection (MAS) have been applied for the identification of multiple QTLs linked with different levels of resistance to several diseases affecting maize foliage, including grey leaf spots (Asea et al., 2012). Furthermore, the application of host resistance in plant has been implemented as a measure to alleviate the impacts of mycotoxins in maize (James and Zikankuba, 2018). The utilization of disease-resistant maize varieties is an economically sustainable strategy that provides durable crop safety.

Plant-derived pesticides

In field conditions in Kenya, the application of unrefined powders from *Tagetes minuta*, *Tephrosia vogelii*, and wide plant ash at a rate of 15-30 kg/ha resulted in a reduction of stem borer population by 18-63% and an improvement in maize grain yields (1.971-2.577 ton/ha) as against the non-treatment (1.534 ton/ha) (Ogendo et al., 2013). In Ethiopia, a research found that aqueous extracts from *Chrysanthemum cinerariaefolium* and *Cymbopogon* citrates at a concentration of 5% resulted in higher mortality rates (58.33% and 75%) on *B. fusca* after three days of treatment (Shiberu, 2013). Previous studies by Ileke and Oni (2011a) and Karunakaran and Arulnandhy (2018) identified several plant species, including *Annona squamosa*, *Alstonia boonei*, *Azadirachta indica*, *Garcina kola*, *Justicia adhatoda*, *Lantana camera*, *Moringa oleifera*, *Nicotiana tabacum*, and *Ocimum tenuiflorum*, as potential alternatives for controlling maize weevil. On the tenth day of treatment, extracts from ginger rhizome, lantana, neem, and pepper leaves significantly reduced adult maize weevil mortality by 53.33, 29.98, 23.33 and 19.99%, respectively (Barre and Jenber, 2022).

According to Temitope's (2014) research, there was an observed rise in weevil mortality as a result of their heightened susceptibility to small amounts of neem seed powder. The active ingredient found in neem seed oil was also found to cause significant weevil mortality, as noted by Danga et al., (2015). Furthermore, seed powder and oil from *Piper guineense*, *Piper nigrum*, *Piper umbrellatum*, and *Capsicum frutescens* were found to cause mortality in maize weevils, *S. zeamais* (Lajide et al., 1998). The application of powder from *L. camara* and *Hasteola suaveolens* at a concentration of 5% reduced the survival rate of S. zeamais and *P. truncatus* by 59% (Gariba et al., 2021). These plant powders demonstrated protective potential against insect species attacking stored maize grains (Ojo and Ogunleye, 2013; Gariba et al., 2021). Increased concentrations of phytopesticides were found to lower the occurrence of weevil attacks (Parwada et al., 2018). Maize grains treated with neem seed oil experienced a substantial decrease in insect weight loss, while untreated maize seeds had higher insect damage (11.1-12.8% weight loss) compared to botanical-treated seeds (1.5-4.2%) (Wahedi, 2012). In Kenya, grains treated with unprocessed powder from *T. vogelii* and *A. indica* showed strong repellency (88-90%), followed by *L. camara* (73%), against adult *P. truncatus* (Chebet et al., 2013). Essential oils from *Cymbopogon citratus*, *Cymbopogon winterianus*, and *Lippia origanoides* caused mortality in fall armyworm (FAW) within 24 hours (Sombra et al., 2020). Essential oil from *Crocus speciosus* exposed to FAW larvae resulted in mortality rates of 33.2% at 0.8% v/v, 86.6% at 1.0% v/v, and 100% at 1.5% v/v after 72 hours (Silvestre et al., 2021). Several studies have demonstrated the harmful effects of essential oils from *Eucalyptus citriodora* and *Syzygium aromaticum* on third-instar larvae of FAW (Cruz et al., 2017), and eugenol, *Citrus aurantium*, *S. aromaticum*, and *Citrus limon* have shown antifeedant activity against FAW (Da Camara et al., 2022). *Lippia javanica* and *N. tabacum* caused larval mortality of 66% in FAW through topical and stomach toxicity treatments (Phambala et al., 2020).

