An outbreak of Fall Armyworm in Indian Subcontinent : A New Invasive Pest on Maize

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Abbreviations *FAW: Fall Armyworm, INR: Indian Rupees,GDP: Gross Domestic Product*

Abstract

The Fall armyworm (Spodopterafrugiperda, J.E. Smith), an economically crucial polyphagous insect pest native to tropical and subtropical regions of America has reached Asia and noticed first time in maize fields South Karnataka in the Indian subcontinent during May 2018, causing substantial damage to the crop. The pest has invaded most of the maize growing area in India within a short period of two months posing a severe threat to maize growers, challenges to the scientific community and administrators. In the context of its economic importance and destructive nature, the identification, biology and life cycle, nature of damage and extent of yield loss, and management of fall armyworm through cultural practices, mechanical and local controls, biological and synthetic pesticides have been reviewed in detail in the present manuscript. Early planting and intercropping with non-host crops are essential cultural practices to reduce pest incidence. The crop which was monitored during the early vegetative stage showed a good response for synthetic pesticides, while crop damage was largest in late vegetative and pre-flowering stages. The pathways of the introduction of fall armyworm into Indian sub-continent are subject to speculations, however considering the lack of diapause mechanisms, its high spreading ability, and wide host plant range it is likely that the pest will soon be able to colonize most of tropical Asia. Hence, there is an urgent need for developing ecologically sustainable, economically profitable, and socially acceptable integrated pest management strategies to mitigate the impact of the fall armyworm in India and Asia.

Introduction

Maize (Zea mays L.) is one of the widely grown (8.71 million hectares) crops and ranks third next to wheat and paddy in production in India. India ranks fourth in maize production (22.57 million tonnes) in the world with a productivity of 2.56 tonnes per hectare (Annual report, IIMR, 2016). Among the cereals grown in India, it is gaining significant importance on account of its growing demand for diversified uses, especially as animal feed and industrial uses. Maize contributes about 100 billion Indian Rupees (INR) to the agricultural Gross Domestic Product (GDP) at current prices apart from the providing employment to nearly 100 million person-days at the farm and downstream agricultural and industrial sectors. In addition to staple food for human being and quality feed for animals, maize serves as a primary raw material to the industry for the production of starch, oil, protein, alcoholic beverages, food sweeteners and more recently bio-fuel (Ethanol). Being a potential crop in India, maize occupies an essential place as a source of human food (25%), animal feed (12%), poultry feed (49%), industrial products mainly as starch (12%) and 1% each in brewery and seed.

The realized corn grain yield in India (2.56 tonnes per hectare) is far less than global productivity (5.62 tonnes per hectare) due to different abiotic stresses, few important diseases like Turcicum and Maydis Leaf Blights, Downy mildew, charcoal rot and infestation of major insects like stem borer, armyworm and earworms (Director's report, IIMR, 2017). The fall armyworm, a polyphagous insect is a new member to the list of maize pests which is identified a first time in the Indian soil which has threatened the farmers and posed the new challenges to the scientists.

The Fall Armyworm (Spodopterafrugiperda, J. E. Smith), (Lepidoptera: Noctuidae), FAW, is an insect native to tropical and subtropical regions of the Americas (Sparks, 1986; Hruska and Gould, 1997; Nagoshi, 2009; FAO, 2018). The pest accounts for annual crop losses of over US$ 500 million throughout the South-East United States and the Atlantic coast (Young, 1979). In Brazil also FAW is a most destructive and economically important pest in maize (Cruz et al., 1999; Lima et al., 2010; Carvalho et al., 2013; Huang et al., 2014)with an annual estimated loss at U$400 million due to attack of this insect (Figueiredo et al., 2005;Cock et al., 2017). During 2016, the FAW was first noticed in Central and

Figure 1 - Young larva with the presence of inverted 'Y' shaped mark on the front head and four dark spots on top of eighth abdominal segment

