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Maize Fall Armyworm, *Spodoptera frugiperda* (JE Smith); (Lepidoptera: Noctuidae) – Arrival, Distribution, Spread and Biology

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ABSTRACT

Fall armyworm (FAW), Spodoptera frugiperda (J. E. Smith) is a native of the Americas. Since the initial identification of invasion into Nigeria and Ghana in 2016, it has swiftly invaded 47 African countries and 18 Asian countries. Its host range (at least 353 host plants), innate capacity to live in a variety of habitats, robust migration ability, high fecundity, quick development of insecticide/virus resistance and gluttonous traits all contribute to its classification as a 'Super Pest'. The outstanding biological characteristics of FAW contribute to its invasiveness. There are still gaps in our understanding of S. frugiperda's invasive mechanisms, how to stop it from spreading and how to improve managemement techniques. An overview of distribution, life stages, behaviour, host strain identification, damage symptoms at various stages and insect biology, a description of are presented here.

Keywords: *Fall Armyworm, Spodoptera frugiperda, Invasion, Host Plants, Distribution, Life cycle, Biology*

Key Messages

- In Tamil Nadu, India, periodical surveys revealed that its reproduction occurs around the year.
- In the Americas, the FAW seen throughout the year
- In Africa, the FAW seen in apecific period.
- The threat was seen in more than 80 crops in the field.

Introduction

Fall armyworm (FAW), one of the most important pests of maize in Latin America, suddenly appeared in Africa in 2016 and spread rapidly to other continents. Fall armyworm (FAW), *Spodoptera frugiperda* (J. E. Smith) (Lepidoptera: Noctuidae) is a polyphagous pest native to tropical and subtropical America, where it is one of the most important maize pests, for example in Central America and Brazil. It belongs to the genus, *Spodoptera*, known as armyworms, the group of Noctuidae that causes the highest monetary losses to Agriculture worldwide. The fall armyworm (FAW) was first reported on the African continent in January, 2016, subsequently spread to all of Sub-Saharan Africa (SSA), where it caused extensive damage to maize and lesser damage in sorghum and other crops globally. Currently, over 50 countries have identified the pest within their borders including the island such as Cape Verde, Madagascar, São Tomé and Príncipe and the Seychelles. FAW is capable of feeding on over 80 different crop species, making it one of the most damaging crop pests (Montezano et al. 2018).

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India was recently invaded by the fall armyworm, which quickly spread throughout the Nation. Since its entry into India in 2018, FAW has quickly spread across the country. Maize crop damage ranged between 20% and 80% from July 2018 to February 2019. The overall output of maize was estimated to have decreased by 37,000 to 75,000 tonnes (Sharanabasappa et al. 2019). FAW is thought to have migrated from either the United States of America or South America to Africa in the early months of 2016 before making its way to India, infecting more than 50 nations on two continents in less than two years (Early et al. 2018). It is also expected to spread from India to other parts of Asia, with South East Asiaincluding Thailand, China, Indonesia, Malaysia, and the Philippines and Australia being at risk. This could endanger the food security and livelihoods of millions of small-scale farmers in the region (Johnson 1987). According to the FAO, it made to continental Australia in the early 2020s (CABI 2020). In this regard, the current review discusses the distribution status, damage severity, biology and genetic similarities of the Indian fall armyworm.

Distribution

S. frugiperda is indigenous to the Americas' tropical and subtropical climates. The moth is a year-round inhabitant of southern Florida and Texas and as far north as Argentina (Nagoshi et al. 2019; Early et al. 2018). In North America, FAW arrived seasonally and killed out in cold winter months, but in Africa, FAW generations will be continuous throughout the year wherever hosts are available, including off-season and irrigated

