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Predominance of Invasive Fall Armyworm (*Spodoptera frugiperda)* In Indian Crop Ecosystem

Anureet Kaur Chandi, Jawala Jindal, R.S. Chandi, Raghav Garg, Aditi Seniaray, Cherryl, Sanhita Chowdhury and Manmeet Kaur

Department of Entomology, College of Agriculture
Punjab Agricultural University, Ludhiana-141 004, India
E-mail: anureetchandi@pau.edu

***Abstract*:** Fall armyworm, *Spodoptera frugiperda* (J.E. Smith) is a noxious lepidopteran pest originated as a key pest of maize crop but it is also common on rice, sorghum, millets, sugarcane and is sporadically important on a vast array of accruing crops and plants, including cotton and vegetables. The introduction of this pest in the tropics is a major concern, as the favorable environment and the absence of natural enemies eventually allow it to thrive without competition. The rapid spread of *S. frugiperda* can be attributed to its sporadic and long-distance migratory behaviour. It is notorious invasive pest with high dispersal ability, broad host range, and high fecundity which makes the fall armyworm one of the most severe economic pests. In the Indian subcontinent, the first record of *S. frugiperda* was observed in 2018 from Karnataka, which later spread to Chhattisgarh, Orrisa, Gujarat, Maharashtra, Bihar, Tamil Nadu and many other states. Larva being the voracious feeder, is the most damaging stage of this pest. Control strategies include cultural practices, biological management, mechanical control, and chemical control. FAW management necessitates an integrated approach that supplements current smallholder pest management techniques. The role of native crop ecosystem adaptability on FAW needs to be explored.

Keywords: Fall armyworm, Maize, Lepidoptera, Invasive, Migratory behaviour

The Fall Armyworm (FAW), *Spodoptera frugiperda* (J.E. Smith) (Lepidoptera: Noctuidae) is an invasive and highly destructive pest of maize, is native to temperate and subtropical regions of the Western hemisphere from the United States of America to Argentina (Gebretsadik et al., 2023). Nonetheless, FAW populations have significantly increased recently throughout the Eastern Hemisphere, notably in countries like Australia, China, India, Africa, and Southeast Asia (Sun et al., 2021, Wan et al., 2021). The pest can cause damage to crops resulting in severe yield reduction and creating devastation impact (Naganna et al., 2020). FAW has a wide host range infesting primarily the maize fields along with rice and some grasses. Being a polyphagous pest, infest more than 100 hosts like sorghum and sugarcane as well as 23 horticultural crops like cabbage, beet, tomato, potato, and onion besides cotton, pasture grasses, peanut, soybean, alfalfa, and millets (Rashed 2023).

The adult moths of FAW exhibits high dispersal ability combined with a marked migratory behavior in the Americas and tend to travel up to 1500-2000 km per year in search of warmer climates, and can travel 500 km in a single season to find oviposition sites and can fly over 100 km per night (Yainna et al., 2022). Since the late 1700s, FAW outbreaks have been reported throughout the Americas (Luginbill 1928). In April 2016, FAW was first detected in the island country of São Tomé and Príncipe, followed by outbreaks recorded in Benin, Nigeria, Ghana and Togo of Western Africa in June, 2016 (Cock et al., 2017). FAW are found in the majority of sub-Saharan Africa as of October, 2017 (FAO 2017). However, populations of this pest have significantly increased in the Eastern Hemisphere in recent years. Afterwards spread across Africa through commercial aircrafts or cargo containers which later travel to Asia reaching Australia in 2019 through the dispersal of wind (Chisonga et al., 2023). In India, it was detected in 2018 from Karnataka and has now spread to several south eastern Asian countries (Nagoshi et al., 2020, Zhang et al., 2020). Subsequently, it extended to various states known for maize cultivation, including Bihar, Chhattisgarh, Gujarat, Maharashtra, Odisha, West Bengal, and numerous others (CABI 2020, Sagar et al., 2020).

In Punjab, *S. frugiperda* was initially documented in grain maize on 15th August 2019 (Rakshit et al., 2019, Cheema et al., 2021). In fodder maize, was first observed in Samrala and Kharar regions of Punjab on 30th September 2019, specifically in crops sown later in the season (Cheema et al., 2021). The presence of this invasive pest has greatly affected the means of subsistence for small and marginal farmers throughout India (Suby et al., 2020, Navik et al., 2021). The larval dispersal is a crucial adaptive characteristic of *S. frugiperda* driven by their substantial reproductive capacity, which assists in sustaining population expansion (Li et al., 2023). The swift and extensive spread of FAW, along with its considerable ability to cause significant yield losses, has garnered global attention (Qi et al., 2021). FAW could threaten the food security and livelihoods of millions of small-scale farmers in India due to its gregarious and fast feeding habits on a wide range of host plants.

Distribution

The fall armyworm is an invasive pest native to the Americas, has become a significant global threat to agriculture, particularly maize production. Since its first detection in West Africa in 2016 (Goergen et al., 2016), it has rapidly spread to nearly 40 African countries by 2018. FAW was initially reported in maize crops in India in 2018, and the University of Agricultural and Horticultural Sciences in Shivamogga, Karnataka, confirmed its existence (Ganiger et al.,2018, Sharanabasappa et al., 2018), marking the first documented occurrence of this pest in Asia. Since then, a trend of temporal extension from peninsular India to the northern, northeastern, and north-western regions has been noted (Suby et al., 2020). Confirmed outbreaks have occurred in Thailand, Bangladesh, Myanmar, China (Yee et al., 2019), Sri Lanka (Perera et al., 2019), Nepal (Bajracharya et al., 2019), Philippines (Navasero et al., 2019), Vietnam (Hang et al., 2020) and Indonesia (Trisyono et al., 2019). By 2020, *S. frugiperda* had also been reported in Oceania and the Middle East, including Australia, South Korea, Papua New Guinea, and the UAE (Ma et al., 2019, Prasanna et al., 2021, Tambo et al., 2023). This extensive geographic spread of FAW highlights the urgent need for integrated and sustainable management approaches.