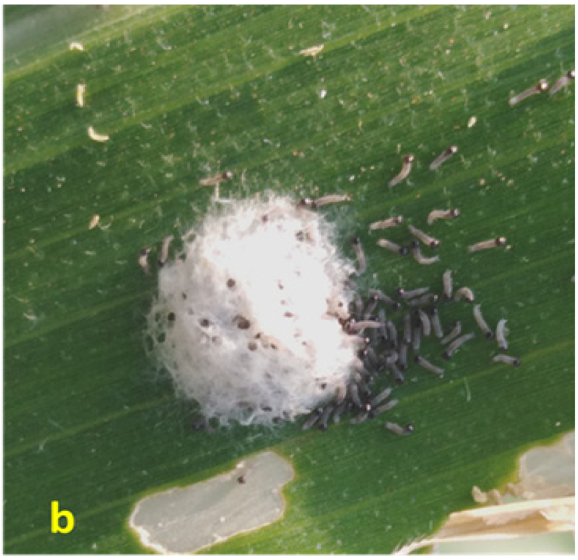
West Africa-Benin, Nigeria, Sao Tome, and Principe, and Togo (Goergen et al., 2016) and further reported and confirmed in the whole of mainland Southern Africa (except Lesotho), Seychelles and Madagascar (FAO, 2018). Later in 2017, the pest was spread to Ghana (Cock et al., 2017) and by January 2018 it was spread toabout44 Sub Saharan African countries, except Djibouti, Eritrea, and Lesotho. A recent investigation by CABI in 12 African countries found that FAW has the potential to inflict yield losses of maize valued at US$2.5-6.2 billion annually (Conrow, 2018).

The FAW was first noticed in the Indian subcontinent at Bangalore Rural and Chikkaballapur districts during May and June 2018 (Ganiger et al., 2018) and South Karnataka during the first fortnight of July 2018 (ICAR-NBAIR pest alert, 2018). An investigation by agricultural officials and researchers found FAW in other districts, including Chikkamagaluru, Chitradurga, and Davangere, where 40 to 70 percent of the crops were infested. The molecular identification of larval populations collected from different regions of South and Central Karnataka confirmed 100% match with populations from Canada and Costa Rica (ICAR-NBAIR pest alert, 2018). Within a short period (By August 2018) this pest has been reported in most of the corn-growing states of India and made the farmers feel panic about the incidence. The modality of introduction, the capacity of biological and ecological adaptation of FAW across India is still speculative. The has FAO warned that FAW could threaten the food security and livelihoods of millions of small-scale farmers in Asia as the invasive crop-eating pest is highly likely to spread further from India, with South East Asia and South China most at risk (www.fao.org). Farmers will need substantial support to sustainably manage this pest in their cropping systems. With this context, in the present article, an effort has been made to discuss the background, biology and life cycle, nature of the damage, and integrated management of FAW.

Description

The fall armyworm larvae is a cosmopolitan (Luginbill, 1928), polyphagous pest which can feed on about 80 different plant species including crops such as corn, rice, small millets, sugarcane, alfalfa, soybean, sorghum, cotton and vegetable crops (Wiseman et al., 1966; Sparks, 1979; Pitre, and Hogg, 1983; Pogue, 2002; Capinera, 2008). Many studies reported that FAW could colonize forage crops and grass species (Buntin, 1986).FAW larvae can be differentiated from

*Figure 2 - **A** – Egg mass of FAW on maize leaves. **B**- Hatched larvae of FAW from the egg mass*



other species by looking at the head. The head has a prominent white, inverted Y-shaped mark between the eyes (Figure 1). The larvae are smooth-skinned, green, or light tan to almost black body color with three yellow stripes and a dark stripe down the back (Capinera, 2000). However, true armyworm larvae have a greenish-brown or gray head with a network of lines. There is an equally broad, wavy, yellow stripe, splotched with red next to the dark stripe. Early instar larvae are dark green with blackheads and usually found in groups on the plant. Larvae have four pairs of abdominal prolegs and a pair of legs at the end of the body. Four dark spots are arranged in a square on top of the 8th abdominal segment. The full-grown larvae are about 1.25 - 1.50 inches in length(Bohnenblust and Tooker, 2012)

Life Cycle

Fall armyworms overwinter and migrate from one location to another. The moth can fly up to 100 km per night (Johnson, 1987). Their arrival time varies from year to year, but the first reported adult captures usually begin around May to June. Adults are nocturnal and mate in the evening when calling to males from the top of the crop canopy by releasing a sex pheromone. Females may mate several times and use pheromones to attract males (Sparks, 1979). Males follow the pheromone plume to locate the females and when populations are high males can be seen flying in groups attempting to find a mate. Upon arrival to a new field, the female moth lay masses of 100-200 (Capinera, 2000) spherical, white to gray eggs on leaves of green plants, including important crop hosts. The maximum fecundity rate is900-1000 (Luginbill, 1928; Johnson, 1987), 1500-2000 (Capinera, 2000) eggs per female. After egg deposition, the female deposits grayish scales over the egg mass, ensuring a hairy or moldy appearance (Figure 2). The eggs hatch about five to seven days after oviposition. The newly hatched pale green with blackheads larvae begins to feed on plants near the ground or in protected areas such as the whorl of corn plants. During the second instar, the head turns an orange-brown color. They usually go unnoticed until they are approximately an inch long. Larval densities are often reduced to one or two per plant in heavy infestations as larvae can exhibit cannibalistic behavior (Johnson, 1987; Chapman, 2000). The larvae can be traced hiding in the whorl of the corn plant. The larva goes through six instars (about 15 to 18 days) before burrowing one to three inches into the soil to pupate. Adults emerge about one to five weeks after pupation depending on soil temperature. Typically, FAW requires about 30 to 45 days to complete one generation.

