Review Article

Agro-ecological alternatives for fall armyworm management in maize: A review

Abstract

Maize, scientifically known as *Zea mays*, stands as one of humanity's most vital and versatile crops, with a rich history dating back thousands of years. Its journey from a wild grass to a staple food crop reflects its adaptability and resilience in various climates and soil conditions worldwide. But, the infestation of fall armyworm in maize represents a significant agricultural challenge globally, including India. Its expansion to India was initially discovered in maize fields at the College of Agriculture in Shivamogga, Karnataka, in 2018. Fall Army Worm (FAW) is regarded a major maize pest due to its ravenous feeding habits and crop damage. Originating from the Americas, the fall armyworm has spread rapidly across continents, facilitated by its ability to migrate long distances and adapt to diverse environmental conditions.In maize fields, fall armyworm larvae feed voraciously on leaves, tassels, and kernels, causing substantial yield losses if left unchecked. Their feeding activity not only reduces crop yields but also increases vulnerability to secondary infections and reduces the overall quality of maize produced. Effective management of fall armyworm infestations in maize often requires a multi-pronged approach, integrating cultural, biological, and chemical control methods.Furthermore, the majority of Indian farmers are smallholders who are unable to afford chemical pesticides that are harmful to the environment. This review delves into the emerging landscape of agro-ecological alternatives aimed at mitigating the impact of this destructive pest.

Keywords:*Agro-ecological approaches, Fall armyworm, Maize, Pest management*.

Introduction

Maize and Fall armyworm

Maize is a popular cereal crop due to its high nutritional value as a staple meal, animal feed, and fuel (Abebe and Feyisa, 2017). Asia accounts for around 32% of global maize production (FAO, 2018a), with China ranking second with 40 million ha. Maize growers in Asia are smallholders;however the majority of the maize is grown for animal feed. Tufa and Ketema (2016) discovered that the low maize yield is attributable to major restrictions such as a lack of efficient pest management techniques, moisture stress, low fertility, and poor cultural practices. More than 40 insect species have been identified as maize pests.*Spodopterafrugiperda,* an invaded species, is the primary insect pest of maize, resulting in extremely low yields.

The insect, fall armyworm (FAW), has been reported to inflict serious damage to maize crops in America. During 2016, it became an invasive pest in Africa and expanded swiftly over the continent in 2016 and 2017. In 2018, it was detected in Yemen and India (FAO, 2018a; Ganiger*et al.,* 2018). Sharanabasappa*et al.* (2018) confirmed the pest's presence for the first time in Karnataka, India. In early 2019, the pest was identified in five Asian countries, including China. The insect is known to affect maize, cotton, rice, and sorghum, among other crops. A study states thatthere are 353 FAW host plants from 76 families, primarily Poaceae, Asteraceae, and Fabaceae, during a survey in Brazil (Montezano et al., 2018).

Fall armyworm biology

The fall armyworm is a noctuid moth native to North and South America that has long been a major production concern (Nagoshi*et al.,* 2012). The pest is polyphagous and migrates over great distances. It can cover more than 100 kilometers in a single night. It feeds on a wide variety of host plants (Pogue, 2002; Johnson, 1987). FAW eggs can be identified by their clustered egg laying habit, which ranges from a few to hundreds in number. Female moths lay eggs on the lower surface of leaves and cover them with scales. The incubation period for eggs varied from 2 to 3 days, with a mean of 2.50 days. (Sharanabasappa*et al.,*2018).

FAW eggs have a dome shape with a flattened base. The eggs measure around 0.4 mm in diameter and 0.3 mm in height. The female moth deposits the majority of her eggs within the first four to five days of her life, but some can take up to three weeks. The fall armyworm moth has both migratory and localised dispersion habits. They can travel more than 500kilometres before oviposition (Prasanna*et al.,*2018). The number of eggs laid by a female over its life cycle ranged from 1342 to 1844 when the larvae fed on millet or maize leaves, and 1839 eggs when it fed on cotton leaves. The larvae cause harm to maize plants, while the adults disseminate the pest by reproducing rapidly and travelling large distances (Barros *et al.,* 2010).

