The Invasive Fall Armyworm *Spodoptera frugiperda* (J. E. Smith) (Lepidoptera: Noctuidae) in Maize, Status and Infestation Taken Control Under Sustainable Management: A Review

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Abstract:

The Fall armyworm (FAW), *Spodoptera frugiperda* (J. E. Smith) (Lepidoptera: Noctuidae), FAW is one of the most devastating pests in terms of crop loss and economic impact, alone developing countries, even in high income countries. This pest has found to affect the maize substantially and damages all the crops entirely declining the yield heavily. Integrated pest management approaches, the combination of physical, chemical, and biological method, is adopted by the majority of the corn producers to reduce the impact of the pest on the crops. The management practices of this pest by synthetic pesticides also affected human health, natural enemies and the environment negatively. The farmers practiced different management which was varied across countries, regions, and places. These practices were safe for the environment and human health. Thus this evaluation focuses on the assessment of biology of the pest and the possible management approaches which the smallholder maize farmers could afford. Integrated pest management approaches, the integration of physical, chemical, and biological method, is assume by the majority of the corn producers to reduce the impact of the pest on the crops.

Key words: Fall armyworm, Integrated pest management, Lepidoptera, Crop loss.

1. Introduction:

Fall Armyworm (FAW), *Spodoptera frugiperda*, an insect belonging to class-Insecta, order-Lepidoptera and family Noctuidae, is native to tropical and subtropical regions of America (CABI, 2017; FAO, 2017) in the western hemisphere (Capinera, 2001). It is a polyphagous natured insect (Hoy, 2013) which feeds on 186 plant species from 42 families (Early *et al*., 2018). Even though it is everywhere present in distribution (Dhungel *et al*, 2019),it is primarily present in the region which have a climate of very little frost cover, a minimum annual temperature of 18-26◦C and 500-700 mm rainfall (Early *et al*., 2018). It is considered as a serious polyphagous

pest of voracious nature with a wide host range of approximately more than 100 recorded plant species including maize, rice, sorghum, sugarcane, cabbage, potato, tomato, soybean, cotton and cause significant losses to agricultural crops (Goergen *et al*., 2016). *Spodoptera frugiperda* has been reported for the first time on the Indian subcontinent in maize fields University of Agricultural and Horticultural Sciences, Shivamogga, Karnataka detected in 18th May, 2018 (Sharanabasappa and Kalleswara Swamy, 2018).

This pest is a dangerous pest. It could relocate from country to country with a high prospects further spread because of its natural distribution size, sporadic, migratory behavior and trans-boundary trade. It has also a number of origination per year and the moth could fly up to 100 km per single night. The caterpillars of FAW feed on leaves, stems and reproductive parts of host plants (FAO,2017). The gravid females of FAW prefer young maize plants that are 30 to 60 centimeters in height for oviposition. The small caterpillars feed on leaves of young maize plants (Prasanna *et al*., 2018). The young larvae eat up leaf tissue from one side initially by leaving the opposite epidermal layer intact. The larger larvae act as cutworms. It caused entirely sectioning the stem base of maize plantlets, skeletonized leaves and laboriously windowed whorls that loaded with larval frass. The FAW larvae could strike maize plants during vegetative and reproductive or flowering phase. It could also bore into the maize ears, stems, and cobs (Dhan *et al.*, 2019).