Nature of damage and extent of yield loss

FAW larvae can damage maize crop at various stages of development by feeding on leaf or ear tissues. The foliage damage is generally typical and feeding on ears can be noticed under heavy infestations. The larva can be found in the whorl feeding on young leaves at 13 days (Harrison, 1986), 14 to 21 days after sowing (Melo and Silva, 1987).In the experimental plots at Main Agricultural Research Station, Dharwad, the foliage feeding was observed as early as the two-leaf stage of the crop (8 days after sowing) (Figure 3). The early (first instar larvae) scrapes leaves and pin-hole symptoms resemble the small holes from stem borer and windowpane feeding injury from European corn borer. However, European corn borer larvae bore into the stalk, while the fall armyworm foliage damage is characterized by ragged appearance as they unfurl from the whorl (Figure 4). In the later vegetative stages, the constant feeding results in skeletonized leaves and heavily windowed whorls(Goergen et al., 2016). Unlike real armyworm (Mythimnaseperata), FAW actively feeds during the day, particularly early in the morning and late afternoon, consuming large amounts of leaf tissue. Larvae can be found deep in the whorl, often protected by moist yellowish-brown sawdust-like frass near the whorl and upper leaves of the plant. The injury to the crop is by foliar consumption and indirect damage to grain production due to a reduction in photosynthetic area (Pitre and Hogg, 1983; Melo and Silva, 1987; Capinera, 2000). Up to 22.6% yield reductions occurred when plants were infested between the first and second weeks after germination. The yields of plants infested 3 and four weeks after germination were intermediate without showing any particular trend (Evans and Stansly, 1990). Infestation with 30 S. frugiperdalarvae per plant resulted in large leaf feeding damage, no reduction in ear height, and a 13% yield reduction (Williams and Davis, 1990). Significant yield losses of 17% were observed when 20 or 100% of the plants were artificially infested by keeping egg masses on corn at the mid-whorl growth stage. The relationship between leaf damage ratings and yield was linear and inverse. Yield losses were directly related to a reduction in kernel numbers on ears from infested plants (Cruz and Turpin, 1983).In another study, 21 to 57.6 % yield reduction was observed when the maize plots with different genotypes were artificially infested with young larvae (Cruz et al., 1999).

Figure 3 - FAW infestation at eight days after germination of maize

Although this pest has been extensively studied in the Americas and Africa, a little is known about its larval movement and feeding behavior on reproductive compared to vegetative corn stages. Larval feeding on silk reduces pollination, and that causes a reduction in kernel number per ear (Harrison, 1984). Larval feeding behavior reproductive stage of crop indicated that maize leaves of reproductive plants were not suitable for early instar development, but silk and kernel tissues had a positive effect on survival and development of larvae on reproductive stage (Pannuti et al., 2015). Such feeding establishment may expose the larvae to a lower toxin concentration found in corn kernels (Nguyen and Jehle, 2007; Burkness et al., 2011). The ear damage is similar to the damage caused by the corn earworm, chewed kernels and visible frass, except that fall armyworm tends to burrow through the husk instead of feeding down through the silks

Integrated pest management

The farmers need not panic much as the maize plants can compensate significant damage by the Fall Armyworm (FAO, 2018). A review of studies in America on the response of maize yield to FAW infestation showed that the crop damage is not devastating, whereas few studies showed yield reductions due to FAW of over 50 percent. Majority of the field trials show yield reductions of less than 20 percent, even with high FAW infestation (up to 100 percent plants infested). Maize

*Figure 4 - **A** – Pinholes on leaves due to FAW infestation **B**- FAW feeding on the whorl **C** – Ragged appearance of leaves. **D**- FAW feeding on the tassel*

plants can compensate for foliar damage, especially if there are proper plant nutrition and moisture.