After hatching, each larva travels through six instars that last 14 to 19 days (Sharanabasappa*et al.,* 2018). The larvae start out green and gradually develop brown and black. It featured four black dots on the eighth segment of larvae, which resembled a square. A fully developed caterpillar can be as long as a matchstick (4 to 5 cm) (CABI, 2019). The epidermis of larvae is rough and granular in texture, and the last instar larva has an inverted Y form (Prasanna *et al.,* 2018).

The caterpillar has three pale yellow stripes down the back of its dark head. In addition to a pair of prolegs at the end of its body, the larvae have four pairs of fleshy abdominal prolegs (CABI, 2019). The larvae hatch from the eggs and feed vertically on the plant or horizontally on nearby plants, causing the pest to spread throughout the farm (Ali *et al.,* 1989, 1990). Larval development lasted 11 to 50 days depending on temperature and habitat (Hogg *et al.,* 1982).In the words of Pitre and Hogg (1983), the larvae fall from the plant and burrow into the soil to a depth of three inches, where they remain in the pre-pupal stage for two to four days. They pupate after 7-10 days. The pupal stage lasts approximately 9 to 12 days (Sharanabasappa*et al.,* 2018).

As stated by Oliver (1981), the adult moth's top forewings are mottled dark grey with a white patch near the dorsal tip, while the lower forewings are light grey to brown in colour. As with other Noctuids, the moths are most active at night. The antennae are filiform. In the study by Prasanna *et al*. (2018), the female moth's forewings range in colour from greyish brown to faint mottling of grey and brown. The hind wing of the male and female moths is silver-white with a short border. The average adult lifespan is 10 days, with a range of 7 to 21 days, and depending on the climate, two to ten generations can be completed in a single cropping cycle.

The reproduction is efficient in tropical climate due to its warmer temperature where the FAW can produce up to ten generations per year, whereas temperate climates produce only two or three generations each year. According to the studies by Early *et al.,* 2018; Li *et al.,* 2020, the least temperature required for egg, larva, and pupa development is 13.8^{o}C. The pest thrives and reproduces all year in warmer places where hosts are always accessible and temperatures rarely fall below specified thresholds.

Fall armyworm and plant damage

The FAW larvae were placed in maize plants at 8 to 10 leaf stage and monitored FAW damage and yield for two years. In the first year, 98% affected plants resulted in a 15% production decrease. There was no change in yield when 31% of the corn was affected. During the second year, 100% maize infestation resulted in an 18% yield drop (Cruz and Turpin, 1983). The response of yield to various levels of infestation in three vegetative phases of irrigated maize grown under hydric stress was studied in Nicaragua. Insecticides were employed to protect maize from FAW and the neotropical cornstalk borer. The maximum infected treatment in all three phases resulted in a 34% loss in yield (Hruska and Gladstone, 1988). Maize yields were reduced by 15 to 73% when FAW infestation was strong during the mid to late growth stages (Hruska and Gould, 1997).

Larvae are cannibalistic at high larval numbers, resulting in only one later instar larva per maize plant. The pest may survive and expand on immature leaves, whereas grown leaves are unsuitable for foraging. So, they eat ear, silk, and cob. It was found that over 90% of larvae recovered within 1.1 m of a maize plant 14 days after being contaminated with an egg mass (Pannuti*et al.,* 2016b).

The research by Goergen *et al.* (2016) states that the fall armyworm larvae live on immature leaves, whorls, tassels and cobs. The FAW damage causes skeletonized leaves and windowed whorls in the late vegetative stages. The full-grown larvae in mature plant whorls can feed on maize cobs, leading to decreased output and quality (Capinera*et al.,* 2017). The hatched larvae graze on the leaves on which the eggs were deposited but once matured; they disperse to other plants (CABI, 2019). The first and second instar larvae scrape the leaves, causing windowing damage, but the later instar larvae create ragged holes in the growing leaves from the whorl.

Hruska (2019) analysed the results of an NCIS study published by the US Department of Agriculture in the Corn Loss Adjustment Standards Handbook in 2013, which revealed that 70% defoliation at the 12 leaf stage is expected to result in a 15% yield drop. A 25% defoliation before the 18th leaf stage may result in a yield drop of less than 5%. Koffi et al. (2020) assessed the effect of fall armyworm incidence on maize in Ghana. The findings revealed that the larval population was larger throughout two cropping seasons (May to June; September and October). FAW mostly targets maize, but can also be seen on rice, onion, millet, sorghum, tomato, and brinjal. The pest targets all phenological stages of maize, with the vegetative stage being the most severe. It has also been reported that fall armyworm larvae can reduce yield by 34 to 38% (Nelly *et al.,* 2021).