FAW is a gregarious, and multivoltine pests with localized and migratory tendency of dissemination. Two distinct strains of FAW are recognized, commonly referred to as the "rice-strain" (R-strain) and "corn-strain" (C-strain) (Pashley 1988). The R-strain is found on rice, pasture, millets, and forage grasses whereas, the C-strain is observed on corn, cotton, and sorghum (Nagoshi and Meagher 2004). Until December 2018, only the rice (R) strain had been identified in India, which was found feeding on maize (Swamy et al., 2018). Subsequently, Chromule et al. (2019) reported the occurrence of the C-strain on sugarcane. Nagoshi and Meagher (2022) concluded substantial disagreements in the literature on presumptive strain differences. The pest later spread to adjoining countries including Bangladesh, Nepal, Pakistan, the Philippines, Korea, Indonesia, China, and Syria. In India, it has been reported on maize and other host crops nationwide (Sharma 2021, Chromule et al., 2019, Sharanabasappa et al., 2018, Swamy et al., 2018).

In India, FAW has been documented on a wide array of crops including maize, paddy, sugarcane, ginger, bajra, sorghum, cotton, Johnson grass, sunflower, banana, fodder grasses, and grain amaranth (Sharma 2021, Chromule et al., 2019, Sharanabasappa et al., 2018, Swamy et al., 2018, Venkateswarlu et al., 2018, Bharadwaj et al., 2020, Ragesh and Balan 2020, Maruthadurai and Ramesh 2019).

Recent Trends Illustrating the Migration Patterns of Faw

In the Indian subcontinent, *S. frugiperda* was observed in 2018 from Karnataka, which later spread to different states of India (Fig 1) *viz.,*Chhattisgarh (Deole and Paul 2018), Gujarat (Sisodiya et al., 2018), Tamil Nadu (Srikanth et al., 2018), Maharashtra (Chormule et al., 2019), Uttarakhand (Maurya et al., 2019), Orrisa (Karketta et al., 2020), Bihar (Reddy et al., 2020), Madhya Pradesh (Vishwakarma et al., 2020) Himachal Pradesh (Sharma 2021)and many other states (Fig. 2). By the end of 2018, FAW outbreaks have been discovered in several countries in Southeast Asia, including Bangladesh, Myanmar, and Thailand (Guo et al., 2018).

ECOLOGY OF FAW:

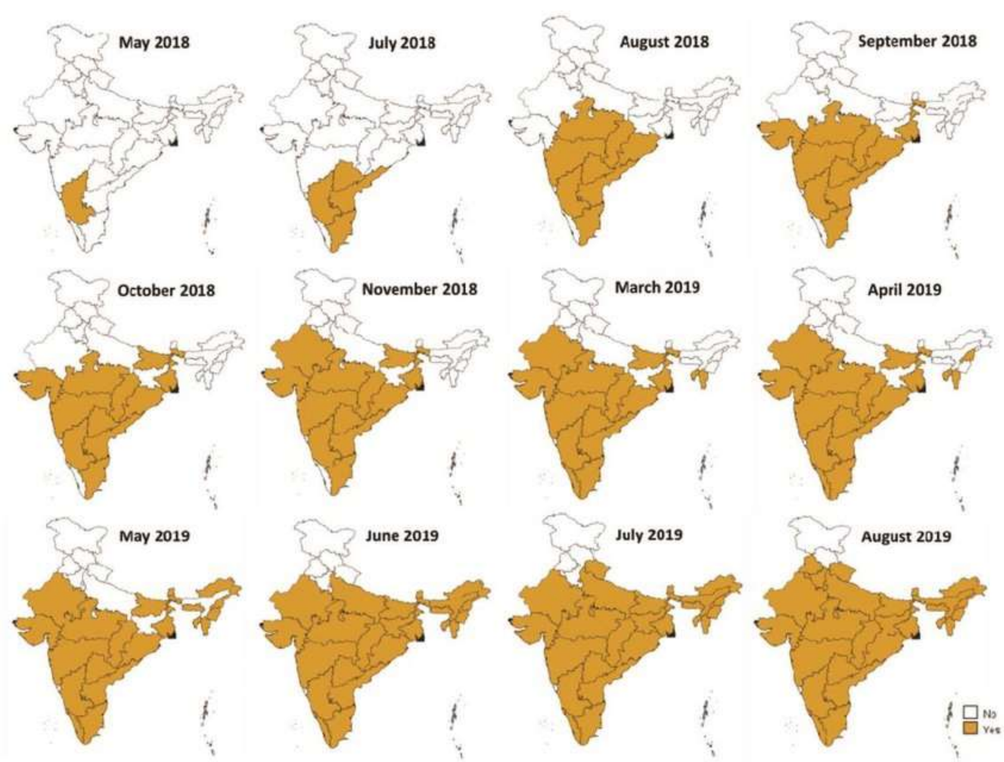
The FAW has become a significant agricultural pest in India since its detection in 2018. Its ecology is shaped by the country's tropical and subtropical climates, with warm temperatures and high humidity favoring its survival and reproduction (Ramzan et al., 2020). Seasonal dynamics are influenced by monsoon patterns, with populations peaking during planting seasons. Integrated pest management approaches, including early detection, host plant resistance, and conservation of natural enemies, are crucial for sustainable control.

The pest generally thrives in warm climates, with optimal temperatures for development ranging from 20°C to 35°C. Higher temperatures can accelerate its life cycle, leading to faster population growth. The temperature below 10°C is detrimental to its survival (Stokstad 2017). While FAW can tolerate various ranges of humidity levels, high humidity conditions favor its survival and reproduction. Dry conditions can reduce egg and larval survival rates. Adequate moisture is essential for FAW egg laying and larval development. Heavy rainfall can disperse neonate larvae and affect their movement and feeding behavior. Wind can aid FAW dispersal over long distances, facilitating its spread to new regions. Wind direction and intensity influence the movement of adult moths and larvae.

Biology and Feeding Behaviour of FAW: FAW is a lepidopteran pest, undergoes complete metamorphosis, and consists of four stages in the life cycle. It has several generations per year with a life cycle consisting of an egg stage, 6 larval instars, pupa, and an adult stage which is completed in 30 days during summer and 60 days during winter. The life cycle of the fall armyworm begins with a female moth depositing white-colored eggs on the underside or upperside of leaves (Ramzan et al., 2020), which later darken to brown just before hatching. The female moth protects the egg masses by covering them with protective scales obtained from her abdomen after oviposition. After 3-6 days, the eggs hatch, and the caterpillars emerge. The early larval stages exhibit a greenish coloration, which later transitions to orange. The larvae measure approximately 1 mm in length during the first instar and grow up to 45 mm by the sixth instar. The full-grown caterpillars may exhibit characteristic markings and spots. These identifying marks often include an inverted 'Y' mark on the head region (Nagoshi et al., 2007), and four smaller dorsal spots arranged in a trapezoidal formation on other segments. Additionally, black dots may be present in a square formation on the last segment.