Genetic resistance

In some occasions, breeding for insect resistance is most important over breeding for yield or other agronomic qualities(Painter, 1951). The long term solution for any disease or pest infestation is the identification of resistant germplasm and elite lines which can be utilized as the potential parents in the development of resistant/tolerant varieties and hybrids which can prevent the early damage of the seedlings. Resistance to Spodopterafrugiperda has been studied extensively, and a series of maize germplasm lines with resistance have been developed at Mississippi State, MS (Brooks et al., 2007). The first germplasm line as a source of resistance to FAW released by USDA-ARS at Mississippi State, America was Mp496 (Scott and Davis, 1981). The germplasm lines Mp708 and FAW7061 showed a resistant reaction to S. frugiperdaunder artificial infestation (Ni et al., 2011). Fall armyworm larvae were placed in the whorls of susceptible and resistant corn genotypes at the 5 and ten leaf stages of growth. Few larvae were recovered from the resistant genotypes than susceptible ones after eight days of infestation. Larvae produced on the resistant corn genotypes were also smaller than those produced on susceptible genotypes (Williams et al., 1982). The widespread approach to FAW resistant maize in America is use of genetically modified (GM) crops containing Bacillus thermogenesis genes (Abrahams et al., 2017) and this may be one of the options for control of this pest in India However, GM crops have not been approved in India; therefore, efforts should be made to develop FAW resistant genotypes with the conventional breeding approach.

Cultural practices

The management of FAW in maize fields begins with prevention of the pest incidence by adopting different cultural practices. Reduced tillage seems to have little effect on FAW populations(All, 1988), though delayed invasion has been observed by moths of fields with extensive crop residue, thus delaying and reducing the need for chemical suppression (Roberts and All 1993). Early planting and growing early maturing varieties are one of the most important cultural practice employed widely in South American states. The early harvest allows maize ears to escape the higher armyworm densities that develop later in the season (Mitchell, 1978). Some farmers in Kenya reported significant yield losses to FAW on late-planted maize plots during January 2018, compared to adjacent plots which were planted earlier (FAO, 2018). Avoidingstaggered planting (i.e., planting of fields at different dates in the same region) is another practice that can be adopted as this would facilitate continued feeding and breeding for FAW (FAO, 2018). This is one of the most important recommendations for smallholders. The farmers should avoid unbalanced inorganic fertilization of maize (especially excessive nitrogen use) that can increase oviposition by female and consider maintaining good soil health and adequate moisture essential to growing healthy plants, which can better withstand pest infestation and damage.

Further, an essential aspect of prevention of FAW infestations is by maintaining plant diversity on farms. Intercropping maize non-host crops are useful means of maintaining diversity rather than host plants. Even if many female moths are found in the field, if egg masses are not laid on maize plants, or if very young larvae do not move onto maize plants, then the maize will not be infested by FAW (Figure 5). Farmers in Central America have noticed fewer pest attacks when they plant maize intercropped with other crops such as beans and squash. Maize-bean intercrop in Nicaragua reduced FAW attack on maize by 20-30% (Abrahams et al., 2017). Intercropping with grasses also exhibited good results in controlling FAW populations. Push-pull is a habitat management strategy in Africa; the technology entails a repellent intercrop (Desmodium as a "push") and an attractive trap plant (Napier/Brachiaria grass as a "pull"). Observations on FAW by about 250 farmers who had adopted the climate-smart Push-pull technology in drier areas of Kenya, Uganda, and Tanzania indicated a reduction of FAW larvae per plant and subsequent reduction in plant damage. Further surveys on climate-smart Push-pull and monocropped maize farms indicated 82.7 percent reduction in an average number of larvae per plant and 86.7 percent reduction in plant damage per plot in climate-adapted push-pull compared to maize monocrop plots (Midega et al., 2018).

Figure 5 - a Lower infestation of FAW in intercropped maize

Mechanical and local controls

A significant management option for small and marginal farmers is to monitor their fields regularly during the vegetative stage and crush egg masses and young larvae. Some smallholder farmers in America reported that pouring ash, sand, sawdust, or dirt into whorls to control FAW larvae (FAO, 2018). Ash, sand, and sawdust may desiccate young larvae. Maize farmers in Central America and Africa also report the use of lime, salt, oil, and soaps as control measures. Lime and ash are alkaline. Some farmers also reported the success in the use of local botanicals like neem, hot pepper, and local plants. Minimal formal scientific studies have been carried out on these local controls, but many farmers in Africa also reported success with them (FAO, 2018).