Fall armyworm management

The extent of damage is determined by geographical region, planting season, cultivar planted, and cultural practices used (Sarmento *et al.,* 2002). The maize plant's ability to compensate for foliar damage is determined by its genetics, nutrition, and water availability. The relationship between FAW infestation and maize yield was influenced by maize varieties, plant density, and agronomic techniques. The FAW infestation was observed to be significant in late planted maize as the moths seek the vegetative stage. Fernández (2002) stated that if maize seedlings are cut by 5% or the whorls of plants (during the first 30 days) are damaged by 20%, an appropriate management mechanism must be used to prevent future damage.

a) Chemical control

In the opinion of Cook *et al.* (2004), the primary method for managing fall armyworm is to use synthetic pesticides. Foster, 1989 stated that keeping plants larva-free throughout the vegetative stage can reduce the amount of sprays necessary during the silking stage. Besides increasing production costs, the continued use of synthetic insecticides to manage crop pests can lead to pest resistance and have serious environmental consequences (Pérez *et al.,* 2000; Xu *et al.,* 2010). To manage FAW in maize, methyl parathion, chlorpyrifos, methamidophos, and phoxim was used in Mexico (Malo *et al.,* 2004).

A study conducted in Makueni, Machakos, and Kenya on the usage of agricultural pesticides in maize cultivation reported that 0.5% and 2% of farmers had used herbicides and insecticides, respectively. The World Bank conducted the same surveys in six countries: Ethiopia, Malawi, Niger, Nigeria, Tanzania, and Uganda between 2010 and 2012. The results showed that 16% of farmers employed agrochemicals in all crops(Muhammad *et al.,*2010). Small farmers in Africa utilise very little insecticide for pest management due to a lack of awareness, unavailability of efficient products, and expensive costs (Midega *et al.,* 2012).

The findings of Day *et al.* (2017) detailed that the use of chemical pesticides for FAW management is ineffective because the pest's frass is so heavy that it forms a plug, reducing the efficacy of chemicals and possibly not reaching the whorl where the larvae feed. Chemical pesticides should not be sprayed during the day because the pest is only active at night.The pest fall armyworm is controlled through the use of genetically modified maize, which contains the gene responsible for producing poisons that kill FAW. This strategy outperformed 85% of maize grown in the United States, Brazil, and Argentina (Briefs, 2017). In the southern United States, it is common practice to use chemical insecticides three to four times a week to control FAW in sweet corn (Capinera*et al.,* 2017).

Togola *et al.* (2018) found that using chemical control methods without addressing the threshold level can result in resistance development, plant damage, and human and environmental risks. Kumela*et al.* (2019) revealed that applying a dry sand mixture with trichlorfon to the whorls of a plastic bottle is effective and is utilised by farmers in Ethiopia and Kenya.

Sisay *et al.* (2019) found that applying Radiant, Tracer, Karate, and Ampligo resulted in over 90% death of FAW larvae after 72 hours of application. Of the chemical combinations used in the study, no larvae were discovered on treatments with Karate 5 EC in the second spraying, and less than one larva was identified in all chemical treatments after the third spray. Chemical insecticides are recommended when larvae are less than 31 mm long, 75% of the whorl has feeding damage, and the plants are stressed (CABI, 2019).

In the study by Koffi *et al.* (2020), the most common pest management practice is the use of insecticides. During severe infestations, pesticide applications began in the second week and varied in frequency from once a week to every other week. Maize yields were lower in years when the autumn armyworm outbreak was reported.

Deshmukh *et al.* (2020) studied the efficiency of several pesticides against the autumn armyworm in India. The results showed that the most lethal insecticides are emamectin benzoate, chlorantraniliprole, and spinetoram, with potency ratios of 119, 38, and 15 respectively. When these pesticides were administered in the field, they found that chlorantraniliprole, spinetoram, and emamectin benzoate had the lowest number of larvae per plant. Chlorantraniliprole, emamectin benzoate, and spinetoram spray treatments had the highest yields.

b) Intercropping and natural enemies

The study by Luginbill (1928) states that the availability or lack of natural enemies determines whether a considerable number of autumn armyworms infest a crop. Maize intercropped with beans reduced FAW infestation in maize by 20-30% (Van Huis, 1981).

