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Spodoptera Frugiperda (Fall Armyworm) Economic Impacts and Management Strategies on Maize Production in Cambodia: A Review Article

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ABSTRACT
Maize is a significant crop in Cambodia and is extensively grown in upland areas with higher rainfall and suitable soil conditions. The production of maize in Cambodia is being affected by the presence of fall armyworm (Spodoptera frugiperda), which can significantly reduce productivity without proper control methods. Fall armyworm (FAW) is a crop insect pest originally from America, which was later discovered in West Africa in 2016 and appeared in Cambodia in March 2019. It affected 11,142 hectares of maize in four provinces within the following four months. The most affected are smallholder farmers with limited access to information, tools, technologies, and management practices to predict, identify, and manage an infestation of FAW in their fields. Cambodia is not yet prepared to address this pest. The main deficiencies are the absence of a control strategy for FAW, the lack of resources for disseminating knowledge, such as farmer field schools and trainer training, and the lack of research on it. This review aims to identify best practices and deficiencies that Cambodian farmers should consider in controlling FAW infestation. These measures are urgently needed and can be quickly tested and expanded to mitigate the impacts of FAW on maize production. This is accomplished through academic literature from scholarly articles, government regulations, international publications, and credible news about the status of FAW worldwide, in Asian nations, and in Cambodia. When using the push-pull method, the number of larvae per plant is reduced by 82.7% to 86.7%, along with a higher yield. In Cambodia, Metarhizium anisoliae is a fungal biopesticide that effectively controls FAW, while Bacillus thuringiensis and neem oil are not effective. Since the efficacy of biopesticide is longer-term and these products are difficult to access, Cambodian farmers prefer to use synthetic insecticides to suppress FAW. Emamectin benzoate, a chemical compound, is found to be popularly used by farmers in Cambodia for controlling FAW, and its efficacy has been proven to be highly effective. There is a significant concern about the resistance of this synthetic pesticide if farmers are not properly advised. Large-scale agro-advisories can play an essential role in minimizing the incidence of FAW and helping smallholder farmers take timely precautions to reduce potential crop loss. Integrated pest management is the best strategy for managing FAW.

Keywords: *Fall Armyworm, Integrated Pest, Maize Production*

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INTRODUCTION

Maize is extensively cultivated in upland regions with higher rainfall and suitable soil conditions in Cambodia (ACIAR, 2015). After rice and cassava, maize is one of the major crops in Cambodia (Department of Commerce of USA, 2024). Cambodia's Ministry of Agriculture, Forestry, and Fisheries (MAFF) has prioritized maize for increased productivity in the National Policy for Agricultural Development 2022-2030 (MAFF, 2022). The primary export destination for Cambodian maize is Taiwan, followed by South Korea and China (EuroCham Cambodia, 2023). In 2021, maize was planted on 52,000 hectares throughout Cambodia, with the largest area planted in the Tonle Sap Lake Zone, estimated at 38,000 hectares with a total quantity of 230,000 tonnes (NIS, 2021). Maize production in Cambodia is invaded by the emergence of FAW, which can badly reduce productivity if no proper control method are delivered, despite its crucial role in improving the livelihoods of small-scale farmers. Spodoptera frugiperda presents a serious risk to economically significant cereal crops, causing extensive damage (Food and Agriculture Organization, 2020). Its presence contributes to global food insecurity, malnutrition, and poverty among smallholder farmers (Altieri & Trujillo, 1987). If Integrated Pest Management (IPM) is not promoted, the increased use of hazardous pesticides becomes a major issue associated with FAW infestation, posing harm to humans, animals, aquatic life, and environmental health (Noah, 2024). Spodoptera frugiperda or FAW was firstly found in America and becomes endemic in southern and northern parts of this country. According to Siday et al. 2018, this insect pest continued to spread to Africa in 2016. By the end of 2017, it was reported to present in more than 30 countries (Sisay et., 2019). In the Asian region, FAW was first detected in 2018 and arrived in Cambodia in May 2019 in four provinces, impacting 11,142 hectares of maize crops (Tay et al., 2023). Most affected are smallholder farmers who have limited access to information, tools, technologies, and management practices to forecast, recognize, and manage an infestation of FAW in their fields. Once their fields are infested, they do not have the financial means or a management strategy to combat it (FAO, 2020). According to ASEAN, Cambodia is not ready yet to tackle this pest. The main gaps are in the lack of a control strategy for FAW, lack of resources for knowledge dissemination such as farmer field schools and training of trainers, and lack of research about it (ASEAN, 2020). This review aims to identify best practices and gaps that Cambodian farmers should consider in controlling FAW infestation. Urgently needed, these measures can be promptly piloted and scaled up to mitigate the impacts of FAW on maize production.

RESEARCH METHODOLOGY

This review paper summarized academic literature: scholarly articles, government regulations, international publications, and credible news pertaining to the status of Fall armyworm (FAW) worldwide, in Asian nations, and specifically in Cambodia. The process of selection depended on reliable databases to ensure a dependable analysis. After a thorough assessment, 56 studies were selected based on their significance and quality, with a focus on the economic impacts of FAW, its epidemiology, conducive environments, and management approaches.

RESULT AND DISCUSSION

3.1 Preferred crop as the host

FAW is able to feed on a variety of crops, such as sorghum, wheat, sugarcane, millets, cotton, and vegetables, but it shows a strong preference for maize. If the above crops are not available, it can switch to 350 other plant species (Montezano et al. 2018). In addition to causing damage to maize crops, the worm infested 55 hectares of rice in Tboung Khmum province and 50 hectares in Siem Reap of Cambodia. The worm also affected cassava in Kratie, Banteay Meanchey, Oddar Meanchey, Stung Treng, and Preah Vihear provinces (Cambodianess, 2024a). Within the following 5 days, the infestation spread to 12 provinces, impacting 13,000 hectares of crops (Cambodianess, 2024b).

3.2 The importance of maize

The importance of corn on a worldwide scale arises from its critical role as a primary food and cash crop for millions of farmers in developing countries. Corn is also extremely important as animal feed and is extensively grown globally. In Asia, corn plays a crucial role in animal feed, food, and various industries, with a rapidly growing demand in these sectors. Unlike in Africa, most corn production in Asia is focused on animal feed rather than direct consumption (FAO, 2020). Corn, scientifically named Zea Mays, belongs to the Poaceae grass family. Commonly known as maize, it is a highly adaptable tropical grass that thrives in a wide range of climates, with maturation periods varying from 70 to 210 days (ACIAR, 2015). The main corn production area in Cambodia is Battambang province, followed by other provinces such as Kampong Cham, Kampot, Kandal, Banteay Meanchey, and Takeo provinces. The predominant local variety of cash crop is red maize, also known as yellow maize, primarily cultivated for the stockfeed market. Red maize, in particular, has been identified as having significant growth potential in production and profitability for Cambodian farmers (Rauser, 2024). As one of the world's most crucial cereal crops, following rice and cassava, corn is set for continued growth in exports due to the increasing global demand for stock feed (EuroCham Cambodia, 2024). Like other staple crops, maize contains high carbohydrates, fiber, and vitamins. Due to these good nutrients, it has been used as ingredients of many foods. Benefiting from a tropical climate all year round, Cambodian producers can harvest corn twice a year. Corn is one of the key crops aimed for enhanced productivity in the National Policy for Agricultural Development 2022–2030, which was developed by MAFF (2022). MAFF has also been actively promoting corn exports to the world. The Ministry successfully negotiated the shipment of Cambodian corn to China in 2022, making it the country's second agricultural product to be permitted for direct export to China that year. The primary export destination for Cambodian corn is Taiwan, which represented over 85% of total exports in 2022 (USD 0.43 million), followed by South Korea (USD 0.06 million) and China (USD 0.01 million) (EuroCham Cambodia, 2023). Corn was planted on 52,000 hectares throughout Cambodia, with the Tonle Sap Lake Zone having an estimated 38,000 hectares of corn planted, making it the leading zone in terms of area planted. The average production per harvested hectare of corn was estimated at 5,000 kilograms, with the total quantity harvested in Cambodia estimated at 230,000 tonnes (NIS, 2021).

