

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 Turicum 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 US\$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 to about 44 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).

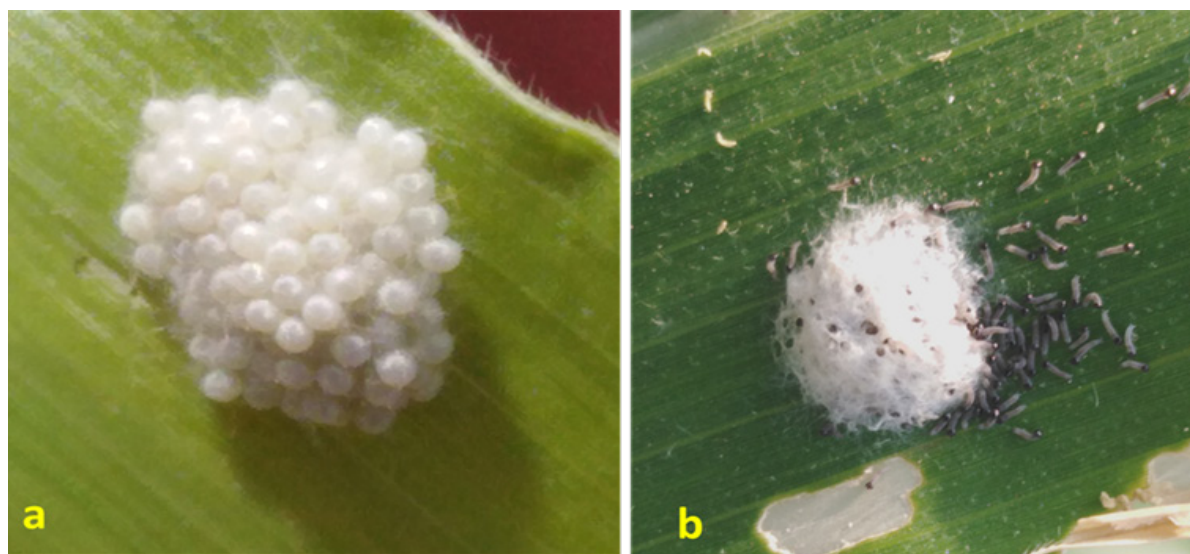
The FAW was first noticed in the Indian subcontinent at Bangalore Rural and Chikkaballapur districts during May and June 2018 (Ganiger et al., 2018) and South Karnataka during the first fortnight of July 2018 (ICAR-NBAIR pest alert, 2018). An investigation by agricultural officials and researchers found 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 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, splotted 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 is 900-1000 (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 (*Mythimna separata*), 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. frugiperda* larvae 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).

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

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



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 *Spodoptera frugiperda* 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. frugiperda* under 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 thuringiensis* 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). Avoiding staggered 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

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

Figure 5 - a Lower infestation of FAW in intercropped maize



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).

Mechanical and local controls

A significant management option for small and marginal farmers is to monitor their fields regularly during 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 *Metarrhiziumanisopliae* @ 2.0 gm/liter of water and insecticides viz., Emamectin benzoate 5 SC @ 0.2 ml or Spinosad 45 SC @ 0.2 ml or Chlorantraniliprole 18.5% 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) recognised *Orius insidiosus* 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. Numerous parasitoids like *Trichogramma* spp. Moreover, microbial pathogens, such as fungi, bacteria, viruses, protozoa, and nematodes, which cause lethal infections (Gardner et al. 1984; FAO, 2018). *Trichogramma* spp 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, *Trichogramma pretiosum* is produced commercially, and releases of around 100,000/ hectare are recommended for FAW (Abrahams et al., 2017). *Telenomus remus* Nixon (Hym., Scelionidae) is another egg parasitoid suitable as a control agent for *Spodoptera* spp that is reported to be mass-reared for commercial or experimental purposes in

several Latin American countries (Cave, 2000). The wasp parasitoids *Cotesia marginiventris* (Cresson) and *Chelonustexanus* (Cresson) are also most frequently reared from larvae in the United States. Among fly parasitoids, the most abundant is usually *Archytas marmoratus* (Townsend) (Luginbill, 1928 and Vickery, 1929). The *Spodoptera frugiperda* nuclear polyhedrosis virus (NPV), and the fungi *Entomophaga aulicae*, *Nomuraearileyi*, and *Eryniaradicans* cause 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.