crops. The climatic conditions were favourable in Africa. FAW was first reported outside of its natural area in North and South America in Nigeria, So Tomé and Prncipe in early 2016, from where it is thought to have spread to additional African nations such as Kenya, Uganda, Rwanda, Ethiopia, and Tanzania. (Goergen et al. 2016) By April 2018, sub-Saharan Africa, Sudan had been invaded. Now, it has been verified in more than 44 African nations (FAO 2018). FAW had been reported in Egypt. The probability of FAW invasion in Europe through migration had been significantly increased by the presence of FAW in North Africa. Beyond Africa, FAW had invaded various Asian countries and Australia (Xun et al. 2021).In early 2018, FAW was found in Yemen and in July it was announced in India prompting consideration of how it crossed the Indian Ocean. There appear to be three main possibilities.In 2018, reports of *S. frugiperda* from the Indian subcontinent, Karnataka (ICAR-NBAIR 2018a) and Andhra Pradesh (Ganiger et al. 2018; Sharanabasappa et al. 2019) were received. Additionally, reports of the pest have been made in the following states: Bihar, Chhattisgarh, Gujarat, Maharashtra, Odisha, Tamil Nadu, Telangana, and West Bengal.Additional reports of *S. frugiperda* have come from Myanmar, Sri Lanka, China, Bangladesh, Thailand, and the Republic of Korea. Fall armyworm had been identified in preliminary reports from the Philippines and Japan. *S. frugiperda* has been reported in the Torres Strait on the islands of Saibai and Erub.Fall armyworm (FAW), *Spodoptera frugiperda*, arrived on mainland Australia in February 2020. Since then, FAW established populations in northern areas of Queensland, the Northern Territory and Western Australia (IPPC, 2020).

Pathways of Spread

The rapid spread of FAW in Africa was attributed due to the strong flight capacity of the insect, though it is possible that it was already more widespread than realised when first detected and the apparent rapid spread was in part due to the lack of spread of awareness.The quick spread happened to the Indian Ocean Islands is more difficult to explain by natural flight, thus regular flights from the mainland to those countries may have played a role. According to Cock et al. (2017), possible spread routes could involved stowaways on or inside aeroplanes, contaminated traded goods and unaided dissemination by wind-assisted flight. Wind-assisted flight alone may not have been sufficient for FAW to cross the Atlantic, but once in Africa, all of the pathways described, including spread to the Indian Ocean Islands, might have occurred. FAW has spread quickly over the world, which may be related to trade and poor phytosanitary restrictions as well as the pest's own migratory patterns. Like other moths of *Spodoptera* genus, FAW moths have both migratory and localised dispersal habit. In the migratory habit, moths can migrate over 500 km before oviposition. When the wind pattern is right, moths can fly much larger distances. For example, a flight of 1,600 km from the southern U.S. state of Mississippi to southern Canada in 30 h has been recorded.

Host Range

S. frugiperda is a polyphagous pest with a definite preference for the Poaceae family (Casmuz et al. 2010). It is most typically found in wild and cultivated grasses, as well as maize, rice, sorghum, and sugarcane. However, Montezano et al. (2018) recently found 353 host plant species from 76 plant families, based on a thorough literature study and further surveys in Brazil, from the Poaceae (106), Asteraceae (31) and Fabaceae families (31).While FAW had a preference for maize, the main staple of Africa, it also found to affect many other major cultivated crops, including sorghum, rice, sugarcane, groundnut, soybean, onion, cotton, pasture grasses, millets, tomato, potato, cabbage, beet and cotton.

The FAW has a very wide host range, 80 plants recorded, but clearly prefers grasses. The most frequently consumed plants are field maize and sweet maize, sorghum, Bermuda grass and grass weeds such as crabgrass (*Digitaria* spp) (Otim et al. 2018). When the larvae are very numerous they defoliate the preferred plants, acquire the typical “armyworm” habit, and disperse in large numbers, consuming early all vegetation in their path. Many host records reflect such periods of abundance and are not a true indication of oviposition and feeding behaviour under normal conditions. Field crops frequently injured include alfalfa, barley, Bermuda grass, buckwheat, cotton, clover, maize, oat, millet, peanut, rice, ryegrass, sorghum, sugar beet, Sudan grass, soybean, sugarcane, timothy, tobacco and wheat (Montezano et al. 2018).

Among vegetable crops, only sweet maize is regularly damaged, but others are attacked occasionally. Other crops sometimes injured are apple, grape, orange, papaya, peach, strawberry, and many flowers. Weeds known to serve as hosts include bent grass, *Agrostis* spp., crabgrass, *Digitaria* spp., Johnson grass, *Sorghum halepense,* morning glory, *Ipomoea* spp., nutsedge, *Cyperus* spp., pigweed, *Amaranthus* spp. and sandspur, *Cenchrus tribuloides* (Silva et al. 2017).

There are some pieces of evidence that fall armyworm strains existed, based primarily on their host plant preferences. One strain is found to feed principally on corn, but also on sorghum, cotton, and a few other hosts if they are found growing near the primary hosts. The other strains found feed principally on rice, Bermuda grass, and Johnson grass (Dumas et al.2015).