Maize (*Zea mays* L.) is a potential crop for doubling farmer's income and is one of the most important cereals consumed as food, feed, fodder and industrial purposes. In India maize is grown in 9.2 mha with production of 28.75 mt. The country represents 4% of global maize area and 2% of global production. India produced over 281 million MT food grains in 2018-19, out of which cereals share the major part. Among cereal grains rice represent 44% of the gross cultivated area followed by wheat (30%), maize (9%), pearl millet (8%) and other millets. Rice and wheat constitute 44% and 39% of cereal production, respectively while maize represents little over 9% of cereal production (Rakshit *et al*., 2017). The world population is expanding exponentially and food requirement is also increasing adequately. Hence, this is to be achieved under the scenario of changing climate and depleting accessibility of arable land and water (Rakshit *et al*., 2014). Maize with its wide adaptability is cultivated all round the country during all the three seasons. However, in few states like Kerala and Goa has very little area under maize, where specialty corns have more presence. Out of 24 million MT requirement of maize in India around 60% is used as feed, 14% for industrial purposes, 13% directly as food, 7% as processed food and around 6% for export and other purposes (Rakshit, 2018). Thus, maize opens up a unique opportunity not only to add on the maize-based industry but the export as well. The demand for maize is increasing not only as grain but for specialty reason as well. Among specialty corns, sweet corn, baby corn and pop corn have not only huge market potential but can contribute significantly towards crop diversification and doubling farers income. Maize is extensively being used in dairy industry not only as feed stock but the as fodder, which is used as both green fodder and silage.

2. Biology and distribution of fall armyworm in India

Fall armyworm (FAW), is native to tropical and subtropical Americas and known as a pest in the United States since 1797. FAW moths were reported to fly 100 km per night (Johnson , 1987), making it potential to invade large swath of land and large area. In the absence of any control measures, FAW is predicted to cause 21-53% loss in annual maize production in Africa (Day *et al*,. 2017). In India, its presence was confirmed in May 2018. Since then it has spread within the country and moved eastwards to countries neighboring India, viz., Sri Lanka, Bangladesh, Myanmar (December 2018, https://www.ippc.int), China (January 2019, https://www.ippc.int) and Nepal; and to Thailand (December 2018, https://www.ippc.int), South Korea and Japan by July 2019 according to the latest report (CABI, 2017) The incidence of FAW in India was first observed in Shivamogga district of Karnataka on 18th May, 2018 (by UAHS, Shivamogga). Since then FAW gradually spread to various states (Rakshit *et al*., 2019) have documented the temporal spread of FAW within India since its report from the state of Karnataka in May 2018. By March 2019, it reached in the NEH zone in Tripura and Mizoram (reported by DAC), and by April 2019 it spread to Nagaland (reported by AICRP on Maize). By May 2019, it was recorded in Manipur, Meghalaya, Arunachal Pradesh and Sikkim (reported by ICAR Complex for NEH). Assam, Jharkhand and Uttar Pradesh reported FAW in June 2019 (reported by DAC). FAW incidence was reported in Uttarkhand (reported by AICRP on Maize) and Delhi (reported by ICAR-IIMR) on 31st July and by 6th August in Haryana (reported by AICRP on Maize) and 15th August in Punjab (reported by ICAR- IIMR). Till date, fall armyworm had spread to almost all states except Himachal Pradesh and Jammu and Kashmir.

Table 1. Distribution of Fall Armyworm

Countries	First reported
India	2018
Nigeria	2016
Benin	2016
Angola	2017
Nepal	2019(May)
Thailand	2018
Pakistan	2019
Srilanka	2019
China	2019
Australia	2020(February)
Papua New Guinea	2020(April)

Source: (FAO, 2020)

2.1 Host range

FAW is a highly polyphagous pest (Montezano *et al.*, 2018) reported 353 host species for FAW belonging to 76 plant families. Maximum number of host taxa (106) belongs to Poaceae family, followed by 31 taxa each to Asteraceae and Fabacea families. (Hardke *et al*., 2015) reported that though the pest can attack large number of cultivated species, it can cause maximum damage to maize and sorghum. FAW consists of two strains, viz., corn strain "C" which feeds predominantly on maize, sorghum and cotton; and rice strain "R" which prefers rice and turf grass dominated habitats (Juarez *et al.*,2014, Nagoshi and Meagher 2016). In India, FAW damage has been documented in sorghum, sugarcane and other millets etc. However, maize is its first preference.