3.3 Strains of the insect

In 2007, Nagoshi et al. discovered the rice strain and corn strain, two variants of FAW. While the corn strain favors feeding on maize, cotton, and sorghum, the rice strain mostly eats rice and other types of grass found in pastures (CABI, 2020). These strains are distinguishable at the molecular level despite having comparable morphological traits. The genetic diversity of the FAW population in Africa is higher than that of the American population, which comprises both strains (Jacobs et al., 2018).

3.4 Epidemiology

The FAW moth can migrate up to 250 km per night (Jia et al., 2021) and can lay as many as 1500 eggs. Under Cambodian conditions, a single generation's life cycle ranges from 30 to 50 days (Delatouche, 2024). One possible explanation for the fast migration rate of FAW is air movement associated with weather fronts (Sparks, 1979). FAW is a major insect pest in tropical portions of the Americas, having originated in tropical and subtropical regions of the continent. After being first documented in West Africa at the end of 2016, it quickly expanded to forty-four countries in Sub-Saharan Africa (Sisay et al., 2019). It is thought that cargo containers, airline holds, or commercial aircraft carried FAW strains from the Americas to Africa, where they were further dispersed by wind. Numerous Asian nations have also been linked to FAW (Day et al., 2018). In May 2019, reports of it were made in Nepal after it was initially reported in India in 2018. By December 2018, FAW had been confirmed in Bangladesh, Sri Lanka, and Thailand. The pest has since been confirmed in several other Asian countries, including Myanmar, China, Indonesia, the Philippines, Laos, Malaysia, Vietnam, South Korea, Japan, and Yemen (CABI, 2020). FAW was first detected in Cambodia in March 2019. By May 2019, Spodoptera frugiperda were found in four provinces, affecting a total of 11,142 ha of maize crop (Tay et al., 2023). Between January and March 2020, FAW reached Mauritania, Timor-Leste, and Australia (FAO, 2020). The genetic diversity and insecticide resistance profiles of S. frugiperda populations in Cambodia are currently unknown. Its proposed population origin is assumed to be from western Africa due to a founder event (Day et al., 2019), although a spread involving human-assisted international trade and tourism activities has also been proposed (Early et al., 2019). According to Tay et al., (2023), Cambodia has limited understanding and a lack of scientific research on the impact, pest genomics, and potential options for managing the fall armyworm S. frugiperda.

3.5 Economic impacts of the FAW

For crops, the larval stage of FAW is especially harmful. Depending on the stage of the plant's growth, FAW larvae can be found on different areas of infected maize plants, including young leaves, leaf whorls, tassels, and cob (Goergen et al., 2016). Pest population, timing, presence of diseases and natural enemies, plant moisture and nutrition condition, and other factors all affect how much a crop is infested by pests (CABI, 2019). In 12 African nations that produce maize, FAW may result in annual losses in maize output of 8.3 to 20.6 million tons, or USD 2.5 to USD 6.2 billion, potentially impacting 40.8 million to 101 million people, according to CABI's 2017 estimate. According to Buadron et al. (2019), there is an 11.57% yield drop in maize for pest incidences ranging from 26.4% to 55.9%. According to Chimweta et al. (2019), damage affecting 25–50% of the leaf, silk, and tassel results in a 58% drop in output, but damage affecting 55–100% of the leaf, silk, and tassel at the mid–to late whorl stage might result in a 73% yield loss. Food security, as well as the lives of millions of smallholder farmers and consumers worldwide, are threatened by FAW, which results in significant yield losses in maize and other major cereal crops. According to estimates, FAW impacted 170,000 hectares of maize crops in ten states in India (Sangomla & Kukreti, 2019). This insect mostly affects 80,000 hectares of land in the Yunnan province of China, harming crops like maize, sorghum, sugarcane, and ginger (Gu & Woo, 2019). In China, 111,992 hectares have been damaged, with maize covering 98.6% of the total area (FAO, 2019). Comparably, it was stated that this worm invaded nearly 10,000 hectares of land in Indonesia, 16,200 ha of land in Myanmar, and 46,000 ha of land in Vietnam. According to FAW, Thailand will have a yield loss of 25–40%, translating into a loss of 130–260 million dollars (FAO, 2020). With the risk of secondary pest outbreaks, resistance development in both target pests and non-target species, and management costs associated with pesticide applications—some of which may not be effective—all taken into account, the direct yield loss caused by larval feeding and indirect costs in the ASEAN region were estimated to be US$884 million. Four months after the pest first appeared in Cambodia in March 2019, four districts in the country suffered losses of around $4 million in US dollars due to damage to more than 10,000 hectares of maize (Cambodia News English, 2019).

3.6 Favorable environment for the pest

Climatic conditions can influence the distribution of FAW. Environmental factors such as temperature, rainfall, and humidity significantly impact the growth, abundance, survival, and mortality of these pests (Ramirez et al., 2017). FAW exhibits significant outbreaks following rainfall and humid circumstances and is most active in cool, wet weather (Westbrook & Sparks, 1986). A growing season that is warm, muggy, and with lots of rainfall is ideal for their survival and procreation. The development of fall armyworms ceases below 10 degrees Celsius. Effective reproduction is more common in tropical and subtropical locations, where fall armyworms are known to reproduce every ten years, as opposed to barely two in temperate zones (Assefa & Ayalew, 2019). Warmer temperatures can accelerate the development of fall armyworms and increase the likelihood of multiple generations (Westbrook & Sparks, 1986). Different temperatures are required at various stages to complete the life cycle of fall armyworms. In soils with sandy clay or clay sand, the minimum temperature required for pupation and adult emergence is 10.9 degrees Celsius (CABI, 2019). At temperatures between 21 and 27 degrees Celsius, eggs normally hatch in two to four days (Assefa & Ayalew, 2019). A temperature of 28 degrees Celsius is ideal for larval growth, while pupation needs a lower threshold temperature of 14.6 degrees Celsius. When the temperature rises above thirty degrees Celsius, the pest's wings get distorted (CABI, 2019).

3.7 Symptoms of pest damage in maize

The signs of FAW infestation in maize become apparent once the eggs have hatched. FAW typically causes irregularly shaped holes with ragged edges on the leaves, which can become loose and detach from the plants. Because of their ravenous eating habits, larvae from severe infestations can leave behind an excessive amount of fecal matter, resulting in widespread defoliation. This may eventually cause the crops to stop growing and developing, which would prevent the creation of cobs or tassels (Reddy, 2019). The first and second instar infestations are characterized by translucent patches that resemble windowpanes, whereas the third to sixth instars are characterized by bigger, elongated holes. In the maize funnel or on the leaves, the FAW fecal matter eventually takes on the appearance of sawdust (CABI, 2018). During the vegetative phase of maize, continuous feeding leads to skeletonized leaves and heavily windowed whorls filled with larval frass. As the maize enters the reproductive and maturity stages, the larvae also feed on the tassels, burrow into the cobs, and feed on the kernels, potentially causing a complete loss of maize stands (FAO, 2020).