Usually, only 1 or 2 caterpillars in each whorl are found as they possess cannibalistic feeding behavior where larger caterpillars consume each other to reduce competition for food. The caterpillar's excreta (frass) can also be seen in the leaf whorls after drying, they resemble sawdust. If the plant has already produced cobs, the caterpillar will burrow through the protective leaf bracts and begin feeding on the developing young kernels inside the cob. The number of larval stages, typically 6-7, depends on environmental factors and food availability. In later stages, the rate of food consumption increases, with the final stages consuming even more food than all previous stages combined. The duration of larval development also varies accordingly, at 25°C, it takes approximately 14-18 days. Orange-Brown pupal case is typical forNoctuid FAW pupa which turns darker with age (Hardke et al., 2015). Inside, the pupa, which is reddish-brown in color and measures 14 to 18 mm in length and breadth, develops into an adult (Kandel and Poudel 2020). During the day, adults hide in whorls and lay eggs on leaves, while fully grown larvae pupate in the soil at a depth of 3 to 10 cm (Ratnakala 2023). The wingspan of an adult FAW is about 3.81 cm with the upper portion of the forewing mottled dark grey and in males, a distinctive triangular white spot near the dorsal tip, or apex of the wing, while the lower portion of the forewing a light gray to brown color. Conversely, the color of the hind wing appears to light gray to white. The adult female has a relatively short life cycle of 7–21 days, with a high fecundity of 900–1000 eggs per female.

The feeding behavior of FAW larvae often results in semi-transparent patches on the leaves, commonly referred to as 'papery windows.' Particularly, they show a preference for leaf whorls in young plants, while in older plants, they tend to consume the leaves around cob silks. The larvae have the ability to spin threads, which they use to catch the wind and



Source: Suby et al., 2020

Fig. 1. Chronological order of spread of FAW through different Indian States

transport themselves to new plants. Their feeding activity is more pronounced during the night. During the early instars, FAW larvae prefer vegetative tissue, but as they mature, they increasingly target reproductive structures such as the cob and silk. Between days 6 to 14 of their lifecycle, they typically reach the leaf whorl, causing the most effective damage, resulting in ragged holes in the leaves. Damage to the leaf whorl in young plants can be particularly detrimental, potentially leading to the death of the growing point and subsequent stunting of plant growth, resulting in limited or no new leaf or cob development.

Nature of Damage and Invasiveness of FAW

Once the eggs of FAW hatch, the early instar secretes silken thread and is dispersed by the wind. The first and second instar larvae can be found on the upper surface of the leaves, where they scrape the epidermis resulting in elongated papery windows all over the leaves. When the larvae reach the third instar, they settle in the whorl and their feeding causes a series of holes and fecal matter in the unfurling leaves. As they grow, their feeding rate increases, which leads to larger holes and greater amounts of fecal matter. By the sixth instar, the larvae can defoliate the plant heavily and leave a large amount of fecal matter in the plant whorl. Older larvae may even bore into the developing internodes of the early whorl stage of maize, which can cause plant death. The larvae may also attack tassels and developing ear (Kaur et al., 2024). During their life cycle, FAW larvae devour a significant amount of foliage: 4.7, 16.3, and 77.2% for the fourth, fifth, and sixth instars, respectively. In contrast, first to third instar larvae are quite small and only consume 2% of the total foliage.

FAW emerged as one of the invasive pests species with broad host range cause significant yield losses. Major invasion mechanism involves expansion of gene families associated with detoxifying processes which makes them polyphagy (Huang et al., 2019), an increase in detoxifying metabolizing enzyme (Yu et al., 2003), mutation of toxin receptor (Xiao and Wu 2019), long distance migration, and down regulation of enzymatic expression (Jakka et al., 2016). Because of its biological traits, FAW has spread to new locations and become an invasive species.FAW infestations have the potential to result in yield reductions varying from 10% to 100%, depending on the severity of damage and the timing of infestation. Infestations occurring in the early stages, particularly during the vegetative phase, can lead to stunted plant growth, diminished leaf coverage, and decreased photosynthetic ability, ultimately leading to yield losses. In severe instances, FAW larvae can completely strip maize plants of their foliage, resulting in nearly complete crop failure. Initially, young larvae consume leaf tissue from one side, leaving the opposite epidermal layer intact. As they progress to the second or third instar, larvae start to create perforations in the leaves, feeding from the edges inward. Feeding within the corn whorl often leaves behind a distinctive row of holes in the leaves.When larvae feed nearby, their numbers typically decrease to one to two per plant due to cannibalistic behavior. Older larvae cause extensive defoliation, often leaving only the veins and stalks of corn plants or giving them a tattered, torn appearance. The early whorl stage is the least affected by damage, the mid-whorl stage moderately affected, and the late whorl stage the most affected.

Comprehensive Strategies for FAW Management

With an emphasis on remedies that can produce pest

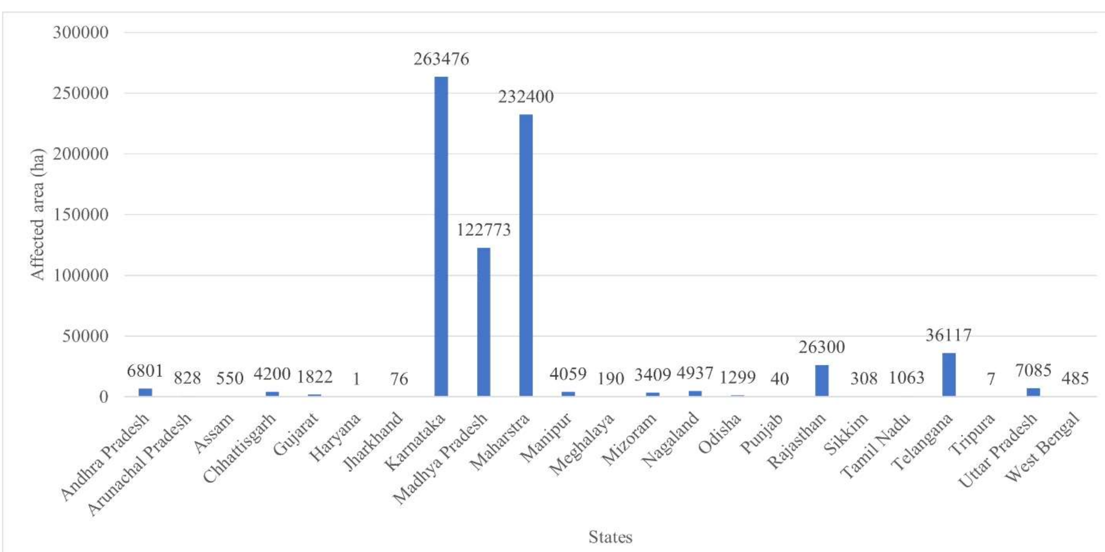


Fig. 2. Selected state-wise area affected due to fall armyworm in India (up to 2020)

control advantages across a wide array of pests and that are appropriate for a diversity of crops and cropping systems, FAW control tactics therefore need to be integrated into a broader pest management viewpoint.