FAW Haplotypes

FAW consists of two strains adapted to different host plants. There are two strains of FAW: the corn strain "C," which liked maize, sorghum, and cotton, and the rice strain "R," which favoured rice and turf grass (Nagoshi and Meagher 2005). The two strains were found morphologically identical but differed in pheromone compositions, mating behaviour and host range. Matings between the two strains resulted in viable offspring. A significant reduction in mating success was seen due to crosses of the two strains, which together with the behavioral and biochemical differences suggested that the two strains are in a state of sympatric speciation. Based on polymorphisms in the Cytochrome oxidase subunit I gene (COI), research on molecular genetic diversity implies that the FAW population in India belonged to the 'R' strain. Later, using additional markers, it was discovered that the Indian FAW population was predominately of type "C" by Tpi and "R" by COI. This strongly suggested that inter-strain hybrids of FAW in Africa and India originated from a common small founder population (Nagoshi et al. 2019).

Damage Symptoms

Constant fecundity of the insect in favorable environmental conditions is expected to result in substantial crop loss (Goergen et al. 2016). The larvae are found to eat both the plant's vegetative and reproductive components. Young larvae initially consumed leaf tissue from one side, leaving the opposite epidermal layer intact. By the second or third instar, larvae were

found to make pinholes in leaves and ate from the edge of the leaves inward. Feeding in the whorl of corn often produced a characteristic row of perforations in the leaves. Larval densities are usually reduced to one to two per plant when larvae feed on close proximity to one another, due to cannibalistic behavior. Older larvae caused extensive defoliation, often leaving only the ribs and stalks of corn plants or a ragged or torn appearance. Marenco et al. (1992) studied the effects of fall armyworm injury on early vegetative growth of sweet corn in Florida. They reported that the early whorl stage was least sensitive to injury, the mid whorl stage intermediate, and the late whorl stage were most sensitive to injury. Further, they noted that mean densities of 0.2 to 0.8 larvae per plant during the late whorl stage were found to reduce yield by 5 to 20 percent.

Larvae also burrowed into the growing point (bud, whorl, etc.), destroying the growth potential of plants, or clipping the leaves. In corn, they sometimes burrowed into the ear, feeding on kernels in the same manner as corn earworm, *Helicoverpa* zea. Unlike corn earworm, which tend to feed down through the silk before attacking the kernels at the tip of the ear, fall armyworm was found to feed by burrowing through the husk on the side of the ear. Windowed holes and moist sawdust-like frass mostly in the form of lumps, near the funnel and upper leaves, paved farmers for easily spotted signs of larval feeding. Dead heart is a symptom caused by the feeding of young plants through the whorl. Older larvae stayed inside the funnel, feeding was mostly observed during the night. Also, nocturnal feeding on maize cobs or kernels lowered yield and quality (Capinera 2002).

Pannuti et al. (2016) studied larval feeding behavior and reported that although young (vegetative stage) leaf tissue is suitable for growth and survival, on more mature plants the leaf tissue was unsuitable and the larvae were found to settle and feed in the ear zone, particularly on the silk tissues. However, silk was not very suitable for growth. FAW larvae caused significant harm to maize by eating immature leaf whorls, ears, and tassels, which occasionally resulted in a complete yield loss (Sarmento et al. 2002). Larvae attained fastest rate of development with corn kernels. Although the closed tassel was suitable for survival, it resulted in poor growth. Thus, tassel tissue may be suitable for initial feeding, perhaps until the larvae locate the silk and ears, but feeding only on tassel tissue is suboptimal.

Biology and Life cycle

A key feature of FAW biology is that it doesn't undergo diapause and several generations can overlap within a single crop when conditions are suitable (Du Plessis et al. 2020). Indeed in several African countries, FAW generation was continuous throughout the year, wherever host plants were available, including off-season and irrigated crops. In such areas, build-up of the population is more likely and main-season crops are more likely to be infested early. This is in contrast with the Americas where the cooer climate killed the pest and the damage was being caused by migrating moths (Westbrook 2006).

Life Cycle

The FAW life cycle is completed in a month (at a daily temperature of ~28°C) during the warm summer months but extended to 60-90 days in cooler temperatures. FAW has no biological resting period (diapause) accordingly, FAW infestations occurred continuously throughout the year where the pest was found endemic. In non-endemic areas, migratory FAW arrived when environmental conditions were favorable, allowing as few as one generations before they become locally extinct (Prasanna et al.2018).