3.8 Lifecycle of the insect

Insect life cycles can be categorized into four groups: egg, larvae, pupae, and adults. The FAW can be distinguished by its physical characteristics, specific damage signs on vulnerable plants, or genetic features (FAO and CABI, 2019). In Latin America, the life cycle of the FAW (FAO, 2017) lasts for approximately 30 days (at an average daily temperature of ~28°C) during the hot summer months. However, in cooler temperatures, it may take 60–90 days to complete.

Egg: The 0.4 mm in diameter and 0.3 mm in length fall armyworm eggs are shaped like a dome with a flattened base (Prasanna et al., 2018). The eggs of the autumn armyworm have reticulate ribs coated with abdominal hairs and are creamy white, according to Bajracharya and Bhat (2019). On the upper and lower surfaces of the leaves, the stalk, and the tassel of the maize plant, the female deposits 100–200 eggs at a time in clusters (Prasanna et al., 2018) (CABI, 2018b). The egg stage only lasts for 2 to 3 days in warm conditions (FAO, 2020).

Larvae: First and second stages of development see the freshly emerged caterpillars as green; third and sixth stages see them turn brown or black (CABI, 2018b). When the larva is fully grown, it has four dark elevated spots that create a square (CABI, 2018b), a rough or granular epidermal texture, and a white inverted "Y" shape on its front (Prasanna et al., 2018). There is evidence of a burrowing behavior in the freshly born larvae (CABI, 2017c). The head capsules of the first through sixth instars are 0.35, 0.45, 0.75, 1.3, 2.0, and 2.6 mm wide, according to Capinera's (2000) documentation, while the body lengths are roughly 1.7, 3.5, 6.4, 10.0, 17.2, and 34.2 mm. The larval stage can last for 14–3 to days, depending on the prevailing temperature, ranging from warm to cooler conditions (FAO, 2020).

Fig. 1. Larvae of FAW (Bajracharya and Bhat, 2019

Pupa: Pupae are reddish-brown, egg-shaped, and produce a 20–30 mm long cocoon that is normally buried 2–8 cm deep in the ground (CABI, 2018b). Pupae typically measure 15 mm in length and are found in earth cocoons with a diameter of 20–30 mm, according to Silva et al. (2017). The larva goes through pupation in the soil at a depth of 2 to 8 cm. It builds a loosely woven cocoon by binding soil particles together with silk. Pupation may also occur if the larva encounters debris but no soil. The pupal stage lasts for 8 to 9 days, after which an adult moth emerges (FAO, 2020).

Adult: The adult FAW people behave in a nocturnal manner (CABI, 2017b). The adult moth's wingspan is between 32 and 40 mm, and it comes in a variety of colors. According to Assef and Ayalew (2019), the forewings of male moths are gray and brown in color, with triangular white markings toward the middle of the wing and at its tip that are absent in female moths. These moths migrate, and they are able to traverse great distances (CABI, 2018m). Following a preoviposition period of 3 to 4 days, the female moth typically lays most of her eggs within the first 4 to 5 days of life. However, some egg-laying continues for up to 3 weeks. The adult moths have a lifespan of about 10 days, with a range of approximately 7–21 days (FAO, 2020).

Fig. 2. Adult female FAW

Fig. 3. Adult male FAW (Ibrahim and Jimma, 2018)

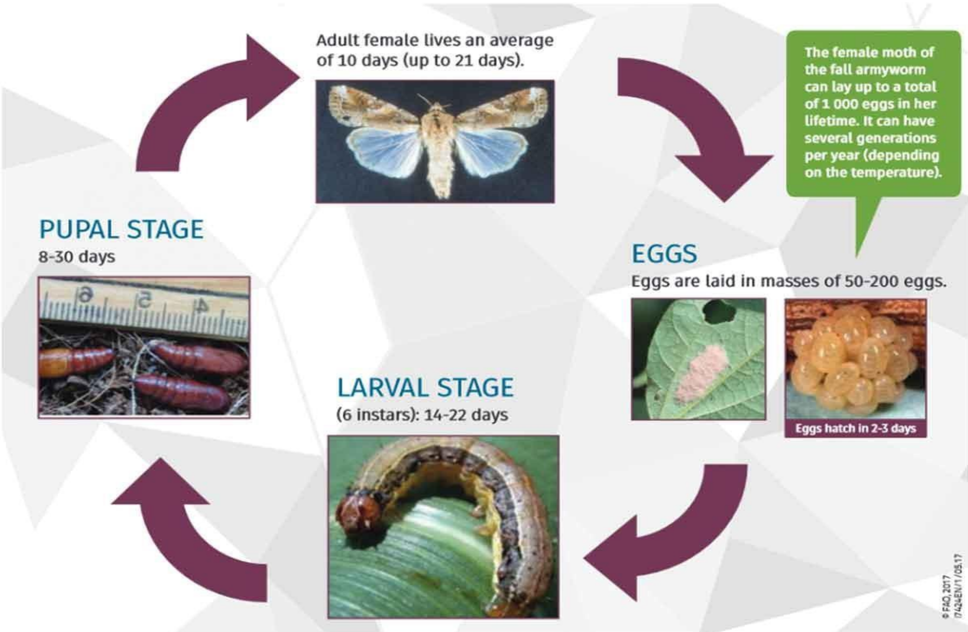

Fig. 4. The lifecycle of FAW (FAO, 2017)

3.9 Integrated Management of FAW

Agroecological methods can work alongside plant breeding and biological control options and may also be compatible with the careful use of safe chemical pesticides. However, most used chemical pesticides are broad spectrum and kill natural enemies, potentially undermining agroecological approaches (Meagher et al., 2016; Perfecto, 1990; van Huis, 1981; Witmer et al., 2003). It is crucial to detect FAW before they cause economic damage. According to Fernandez (2002), management techniques in maize should only be applied when fall armyworm infestation affects 20% of whorls of tiny plants (during the first 30 days) or 5% of seedlings are chopped. According to Assefa and Ayalew (2019), controlling the pest is most successful when done during the larval stage of FAW. The time of management activities—morning, afternoon, or evening—is also crucial.

a. Advisory Services

A combination of public and private sector communication approaches are needed to effectively disseminate the information and promote the control strategies (Day et al., 2017). This initial step is crucial for effectively managing FAW. While it is attractive for farmers to receive handouts for large purchases of pesticides from their governments, this approach is not always a sustainable response. Recognizing the significance of the threat posed by FAW, several African countries (and similarly in recently affected Asian countries) have already begun programs, but primarily by providing pesticides to farmers. These expensive emergency responses are mostly not economic, lead to the development of resistance, have long-term risks to humans and the environment, and are ultimately not sustainable. The Government of Zambia, for instance, allocated USD 3 million to smallholder maize farmers in 2017 for pesticides, including provision for replanting 90,000 affected hectares. Similarly, the Government of Ghana provided USD 4 million as an emergency measure to procure plant protection products. The Government of Rwanda mobilized the armed forces to engage in mechanical control, crushing egg masses and treating infested fields. (FAO, 2020). Countries in Asia, such as China, Bangladesh, Indonesia, Japan, Myanmar, and Sri Lanka, are employing this strategy to increase awareness about controlling destructive pests (FAO, 2019). Additionally, the FAW Program was initiated by the Philippine government as part of efforts to contain the FAW outbreak (Tay et al., 2023).