References

- Abrahams Phil, Melanie Bateman, Tim Beale, Victor Clottey, Matthew Cock, Yelitza Colmenarez, Natalia Corniani, Roger Day, Regan Early, Julien Godwin, Jose Gomez, Moreno PG, Murphy ST, Birgitta OM, Noah Phiri, Corin Pratt, Silvia Silvestri, Arne Witt, 2017. Fall Armyworm: Impacts and Implications for Africa. CABI, 1-141
- All JN, 1988. Fall armyworm (Lepidoptera: Noctuidae) infestations in no-tillage cropping systems. *Florida Entomol* 71: 268-272
- Annual report, 2016, Indian Institute of Maize Research, Ludhiana, 1-75
- Bohnenblust Eric and Tooker John, 2012. Entomological notes. Pennsylvania State University.
- Johnson SJ, 1987. Migration and the life history strategy of the fall armyworm, *Spodoptera frugiperda* in the Western Hemisphere. *Insect Sci. Appl* 8:543-549.
- Brooks TD, Bushman BS, Williams WP, McMullen MD, and Buckley PM, 2007. The genetic basis of resistance to fall armyworm (Lepidoptera: Noctuidae) and southwestern corn borer (Lepidoptera: Crambidae) leaf-feeding damage in maize. *J. Econ. Entomol* 100:1470-1475
- Buntin GD, 1986. A review of plant response to fall armyworm, *Spodoptera frugiperda* (J. E. Smith), injury in selected field and forage crops. *Florida Entomol* 69(3):549-559
- Burkness EC, O'Rourke PK., and Hutchison WD, 2011. Cross-pollination of nontransgenic corn ears with transgenic bt corn: efficacy against lepidopteran pests and implications for resistance management. *J. Econ. Entomol* 104(5):1476-1479, DOI: <http://dx.doi.org/10.1603/EC11081>
- Capinera JL, 2000. Fall armyworm, *Spodoptera frugiperda* (J.E. Smith) (Insecta:Lepidoptera: Noctuidae). The University of Florida, Institute of Food and Agricultural Sciences. (UF/IFAS), Gainesville, FL
- Capinera JL, 2008. *Encyclopedia of entomology*, 2nd ed. Springer, Dordrecht, The Netherlands.
- Carvalho RA, Omoto C, Field LM, Williamson M.S, and Bass C, 2013. Investigating the molecular mechanisms of organophosphate and pyrethroid resistance in the fall armyworm *Spodoptera frugiperda*. *PLoS ONE* 8: 62268
- Cave, RD, 2000. Biology, ecology, and use in pest management of *Telenomus remus* Nixon. *Biocontrol News and Information* 21(1), pp.21N-26N.
- Chapman JW, Williams T, Martinez AM, Cisneros J, Caballero P, Cave RD, and Goulson D, 2000. Does cannibalism in *Spodoptera frugiperda* (Lepidoptera: Noctuidae) reduce the risk of predation? *Behav Ecol Sociobiol* 48:321-327
- Cock MJW, 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. *Sci Rep* 7:4103; doi:10.1038/s41598-01704238-y
- Conrow Joan, 2018. Destructive fall armyworm now invading India. <https://allianceforscience.cornell.edu>
- Cruz I, 2007. Alternativas para o controle da lagarta-do-cartucho, *Spodoptera frugiperda* e principais cuidados no uso de milho transgênicos resistentes a insetos. In: Fancelli, A. L.; Dourado Neto, D. (Ed.). *Milho - Fatores determinantes da produtividade*. Piracicaba: USPESALQ
- Cruz I and Turpin FT, 1983. Yield impact of larval infestations of the Fall armyworm (Lepidoptera: Noctuidae) to the midwhorl growth stage of corn. *J Economic Entomol* 76(5):1052-1054
- Cruz I, Figueiredo MLC, Oliveira AC, and