Egg Stage

The egg, dome dome-shaped with a flattened base and curved upward to a broadly rounded at the apex. The egg measured about 0.4 mm in diameter and 0.3 mm in height. The number of eggs per mass varied considerably but is often 100 to 200 and the total egg production per female averaged about 1500 with a maximum of over 2,000. Eggs were sometimes deposited in layers, but most eggs were seen spread over a single layer attached to foliage. The female also deposited a layer of greyish scales between the eggs and over the egg mass, imparting a furry or moldy appearance. The duration of the egg stage was about 2 to 3 days in the warm summer months (Kalleshwaraswamy et al. 2018).

Larval Stage

The FAW typically had six larval instars. Young larvae were green-coloured with blackheads, later the head turned into orange in the second instar. Head capsule width ranged from about 0.3 mm (instar 1) to 2.6 mm (instar 6) and larvae attained the length of about 1 mm (instar 1) to 45 mm (instar 6). In the third instar, the body surface had brownish hairs with lateral white lines. In the fourth to sixth instars, the head was reddish brown, mottled with white lines. Elevated spots occur dorsally on the body, they are usually dark in color and beared spines. The face of the mature larva was marked with an inverted "Y" shaped white marking on the epidermis of the larva which was rough or granular in texture when examined closely. In addition to the typical brownish form of the FAW larva, the larva may be mostly green dorsally. In the green form, the dorsal elevated spots were pale rather than dark (Levy and Habeck 1976). The clear identification of FAW was due to four large spots in square shaped from the second last segment of the larva. Larvae concealed themselves during the brightest time of the day. The duration of the larval stage was 14 days during the warm summer months and 30 days during cooler weather. Mean development time was determined to be 3.3, 1.7, 1.5, 1.5, 2.0, and 3.7 days for instars 1 to 6, respectively, when larvae were reared at 25°C (Pitre and Hogg 1983).

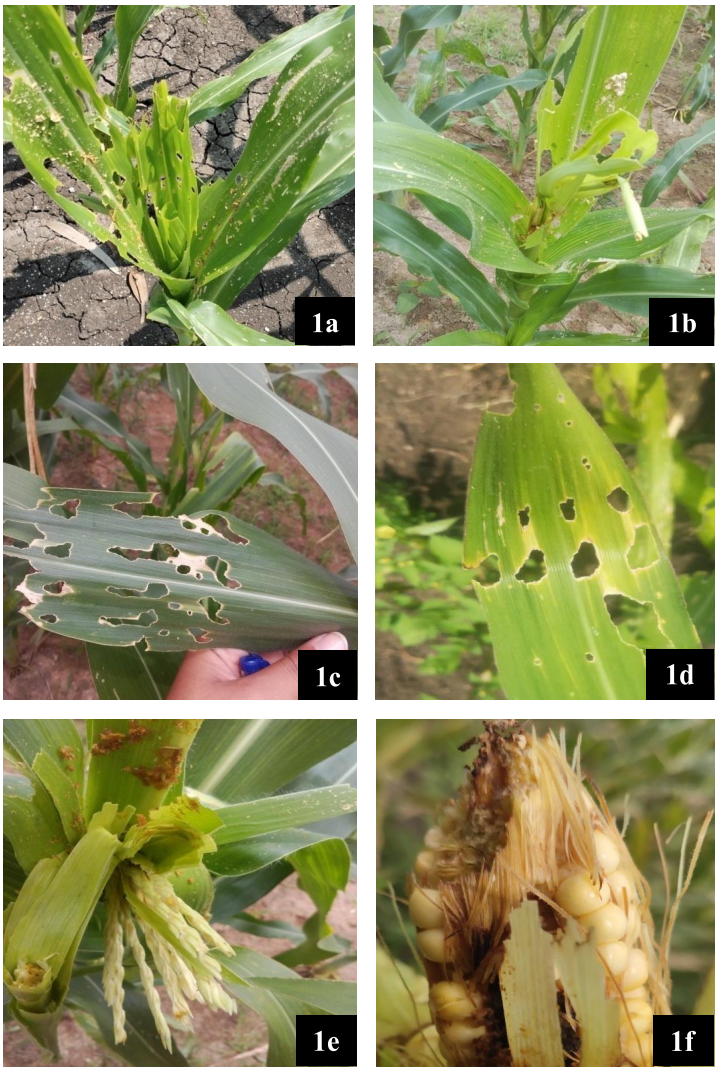
Pupal Stage

FAW larvae normally pupated in the soil at a depth of 2 to 8 cm. The larva constructs a loose cocoon by tying it together with a particle of soil with silk. The cocoon was oval with 20 to 30 mm in length. If the soil was found too hard, larvae webbed together with leaf debris and other material to form a cocoon on the soil surface. The pupa was reddish brown, measuring 14 to 18 mm in length and about 4.5 mm in width. Duration of the pupal stage was about 8 to 9 days during the summer but reached 20 to 30 days during cooler weather. The pupal stage of FAW cannot withstand protracted periods of cold weather (Kenis et al. 2022).