2.2 Biology of the pest

The lepidopteron pest, fall armyworm has four stages in life cycle; *viz*: egg, larva, pupa, and adult. The fall armyworm feeds on leaves and stems of more than 80 plant species, causing significant damage to maize, rice, sorghum, sugarcane but also other vegetable crops and cotton (CABI, 2020). It takes 60 days in the spring and autumn, and 80 to 90 days during the winter (Capinera, 1999). Adults of FAW are nocturnal (CABI, 2017b). After a pre-oviposition period of three to four days, the female normally deposits most of her eggs during the first four to five days of life, but some oviposition occurs for up to three weeks (Prasanna *et al*., 2018). Duration of adult life averages about 10 days, with a range of about 7 to 21 days (Capinera, 2000) and due to the duration of the lifecycle, 2 to 10 generations can be completed in each cropping cycle depending on climate. The number of eggs per female during its lifetime ranged from 1,342 up to 1,844 when larvae were fed millet or corn and soybean leaves, respectively, and 1,839 eggs when fed on cotton (Barros, Torres, & Bueno, 2010). Eggs are usually laid on the upper surface of leaves but occasionally may be deposited on other parts of the host plants. The number of eggs per mass can vary from 100 to 200 (Prasanna *et al*., 2018). Eggs hatch in two to four days at temperatures ranges of 21–27 °C. The larvae develop through six developmental instars. Pupation normally takes place in the soil at a depth 2 to 8 cm (CABI, 2017b; Capinera, 2000). The larva constructs a loose cocoon, oval in shape and 20 to 30 mm in length, by tying together particles of soil with silk. If the soil is too hard, larvae may web together leaf debris and other material to form a cocoon on the soil surface. The pupal stage of FAW cannot enter a diapause period to withstand protracted periods of cold weather or a dry season without host plants (Sparks, 1979). The older larvae of FAW exhibit a cannibalistic behaviour on other smaller larvae, when they co-occur

Eggs: Eggs are spherical in shape and the number of eggs per mass varies often between 100 and 200. Total egg production per female over her lifetime averages about 1500, with a maximum of over 2,000 (CABI, 2019, p. 21).

Larva: There are six larval instar of fall armyworm. The duration of the stage of larva tends to be almost 14 days during the summer and 30 days during cool weather. The larvae in the back consists of 3 yellow stripes followed by a black and again yellow stripe. The side whereas on the second to last segment, four dark spots are seen that forms a square (FAO,2018).

Pupa: The larva binds the particles of soil together to form a loose, oval and 20-30 mm long cocoon inside which a reddish brown pupa measuring 14 to18 mm in length and 4.5 mm in width resides. The duration of the stage of pupa is nearly eight to nine days during the summer, but reaches 20 to 30 days during the winter (CABI, 2019).

Adult: Adults are nocturnal, and are most active during warm, humid evenings. Females deposit most of their eggs during the first four to five days of life, but some eggs may be laid for up to three weeks. Females can mate multiple times during this period and lay multiple egg masses, with a potential fecundity of up to 1,000 eggs per female (Heinrichs *et al.*, 2018, p. 12). The adult can liveupto an average 10 days, with a range of about 7-21 days (Prasanna *et al*., 2018).The favorable temperature for adult is less than 30°C (CABI,2017).

3. Damage by FAW

The fall armyworm (FAW) has harshly affected maize production across the country this year, 2020, as compared to previous year, 2019, hitting farmers who have already had to confront the burden of the coronavirus pandemic (The Himalayan Times, 2020). FAW attacks all crop stages of maize from seedling emergence (V2) to ear development (R6). The young larvae of FAW feed on the opened leaves by scraping and skeletonizing the upper epidermis leaving a silvery transparent membrane resulting into papery spots. Adult moths of FAW are variable in colour and wingspan (32 to 40 mm). Male moths have a shaded grey and brown forewing with triangular white spots at the tip and near the centre of the wing. Forewings of females are less distinctly marked, ranging from a uniform greyish brown to a fine mottling of grey and brown. The hind wing of both sexes is shining silver-white with a narrow dark border (Prasanna *et al.*, 2018). Studied larval feeding behaviour, and reported that although young (vegetative stage) leaf tissue is suitable for growth and survival, on more mature plants the leaf tissue is unsuitable, and the larvae tend to settle and feed in the ear zone, and particularly on the silk tissues. Larger caterpillars act as cutworms by entirely sectioning the stem base of maize seedlings. Following hatching, neonate larvae usually bore into the host plant and develop under protected conditions. The consumption rate is high and the major damage is due to the feeding on the foliage. The pest also impact the import and export of the maize within or outside the country as it carries the risk of introducing pests to areas where the pests are not yet present. For the reasons, it has become a great nightmare particularly to maize crop farmers.

