Biological Control of Fall Armyworm

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The fall armyworm (FAW), *Spodoptera frugiperda*, is one of the most important invasive pests worldwide, resulting in considerable losses in host crops. FAW comprises two genetic strains, such as the “rice strain”, which prefers rice and other grass species, and the “maize strain”, which feeds upon maize and sorghum. Potential control measures are generally more applicable to the farmers who lack financial assets to buy chemical insecticides or costly pure seeds. The adverse effects of pesticides on the ecosystem and human’s health and the development of resistance to insect pests have exaggerated efforts to find an alternative strategy that is cost-effective, low-risk and target-specific. Therefore, biological control is widely considered as one of the most important options for insect pest management.

Keywords: fall armyworm ; biopesticides ; predators ; parasitoids ; entomopathogens

1. Introduction

The fall armyworm (FAW), *Spodoptera frugiperda*, is the most important pest worldwide, resulting in considerable yield losses in maize. FAW was first reported in 1797 as a devouring pest endemic to subtropical and tropical regions of America. It belongs to the family Noctuidae under the order Lepidoptera and was first reported in the African continent [1]. FAW is a devastating pest that damages 186 plant species belonging to 42 families. Poaceae, Fabaceae, Solanaceae, Asteraceae, Rosaceae, Chenopodiaceous Brassicaceae, and Cyperaceae are mostly affected. It results in about 58% yield loss in maize [2][3]. FAW is known to feed voraciously on more than 350 plant species, especially maize, rice, and sorghum, which might cause significant agricultural losses worldwide [3][4][5]. The first confirmed reports of FAW invasion were documented from West Africa in early 2016, and then spread throughout sub-Saharan Africa and Southeast Asia [1][6]. Now, this pest has been spread in more than 109 countries [3]. In India, it was first identified in May 2018, causing major losses to farmers in Karnataka and other southern Indian states [7]. FAW was first discovered in Nepal in May 2019 through morphological and genetic identification approaches [8].

FAW is an important notorious pest which attacks maize and various other crops belonging to the family Gramineae [9]. It is a polyphagous insect pest with over 80 host plants that causes severe damage to cereal crops and vegetables [1][10][11]. The young curl of leaves, ears, and tassels have been preferred, resulting in significant loss to maize crop [12]. FAW travels approximately 500 km before starting oviposition [10]. A single generation of FAW moths can disperse more than 500 km distance from the emergence location, owing to the wind, until they are sexually mature [11][13][14].

FAW is comprised of two genetic strains: the “rice strain”, which prefers rice and other grass species, and the “maize strain”, which feeds primarily on maize and occasionally on sorghum [15]. When FAW arrives in large numbers, especially with an offensive effect, it is determined to pose a long-term and damaging threat to many important crops, as the surrounding circumstances provide a comfortable environment for a variety of host plant species pre-favorable weather conditions for reproduction in various areas [1][4][16].

Biological control strategies are more appropriate to farmers who do not have the financial capability to purchase chemical insecticides and expensive seeds [17]. Microbial formulations are available in the market that are made from pathogens, arthropod natural enemies, and are more profitable in agricultural systems [3][18]. Recently, the microbial formulation production costs have been significantly reduced because these are mainly mass produced in liquid medium [3][19]. The repetitive use of synthetic pesticides in the field may prove detrimental to humans and the environment, have increased input cost, and, furthermore, initiate resistance and resurgence [20][21][22][23][24][25]. The larvae of the FAW caterpillar are deeply embedded in the leaf curls and corn ears, resulting in control failures. However, it comes to feed on plants at night or dawn and twilight [26].