b. Physical and mechanical method

Firake (2019) stated that one method of controlling fall armyworms is to manually remove and destroy egg masses and young larvae by crushing them or immersing them in kerosene water. Another control measure involves applying dry sand into the center of affected maize plants soon after the infestation is observed. Since the number of fall armyworm eggs or caterpillars is usually low, manually picking and crushing them can be a practical approach for small gardens or a few affected plants. Mechanical management control has achieved a 54% success rate in pest control (Assefa, 2018). To control fall armyworm infestations, it is recommended to place pheromone traps at a rate of 5 traps per acre in the potential spreading areas during the crop season and off-season. FAO (2017) states that because scaling is an easy procedure, pheromone traps that draw male armyworm moths are advised. The most effective trap for capturing FAW moths is the standard bucket trap with a green canopy, yellow funnel, and white bucket (Meagher, 2001; Hardke et al., 2015). CABI recommends tillage of approximately 10 cm to reduce the survival of pupae for maize growers in Myanmar, and this practice is also observed in Vietnam. In Vietnam, flooding crop fields for 2-3 days has been used to eliminate pupae (Nguyen, 2022).

c. Cultural method

Using different cultural practices could lessen the harm that FAW does to crops. Proper fertilization, utilizing legume crops and fertilizer trees, organic manure, and inorganic fertilizers, is highly effective in controlling FAW (Altieri & Nicholls, 2003). Firake (2019) discovered that managing FAW infestations can be accomplished by growing maize alongside legume crops. Similarly, reducing ear damage caused by FAW and other insects can be achieved by cultivating cleanly, applying fertilizers sparingly, and planting hybrid maize plants with firmly closed husks. According to Kumela et al. (2019), smallholder farmers in Ethiopia and Kenya have been using a dry mixture of sand and trichlorfon, which is applied to the whorls in the form of granules or powder. According to Van Huis (1981), using sawdust combined with chlorpyrifos has resulted in a 20% decrease in pesticide consumption. Prasanna et al. (2018) also reported that early planting and the use of early maturing varieties effectively manage FAW. Although it takes more time and money, the "Push-Pull" companion cropping strategy has demonstrated promise in halting the spread of FAW (Pradhan et al., 2019). When push-pull corn is used, research has demonstrated a reduction of 82.7% in the average number of larvae per plant and an 86.7% reduction in plant damage per plot. Additionally, the yield of maize grain is 2.7 times higher than when maize is cultivated as a solitary crop (Midega et al., 2018). The removal of eggs, larvae, pupae, and adult FAW left in the field can be facilitated by early crop planting, intercropping maize with non-host plants like sunflower and bean (FAO, 2018), crop rotation, varietal selection, proper soil preparation, frequent field monitoring, and burning of crop residues (Assefa, 2018). Regular weeding greatly minimizes FAW damage because the main hosts are graminaceous weeds, which are frequently seen in maize fields. In established maize plots with limited or zero tillage, where natural enemies are present in higher densities, insect damage was similarly noticeably low (Buadron et al., 2019). According to Kumela et al. (2019), 39% of Kenyan farmers handle FAW by using cultural control techniques include applying tobacco extract to injured plants and adding soil to the plant whorl. According to a survey, 56% of pest management is done via cultural techniques (Assefa & Ayalew, 2019). In Laos, it is customary to intercrop maize fields with other food crops such ground beans, cassava, and pumpkin. agricultural rotations and modifications to agricultural cultural practices are two of the current FAW management methods available in Vietnam (Tay et al., 2023). Cultural approaches are safe, affordable, and don't produce any unfavorable aftereffects on the environment, food, or human health. However, compared to other management techniques, they typically call for long-term planning and have a lower pest control percentage.

d. Biocontrol method

Certain biological control agents efficiently manage the fall armyworm (FAW). Numerous natural enemies have risen as a result of habitat management, in-situ protection of natural enemies through planting pulses and attractive blooming plants, and enhanced plant variety (Firake, 2019). Increasing diversity through crop rotation and agroforestry in the farm environment can promote living space for natural enemies and reduce pest build-up by limiting available habitats for each pest (Andow, 1991). To effectively control FAW, Bacillus thuringiensis var kurstaki formulations at 2g/liter or 400g/acre can be applied while applying Metarhizium anisopliae talc formulation at 5g/liter on whorl 15-25 days after sowing is beneficial. Furthermore, 1-2 sprays spaced ten days apart, contingent on the extent of pest damage, have demonstrated efficacy in containing the spread of pest infection. The study of Rausser (2024) in Battambang of Cambodia also proved that Metarrhizium anisoliae is effective to reduce larval damage on plants. According to FAO (2018), biopesticides—fumi (e.g., Beauveria bassiana), bacteria (e.g., Bacillus thuringiensis, Bt), and Baculoviruses—are an efficient way to manage FAW. Crop leaf defoliation is also decreased by these biotic agents (Molina et al., 2003). According to Pilkington et al. (2010), managing FAW can be accomplished by the effective employment of a variety of microbial diseases and arthropod bio-control agents. Globally, 53 parasite species from forty-three genera and 10 families effectively control FAW (Ashley, 1979; Sparks, 1986; Assefa, 2018). Aktuse et al. (2019) revealed a 30% mortality of second-instar larvae by the Beauveria isolates and 87% and 96.5% mortality of egg and neonate larvae by Metarhizium isolates. Numerous Noctuidae family lepidopteran insects are readily under the control of numerous natural enemies.

As prospective biological control agents for a variety of insect pests, Tefera et al. (2019) have suggested these natural enemies. It's been discovered that the larval parasitoid Cotesia icipe in Ethiopia and the effective Plaexorista zonata in Kenya are responsible for suppressing fall armyworm infestation (Sisay et al., 2018). For FAW management, a variety of parasitoid species from the Trichogramma and Telenomus families that are simple to raise in a lab are frequently employed (Tefera, 2019). (Gutierrez-Martinez et al., 2012). Biological control agents for foot and mouth disease (FAO, 2018) have been identified as Telenomus Remus, Chelonus insular, Cotesia marginiventris, Trichogramma apps, Archytas, Winthemia and Lespesia, earwigs, Ladybird beetles, Assassin, and flower bugs such as Zelus, Podisus, Nabis, Geocoris, Orius, and Anthocoris, as well as ants, birds, and bats. In Cambodia, initial trials of using Beauveria bassiana to infect FAW larvae is unsuccessful (Sathya et al., 2022) and also confirmed by Rauser 2024. Bt was suggested for the integrated pest management (IPM) solution for early FAW management in maize fields in Malaysia, Vietnam, and Laos, although with limited success in Laos (Soysouvanh and Phathanivog 2021). Using natural enemies is advantageous as it does not lead to pest resistance, is safe to use with no adverse effects on humans and the environment, poses no danger to non-target pests, and is a cost-effective pest management method in the long run. However, the initial management cost is usually high, the process is slow, and the effectiveness percentage is lower than that of chemical methods.

e. Botanical method

Worldwide, local resources and botanical methods—such as soil, sand, wood ash, lime, oils, and soaps—as well as plant extracts are used to manage FAW (Hruska, 2019).