4. Control measures for fall armyworm

The Fall Armyworm (FAW) *Spodoptera frugiperda* (Lepidoptera: Noctuidae) is native to the tropical and subtropical region of America. It has invaded many African and Asian countries and caused huge economic losses. Detecting fall armyworm infestations before they cause economic damage is the key to their management. Sustainable management of FAW starts with prevention. Different modules have been developed for different kinds of maize crops *viz*., grain corn, sweet corn, baby corn, fodder and silage maize. Since FAW infests maize crop as early as two leaves stage to development of corn ears, different measures are adopted as the crop grows. IPM emphasizes the growth of a healthy crop with the least possible disruption to agro-ecosystems so as to encourage natural control mechanisms. The techniques and options involved for FAW management are detailed below.

4.1. Monitoring of FAW

Good FAW management approach is mainly monitoring-based Integrated Pest Management. The FAW can be monitored using different techniques such as regular field inspection, pheromone traps and light traps (FAO, 2017 and Haftay *et al*., 2020). The efficient method of monitoring this pest in the field is by using black light trap and Pheromone trap. Upto four pheromone traps per acre should be suspended at canopy height during the whorl stage of maize (Mwangi, 2019, May, p. 9). Since, FAW induces rapidly in growth and deliberately damaged the crops in due course of time. A sustainable integrated management to check the massive growth of the FAW population is altered. Light traps can be used to control the adult fall armyworm which helps to trap both male and female insects. Since the severity of damage depends upon size of larvae, the choice of pest control intervention is chosen upon the prevailing symptom. Early detection and adoption of control measures at the earliest is the motto of FAW management.

4.2 Cultural control

Cultural control is an important component of a pest management strategy for FAW. The cultural control includes avoiding late planting since the maize ears would be heavily attacked by a higher FAW infestation than those of the early plantings. Also, intercropping and rotating maize with non-host crops like sunflower and bean may be useful to minimize the invasion of FAW (FAO, 2018). Deep ploughing has shown effective for controlling eggs and pupal stages of FAW. Planting of legumes as a trap crop and ploughing field rightly before planting the field can be an effective possible cultural method for managing the pest. Cultural practices like clean cultivation and proper use of fertilizers, grown of maize hybrids with tight husk cover will reduce ear damage by FAW (Firake, 2019). Neem based pesticide (Azadirachtin 1500 ppm) should be applied if there seems papery window on leave. Use of Intercropping with leguminous crop i.e. French bean, soyabean, groundnut and other beans provide better protection to the crop compared to mono-cropping (Hailu *et al*.,

2018). Some GMO's including Bt-maize reported resistant in Africa, however FAW has overcome Btmaize in case of America (FAO, 2018).

4.2.1. Light trap

The moths of FAW are attracted to light sources(Haftay, 2020). Therefore, use of night-time light traps can be one of the monitoring mechanisms for FAW. If moths are caught in light traps, it is an indication of presence of the pest and possibly can damage the crops. Thus, management methods that are mentioned from 3.4 to 3.8 can be applied separately or in integrated approach.

4.2.2. Pheremone trap

Funnel trap with FAW lure should be installed at a height adjusted each week matching with crop canopy. Traps should be separated by a minimum distance of 75 feet. Observe traps for number of moths caught twice or once in a week and work out the catch/day. FAW in various countries such as USA, mainly involve use of specific pheromone traps (involving [(Z)-7-dodecenyl acetate (Z)-7-12: Ac), (Z)-9-dodecenyl acetate (Z)-9-12: Ac), (Z)-9-tetradecenyl acetate (Z)-9-14: Ac), and (Z)-11- hexadecenyl acetate (Guerrero *et al*., 2014 and Cruz *et al*., 2012). FAW lures should be changed once in 30 days in case of monitoring and no lure change is required for mass trapping.