2. Categories of Biological Control Agents

Predators and Parasitoids

About 150 parasitoid species have been identified from different regions of America and Caribbean. Ashley [27] reported 53 different parasitoid species, including *Apanteles marginiventris*, *Chelonus insularis*, *Ophion* spp. *Ternelucha* spp. *Rogus laphygmae*, *Campoletis grioti*, *Ephisoma vitticole*, and *Meteorus autographae* in *S. frugiperda* eggs and larvae. More than 44% of natural parasitism has been recorded in the non-sprayed fields of America [13]. These species showed at least 45.3% of parasitism level [28]. Seven species of parasitoids and three species of predators were identified from Ghana to control *S. frugiperda* [29]. These seven parasitoid species are listed as *Anatrichus erinaceus* (Loew), *M. testacea*, *C. icipe*, *Bracon* sp., *C. bifoveolatus*, *C. luteum*, and an uncertain *tachinid* fly (Diptera: Tachinidae), while the three species of predators include *Peprius nodulipes* (Signoret), *Haematochares obscuripennis* (Stal), and *Pheidole megacephala* F. [29]. The parasitism degree and regional differences in the presence of species have been reported [28][29][30]. This finding is based on crop stage and type changes, agronomic methods, and geographic regions [31][32]. *Coccygidium luteum* was reported from Kenya and Tanzania, which causes up to 9–19% parasitism in *S. frugipera* [28].

To control the increasing pest population of *S. frugiperda* in America, mass breeding and release of predators and parasitoids have been used to manage other pests [2][33][34][35]. In Sub-Saharan Africa, the implementation of classical biocontrol due to its high cost is required by the Government to control *S. frugiperda* [33]. Native parasitoids having a better level of parasitism have been observed from different vicinities of SSA [28][29][30][36]. The best way to control FAW is augmentative biocontrol, releasing predators to overcome the increasing pest population of FAW [33]. In America, *Trichogramma* parasitoids have been used to efficiently control the eggs of *S. frugiperda* [10][35]. Scientists at ICIPE in Kenya and Agboyi et al. [36] observed that *Trichogramma* and *Telenomus* parasitoid can efficiently augmentative biocontrol against *S. frugiperda*. Before FAW neonates emerge, parasitoids (*Trichogramma* and *Telenomus*) are introduced into maize fields, search for FAW egg masses, and lay their eggs on them to limit the FAW population at the egg stage [37].

In Africa, Lepidopterous species have been parasitized by *C. luteum*, the lepidopterous species including *Crypsotidia mesosema* (Hampson), *Spodoptera exigua* (Hübner), *Prophanti* ssp. *Spodoptera exempta* (Walker), *Condica capensis* (Guenée), and *Cydia ptychora* (Meyrick) [38]. *Coccygidium luteum* has been reported in Africa and many other countries, such as Nigeria, Madagascar, Kenya, Guinea, Congo, Ethiopia, Namibia, Mauritius, Rodrigues Island, Tanzania, Uganda, Somalia, South Africa, and Cameroon [36]. *Coccygidium luteum* is a solitary koinobiont parasitoid that belongs to the Braconid subfamily Agathidinae, which includes more than 46 species [39][40]. As biocontrol agents, Agathidinae species in this subfamily are not well known regarding their efficacy against insect pests and are rarely studied [41]. In China, *C. luteum* controls the eggs of many Spodoptera species [42][43]. Parasitoids can complete several generations in 90 days, leading to the emergence of early-maturing varieties of maize in West Africa [44]. Populations of natural enemies are affected due to the occurrence of variation in parasitism [45]. In the United States, parasitism levels were lower on average than previously reported levels, i.e., 15.5% [46], 35% [47], 8.1% [48], 28.3% [49], 18.3% [50], and 13.8% [51]. Agboyi et al. [36] reported parasitoids of 10 different species from the various localities of Ghana and Benin. These species are *Trichogramma* spp. *Meteoridea cf*, *Charops* spp, *Drino quadrizonula* (Thomson), *Metopius discolour* (Tosquinet), *Telenomus remus*, *Chelonus bifoveolatus* (Szpligeti), *Coccygidium luteum*, *Pristomerus pallidus* (Kriechbaumer), and *Cotesia icipe* [36]. Introduction, conservation, and augmentation are the three basic techniques for promotion of a biological control system in an ecosystem. Hymenoptera insects act as egg and larval parasitoids that are collected from FAW-infested areas. Further assistance might be given to stabilize the system either through inoculative or inundative releases.

3. Botanical Pesticides

Local farmers have claimed that botanical extracts from local plants are beneficial [10]. Botanical pesticides are a better alternative to synthetic insecticides, which could be more harmful to the environment, increase consumer cost, and delay recovery [52][53][54][55]. Such pesticides are also responsible for increased pest resistance [56][57][58][59]. Few botanical extracts include *Chrysanthemum cinerariifollium*, *Jatropha curcas*, *Nicotina tabacum*, *Milletia ferruginea*, *Phytolacea docendra*, and *Croton macrostachyus*, which could be used as insect pest control [60]. Around 50 botanical pesticides were found to be registered for controlling FAW in more than 30 countries. Among those, 23 are recommended for field trials and bioassays [2][61]. Solaris 6 SC® was shown to be the most effective insecticide against immature fall armyworms, followed by botanical extracts of garlic and neem, as well as detergent [10].