According to Souza et al. (2010), plant oils derived from Eucalyptus urograndis, Corymbia citriodora, and Eucalyptus urograndis successfully protected maize plants against FAW larvae. In lab settings, neem seed powder has been shown to eradicate more than 70% of FAW larvae (Maredia, 1992). Use of Carica papaya aqueous seed extract has been shown to significantly reduce FAW larval mortality, similar to the effects of malathion (Figueroa-Brito et al., 2013). Similar to this, FAW larvae in their first and second instar are considerably managed by plant oils derived from neem, palmarosa, clove, and turmeric (Barbosa et al., 2018). A number of plant extracts, including those from Azadirachta indica, Millettia ferruginea, Croton macrostachyus, Phytolacca dicentra, Jatropha curcas, Nicotiana tabacum, and Chrysanthemum cinerariifolium, have been successfully used to suppress FAW, according to reports from Jirnmci (2013) and Schmutterer (1985). The ethanolic extracts of Argemone ochroleuca (Martinez et al., 2017) and seed cake extracts of Azadirachta indica (Silva et al., 2015) cause a significant death rate of FAW larvae because they consume less food, which slows their growth. By encouraging the growth of select pesticidal plants and having less of an effect on non-target creatures, botanical pesticides can be effective while using fewer synthetic insecticides (Rioba et al., 2020).

The effectiveness of Chenopodium ambrosioides and Ageratum conyzoides (Rioba & Stevenson, 2017) against FAW has been assessed (Sisay et al., 2019). The following plants have insecticidal properties against FAW: extracts of castor plant, Carica papaya (Figueoroa et al., 2002), Ruta graveolens, Petiveria alliacea, Zingiber officinale, Bacharis genistelloides, Artemisia verlotiorum (Tagliari et al., 2010), and Moringa (Rioba et al., 2020). In contact toxicity tests, Nicotiana tobacco and Lippia javanica showed the highest larval mortality of 66%, while in a feeding bioassay, L. javanica and N. tabacum showed the highest larval mortality of 62% and 60%, respectively, at a concentration of 10%. The most successful feeding deterrents were discovered to be Cymbopogon citratus and Azadirachta indica, with 36 percent and 20 percent, respectively (Phambala et al., 2020). In Laos, the use of botanical extracts was accompanied by the simultaneous release of beneficial/predatorial insects such as stink bugs and the manual removal of FAW caterpillars. In Vietnam, Neem application was combined with food spray (rice flour) to attract beneficial insects. In Cambodia, the use of neem oil to manage FAW was found to be ineffective by CARDI. Field surveys in various provinces have been conducted to assess damage levels and pest incidences, with attempts to manage this pest using neem oil proving unsuccessful (Sathya et al., 2022), similar to the result conducted by Rauser, 2024 in Battambang. The advantage of the botanical method lies in its local availability, cost-effectiveness, safety, and environmental friendliness. However, compared to chemical approaches, the percentage of pests controlled by the botanical method is lower.

f. Chemical method

Timing is crucial when applying chemicals to control the FAW. One must understand the life cycle and when to apply pesticides. Spraying is ineffective when the larvae are deeply hidden inside the maize plants and during the daytime, as the larvae only come out to feed at night or during dawn and dusk (Day et al., 2017). Various chemicals, including Methomyl, Pyrethroids, Cyfluthrin, an organophosphate insecticide, and methyl parathion, have been recommended for controlling FAW (Tumma & Chandrika, 2018). Foliar sprays against FAW in soya have become unnecessary due to the application of cyantraniliprole and chlorantraniliprole as seed treatments (Thrash et al., 2013). According to Van Huis (1981), a treatment consisting of a mixture of sawdust and chlorpyrifos produced a 20% control. To manage the fall armyworm, several chemicals have been used extensively in Africa, including beta cypermethrin, emamectin benzoate, carbosulfan, and cartap hydrochloride. It is also advised to apply beta cypermethrin, cartap hydrochloride, and emamectin benzoate on vegetables (IRAC et al., 2018). Using Spinosad and the novel insecticides Chlorantraniliprole, flubendiamide, and spinetoram, Cruz et al. (2012) and Bhusal & Bhattarai (2019) observed over 90% larval mortality, which performed better than the conventional insecticides lambda-cyhalothrin and novaluron (Hardke et al., 2015). While the chemical method offers a higher success rate when the proper concentration and quantity are applied, it also has side effects that harm human health and the environment (Lewis et al., 2016).

Additionally, it hurts beneficial insects (Halley et al., 1996). Furthermore, the molecular characterization of the fall armyworm genome at the population level across different invasive populations from Australia and Asia revealed the widespread presence of resistance alleles to carbamate/organophosphate pesticides (Tay et al., 2023). The development of resistance to insecticides in the fall armyworm is a valid concern, as native populations of fall armyworm in the Americas are known to be resistant to various insecticidal compounds (Carvalho et al., 2013), and resistance alleles to pyrethroids (Zhang et al., 2020), organophosphates (Guan et al., 2021; Bauventura et al., 2020a; Tay et al., 2022b), and diamides (Lv et al 2021) have been detected in various invasive populations. In Cambodia, farmers relied most heavily on input sellers for advice on weed, insect pests, and disease management, resulting in over-reliance on chemical pesticides. However, some of these suppliers lack professional knowledge of agronomy. This raises concerns about the potential for inaccurate information and the development of future resistance (ASR, 2024).

3.10 Barriers to effectively control the FAW in Cambodia

It has been understood that through the review, in most Asian countries and in Cambodia, the continuous spread of FAW is aided by several critical deficiencies as below:

- Key stakeholders lack adequate coordination, which hinders effective management.
- There is a shortage of effective pest monitoring and early warning systems.
- Knowledge of sustainable FAW management is either lacking or inadequate.
- Phytosanitary measures are either poor or inadequately implemented.
- Agricultural extension and farmer communication systems are either poor or lacking.

- Both scientific researchers and farmers in Cambodia have a limited understanding of the new exotic lepidopteran pest.
- The severity of pest infestation and maize crop damage varies between different districts and provinces.
- There is currently a lack of national coordination regarding the use of chemical insecticides for managing S. frugiperda in Cambodia.
- Biopesticide production is not available in Cambodia, and only a few companies import these products from other countries. This increases the cost for farmers, who are reluctant to invest in them. Furthermore, these biopesticides are difficult for farmers to find in rural areas.
- Local legislation related to sharing biological material, including non-native invasive species, poses challenges and hinders efforts that could negatively impact local farmers' ability to manage the pest and their livelihood (FAO, 2022; Tay et al., 2023; Rauser, 2024).

CONCLUSION

Maize production in Cambodia is under a potential threat by FAW. Although there are many scientific findings that prove the efficacy of some bioproducts and synthetic pesticides in other countries, data to confirm the effectiveness is not much in Cambodia, while initiating new research on this topic is also limited. This leads to the non-existence of adequate FAW strategies for farmers to deal with this invasive pest. Since there are no biopesticide and synthetic production companies in Cambodia, these products need to be imported from other countries, such as Thailand, Vietnam, Korea, and China, with added value to the cost. Since the efficacy of biopesticide is longer-term and these products are difficult to access, Cambodian farmers prefer to use synthetic insecticides to suppress FAW. An awareness program regarding pest identification, damage symptoms, and control measures can significantly reduce the incidence of the pest. It is urgent to sensitize smallholder farmers in Cambodia against FAW and provide them with the necessary resources and methods for effective management. Collective action is recommended for managing the fall armyworm, focusing on the challenges smallholder farmers face with limited access to information and resources. Short-term research is needed to validate additional management practices rapidly.