Cultural management: Cultural management practices play a crucial role in controlling FAW infestations. These practices aim to disrupt the pest's life cycle and reduce its population. Some effective cultural management strategies include crop rotation, weed management, intercropping, trap cropping, and many more. To disrupt the pest's life cycle, alternate maize with crops that do not host it and avoid planting maize continuously in the same field. Early planting is advisable as it reduces susceptibility to significant damage. Mix maize with non-preferred crops or those less favored by the fall armyworm. Interplanting maize with legumes or other crops can alleviate pest pressure. Although it requires labor and additional costs, the idea of "Push-Pull" cropping (Dash et al., 2024), where intercropping maize with a pest-repellent ("push") plant (*Desmodium* spp.) surrounded by a border with pest-attractive trap ("pull") plant, like Napier grass (*Pennisetum purpureum* or *Brachiaria* spp.) has shown some promise in controlling the spread of FAW (Sagar et al., 2020).Surround the maize fields with trap crops like sorghum or millet to attract and capture adult fall armyworms, thus alleviating pressure on the main maize crop. This push–pull strategy has been shown to reduce larval density per plant by 82.7% and minimize plant damage per plot by 86.7% (Midega et al., 2018). Additionally, studies indicate that intercropping maize with *Tephrosia* and *Desmodium* can significantly suppress FAW oviposition (Harrison et al., 2019). Maintain weed-free fields to remove alternative hosts and breeding grounds for the fall armyworms, diminishing their food and shelter sources. Employ resistant maize varieties to decrease fall armyworm damage and reduce reliance on chemical measures. Prompt detection enables timely intervention and minimizes crop damage.

Mechanical management: Mechanical management techniques employ physical measures to control fall armyworm populations, aiming to directly decrease pest numbers or interfere with their life cycle. These methods include manually removing and destroying FAW eggs, larvae, and pupae from maize plants, consistent scouting to detect and eliminate pests before substantial damage occurs, utilizing pheromone traps for monitoring and trapping FAW adult populations efficiently, installing light traps to attract and capture adult moths in and around maize fields, employing physical barriers like mesh nets or row covers to shield maize crops from FAW infestations, deep plowing or tilling the soil to expose FAW pupae to natural predators and unfavorable environmental conditions, eliminating infested plant material to reduce FAW populations and halt further spread, and deploying sticky traps to ensnare adult moths and hinder mating success.

Biological control: Due to the inherently gregarious behavior of *Spodoptera frugiperda*, early identification of infestations is vital for preventing significant crop damage. It is recommended that pest management actions be initiated promptly when early signs of leaf injury are detected on seedlings or when plant whorls show substantial infestation within the first 30 days post-planting (Fernandes et al., 2012). Biological management of fall armyworm involves a multifaceted approach utilizing various natural enemies and control agents. Parasitoids like *Cotesia* spp. and *Chelonus* spp. lay eggs on fall armyworm larvae, which hatch into larvae that consume the host from within. Predators such as birds, ants, ground beetles, and spiders' prey on fall armyworm eggs and larvae, aiding in population reduction (Dash et al., 2024). Conservation of natural enemies through reduced pesticide use, habitat preservation, and diverse vegetation planting further supports population regulation of fall armyworms. These integrated strategies foster sustainable pest management while minimizing environmental impact.

Microbial control: FAW is attacked by a number of microorganisms, including entomopathogenic nematodes, viruses, and bacteria (Guo et al., 2020). *Bacillus thuringiensis* (Bt) strains produce toxins lethal to fall armyworm larvae when ingested, offering environmentally friendly control (Dash et al., 2024). Since the entomopathogenic nematode (EPN), *Heterorhabiditis bacteriophora* and the entomopathogenic fungus (EPF), *Metarhizium anisopliae* were discovered to be compatible when combined and treated together, they may be taken into consideration for FAW management in combination (Bissiwu and Pérez2016).A combination in laboratory bioassays using the commercial product Bt Dipel (Sumitomo Chemical) and the EPN, *Steinernema carpocapsae* (Viteri et al., 2018) as well as the results showed high larval mortality rates of 81.3% after 96 hr. as compared to larval mortality caused by Bt (6.7%) or *S. carpocapsae* (35%) when applied alone. Field trials in Karnataka demonstrated that the entomopathogenic fungus *Metarhizium rileyi* can induce larval mortality in *S. frugiperda*, with rates varying between 1.87% and 18.30% (Mallapur et al., 2018). In addition, *Nomuraea rileyi* was reported to infect 10–15% of larvae (Sharanabasappa et al., 2019). According to El-Sheikh (2015), *Spodoptera littoralis* nucleopolyhedrovirus (SpliNPV) has also been demonstrated to be virulent against FAW larvae in their first to third instar. It has been also observed considerable increase in larval time, decrease in pupation, larval weight, and adult emergence. Research has highlighted the effectiveness of the *Spodoptera frugiperda* Multiple Nucleopolyhedrosis Virus (SfMNPV) as a potential biocontrol agent (Komivi et al., 2019).