Pair and Gross, Jr. (1984) observed that predators account for 73% of FAW pupal mortality. Wheeler *et al.* (1989) reported that the parasitoid *Chelonusinsularis* (Cresson) (Hymenoptera; Braconidae) killed 42% of FAWs. Castro *et al.* (1989) found that endoparasitic nematodes (Mermithidae) parasitized up to 71% of FAW larvae.

According to Van den Berg *et al.* (1998), the majority of small farmers growing maize in Africa use cultural pest control methods such as planting date manipulation, crop residue destruction, tillage methods, the use of locally available substances, and intercropping (Abate et al., 2000). Girma et al. (2000) found that maize grown closer to hedges of Gliricidia, Crotalaria, Calliandra, and Croton had a lower degree of stem borer attack.

Meagher Jr. *et al.* (2004) investigated the larval growth and feeding behaviour of FAW on various crops, including maize, sorghum-sudangrass (SSG), cowpea, and sunflower. It was discovered that larvae reared on the cover crop sunflower were smaller than those grown on maize. Cowpea and sunflower larvae had longer to grow, and their pupae weight was 20 to 25% lower than that of maize and

SSG. It confirms that cowpea and sunflower have the potential to diminish FAW populations by prolonging larval development. This, in turn, slows the timing of FAW infestation in the subsequent maize planting season.

Adopting plant diversity in cropping systems in which one crop attract the pest whereas the other repels the pest is push-pull method. Desmodium (Leguminaceae) releases volatiles that repel pests, whereas Napier grass, a trap crop, attracts pests. Wyckhuys*et al.* (2006) demonstrated that the combination of different agricultural systems and natural enemies keeps FAW populations at low levels in Central America for smallholders. Growing wild flowers along field borders enhances the availability of food for natural enemies, which increases their abundance and lowers FAW survival (Wyckhuys and O'Neil, 2007; Hay-Roe *et al.,* 2016).

In the words of Seran and Brintha (2010), crop diversification is one of the management options for FAW. Crop diversity on a temporal and spatial scale minimizes pest incidence by boosting the population of beneficial arthropods. González *et al.* (2010) discovered that maize intercropped with pumpkin had less FAW infections than sole maize. However, Baudron*et al.* (2019) found a greater infestation of FAW in pumpkin intercropped maize. According to Khan *et al.* (2010), several companion plants produce semiochemicals that either repel or attract pests from the primary crop.

Letourneau *et al.* (2011) shown that intercropping reduces herbivore populations while increasing the natural enemy count, hence reducing crop damage. Varella *et al*. (2015) investigated the mortality of FAW eggs and larvae over a three-year period. The data showed that egg mortality ranged between 73 and 81% due to dislodgement, unviability, and predation. More than 95% of larvae died during the early larval stage as a result of flooding and dislodgement caused by rainfall and predation.

Growing crops with woody perennials is another strategy to increase habitat diversity and protect natural enemies. Trees increase the diversity of vertebrate natural enemies such as bats and birds, which could be predators of FAW moths (Maine and Boyles, 2015). Rundlöf*et al.* (2015) and Potts *et al.* (2016) found that synthetic pesticides had a deleterious impact on pollinators and natural enemies.

The findings of Cook *et al.* (2004), Dalvi *et al.* (2011), and Stokstad (2017) stated intercropping systems, botanical pesticides, and beneficial bacteria are the most effective alternatives to insecticide use. Growing beans as a companion crop provide a distinct biological niche for FAW larvae while also releasing semiochemicals that prevent the FAW pest and oviposition (Ndakidemi*et al.,* 2016). Many parasites are sensitive to chemical pesticides. In Florida, Meagher *et al.* (2016) found that the parasitism level of FAW ranged from 1% (sprayed field) to 95% (unsprayed field).

The use of push-pull technology (PPT) to manage FAW in Uganda was studied by Hailu et al., (2018). When compared to mono-cropped maize (95%), climate-smart (36%) and standard PPT (38%) treatments had lower FAW infestation rates. FAW attack proved to be lower in the seedling stage with less tillage, and as plant height increased, the infestation became similar to the tillage treatments used. Intercropping maize with beans or peanuts reduced FAW infection by 30%. This demonstrates that intercropped maize receives higher protection than monocrop maize.