Communication and training campaigns must be scaled up to educate farmers and decision-makers about FAW biology, ecology, and effective management strategies. Assessing suitable crop varieties that can tolerate FAW needs to be initiated. National policies should promote lower-risk control options through short-term subsidies and rapid assessment of bio-pesticides and biological control products. Field trials should be embedded into upscaling programs to fine-tune interventions, requiring a comprehensive understanding of cost/benefit ratios across various contexts. Determining which FAW strains are present in an area and which pose a threat to crops is crucial. Research on smallholders' pest management strategies, effective communication of evidence-based pest control advice, and establishing market chains to support agroecological approaches are essential. Integrated Pest Management (IPM) would be a sustainable means of controlling FAW, emphasizing chemical pesticides as a last resort when other control measures are ineffective. Additional FAW migration patterns, flight behavior, ecology, and pest management studies are urgently required. Better research on IPM options for managing Spodoptera frugiperda in Cambodia is essential. It is imperative to conduct different pest control methods and assess their effectiveness in decreasing environmental contamination from pesticides seeping into soils and water systems.

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REFERENCES

Akutse, K.S., Kimemia, J.W., Ekesi, S., Khamis, F.M., Ombura, O.L., Subramanian, S. (2019). Ovicidal effects of entomopathogenic fungal isolates on the invasive Fall armyworm Spodoptera frugiperda (Lepidoptera: Noctuidae). *Journal of Applied Entomology*, 143(6), 626-634.

Agricultural System Research. (2024). *Strengthening the climate resilience of smallholder farmers: baseline survey in Battambang*.

Altieri, M.A., Trujillo, J. (1987). The agroecology of corn production in Tlaxcala, Mexico. *Hum. Ecol*. 15, 189–220.

Altieri, M.A., Nicholls, C.I (2003). Soil fertility management and insect pests: harmonizing soil and plant health in agroecosystems. *Soil Tillage Res*. 72, 203–211. https://doi.org/10.1016/S0167-1987(03)00089-8.

Andow, D.A. (1991). Yield loss to arthropods in vegetationally diverse agroecosystems. *Environ. Entomol.* 20, 1228–1235. https://doi.org/10.1093/ee/20.5.1228.

Ashley, T.R. (1979). Classification and distribution of fall armyworm parasites. *Florida Entomologist*, 114-123.

The association of Southeast Asian nations. (2020). *Asian action plan on fall armyworm-Final version-20 May, 2020*.

Assefa, F. (2018). Status of Fall Armyworm (Spodoptera frugiperda), Biology and Control Measures on Maize Crop in Ethiopia: A Review. *International Journal of Entomological Research*, 6(2), 75-85.

Assefa, F., Ayalew, D. (2019). Status and control measures of fall armyworm (Spodoptera frugiperda) infestations in maize fields in Ethiopia: A review. *Cogent Food & Agriculture*, 5(1), 1641902.

Australia Centre for International Agricultural Research. (2015). *Maize production guide for Cambodian* conditions.https://www.aciar.gov.au/sites/default/files/legacy/maize_167_lr.pdf

Bajracharya, A.R., Bhat, B. (2019). *The first record of Fall Armyworm Spodoptera frugiperda in Nepal. Khumaltar,Nepal, 2019* NARC http://narc.gov.np/the-first-record-of-fall-armyworm-spodoptera-frugiperdain-nepal/

Barbosa, M.S., Dias, B.B., Guerra, M.S., Haralampidou da Costa Vieira, G., (2018). Applying plant oils to control fall armyworm (Spodoptera frugiperda) in corn. *Australian Journal Crop Science* 12(04):557–62.

Baudron, F., Zaman-Allah, M.A., Chaipa, I., Chari, N., Chinwada, P. (2019). Understanding the factors influencing fall armyworm (Spodoptera frugiperda JE Smith) damage in African smallholder maize fields and quantifying its impact on yield. A case study in Eastern Zimbabwe. *Crop Protection*, 120, 141-150.

Bhusal, K., Bhattarai, K. (2019). A review on fall armyworm (Spodoptera frugiperda) and its possible management options in Nepal. *Journal of Entomology and Zoology Studies*, 7(4), 1289-1292

CABI. (2017b). *Fall Armyworm Status Impacts and control options in Africa: Preliminary Evidence Note (April 2017)* P. Abrahams, T. Beale, M. Cock, N. Corniani, R.Day*, J.Godwin, S. Murphy, G. Richards & J. Vos. Retrived from: https://www.cabi.org/ISC/abstract/20187200430

CABI. (2017c). *Spodoptera frugiperda (fall armyworm) invasive species compendium.* Retrieved from: http://www.cabi.org/isc/datasheet/29810

CABI. (2018). *Crop Protection Compendium*. Retrived from: https://www.cabi.org/cpc/

CABI. (2019).*Fall armyworm Technical Brief with reference to Maize production in Uganda*. Retrived from: https://www.cabi.org/ISC/FullTextPDF/2018/20187200504

CABI. (2020). Spodoptera frugiperda (fall armyworm). *Invasive Species Compendium*. Retrived from:https://www.cabi.org/isc/datasheet/29810

Chimweta, M., Nyakudya, I.W., Jimu, L., Bray Mashingaidze, A. (2019). Fall armyworm [Spodoptera frugiperda (JE Smith)] damage in maize: management options for flood-recession cropping smallholder farmers. *International Journal of Pest Management*, 1-13.

Day, R., Abrahams, P., Bateman, M., Beale, T., Clottey, V., Cock, M., Gomez, J. (2017). Fall armyworm: impacts and implications for Africa. *Outlooks on Pest Management*, 28(5), 196-201.

Department of Commerce. (2024). *Cambodia country commercial guide.* https://www.trade.gov/country-commercial-guides/cambodia-agriculture

Early R, Gonzalez-Moreno P, Murphy ST, Day R. (2018) Forecasting the global extent of invasion of the cereal pest Spodoptera frugiperda, the fall armyworm. *NeoBiota* 40: 25–50.

EuroCham Cambodia. (2023). *Products and supply brochure*—https: www.eurocham-cambodia.org/uploads/d0986-sourcing-from-cambodia-maize-2023.pdf

Fall Armyworm Spreads to 12 Provinces. (2024, June 21). *Cambodianess*. https://cambodianess.com/article/fall-armyworm-spreads-to-12-provinces

Fall armyworm destroys rice fields. (2024, June 19). *Cambodianess*. https://cambodianess.com/article/fall-armyworm-destroys-rice-fields#:~:text=GDA%20said%20that%20the%20fall,is%20approaching %2C%E2%80%9D% 20it% 20 said.