Use of biological and synthetic insecticides

The ideal time of spraying is more critical than the amount of insecticide to adequate control of the fall armyworm (Pogetto et al., 2012). Early infestations should be controlled at lower levels than later infestations to achieve the same economic result (Evans and Stansly, 1990). Foster (1989) reported that keeping the plants free of larvae during the vegetative period reduced the number of sprays needed during the silking period. The late vegetative or flowering time make it challenging to manage the pest because insecticide application may require specialized

Figure 6 - Broadcasting and whorl application of poison bait in the FAW infested field

equipment to pass over tall maize. In India, as the FAW is the new pest in maize, the scientific studies are to be carried out to control the FAW infestation using bio-pesticides and chemical pesticides. However, the farmers have reported the success in the control of this pest at early vegetative stages of the crop using the Adhoc recommended bio-pesticides like Nomuraearileyi @ 1.0 gm or Metarrhiziumanisophliae @ 2.0 gm/liter of water and insecticidesviz., Emamectin benzoate 5 SC @ 0.2 ml or Spinosad 45 SC @ 0.2 ml or Chroranthraniliprole18.5% SC @ 0.2 ml/ litre of water (Patil et al., 2018). The application of poison bait in the whorls at vegetative and broadcasting in the grown-up crop has also shown good response to control the infestation. For one hectare area, mix 5.0 kg of jaggery in 4-5 liter of water and prepare the jaggery water. Add Monocrotophos 36 SL @625.0 ml to the jaggery water. Further, mix 50 kg of rice or wheat bran to jaggery water with the chemical and mix it properly and pack in the gunny or plastic bags and allow for fermentation for 48 hours (R. K. Patil et al., 2018). Then apply the fermented bait either through broadcasting or in maize whorls, preferably in the evening hours (Figure 6).

Apart from these management strategies, the FAW has many natural enemies who have the potential to reduce the FAW populations substantially. The important predatory insects are earwigs, ladybird beetles, flower bugs, and ants (FAO, 2018). Luginbill (1928) recognisedOriusinsidiosus as a primary predator of the FAW, preying upon both eggs and larvae. The presence and abundance of O. insidiosus in maize have been reported by several authors(Isenhour et al., 1990; Mendes et al., 2008). The earwig Doruluteipes is an essential predatory insect for FAW (Sueldo et al., 2010), that has been recommended by the Maize and Sorghum Agricultural Research Center of the Brazilian Agricultural Research Corporation in Brazil(Cruz, 2007). It can be noted that predators may be quite significant, as Pair and Gross (1984) reported 60 to 90 percent loss of pupae to predators in Georgia.Numerousparasitoids like Trichogramma spp. Moreover, microbial pathogens, such as fungi, bacteria, viruses, protozoa, and nematodes, which cause lethal infections (Gardner et al. 1984; FAO, 2018). Trichogrammaspp have been used for controlling insect pests in crops such as corn, sugarcane, tomatoes, rice, cotton, sugar beet, apple, prune, vegetables, and forests (Parra et al. 2010). In Latin America, Trichogrammapretiosum is produced commercially, and releases of around 100,000/ hectare are recommended for FAW (Abrahams et al., 2017). Telenomusremus Nixon (Hym., Scelionidae) is another egg parasitoid suitable as a control agent for Spodopteraspp that is reported to be mass-reared for commercial or experimental purposes in several Latin American countries (Cave, 2000). The wasp parasitoidsCotesiamarginiventris (Cresson) and Chelonustexanus (Cresson) are also most frequently reared from larvae in the United States. Among fly parasitoids, the most abundant is usually Archytasmarmoratus (Townsend)(Luginbill,1928 and Vickery,1929). The Spodopterafrugiperda nuclear polyhedrosis virus (NPV), and the fungi Entomophagaaulicae, Nomuraearileyi, and Eryniaradicanscause high levels of mortality in some populations(Gardner et al. 1984).

Conclusions

The pathways of the introduction of fall armyworm into Indian sub-continent are subject to speculations. The FAW has a feature of remarkable dispersal capacity that is evolved as part of its life history strategy. How far the pest has already expanded into the Indian sub-continent remains to be determined, however considering the lack of diapause mechanisms, its high spreading ability and wide host plant range it is likely that the pest will soon be able to colonize most of tropical Asia. Hence, there is an urgent need for developing ecologically sustainable, economically profitable, and socially acceptable integrated pest management strategies to mitigate the impact of the fall armyworm in India and Asia.

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