4.3. Botanical

The botanical pesticides are biodegradable, environmentally safe, less harmful to farmers and consumers, and often safe to natural enemies and hence amenable for use in biocontrol based on IPM strategies (Prasanna *et.al*., 2019). Bio-pesticides are made from plant-derived pesticides and are harmless to natural environment. Bio-pesticides are substance or mixture of substance that are intended to suppress pest and prevent the damage or loss that they caused. Plant derived pesticides like neem based bio-pesticides can be used to control the larva of FAW as it is easily available to the local market. Different researches conducted by researcher shows that seeds or leaves of plants of Meliaceae family (*Azadirachta indica*) and Asteraceae family (Pyrethrum) and other plants such as *Tephrosia vogelii* or *Thevetia nerifolia* are showing capacity in the management of FAW. Natural pesticide that is derived from plants having defensive properties is known as Botanical pesticides. More than 6000 plant species from at least 235 plant families have been screened for pest control properties.

4.4. Biological control

Biological control can be considered as a powerful tool and one of the most important alternative control measures providing environmentally safe and sustainable plant protection (Assefa.F *.et .al*., 2019). The success of biological control depends on understanding the adaptation and establishment of applied biological control agents in agricultural ecosystems. Microbial pathogens and arthropod biocontrol agents have been

successfully used in agricultural systemsEven though biological control may not replace conventional insecticides, a number of parasitoids, predators and pathogens readily attack larval and adult stages of FAW. According to (Birhanu,2018) three species of parasitoids namely, *Cotesia icipe* (Hymenoptera: Braconidae), *Palexorista zonata* (Diptera: Tachinidae) and *Charops ater* (Hymenoptera: Icheneumonidae) were recovered from FAW larvae in eleven districts of Ethiopia.

Parasitoid: For the management of lepidopteron pest in maize crops, use of egg parasitoids like T. chilonis @ 2 cc/ release and *Cotesia flavipes* and *Campoletis chlorideae* larval parasites @ 2000 to 3000/ acre are recomented accordingly dominant stage of the insect pests. The larval and pupal parasitoid *Sturmiopsis parasitica* also recommended for pest management in maize crops.

Predators: Chrysoperla carnea @ 5000 first instars grub/acre for two releases for 15 days to control maize aphids, Rhopalosiphum maidis and conserve predators such as mirid bug, lady birdbeetles, lacewing, wasp, dragonfly, spiders, robber fly, reduviid bug, praying mantis, fire ants, big eyed bugs, pentatomid bug, earwigs, ground beetles, rove beetles etc.

4.5. Chemical control

Chemical pesticides expose the major hazard in sustainable agriculture. However, in severe condition, the steps should be taken quickly in that case chemical pesticides are used. Chemical pesticide provide a protection level which cannot be guaranteed by other methods, however, they are expensive to afford by poor farmers. There use isn't economically feasible to smallholder farmers, cause environmental contamination; develop resistance to chemicals and often pest resurgence. One should always wear aprons and other safety measures while applying insecticides as it is harmful to human health. Synthetic pesticides like methomyl, acephate, cyfluthrin, benfuracarb, methyl parathion, carbaryl carbosulfan, lindane, chloropyrifos, diazinon, and methyl parathion are found effective to control FAW (Dhungel *et al*., 2019). Control of FAW is usually achieved through the application of synthetic insecticides but it involves high cost, potential environmental contamination, and development of resistance to chemicals, and often pest resurgence. The exact timing for applying chemicals is very important for effective pest control; both the life cycle and the time of day matter i.e. spraying when larvae are deeply embedded inside the whorls and ears of maize is ineffective; and spraying during the day is ineffective because larvae only come to feed on plants at night, dawn or dusk (Day *et al*., 2017). However, during selection of chemical pesticide we should use less hazardous pesticide reading from level. FAO has been assigned authority by the council in 2006 and again in 2013 to assist member countries in reducing risks posed by highly hazardous pest (FAO, 2018)