Genetic engineering and gene editing approaches

Genome engineering techniques offer a precise, informative, and time-efficient approach to enhancing cereal crops. Relying solely on traditional crop improvement methods, which are labor-intensive, time-consuming, and often ineffective, hinders progress in crop innovation needed to meet the world's food requirements. Gene editing is a potential tool which enables targeted exploitation of the genome, expediting the development of improved crop varieties.

Maize, as one of the earliest successful model crops, has demonstrated trait improvement through gene editing (Tripathi et al., 2022). Shukla et al., (2019) successfully utilized Zinc finger nuclease editing to enhance herbicide tolerance and nutrient enrichment in maize, specifically for herbicide tolerance and seed bio-fortification.

The emergence of clustered regularly interspaced short palindromic repeats (CRISPR/Cas9) technology has revolutionized genome engineering. Using CRISPR, complementary guide RNAs with 20 nucleotides are designed to target specific DNA sequences. Cas9 nuclease enzyme cleaves the DNA strands just after the protospacer adjacent motif, resulting in precise DNA cleavage (Jaganathan et al., 2018). The remarkable precision associated with CRISPR-based platforms has significantly advanced plant breeding programs, including enabling speed breeding (Tripathi et al., 2022). CRISPR approaches have been successfully applied in various crops to improve agronomic traits such as biomass, pest resistance, and disease resistance (Ricroch et al., 2017; Jaganathan et al., 2018). Notably, Svitashev et al., (2015) employed CRISPR/Cas9 in maize to edit genes associated with male fertility and acetolactate synthase. Gao et al., (2020) used SDN1 editing to delete waxy allele genes in maize, while Wang et al. (2018) knocked out TaGW2 genes to enhance seed size in wheat. In rice, Wang et al. (2016) developed blast-resistant elite lines by modifying the OsERF922 gene through the pC-ERF922 vector. Furthermore, virus sequence knockouts have led to the development of disease-resistant banana genotypes (Tripathi et al., 2019). The deployment of CRISPR-mediated Maize Lethal Necrosis resilient maize lines in Sub- Saharan Africa is currently underway (Boddupalli et al., 2020). The utilization of CRISPR/Cas9 technology to eliminate the abdominal-A homeotic gene in *S. frugiperda* showcased the remarkable effectiveness of CRISPR/Cas9 in modifying the genome of *S. frugiperda*, as evidenced by Wu (2020) findings. The advent of CRISPR technology opens up possibilities for stacking multiple traits and accelerating the production of maize cultivars resistant to various insect pests and fungal diseases.

CONCLUSION AND RECOMMENDATIONS

In order to meet the increasing food demands of the sub-Saharan African population, it is crucial to enhance and implement effective and sustainable management strategies for smallholder farmers who play a key role in intensifying food production. Although smallholder farmers are vital to the agricultural systems in sub-Saharan Africa, they often lack resilience to biotic stresses (pests and diseases). Given the intricate influence of climate crisis on African food systems, it becomes crucial to enhance the durability and transformation of farming systems in sub-Saharan Africa. This can be achieved through the enhancement of techniques for managing plant pests and pathogens, thus ensuring their ability to withstand and adapt to changing climatic conditions. The review highlights various management strategies that have shown positive results in managing insect pests and pathogens in maize. However, it is important to note that no single control method can effectively and adequately manage pests and pathogens below an acceptable level. Relying solely on specific control methods, particularly chemical control, can be expensive and environmentally unsustainable especially for economically disadvantaged farmers in maize production systems in sub-Saharan Africa. Considering the notable effects of the important control measures mentioned, the review proposes these essential suggestions:

1) To effectively avoid pest and pathogen outbreaks in maize fields in sub-Saharan Africa, it is important to implement IPM strategies that incorporate multiple approaches.
2) Collaborative research is necessary to improve and expand area-wide management strategies in partnership with farmers. The goal is to encourage widespread adoption of these technologies and gather feedback from users.
3) The utilization of genomic selection and gene editing methods provides an opportunity to enhance the inherent resistance of maize.
4) Molecular marker technology plays a critical role in rapidly identifying resilient maize lines. This has the capacity to increase maize production and mitigate the effects of climate crises on food security in sub-Saharan Africa.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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