FAO, CABI. (2019). *Community-Based Fall Armyworm (Spodoptera frugiperda) Monitoring, Early warning and Management, Training of Trainers Manual, First Edition*. 112. Retrived from http://www.fao.org/3/CA2924EN/ca2924en

FAO. (2017). *FAO Advisory Note on Fall Armyworm (FAW) in Africa. Food and agriculture Organization of the United Nations*, 7

FAO. (2018). *Integrated management of the Fall Armyworm on maize: A guide for Farmer Field Schools in Africa*.

Retrived frm http://www.fao.org/family-farming/detail/en/c/1112643/

FAO. (2019). *Regional Workshop for Asia Sustainable Management of Fall Armyworm*. Retrived from: http://www.fao.org/3/ca7615en/ca7615en

FAO. (2017). *Fall armyworm life cycle (in Latin America)*. http://www.fao.org/3/a-i7424e.pdf.

FAO (2020). *The global action for fall armyworm control. Action framework (2020-2022).*

Fernández, J.L. (2002). Nota corta: Estimación de umbrales económicos para Spodoptera frugiperda (JE Smith)(Lepidoptera: Noctuidae) en el cultivo del maíz. Invest. *Agric. Prod. Prot*. Veg, 17, 467-474.

Figueroa, R., Camino, M., Pérez-Amador, M.C., Muñoz, V., Bratoeff, E., Labastida, C. (2002). Fatty acid composition and toxic activity of the acetonic extract of Carica papaya L. (Caricaceae) seeds (with 2 tables).*Phyton*, 97-99.

Firake, D.M., Behere, G.T., Babu, S., Prakash, N. (2019). Fall Armyworm: Diagnosis and Management (Anextension pocket book). ICAR Research Complex for NEH Region, Umiam-793 103, Meghalaya, India. 48

Goergen, G., Kumar, P.L., Sankung, S.B., Togola, A., Tamo, M. (2016). First report of outbreaks of the fallarmyworm Spodoptera frugiperda (JE Smith)(Lepidoptera, Noctuidae), a new alien invasive pest in West

and Central Africa. *PloS One*, 11(10).

Guan F, Zhang J, Shen H, Wang X, Padovan A, Walsh TK, Tay WT, et al. (2021) Whole-genome sequencing to detect mutations associated with resistance to insecticides and Bt proteins in Spodoptera frugiperda. *Insect Sci*. 28: 627–638

Gu, H., Woo, R. (2019).*Crop invaders: China's small farmers struggle to defeat armyworm. Environment*. Retrived from: https://www.reuters.com/article/us-crops-armyworm-china-idUSKCN1UZ0LL

Gutierrez-Martinez, A., Tolon-Becerra, A., Lastra-Bravo, X.B. (2012). Biological control of spodoptera frugiperda eggs using Telenomus remus Nixon in maize-bean-squash polyculture. American Journal of Agricultural and*Biological Sciences*, 7(3), 285-292.

Halley, J.M., Thomas, C.F.G., Jepson, P.C. (1996). A model for the spatial dynamics of linyphiid spiders in farmland. J. Appl. *Ecol*. 33, 471–492.

New pest destroys thousands of hectares of crops (2019, June 14). *Cambodia news English.* https://cne.wtf/2019 /06/14/new-pest-destroys-thousands-of-hectares-of-crops/

Hardke, J.T., Lorenz III, G.M., Leonard, B.R. (2015). Fall armyworm (Lepidoptera: Noctuidae) ecology in southeastern cotton. *Journal of Integrated Pest Management*, 6(1), 10.

Hruska, A.J., Gould, F. (1997). Fall armyworm (Lepidoptera: Noctuidae) and Diatraea lineolata (Lepidoptera: Pyralidae): Impact of larval population level and temporal occurrence on maize yield in Nicaragua. *Journal of Economic Entomology*, 90(2), 611–622.

IRAC South Africa. (2018). *Integrated Pest Management (IPM) & Insect Resistance Management (IRM) for Fall Armyworm in South African Maize*. Retrieved from: https://www.irac-online.org/documents/ipm-irm-for- fall-armyworm-in-s-african-maize/

Jacobs, A., van Vuuren, A., Rong, I.H. (2018). Characterisation of the fall armyworm (Spodoptera frugiperda JE Smith) (Lepidoptera: Noctuidae) from South Africa. *African Entomology*, 26(1), 45-49.

Jia, Z.Q., Zhan, E., Zhang, S., Jones, A., Zhu, L., Wang, Y.N, Huang, Q.T., Han, Z.J., & Zhao, C.Q. (2022). Sublethal doses of broflanilide prevents molting in the fall armyworm, Spodoptera frugiperda via altering molting hormone biosynthesis. *Elsevier*. https://doi.org/10.1016/j.pestbp.2021.105017

Kumela, T., Simiyu, J., Sisay, B., Likhayo, P., Mendesil, E., Gohole, L., Tefera, T. (2019). Farmers' knowledge, perceptions, and management practices of the new invasive pest, fall armyworm (Spodoptera frugiperda) inEthiopia and Kenya. *International Journal of Pest Management*, 65(1), 1-9.

Lewis, S.E., Silburn, D.M., Kookana, R.S., Shaw, M. (2016). Pesticide behavior, fate, and effects in the tropics: an overview of the current state of knowledge. J. Agric. *Food Chem*. 64, 3917–3924. https://doi.org/10.1021 /acs .ja fc.6b01320.

Martínez, A.M., Aguado-Pedraza, A.J., Viñuela, E., Rodríguez-Enríquez, C.L., Lobit, P., Gómez, B., Pineda, S. (2017). Effects of ethanolic extracts of Argemone ochroleuca (Papaveraceae) on the food consumption and development of Spodoptera frugiperda (Lepidoptera: Noctuidae). *Florida Entomologist*, 100(2), 339-345.

Meagher, R.L., Nuessly, G.S., Nagoshi, R.N., Hay-Roe, M.M., (2016). Parasitoids attacking Fall Armyworm (Lepidoptera: Noctuidae) in sweet corn habitats. *Biol. Control* 95,66–72. https://doi.org/10.1016/j.biocontrol.2016.01.006.

Midega, C.A., Pittchar, J.O., Pickett, J.A., Hailu, G.W., Khan, Z.R. (2018). A climate-adapted push-pull system effectively controls fall armyworm, Spodoptera frugiperda (JE Smith), in maize in East Africa. Crop protection, 105, 10-15.

Ministry of Agriculture, Forestry and Fisheries. (2022). *National Policy for Agricultural Development* 2022-2030

Molina-Ochoa, J., Lezama-Gutierrez, R., Gonzalez-Ramirez, M., Lopez-Edwards, M., Rodriguez-Vega, M. A., & Arceo-Palacios, F. (2003). Pathogens and parasitic nematodes associated with populations of fall armyworm(Lepidoptera: Noctuidae) larvae in Mexico. *Florida Entomologist*, 86(3), 244-253.

Montezano, G., Specht, A., Ricardo, D., Sosa-Gómez, Roque-Specht, V., & Sousa-Silva, J. (2018). Host plants of Spodoptera frugiperda(Lepidoptera:Noctuidae) in the Americas. *Research gate*.https://www.researchgate.net/publication/329739490_Host_Plants_of_Spodoptera_frugiperda_Lepidoptera_Noctuidae_in_the_Americas

Nagoshi, R.N., Silvie, P., Meagher, R.L., Lopez, J., Machado, V. (2007). Identification and comparison of fall armyworm (Lepidoptera: Noctuidae) host strains in Brazil, Texas, and Florida. Annals of the EntomologicalSociety of America, 100(3), 394-402.