Chemical control: The Central Insecticide Board and Registration Committee (CIB & RC), India now recommends the pesticides, *viz.,* broflanilide 20% SC, chlorantraniliprole 50% w/w fs, isocycloseram 18.1% W/W SC (20 % w/v SC), spinetoram 11.70 % SC, emamectin benzoate 1.5% + profenofos 35% w/w WDG in order to reduce damage to maize (CIB & RC 2025). The spray technology is almost important in realizing efficacy of the chemical. Spray the crop with chlorantraniliprole 18.5 SC @ 0.4 ml per liter water or spinetoram 11.7 SC @ 0.5 ml per liter or emamectin benzoate 5 SG @ 0.4 g per liter using 120 liters of water per acre, for crops up to 20 days old. Thereafter for older crops, the amount of water used per acre needs to be increased up to 200 liters with corresponding increase in dosage of above insecticides. For effective management of this pest, direct the nozzle towards the whorl. Moreover, in order to prepare poison bait, Patil et al., (2017) described a procedure that involved mixing 5.0 kg of jaggery with 4-5 littersof water

Biotechnological approaches: In insect pest control, biotechnological interventions may improve crop resistance and tolerance. This includes a number of methods, such as protoplast fusion, RNA interference, marker-assisted selection, trait mapping, gene transformation, protoplast fusion, and the incorporation of novel genes into crops (Romeis et al., 2019, Warburton et al., 2023). To identify genes or genomic areas linked to FAW resistance, a variety of genetic techniques have been employed, such as genome-wide association mapping and quantitative trait loci (QTL) mapping (Kamweru et al., 2022). QTL mapping is a technique that finds genomic areas associated with a certain characteristic by analyzing or correlating genotypic and phenotypic data. Numerous investigations have been conducted to identify the genes causing a range of characteristics, such as resistance to disease (Jha et al., 2023), insect pest resistance (Cosme et al., 2022) and biofortification (Juliana et al., 2022). Moreover, genes that encode toxins such as *Bacillus thuringiensis* (Bt) or enhance plant defences against FAW are introduced using genetic engineering techniques (Burtet et al., 2017, Li et al., 2021). Newer biotechnological approaches to insect pest management, including gene editing (RNA interference (RNAi), gene drives, and, most recently, the CRISPR-Cas9 system (Gouda et al., 2024), have emerged as a result of insect resistance, despite the fact that transgenic Bt crops have significantly improved crop protection (Ullah et al., 2022, Li et al., 2021).

CONCLUSION

The fall armyworm is expanding quickly, encroaching on new territory owing to its remarkable dispersal ability. The food and nutritional security of the global populace has already been alerted by the FAO to the recent insect outbreak in Asia. FAW primarily targets members of the poaceae family, attacking 353 host plant species from 76 different plant families. Also regarding FAW strains like assumption on strain-specific traits are need to be explored. Implementation of an appropriate management approach is the one important factor in managing the fall armyworm. As an emergency response to tackle FAW menace, chemical control is advisable but it causes environmental deterioration. Therefore, FAW control tactics are to be integrated in a sustainable way to protect the crops.

REFERENCES

Bajracharya ASR, Bhat B, Sharma P, Pathour SR, Naresh MM and Raza HT 2019. First record of fall army worm *Spodoptera frugiperda* (J. E. Smith) from Nepal. *Indian Journal of Entomology* **81**: 635-639.

Bharadwaj GS, Mutkule DS, Thakre BA, Ingale AS and Jadhav AS 2020. Extent of host range of fall armyworm, *Spodoptera frugiperda* (J.E. Smith) in Latur district (Maharashtra, India). *Journal of Pharmacognosy and Phytochemistry* **9**(5): 608-613.

Bissiwu P, Pérez MJ and Walter NT 2016. *Control efficacy of Spodoptera frugiperda using the entomopathogens Heterorhabditis bacteriophora and Metarhizium anisopliae with insecticide mixtures in corn.* Universidad EARTH.

Burtet LM, Bernardi O, Melo AA, Pes MP, Strahl TT and Guedes JV 2017. Managing fall armyworm, *Spodoptera frugiperda* (Lepidoptera: Noctuidae), with Bt maize and insecticides in southern Brazil. *Pest Managment Science* **73**: 2569-2577.

CABI 2020. *Spodoptera frugiperda* (fall armyworm). Invasive species compendium. https://www.cabi.org/isc/datasheet/29810

Cheema HK, Jindal J, Aggarwal N, Kumar S and Sharma U 2021. Insecticidal management of *Spodoptera frugiperda* (JE Smith) on grain and fodder maize in Punjab. *Pesticide Research Journal* **33**(1): 72-77.

Chisonga C, Chipabika G, Sohati PH and Harrison RD 2023. Understanding the impact of fall armyworm (*Spodoptera frugiperda* JE Smith) leaf damage on maize yields. *PLoS One* **18**(6): e0279138.

Chormule A, Shejawal N, Sharanabasappa CM, Asokan R, Swamy HM and Studies Z 2019. First report of the fall Armyworm, *Spodoptera frugiperda* (JE Smith) (Lepidoptera, Noctuidae) on sugarcane and other crops from Maharashtra, India. *Journal of Entomology and Zoology Studies* **7**(1): 114-117.

CIB and RC 2025. https://ppqs.gov.in/divisions/cib-rc/major-uses-of-pesticides

Cock MJ, Beseh PK, Buddie AG, Cafá G and Crozier J 2017. Molecular methods to detect *Spodoptera frugiperda* in Ghana, and implications for monitoring the spread of invasive species in developing countries. *Scientific Reports* **7**(1): 4103.

Cosme LV, Lima JBP, Powell JR and Martins AJ 2022. Genome-wide association study reveals new loci associated with pyrethroid resistance in *Aedes aegypti*. *Frontier in Genetics* **13**: 1-17.

Dash S, Korada RR and Mishra BK 2024. *Spodoptera frugiperda* (JE Smith) in India: Pervasiveness, host range, and management. *Environment and Ecology* **42**(2B): 780-789.

Deole S and Paul N 2018. First report of fall army worm, *Spodoptera* *frugiperda* (JE Smith), their nature of damage and biology on maize crop at Raipur, Chhattisgarh. *Journal of Entomology and Zoology Studies* **6**(6): 219-221.

El-Sheikh EA 2015. Efficacy of *Spodoptera littoralis* nucleopolyherdovirus on *Spodoptera frugiperda* (JE Smith) and *Spodoptera exigua* (Hübner): virulence, biological effects, and inhibition of juvenile hormone esterase. *Egyptian Journal of Biological Pest Control* **25**(3): 587.

FAO 2017. *Briefing Note on FAO Actions on Fall Armyworm in Africa*, Oct. 1, 2017, http://www.fao.org/3/a-bt415e.pdf.

Fernandes FL, Diniz JF, Alves FM and Silva LO 2012. Injury and spatial distribution of *Spodoptera frugiperda* (JE Smith) (Lepidoptera: Noctuidae) in Onion *Allium cepa* (Alliaceae) in Alto Paranaıba, Minas Gerais, Brazil. *Entomological News* **122** (3): 257-260.

Ganiger PC, Yeshwanth HM, Muralimohan K, Vinay N, Kumar ARV and Chandrashekara KJCS 2018. Occurrence of the new invasive pest, fall armyworm, *Spodoptera frugiperda* (JE Smith) (Lepidoptera: Noctuidae), in the maize fields of Karnataka, India. *Current Science* **115**(4): 621-623.