Botanical pesticides caused 80% mortality under laboratory conditions [62]. According to different reports and studies, these botanicals are effective against FAW [63][64]. Neem extracts have shown 70% mortality in FAW [65][66]. *Eucalyptus urograndis* was found to be more helpful in saving maize from pests [64]. The seed powder of *Carica papaya* was discovered as an efficient chemical insecticide [67]. Neem oil containing 0.17–0.33% concentration reduces FAW damage in maize [63].

Botanical insecticides are target-specific, non-hazardous for the environment, and safe for natural enemies as compared to chemical pesticides [68]. Thus, their application promotes FAW natural parasitism up to 60% in comparison with pesticide-treated areas [49].

A recent study conducted in Ghana recommends farmers to use intercropping technique during the first nine weeks of crop establishment because foliage of a crop remains too soft for FAW neonates; therefore, moths are attracted by crop to lay eggs [69]. Under this duration, intercropping encouraged natural biological control agents to establish under the prevailing conditions. It resultantly checked the FAW population [13]. Push–pull technology (PPT) is now suggested for FAW management [37]. International Centre of Insect Physiology and Ecology (ICIPE) introduced this method to control stem borers in maize. The push–pull technology comprises intercropping maize with drought-tolerant greenleaf Desmodium intortum (Mill.) Urb., while Brachiaria cv Mulato II is planted as a border crop surrounding the intercrop. Desmodium plays an important role in protecting maize crops by repelling moths away with the emission of semiochemicals [16]. At least 80% of FAW infestations can be eliminated using this technique [16][37]. In Uganda, FAW infestation levels on maize using PPT were 36–38%, compared to 95% when single cropping was used. PPT is better than maize-legume intercropping for controlling FAW infestation [70]. Botanical or biopesticides are recommended as an alternative to hazardous synthetic insecticides, such as pyrethroids and organophosphorus compounds, which can influence and interfere with environmental conditions, and increase expense, resurgence, and insect resistance.

Because of their low cost and accessibility, farmers and growers in developing countries use botanical, eco-friendly, sustainable techniques to manage insect pests of field crops and stored goods. *Milletia ferruginea*, *Azadirachta indica*, *Croton macrostachyus*, *Jatropha curcas*, *Phytolacea docendra*, *Chrysanthemum cinerariifollium*, and *Nicotina tabacum* extracts have been exploited successfully against insect pests [71]. *Azadirachta indica* seed extract causes the highest mortality in FAW at the larval stage [66]. Martínez et al. [72] discovered that the *Argemone ochroleuca* causes FAW mortality by reducing feeding behavior and stunting larval growth. Various botanical plant extracts could increase insecticidal efficiency against FAW [73]. Several products, such as extracts of *Azadirachtin* from neem and pyrethrins from pyrethrum, have been successfully commercialized, while others, such as those based on garlic, ryanodine, quassia, nicotine, and rotenone, have been registered worldwide [74]. Commercial products are available under different formulations and mode of action, applied diluted with water or sprayed with chemical insecticides and dust formulation. Furthermore, there are difficulties in application mode, such as neem-based solutions having high photosensitivity for Azadirachtin, resulting in a lower residual impact in fields due to sunlight exposure [62]. Few botanicals, including neem (*Azadirachta indica*), pyrethrum (*Tanacetum cinerariifolium*), fish-poison bean (*Tephrosia vogelii*), wild sage (*Lantana camara*), West African pepper (*Piper guineense*), wild marigold (*Tagetes minuta*), onion (*Allium sativum*, *Allium cepa*), tobacco (*Nicotiana* sp.), chilies (*Capsicum* sp.), lemongrass (*Cymbopogon citratus*), chrysanthemum (*Chrysanthemum* sp.), wild sunflower (*Tithonia diversifolia*), acacia (*Acacia* sp.), jatropha (*Jatropha curcas*), and Persian lilac (*Melia azedarach*), have good insecticidal properties in managing stemborers in Africa [75][76][77].

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