- Vasconcelos CA, 1999. Damage of *Spodoptera frugiperda* (J.E. Smith) in different maize genotypes cultivated in soil under three levels of aluminum saturation. *Intl J Pest Manage* 45(4):293-296
- Director's report, 2017. Indian Institute of Maize Research, Ludhiana, 1-10
- Evans DC and PA Stansly, 1990. Weekly Economic Injury Levels for Fall Armyworm (Lepidoptera: Noctuidae) Infestation of Corn in Lowland Ecuador. *J Economic Entomol* 83 (6):2452-2454
- FAO, 2018. Integrated management of the Fall Armyworm on maize: A guide for Farmer Field Schools in Africa, 1-139
- Figueiredo MLC, Pentead-Dias AM, Cruz I, 2005. Danos provocados por *Spodoptera frugiperda* na produção de matéria seca e nos rendimentos de grãos, na cultura do milho. *Sete Lagoas: Embrapa/CNPMS*, p6
- Foster RE, 1989. Strategies for protecting sweet corn ears from damage by fall armyworms (Lepidoptera: Noctuidae) in southern Florida. *Florida Entomol* 72: 146-151.
- Ganiger PC, Yeshwanth HM, Muralimohan K, Vinay N, Kumar ARV, and Chandrashekhara K, 2018. The occurrence of the new invasive pest, fall armyworm, *Spodoptera frugiperda* (J.E. Smith) (Lepidoptera: Noctuidae), in the maize fields of Karnataka, India. *CurrSci* 115 (4): 25
- Gardner WA, Raymond Noblet, and Schwehr RD, 1984. The Potential of Microbial Agents in Managing Populations of the Fall Armyworm (Lepidoptera: Noctuidae). *The Florida Entomol* 67 (3) : 325-332
- Goergen G, Lava K. P, Sankung SB, AbouTogola and ManueleTamo, 2016. First Report of Outbreaks of the Fall Armyworm *Spodoptera frugiperda* (J E Smith) (Lepidoptera, Noctuidae), a New Alien Invasive Pest in West and Central Africa. *PLoS ONE* DOI:10.1371/journal.pone.0165632
- Harrison FP, 1984. Observations on the infestations on corn by fall armyworm (Lepidoptera: Noctuidae) concerning plant maturity. *Florida Entomol* 67:333-335
- Harrison FP, 1986. Oviposition and subsequent infestations of corn by the fall armyworm. *Florida Entomol* 69:588-592
- Hruska AJ and 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. *J Economic Entomol* 90(2):611-622
- Huang F, Qureshi JA, Meagher RL, Reisig DD, Head GP, and Andow DA, 2014. Cry1F resistance in fall armyworm *Spodoptera frugiperda*: single gene versus pyramided Bt maize. *PLoS ONE* 9:e112958
- ICAR (Indian Council for Agricultural Research)-NBAIR Pest alert, *Spodoptera frugiperda* (J.E. Smith), 2018
- Isenhour DJ, Layton RC; Wiseman BR, 1990. Potential of adult *Orius insidiosus* (Hemiptera: Anthicoridae) as a predator of the fall armyworm, *Spodoptera frugiperda* (Lepidoptera: Noctuidae) *Biocontrol* 35(2):269-275
- Johnson SJ, 1897. Migration and the life history strategy of the fall armyworm, *Spodoptera frugiperda* in the Western Hemisphere. *Insect Sci Appl* 8: 543-549.
- Lima MS, Silva PSL, Oliveir OF, Silva KMB and Freitas FCL, 2010. Corn yield response to weed and fall armyworm controls. *Planta Daninha* 28(1): 103-111.
- Luginbill P, 1928. The fall armyworm. *USDA Tech Bull* 34: 92
- Melo M and Silva RFP, 1987. Influência de trêscultivares de milho no desenvolvimento de *Spodoptera frugiperda* (J. E. Smith, 1797) (Lepidoptera: Noctuidae). *AnSocEntomol Bras* 16: 37-49
- Mendes SM, Boregas KGB, Fermino TC, Macedo SC, Waquil JM 2008. Aspectos biológicos de *Orius insidiosus* (Say, 1832) (Hemiptera: Anthicoridae) alimentados com ovos de *Spodoptera frugiperda* (J.E. Smith, 1797) (Lepidoptera: Noctuidae). In: CONGRESSO NACIONAL DE MILHO E SORGO, Londrina. Agroenergia, produção de alimentos e mudanças climáticas: desafios para milho e sorgo: trabalhos e palestras. [Londrina]: IAPAR; [Sete Lagoas]: Embrapa Milho e Sorgo.
- Midega CAO, Pittchar J, Pickett JA, Hailu G and Khan ZR, 2018. A climate-adapted push-pull system effectively controls fall armyworm, *Spodoptera frugiperda* (J E Smith), in maize in East Africa. *Crop Prot* 105: 10-15
- Mitchell ER, 1978. Relationship of planting date to damage by earworms in commercial sweet corn in north-central Florida. *Florida Entomol* 61: 251-255
- Nagoshi R, 2009. Can the amount of corn acreage predict fall armyworm (Lepidoptera: Noctuidae) infestation levels in nearby cotton? *J EconEntomol* 102:210-218
- Nguyen HT and Jehle JA, 2007. Quantitative analysis of the seasonal and tissue-specific