Gebretsadik KG, Liu Y, Yin Y, Zhao X, Li X, Chen F, Zhang Y, Chen J and Chen A 2023. Population growth of fall armyworm, *Spodoptera frugiperda* fed on cereal and pulse host plants cultivated in Yunnan Province, China. *Plants* **12**(4): 950.

Goergen G, Kumar PL, Sankung SB, Togola A and Tamò M 2016. First report of outbreaks of the fall armyworm *Spodoptera frugiperda* (JE Smith) (Lepidoptera, Noctuidae), a newalien invasive pest in West and Central Africa. *PloS one* **11**(10): e0165632.

Gouda MR, Jeevan H and Shashank HG 2024. CRISPR/Cas9: a cutting-edge solution for combatting the fall armyworm, *Spodoptera frugiperda*. *Molecular Biology Reports* **51**(1): 13.

Guo J, Wu S, Zhang F, Huang C, He K, Babendreier D and Wang Z 2020. Prospects for microbial control of the fall armyworm *Spodoptera frugiperda*: a review. *BioControl* **65**: 647-662.

Guo J, Zhao J, He K, Zhang F and Wang Z 2018. Potential invasion of the crop-devastating insect pest fall armyworm *Spodoptera frugiperda* to China. *Plant Protection* **44**: 1-10.

Hang DT, Liem NV, Lama PV and Wyckhuys K 2020. First record of fall armyworm *Spodoptera frugiperda* (J.E. Smith) (Lepidop tera: Noctuidae) on maize in Viet Nam. *Zootaxa* **4772**: 396-400.

Hardke JT, Jackson RE, Leonard BR and Temple JH 2015. Fall armyworm (Lepidoptera: Noctuidae) development, survivorship, and damage on cotton plants expressing insecticidal plant-incorporated protectants. *Journal of Economic Entomology* **108**(3): 1086-1093.

Harrison RD, Thierfelder C, Baudron F, Chinwada P, Midega C and Schaffner C 2019. Agro-ecological options for fall army worm (*Spodoptera frugiperda* JE Smith) management: Providing low-cost, smallholder friendly solutions to an invasive pest. *Journal of Environmental Management* **243**: 318-330.

Huang C, Li YZ, Yang NW, Wu Q, Xing LS, Qian W Q, Xi Y, Li F and Wan FH 2019. Progresses in invasive insect genomics. *Plant Protection* **45**(5):112-120.

Jakka SR, Gong L, Hasler J, Banerjee R, Sheets JJ, Narva K, Blanco CA and Jurat-Fuentes JL 2016. Field-evolved mode 1 resistance of the fall armyworm to transgenic Cry1Fa-expressing corn associated with reduced Cry1Fa toxin binding and midgut alkaline phosphatase expression. *Applied and Environmental Microbiology* **82**(4): 1023-1034.

Jha UC, Nayyar H, Chattopadhyay A, Beena R, Lone AA, Naik YD, Thudi M, Prasad PVV, Gupta S, Dixit GP and Siddique KH 2023. Major viral diseases in grain legumes: Designing disease resistant legumes from plant breeding and OMICS integration. *Frontiers in Plant Science* **14:**1183505.

Juliana P, Govindan V, Crespo-Herrera L, Mondal S, Huerta-Espino J, Shrestha S, Poland J and Singh R 2022. Genome-wide association mapping identifies key genomic regions for grain zinc and iron biofortification in bread wheat. *Frontiers in Plant Science* **13**: 903819.

Kamweru I, Anani BY, Beyene Y, Makumbi D, Adetimirin VO and Prasanna BM 2022. genomic analysis of resistance to fall armyworm (*Spodoptera frugiperda*) in CIMMYT Maize Lines. *Genes* (Basel) **13**: 251.

Kandel S and Poudel R 2020. Fall armyworm (*Spodoptera Frugiperda*) in maize: An emerging threat in Nepal and its management. *International Journal of Applied Sciences and Biotechnology* **8**(3): 305-309.

Kaur K, Cheema HK, Jindal J, Garg T, Singh G and Atri A 2024. Categorization of resistance against the fall armyworm, *Spodoptera frugiperda* (JE Smith) in select maize inbred lines. *Crop Protection* 178: 106581.

Kerketta D, Verma LR, Ayam GP and Yadav RS 2020. First invasive report of fall armyworm, *Spodoptera frugiperda* (JE Smith) (Lepidoptera: Noctuidae) from Orissa, India. J*ournal of Experimental Zoology* **23**(1): 465-468.

Komivi S, Kimemia A, Ekesi JWS, Khamis FM, Ombura OL and Subramanian S 2019. Ovicidal effects of entomopathogenic fungal isolates on the invasive fall armyworm. *Journal of Applied Entomology* **143**: 626-634.

Li JJ, Shi Y, Wu JN, Li H, Smagghe G and Liu TX 2021. CRISPR/Cas9 in lepidopteran insects: Progress, application and prospects. *Journal of Insect Physiology* **135**: 104325.

Li YP, Yao SY, Feng D, Haack RA, Yang Y, Hou JL and Ye H 2023. Dispersal behavior characters of *Spodoptera frugiperda* larvae. *Insects* **14**(6): 488.

Li Y, Wang Z and Romeis J 2021. Managing the invasive fall armyworm through biotech crops: A Chinese perspective. *Trends in biotechnology* **39**(2): 105-107.

Luginbill P 1928. *The fall army worm* (No. 34). US Department of Agriculture.

Ma J, Wang YP, Wu MF, Gao BY, Liu J, Lee GS, Otuka A and Hu G 2019. High risk of the fall armyworm invading Japan and the Korean Peninsula via overseas migration. *Journal of Applied Entomology* **143**(9): 911-920.

Mallapur CP, Naik AK, Hagari S, Praveen T, Patil RK and Lingappa S 2018. Potentiality of *Nomuraea rileyi* (Farlow) Samson against the fall armyworm infesting maize. *Journal of Entomology and Zoology Studies* **6**: 1062-1067.

Maruthadurai R and Ramesh R 2019. Occurrence, damage pattern and biology of fall armyworm, *Spodoptera frugiperda* (J.E. Smith) (Lepidoptera: Noctuidae) on fodder crops and green amaranth in Goa, India. *Phytoparasitica* **48** (1): 15-23.