4.6. Push-pull technology (PPT)

It is one of the important strategies for controlling the infestations of FAW. In this method, maize is intercropped with pest-repellent *Desmodium* spp. (Pushcrop), surrounded by pest-attractive Napier Grass,

Pennisetum purpureum or *Bracharia* spp. as pull-crop (Dively, 2018). Combination of *Desmodium* green leaf and *Bracharia* cv. *Mulato* II known as 'Push-pull climate smart' was proved to be effective from different researches. In the PPT, the push plant release volatile chemicals such as (E)-β-ocimene and (E)-4, 8- dimethyl-1, 3, 7-nonatriene, that have repellent characteristics to the female moths .FAW, whereas, chemicals released by the pull plant are more attractive than maize to adult moths of FAW and stem borer, facilitating its concentration in the pull plant. In a field experiment in Ethiopia, PPT treated maize plots significantly reduced infestation of maize by FAW compared to monocropped maize plots (Haftay, 2020). In another study in western Kenya, eastern Uganda and northern Tanzania, there were highly significant reductions in infestation levels of FAW (average of 82.7%) in climate adapted push-pull relative to the maize monocrop across study sites. 'Push-pull climate smart' was proved to be effective from different researches. Reduction of 82.7% in average number of larvae per plant and 86.7% in plant damage per plot have been observed in push-pull plot , compared to maize monocrop plots. Likewise, maize grain yields are recorded to be significantly higher, 2.7 times, in push-pull plots (Midega *et al*., 2018). Therefore, PPT is an appropriate technology for smallholder farmers to control FAW and is friendly and be integrated with other control methods for more efficiency in controlling the pest.

4.7. Indigenous Knowledge and Practices of Farmers

Indigenous knowledge of farmers encompasses the relationship of peoples with the spiritual, natural environment, use of natural resources, social organizations, values, institutions and laws which was a basis for scientific systems radically (Kazmi *et al*., 2014 and IUCN 1997). It provides the basis for problem-solving strategies for local poor and underutilized resource communities. The traditional ways of agriculture is based on sustainability in long terms rather than maximizing yield in short terms, which is safe for environmental health. FAW introduced in 2016 and most of the farmers lack indigenous knowledge to manage it culturally(Kazmi *et al*., 2014). Locally, farmers use different management practices across countries, regions, and places which has no negative impact on the environment and human health. Indigenous knowledge used by all farmer categories are varied based on application and attainability. Some of them are dominant, easily accessible, and safe for man, animals and thus promotes social cohesion due to the mechanism of their dissemination. (Chandola *et al*., 2011) reported that indigenous practices of pest management are effective without having a deteriorating effect on the environment and cheap. Intercropping, conservation agriculture, proper weed management, use of manure, compost, companion cropping, agroforestry, diversify food, shelter and alternative food sources for natural enemies could reduce the ability of FAW larvae to move between host plants. Moreover, the indiscriminate use of chemical pesticides in the agricultural field caused the development of pest-resistant, affected insect pollinators, natural enemies of crop pests, farm communities and lead to environmental degradation via polluting the soils and water.

5. Conclusion

Fall armyworm is a polyphagous insect pest that devastates mostly maize, sorghum, and rice. It caused both yield and economic losses. The challenges in maize production are dynamic. Different local practices of farmers were reviewed which is considered safe to the environment, effective and cheap. Indigenous knowledge of farmers is also the basis for problem-solving strategies for local poor and underutilized resource communities and scientific knowledge development. FAW management involving a combination of preventative and monitoring methods, integrated with two or more than two control methods such as cultural methods, botanicals, push-pull technology, or biological control methods. Therefore, effective control should focus since it is impossible to avoid this pest unless developing sustainable management.

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