Midega *et al.* (2018) investigated the effectiveness of a climate-adapted push-pull system against autumn armyworms in Africa. The results showed that the climate-adapted push-pull maize crop had fewer fall armyworm infestations and produced more than the monocrop maize. The average number of larvae per maize plant was also found to be lower than for solitary maize. Rotating maize with non-host crops such as sunflower and bean can help reduce FAW attacks (FAO, 2018). According to Sisay *et al.* (2018), *Cotesiaicipe* is the most common larval parasitoid of FAW in Ethiopia, accounting for 33.8 to 45.3%. Planting additional crops among maize plants can improve overall plant health by contributing to soil health, interfering with host search by releasing repellent volatiles, inhibiting larval movement between rows, and increasing the number of natural enemies by providing food and shelter (Harrison *et al.,* 2019). A study conducted by Baudron*et al.* (2019) to quantify FAW damage to smallholder maize crops in two districts of Eastern Zimbabwe. FAW incidence was greater in pumpkin-intercropped maize. FAW damage was shown to be lower in zero-tillage systems with frequent weeding. Of the three models used in the study, two that used limited tillage, manure, and compost showed lesser FAW damage.

Tanyi *et al.* (2020) investigated bean intercropping and the application of botanical extracts to control fall armyworm infestations in maize. The study found that the control group had the highest FAW infestation in maize, followed by dwarf and climbing bean intercropping. The pesticide and black pepper extract treatments resulted in the lowest infestation. Maize yields were shown to be greater in the pesticide and black pepper extract treatments, followed by bean intercropping, with the lowest yield recorded in the control.

c) Time of planting

Van Rensburg *et al.* (1985) observed that the time of planting of maize have influence on the levels of infestation and loss in yield caused by maize stalk borers. Pogue (2002) conveyed that the fall armyworm can cause severe damage by feeding on the leaves and stems of more than 100 plant species during June to August when the minimum temperature exceeds 10^{o}C.Biradar*et al.* (2011)studied the difference in the incidence of maize pest during different sowings taken. The eggs of shoot fly were found in greater amount during the months of September, March and April. The pin holes and activity of hairy caterpillar were found to be higher in the month of August. The larval population and the damage were found to be minimum in the month of June.

Early planting of crops reduces the pest pressure at the time of growing season. But early planting is connected with the risk of crop failure due to irregular rainfall at initial stages. So, the small holder farmers hesitate to take early sowings and choose to take either delayed sowing or staggered planting (Thierfelder*et al.*, 2016). However, Baudron*et al.*(2019) found that the planting dates have no influence on FAW damage. The FAW pest requires warm, humid areas with heavy rainfall for its population growth as it cannot breed at temperatures lower than 10^{o}C (Stokstad, 2017).

Bhandari*et al.* (2018)informed that the infestation of stalk borer on leaves was higher in summer than on spring and winter when tested with two different maize genotypes. They also observed that the tunnel length and exit holes increased with the progress of planting time from first week of January to

March in both the maize genotypes used for study. Further, they found that under natural field conditions, the infestation was higher at high temperature of 25-31^{o}C and vegetative stages were more vulnerable to the damage of maize stem borer than the later stages. The FAW heavily infest the ears of maize that are sown late than early plantings (Bilbo, 2019). The early planting after the first effective rains usually provides better growing conditions for maize, making use of more heat units at the beginning of the cropping season. Control of pests in early planted crops derives from low pest pressure at this time of the season (Harrison*et al.,*2019).

d) Soil fertility and plant health

Soils with good organic matter content and minerals encourage the balanced release of nutrients which guarantees overall plant health. This, in turn fights the pest and disease attack. Jones (1976) revealed that soil fertility management can have many influences on plant quality which in turn can affect the abundance and damage of insects. The reallocation of minerals can affect oviposition, growth rates, survival and reproduction of insects. Perfecto *et al.* (1991) reported that ants found in fields of healthy soil biota killed over 95% of FAW pupae. Magdoff and Van (2000) suggested that cultivation practices that cause nutrition imbalances can reduce pest resistance. Besides affecting the amount of damage that plants receive from herbivores, the soil nutrient availability also affects the ability of plants to recover from herbivory (Meyer, 2000). The use of high quality seed and balanced fertilization to ensure healthy plants which in turn fight back the pest attack (Morales*et al.*, 2001).