National institute of statistics. (2021). *Cambodia agriculture survey 2021: crop production*.

Nguyen, D. T., Y. Z. Chen, and G. A. Herron. 2021. Preliminary characterisation of known pesticide resistance alleles in Spodoptera frugiperda (Lepidoptera: Noctuidae) in its invasive Australian range. *Austral Entomol*. 60: 782-790.

Perfecto, I., (1990). Indirect and direct effects in a tropical agroecosystem: the maize-pestant system in Nicaragua. Ecology 71, 2125–2134. https://doi.org/10.2307/1938626.

Phambala, K., Tembo, Y., Kabambe, V.H., Stevenson, P. C., Belmain, S.R. (2020). Bioactivity of Common PesticidalPlants on Fall Armyworm Larvae (Spodoptera frugiperda). *Plants*, 9(1), 112.

Pilkington, L.J., Messelink, G., van Lenteren, J.C., Le Mottee, K. (2010). "Protected Biological Control"–Biological pest management in the greenhouse industry. *Biological Control*, 52(3), 216-220.

Pradhan, B., Rusinamhodzi, L., Subedi, R. (2019). *System uses plants to lure fall armyworm away from maize fields*.Retrived from https://www.cimmyt.org/news/system-uses-plants-to-lure-fall-armyworm-away-from-maize-fields/

Ramirez-cabral, N. Y. Z., Kumar, L., Shabani, F. (2017). Future climate scenarios project a decrease in the risk of fall armyworm outbreaks. *The Journal of Agricultural Science*, 155(8), 1219-1238.

Rauser, N. (2024). *Are biopesticides and integrated pest management feasible for controlling fall armyworm among smallholders in Battambang, Cambodia?* noah.rauser@students.bfh.ch

Reddy, J. (2019). *Fall Armyworm control methods and symptoms*. Agrifarming. Retrived fromhttps://www.agrifarming.in/fall-armyworm-control-methods-and-symptoms

Rioba, N.B., Stevenson, P.C. (2017). Ageratum conyzoides L. for the management of pests and diseases by small holder farmers. *Industrial crops and products*, 110, 22-29.

Rioba, N.B., Stevenson, P.C. (2020). Opportunities and scope for botanical extracts and products for the management of fall armyworm (spodoptera frugiperda) for smallholders in Africa. *Plants,* 9(2), 207.

Sangomla, A., Kukreti, I. (2019).Fall Armyworm attack: The damage done. https://www.downtoearth.org.in/coverage/agriculture/fall-armyworm-attack-the-damage-done-63445

Sathya K, Sokvisal K, Sovanroth H, Tay WT. (2022) Updates on Spodoptera frugiperda (fall armyworm, FAW) in Cambodia. Final Report CROP-2020-144 Appendix 2. Pp 48-58.

Silva, D.M.D., Bueno, A.D.F., Andrade, K., Stecca, C.D.S., Neves, P. M.O.J., Oliveira, M.C.N.D. (2017). Biology and nutrition of Spodoptera frugiperda (Lepidoptera: Noctuidae) fed on different food sources. *Scientia Agricola*, 74(1), 18-31.

Silva, M.S., Broglio, S.M.F., Trindade, R.C.P., Ferreira, E.S., Gomes, I.B., Micheletti, L.B. (2015). Toxicity and application of neem in fall armyworm. *Comunicata Scientiae*, 6(3), 359-364.

Sisay, B., Simiyu, J., Malusi, P., Likhayo, P., Mendesil, E., Elibariki, N., Tefera, T. (2018). First report of the fall armyworm, Spodoptera frugiperda (Lepidoptera: Noctuidae), natural enemies from Africa. *Journal of Applied Entomology*, 142(8), 800-804.

Sisay, B., Tefera, T., Wakgari, M., Ayalew, G., Mendesil, E. (2019). The efficacy of selected synthetic insecticides and botanicals against fall armyworm, Spodoptera frugiperda, in maize. *Insects*, 10(2), 45.

Souza, T.F., Fevero, S., Conte, C.D.O. (2010). Bioatividade de óleos essenciais de espécies de eucalipto para o controle de Spodoptera frugiperda (JE Smith, 1797)(Lepidoptera: Noctuidae). Revista Brasileira de Agroecologia, 5(2), 157-164.

Soysouvanh P, Phanthanivong I. (2021) Final report on Fall armyworm (FAW) research in Kham, Xieng Khouang and Thatom, Xaisomboun (2020-2021). Report submitted to Lao Upland Rural Advisory Service (LURAS) 13pp. https://www.laofab.org/document/view/5037

Sparks, A.N. (1979). A review of the biology of the fall armyworm. *Florida Entomologist*, 82-87

Sparks, A.N. (1986). Fall armyworm (Lepidoptera: Noctuidae): potential for area-wide management. *FloridaEntomologist*, 603-614.

Tagliari, M.S., Knaak, N., Fiuza, L.M. (2010). Efeito de extratos de plantas na mortalidade de lagartas de Spodoptera frugiperda (j. E. Smith) (Lepidoptera: Noctuidae). Arquivos do Instituto Biológico, *São Paulo*, 77, 259-264.

Tay, W., Rane, R., James, B., Gock, A., Aryuwandari, V., Trisoyono, Y., Amalin, D., Liem, N., Hang, D., Annamalay, S., Faheem, M., Thannarajo, S., Khin, T., Chittarath, K., Khay, S., Kaliebe, A., Otim, M., Watson, A., Fyfield, A., Kim, A., Kuniata., L., Mat, M.B., & Walsh, T. (2023). *Characterisation of Spodoptera frugiperda (fall armyworm) populations in South-East Asia and Northern Australia (co-funded with GRDC).* Australian Centre for International Agricultural Research.

Tefera, T., Goftishu, M., Ba, M., Muniappan, R.M. (2019). *A Guide to Biological Control of Fall Armyworm in Africa Using Egg Parasitoids.*

Thrash, B., Adamczyk, J.J., Lorenz, G., Scott, A.W., Armstrong, J.S., Pfannenstiel, R., Taillon, N. (2013). Laboratory evaluations of lepidopteran-active soybean seed treatments on survivorship of fall armyworm (Lepidoptera: Noctuidae) larvae. *Florida Entomologist*, 96(3), 724-728.

Tumma, M., Chandrika, K. (2018). *Fall Armyworm*. Retrieved from http://vikaspedia.in/agriculture/crop- production/integrated-pest-management/fall armyworm-faw.

Van Huis, A. (1981). *Integrated pest management in Nicaragua's small farmer's maize crop* (Doctoraldissertation, van Huis).

Westbrook, J.K., Sparks, A.N. (1986). The role of atmospheric transport in the economic fall armyworm (Lepidoptera: Noctuidae) infestations in the southeastern United States in 1977. *Florida Entomologist*, 492-502.

Witmer, J.E., Hough-Goldstein, J.A., Pesek, J.D. (2003). Ground-dwelling and foliar arthropods in four cropping systems. *Environ. Entomol*. 32, 366–376. https://doi.org/10.1603/0046-225X-32.2.366.

Zhang L, Liu B, Zheng WG, Liu CH, Zhang DN, Zhao SY, et al. (2020) Genetic structure and insecticide resistance characteristics of fall armyworm populations invading China. *Molecular Ecology Resources* 20: 1682–1696.