Maurya RP, Brijwal L, Suyal P, Patwal H and Singh MK 2019. First report of a new invasive pest fall army worm, *Spodoptera frugiperda* (JE Smith) in maize crop at Pantnagar, Uttarakhand. *Journal of Entomology and Zoology Studies* **7**(6): 648-654.

Midega CAO, Pittchar JO, Pickett JA, Hailu GW and Khan ZR 2018. A climate-adapted pushpull system effectively controls fall armyworm, *Spodoptera frugiperda* (J E Smith), in maize in East Africa. *Crop Protection* **105**: 10-15.

Naganna R, Jethva DM, Bhut JB, Wadaskar PS and Kachot A 2020. Present status of new invasive pest fall armyworm, *Spodoptera frugiperda* in India: A review. *Journal of Entomology and Zoology Studies* **8**(2): 150-156.

Nagoshi RN and Meagher RL 2004. Behavior and distribution of the two fall armyworm host strains in Florida. *Florida Entomologist* **87**(4): 440-449.

Nagoshi RN and Meagher RL 2022. The *Spodoptera frugiperda* host strains: What they are and why they matter for understanding and controlling this global agricultural pest. *Journal of Economic Entomology* **115**(6): 1729-1743.

Nagoshi RN, Htain NN, Boughton D, Zhang L, Xiao Y, Nagoshi BY and Mota-Sanchez D 2020. Southeastern Asia fall armyworms are closely related to populations in Africa and India, consistent with common origin and recent migration. *Scientific Reports* **10**(1): 1421.

Nagoshi RN, Silvie P and Meagher RL 2007. Comparison of haplotype frequencies differentiate fall armyworm (Lepidoptera: Noctuidae) corn-strain populations from Florida and Brazil. *Journal of Economic Entomology* **100**(3): 954-961.

Navasero MV, Navasero MM, Burgonio GAS and Ardez KP 2019. Detection of the Fall Armyworm, *Spodoptera frugiperda* (J.E. Smith) (Lepidoptera: Noctuidae) using larval morpho logical characters, and observations on its current local distribution in the Philippines. *The Philippine Entomologist* **33**: 171-184.

Navik O, Shylesha AN, Patil J, Venkatesan T, Lalitha Y and Ashika TR 2021. Damage, distribution and natural enemies of invasive fall armyworm *Spodoptera frugiperda* (JE smith) under rainfed maize in Karnataka, India. *Crop Protection* **143**: 105536.

Pashley DP 1988. Current status of fall armyworm host strains. *Florida Entomologist* **71**(3): 227-234.

Patil SB, Goyal A, Chitgupekar SS, Kumar S and El-Bouhssini M 2017. Sustainable management of chickpea pod borer. A review. *Agronomy for sustainable development* **37**(20): 1-17.

Perera N, Magamage M, Kumara A and Galahitigama 2019. Fall armyworm (FAW) epidemic in Sri Lanka: Ratnapura District Perspectives. *International Journal of Entomological Research* **7**: 9-18.

Prasanna BM, Huesing JE, Peschke VM, Nagoshi, Jia X, Wu K, Trisyono YA, Tay T, Watson A, Day R and Eddy R 2021. *Fall armyworm in Asia: Invasion, impacts, and strategies for sustainable management*. CIMMYT, pp 99-113.

Qi G J, Ma J, Wan J, Ren Y L, McKirdy S, Hu G and Zhang ZF 2021. Source regions of the first immigration of fall armyworm, *Spodoptera frugiperda* (Lepidoptera: Noctuidae) invading Australia. *Insects* **12**(12): 1104.

Ragesh Gavas and Balan Sanju 2020. The first report on Fall Army worm, *Spodoptera frugiperda* (J. E. Smith) (Lepidoptera: Noctuidae) as an invasive pest in banana from Kerala, South India and notes on its behavior. *Insect Environment* **23**: 20-24.

Rakshit S, Ballal CR, Prasad YG, Sekhar JC, Lakshmi SP, Suby SB, Jat SL, Sivakumar G and Prasad JV 2019. Fight against fall armyworm *Spodoptera frugiperda* (JE Smith), pp.52. ICAR - Indian Institute of Maize Research, Ludhiana, Punjab, India.

Ramzan M, Usman M, Sajid Z, Ghani U, Basit MA, Razzaq M, Shafee W and Shahid MR 2020. Bio-ecology and management of *Spodoptera frugiperda* (Lepidoptera: Noctuidae): A review. *Journal of Pure and Applied Agriculture* **5**(4): 1-9.

Rashed HS 2023. Biology, Host selection behavior and growth indices of invasive Fall Armyworm, *Spodoptera frugiperda* (JE Smith) (Lepidoptera: Noctuidae) on two host plants under laboratory conditions. *Journal of Plant Protection and Pathology* **14**(6): 181-186.

Ratnakala B, Kalleshwaraswamy CM, Rajkumar M and Mallikarjuna HB 2023. Biocontrol potential of entomopathogenic nematodes against invasive fall armyworm, *Spodoptera frugiperda* in India. *Biological Control* **185:** 105304.

Reddy KJM, Kumari K, Saha T and Singh SN 2020. First record, seasonal incidence and life cycle of fall armyworm, *Spodoptera frugiperda* (JE Smith) in maize at Sabour, Bhagalpur, Bihar. *Journal of Entomology and Zoology Studies* **8**(5): 1631-1635.

Romeis J, Naranjo SE, Meissle M and Shelton AM 2019. Genetically engineered crops help support conservation biological control. *Biological Control* **130**: 136-154.

Sagar GC, Aastha B and Laxman K 2020. An introduction of fall armyworm (*Spodoptera frugiperda*) with management strategies: a review paper. *Nippon Journal of Environmental Science* **1**(4): 1010.

Sharanabasappa D, Kalleshwaraswamy CM, Asokan R, Swamy HM, Maruthi MS, Pavithra HB, Kavita H, Navi S, Prabhu ST and Goergen G 2018. First report of the fall armyworm, *Spodoptera frugiperda* (J. E. Smith) (Lepidoptera: Noctuidae), an alien invasive pest on maize in India. *Pest Management in Horticultural Ecosystem* **24**(1): 23-29.

Sharanabasappa K, Poorani CM, Maruthi J, Pavithra HB and Diraviam J 2019. Natural enemies of *Spodoptera frugiperda* (J. E. Smith) (Lepidoptera: Noctuidae), A recent invasive pest on maize in South India. *Florida Entomologist* **102**: 619 623.