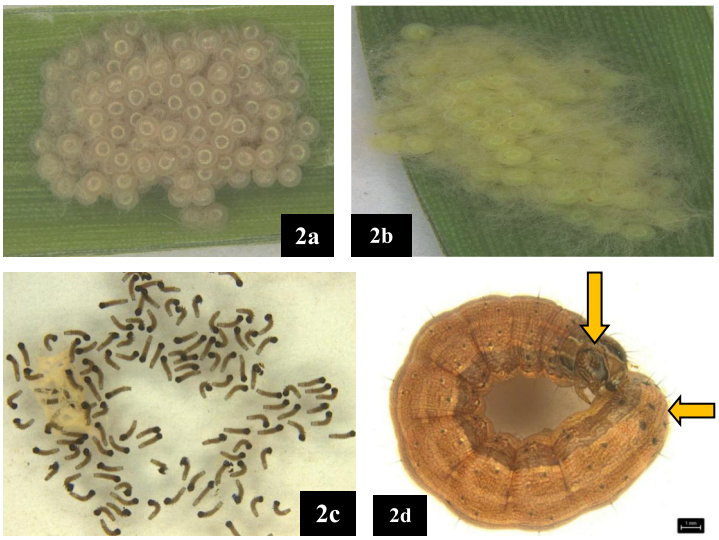
Adult Stage

Adult FAW moths had a wingspan of 32 to 40 mm. In the male moth, the forewing was shaded grey and brown, with triangular white spots at the tip and near the center of the wing. The forewings of females were less distinctly marked and ranged from a uniform greyish brown to a fine mottling of grey and brown. The hind wing is iridescent silver-white with a narrow dark border in both sexes (Sparks 1979). Adults are nocturnal

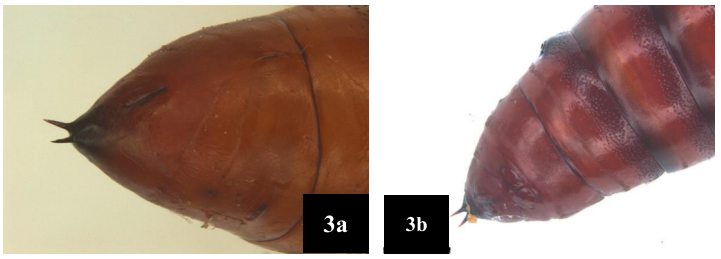
and are most active during warm and humid evenings. After a preoviposition period of 3 to 4 days, the female moth normally deposited most of her eggs during the first 4 to 5 days of life, but some oviposition also occurred for up to 3 weeks. The duration of adult life is estimated to average about 10 days, with a range of about 7-21 days (Kalleshwaraswamy et al. 2018).

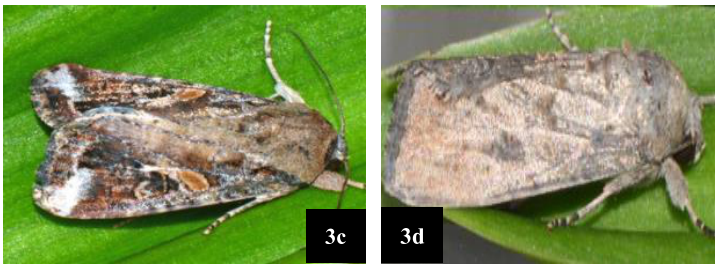


1a,b -Whorl Damage 1c,d - Leaf Damage 1e – Tassel Damage, 1f - Ear Damage



2a, b – Eggmass, 2c – Neonates, 2d- V instar (Down arrow inverted Y shaped marking on face; Left Arrow- square shaped four spots in the second last segment); 2e- Male Pupa; 2f- Female Pupa of the fall armyworm, S. frugiperda





3a- MalePupa ; 3b- Female Pupa; 3c- Male Adult; 3d-Female Pupa; 3e-Adult Mating

Conclusion

The periodical surveys and observations done on the FAW revealed that its reproduction occurs all year, making it a threat to the various crops in the field. More research into the biology and ecology of the FAW is therefore suggested to select an appropriate time for its effective management in the future.

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