Yardım and Edwards (2003) observed that the use of synthetic fertilizers can reduce plant resistance to pests which may increase pest population and can increase the need for insecticide application. Chaboussou (2004) told that balanced mineral nutrition makes crop more resistant to pest and diseases. Besides repelling the pest, the legume intercropping can enhance the soil health by improving the soil fertility status (Proctor*et al.*, 2007; Vanlauwe *et al.*, 2010). Practices such as mulching, no or low tillage or other soil management techniques and the soil predators may help reduce survival of FAW pupae in soil (Rivers*et al.*, 2016).

e) Other management practices

Ebeling (1971) indicated that the diatomaceous earth is one of the safest and effective naturally occurring insecticides. The diatomaceous earth sticks to the insect body and harms the cuticle by absorption and a lesser degree by abrasion. It results in the death of insect because of water loss. The locally available materials are used by small holder farmers all over the world to control FAW. They include local botanical extracts, soil, wood ash, sand, soaps, lime and oils. The effectiveness of neem seed powder was studied by Marediа*et al.* (1992).

Archundia*et al.*(2006) got 100% larval mortality of FAW with the water extracts of *Carica papaya* seed at 10% concentration. Souza *et al.*(2010) stated that the plant oils of *Corymbiacitriodora* and *Eucalyptus urograndis* had negative effect on FAW larvae in maize. Tavares*et al.* (2010) studied the influence of neem based bio-pesticide on the larva of FAW. The outcome showed that the use of neem oil and synthetic insecticide lufenuron reported higher mortality when tested in four and six day old

S. frugiperda caterpillars. Salinas-Sánchez*et al.* (2012) told that hexane, acetone and ethanol extracts of *Tageteserecta* produced 48%, 60% and 72% mortality of FAW larvae. Delgado Cáceres and Gaona Mena (2012) attained mortality of FAW larvae (82%) with *Polygonumhydropiperoide* extract at 50g/100 ml of water. Arya and Tiwari (2013) said that the use of botanical insecticides is harmless, inexpensive and environment friendly than the chemical ones which cause higher cost, pest resistance to pesticides and disturbances in the environment.

Constanski*et al.* (2016) researched on the effects of various inert powders on FAW. The use of bentonite caused 93% and diatomaceous earth caused 47% mortality of FAW. The other biological methods are the use of predatory insects, parasitoids, use of genetically modified crops, pheromone trapping of male moths and *S.frugiperda*Multiple NucleoPolyhedro Virus (*Sf*MNPV) prevents the pest from mating (Day *et al.,* 2017).

Martinez *et al.* (2017) reported that the ethanolic extracts of *Argemoneochroleuca* caused mortality of FAW larva due to reduced feeding and larval growth. The sand, ash, sawdust and dirt are used in the whorls by the small holder farmers of America are effective against FAW larva (FAO, 2018a). The farmers in America and Africa use lime, salt, oil and soaps to manage FAW. Flooding the maize fields after harvest kills the FAW pupae in the soil. During regular monitoring of the field, the egg masses of the FAW are hand-picked and killed were shown slightly successful (Rwomushana*et al.*, 2018).

Akutse*et al.* (2019) disclosed that *Metarhiziumanisopliae* and *Beauvariabassiana* are verified effective against fall armyworm eggs and second instar larvae. The fifteen percent of farmers in Ethiopia have done only handpicking of egg masses and larva for FAW management (Kumela*et al.,* 2019). The use of botanicals like *A. indica, Schinnusmolle*and *Phytolaccadodecandra*recorded more than 95% of larval mortality after 72 hours of application (Sisay *et al.,* 2019). A bioassay test done by Phambala*et al.*(2020) observed that *Nicotiana tabacum* shown the highest larval mortality (66%) and *Lippiajavanica* also showed 66% larval mortality by contact toxicity test.

Conclusion

In conclusion, the review of agro-ecological alternatives for fall armyworm management in maize underscores the importance of sustainable, nature-based approaches in confronting this pervasive agricultural challenge. By emphasizing strategies such as biological control, crop diversification, habitat management, and integrated pest management (IPM), this study highlights the potential to reduce reliance on synthetic pesticides while promoting biodiversity and ecosystem resilience.At the same time, it is important to introduce, validate, and deploy low-cost, environmentally safer, and effective technological interventions to control the pest.

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