Sharma SK 2021. First report of fall armyworm, *Spodoptera frugiperda* (JE Smith)(Lepidoptera: Noctuidae) incidence in Himachal Pradesh (HP), India. *Journal of Entomological Research* **45**(1): 159-164.

Sharma S, Tiwari S, Thapa RB, Neupane S, Reddy GV, Pokhrel S and Muniappan R 2022. Life cycle and morphometrics of fall armyworm (*Spodoptera frugiperda*)(Lepidoptera: Noctuidae) on maize crop. *SAARC Journal of Agriculture* **20:** 77-86.

Sisodiya DB, Raghunandan BL, Bhatt NA, Verma HS, Shewale CP, Timbadiya BG and Borad PK 2018. The fall armyworm, *Spodoptera frugiperda* (JE Smith)(Lepidoptera: Noctuidae); first report of new invasive pest in maize fields of Gujarat, India. *Journal of Entomology and Zoology Studies* **6**(5): 2089-2091.

Srikanth J, Geetha N, Singaravelu B, Ramasubramanian T, Mahesh P, Saravanan L, Salin KP, Chitra N and Muthukumar M 2018. First report of occurrence of fall armyworm *Spodoptera frugiperda* in sugarcane from Tamil Nadu, India. *Journal of Sugarcane Research* **8**:195-202.

Stokstad E 2017. New crop pest takes Africa at lightning speed. *Science* **356**: 473-474.

Suby SB, Soujanya PL, Yadava P, Patil J, Subaharan K, Prasad GS, Babu KS, Jat SL, Yathish KR, Vasassery J, Kalia VK, Bakthavatsalam N, Shekhar JC and Rakshit S 2020. Invasion of fall armyworm (*Spodoptera frugiperda*) in India: nature, distribution, management and potential impact. *Current Science* **119**(1): 44-51.

Sun XX, Hu CX, Jia HR, Wu QL, Shen XJ, Zhao SY, Jiang YY and Wu KM 2021. Case study on the first immigration of fall armyworm, *Spodoptera frugiperda* invading into China. *Journal of Integrative Agriculture* **20**(3): 664-672.

Swamy HM, Asokan R, Kalleshwaraswamy CM, Sharanabasappa SD, Prasad YG, Maruthi MS, Shashank PR, Ibemu DN, Anusha S, Adarsha S, Srinivas A, Srinivasa R, Vidyasekhar RMS, Sunder RGS and Nagesh SN 2018. Prevalence of "R" strain and molecular diversity of fall army worm *Spodoptera frugiperda* (JE Smith) (Lepidoptera: Noctuidae) in India. *Indian Journal of Entomology* **80**(3): 544-553.

Tambo JA, Mbugua F and Duah SA 2023. Pest risk information, agricultural outcomes and food security: Evidence from Ghana. *Food Security* **15**: 1667-1683.

Trisyono Y, Suputa S, Aryuwandari V, Hartaman M and Jumari J 2019. Occurrence of heavy infestation by the fall army worm *Spodoptera frugiperda*, a new alien invasive pest, in Corn Lampung Indonesia. *Jurnal Perlindungan Tanaman Indonesia* **23**: 156.

Ullah F, Gul H, Tariq K, Hafeez M, Desneux N, Gao X and Song D 2022. RNA interference-mediated silencing of ecdysone receptor (EcR) gene causes lethal and sublethal effects on melon aphid, *Aphis gossypii*. *Entomologia Generalis* **42**(5): 791-797.

Venkateswarlu U, Johnson M, Narasimhulu R and Muralikrishna T 2018. Occurrence of the fall armyworm, *Spodoptera frugiperda* (JE Smith) (Lepidoptera: Noctuidae), a new pest on bajra and sorghum in the fields of agricultural research station, Ananthapuramu, Andhra Pradesh, India. *Journal of Entomology and Zoology Studies* **6**(6): 811-813.

Vishwakarma R, Pragya K, Patidar S, Das SB and Nema A 2020. First report of fall army worm, *Spodoptera frugiperda* (JE Smith) (Lepidoptera: Noctuidae) on maize (*Zea mays*) from Madhya Pradesh, India. *Journal of Entomology and Zoology Studies* **8**(6): 819-823.

Viteri DM, Linares AM and Flores L 2018. Use of the entomopathogenic nematode *Steinernema carpocapsae* in combination with low-toxicity insecticides to control fall armyworm (Lepidoptera: Noctuidae) larvae. *Florida*

Entomologist **101**(2): 327-329.

Wan J, Huang C, Li CY, Zhou HX, Ren YL, Li ZY, Xing LS, Zhang B, Xi QI, Bo LI and Liu CH, Xi Y, Liu W X, Wang WK, Qian WQ, Mckirdy S and Wan FH 2021. Biology, invasion and management of the agricultural invader: Fall armyworm, Spodoptera frugiperda (Lepidoptera: Noctuidae). *Journal of Integrative Agriculture* **20**(3): 646-663.

Warburton ML, Woolfolk SW, Smith JS, Hawkins LK, Castano□Duque L, Lebar MD and Williams WP 2023. Genes and genetic mechanisms contributing to fall armyworm resistance in maize. *The Plant Genome* **16**(2): 1-13.

Xiao YT and Wu K 2019. Recent progress on the interaction between insects and *Bacillus thuringiensis* crops. *Philosophical Transactions of the Royal Society B: Biological Science* **374**(1767): 20180316.

Yainna S, Tay WT, Durand K, Fiteni E, Hilliou F, Legeai F, Clamens AL, Gimenez S, Asokan R, Kalleshwaraswamy CM and Deshmukh SS 2022. The evolutionary process of invasion in the fall armyworm (*Spodoptera frugiperda*). *Scientific Reports* **12**(1): 21063.

Yee KN, Aye MM, Htain NN, Oo AK, Kyi PP, Thein MM and Saing NN 2019. *First detection report of the fall armyworm Spodoptera frugiperda (Lepidoptra: Noctuidae) on maize in Myanmar*. IPPC Official Pest Report No. MMR-19/2

Yu SJ, Nguyen SN and Abo-Elghar GE 2003. Biochemical characteristics of insecticide resistance in the fall armyworm, *Spodoptera frugiperda* (J. E. Smith). *Pesticide Biochemistry and Physiology* **77**(1): 1-11.

Zhang L, Liu B, Zheng W, Liu C, Zhang D, Zhao S and Xiao Y 2020. Genetic structure and insecticide resistance characteristics of fall armyworm populations invading China. *Molecular Ecology Resources* **20**(6): 1682-1696.

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