- expression of Cry1Ab in transgenic maize Mon810. *J Plant DisProt* 114:82–87
- Ni Xinzhi, Yigen Chen, Bruce EH, Wilson JP, Williams WP, Buntin GD, Roberson JR and Xianchun Li, 2011. Foliar resistance to fall armyworm in corn germplasm lines that confer resistance to root- and ear-feeding insects. *Florida Entomol* 94(4):971-981
- Painter RH, 1951. *Insect Resistance in Crop Plants*. McMillan Company, New York
- Pair SD, Gross Jr HR, 1984. Field mortality of pupae of the fall armyworm, *Spodoptera frugiperda* (J.E. Smith), by predators and a newly discovered parasitoid, *Diapetimorphaintroita*. *J Georgia Entomol Society* 19: 22-26
- Pannuti LER, Baldin ELL, Hunt TE, Paula-Moraes SV, 2015. On-plant larval movement and feeding behavior of fall armyworm (Lepidoptera: Noctuidae) on reproductive corn stages. *Environ Entomol* 45:192-200
- Parra JRP, 2010. Egg parasitoids commercialization in the new world, "Egg parasitoids. Agroecosystems with emphasis on *Trichogramma*" pp373-388. Springer, London
- Pitre HN and Hogg DB, 1983. Development of the fall armyworm on cotton, soybean and corn. *J GaEntomolSoc* 18:187–194
- Pogetto Dal MHFA, Prado EP, Gimenes MJ, Christovam RS, and Rezende DT, 2012. Corn yield reductions with insecticidal sprayings against fall armyworm *Spodoptera frugiperda* (Lepidoptera: Noctuidae). *J Agron* 11 (1):17-21.
- Pogue, GM, 2002. A world revision of the genus *Spodoptera* Guenée (Lepidoptera: Noctuidae). *Mem AmEntomolSoc* 43:1–202.
- Patil RK, Patil RR, Vastrad AS, Mallapur CP, and Hugar PS, 2018. Management of fall armyworm (*Spodoptera frugiperda*) in maize: Extension bulletin.
- Roberts PM and All JN, 1993. Hazard for fall armyworm (Lepidoptera: Noctuidae) infestation of maize in double-cropping systems using sustainable agricultural practices. *Florida Entomologist* 76: 276-283
- Scott GE and Davis FM, 1981. Registration of Mp496 inbred of maize. *Crop Sci* 21:353
- Sparks AN, 1979. A review of the biology of the fall armyworm. *Florida Entomol* 62, 82–87
- Sparks AN, 1986. Fall armyworm (Lepidoptera: Noctuidae) potential for area-wide management. *Florida Entomol* 69(3):603–614
- Sueldo MR, Bruzzone OA, Virla EG, 2010. Characterization of the earwig, *Dorulineri*, as a predator of larvae of the fall armyworm, *Spodoptera frugiperda*: a functional response study. *J Insect Sci* 10:1-10
- Vickery RA, 1929. Studies of the fall armyworm in the Gulf Coast region of Texas. *USDA Technical Bulletin* 138:63
- Williams WP and Davis FM, 1990. The response of corn to artificial infestation with fall armyworm and southwestern corn borer larvae. *Southwestern Entomol* 15:163-166
- Williams WP, Davis FM, and Wiseman BR, 1982. Fall Armyworm Resistance in Corn and Its Suppression of Larval Survival and Growth. *Agron J* 75(5):831-832 doi:10.2134/agronj1983.00021962007500050023x
- Wiseman BR, Painter RH, and Wasson CE, 1966. Detecting corn seedling differences in the greenhouse by visual classification of damage by the fall armyworm. *J Economic Entomol* 59:1211-1214
- www.fao.org.2018, media-new articles.
- Young JR, 1979. Fall armyworm: control with insecticides. *Florida Entomol* 62:130–133.