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MANAGEMENT OF FALL ARMY WORM *SPODOPTERA FRUGIPERDA* (J E SMITH) IN SOUTH ASIA-CURRENT STATUS AND FUTURE STRATEGIES

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ABSTRACT

Fall armyworm (FAW) *Spodoptera frugiperda* (J E Smtih) is a native of the neotropics and it has invaded Nigeria region of Africa in 2016 and reached India in May 2018. Since then it has spread to most of the South and Southeast Asian countries, Australia and recently reached New Zealand and some South Pacific islands. Even though FAW has many hosts in its native region, the population that reached Africa and spread to Asia and Oceania prefers maize the most. In its biology, the capability of adults to fly more than 100 km in a night, females laying eggs in clusters of 100 or more to a maximum of 2,000 eggs in five days of their lifetime, later instar larvae becoming cannibalistic, pupating in soil, not diapausing and inability to survive at temperatures below 10ºC, offers a unique opportunity to devise an effective management strategy. The IPM package for maize incorporating management of FAW involve: seed treatment with a systemic insecticide to protect young plants up to three weeks after planting; release of egg parasitoids *Trichogramma pretiosum* (Hymenoptera: Trichogrammatidae) and *Telenomus remus* (Hymenoptera: Platygastridae) immediately after finding FAW moths caught in the pheromone traps in the field; and release of larval parasitoids *Bracon* (*Habrobracon*) *hebetor,* and *Bracon* (*Habrobracon*) *brevicornis* (Hymenoptera: Braconidae) and treating with bio- and botanical pesticides, when whorl damage in observed.

Key words: *Spodoptera frugiperda*, fall armyworm, maize, IPM, South Asia, insecticides, seed treatment, biology, egg laying, pupation, diapause, survival, temperature, IPM package, biological control, biopesticides

Fall armyworm (FAW), *Spodoptera frugiperda* (J.E. Smith) (Lepidoptera: Noctuidae) is a native of tropical and subtropical North and South American continents. Outside its native range, it was first reported in Nigeria region of West Africa in January 2016 (Goergen et al., 2016). By the end of 2017 it has covered most of the Sub-Saharan Africa (Njuguna et al., 2021). In May 2018, it was found in the Shivamogga region of the Karnataka state in southern India (Sharanabasappa et al., 2018a) and before the end of that year, it has spread to Bangladesh (Alam et al., 2018), Myanmar (FAO, 2019), Thailand (FAO, 2018), and China (Sun et al., 2021). In 2019, it was reported from Nepal (Bajracharya et al., 2019), Sri Lanka (Perera et al., 2019), Pakistan (EPPO, 2020), Indonesia (Trisyono et al., 2019), the Philippines (Navasero et al., 2019) and Vietnam (Hang et al., 2020). In 2020, it was reported from Australia (GRDC, 2020), Papua New Guinea (Pacific Community, 2020) and New Caledonia in 2020 (FAO, 2021a), in 2021 from Solomon Islands (FAO, 2021b) in the Pacific and New Zealand in 2022 (RNG News, 2022).

Biology

Fall armyworm is a migratory pest. The adults are nocturnal and capable of flying about 100 km per night. Two genetic strains namely corn/maize and rice are known to occur in the Americas and over 350 species of plants have been recorded as hosts. The corn/maize strain prefers maize, cotton, and sorghum, and the rice strain rice and pasture grasses (Dumas et al., 2015). The population that reached Africa and then to Asia seems to be a hybrid and prefers maize over other crops. Female moth lays 100 to 200 eggs in batches covered with scales on the leaves, with an average of about 2,000 eggs/ moth in its three days lifetime (Barnard, 2022). Eggs hatch in two to three days and the emerged larvae feed on the shells of the eggs before start feeding on the leaves. Young larvae feed by scraping the leaves and leaving the epidermis intact exhibiting window like appearances. Wind helps them in dispersal from the plant on which they emerged from eggs to the neighboring plants when they produce silken threads and hang from the leaves. Later instars devour chunks of leaves and are strongly cannibalistic resulting one larva causing major damage to the plant by remaining in the whorl. The larva hides deep in the whorl during day time and feeds on the leaves at night. Pupation takes place in the soil and it lasts for 8 to 9 days in the tropics (Sharanabasappa et al., 2018b). There is no diapause stage in its life cycle.

Effect of abiotic factors

Long distance dispersal of FAW is aided by wind currents and their directions. In North America, every summer FAW moths migrate from Florida, Texas and Mexico regions in the south to as far north as Canada covering over 2700 km (Mitchell, 1979). In India, FAW was first observed in the Southwestern part in May 2018 and it spread eastwards to Bangladesh by November 2018, and by December, it reached China, a distance of over 5,500 km, was aided possibly by the summer southwest monsoon winds. However, its migration towards north and northeasterly directions was comparatively slow as it reached Nepal, about 1,750 km and Pakistan, about 2,500 km from southern India, in May 2019 (Bajracharya et al., 2019) and March 2019 (EPPO 2020), respectively. Northeasterly monsoon winds coincide with winter season and the survival rate of the moth in Nepal and Pakistan, which are north of India, is low because of cold weather and lack of preferred host plants. It took only seven months to move from southern India to China in the easterly direction, however, it took ten to twelve months to reach Pakistan and Nepal, even though they are only about a third of the distance compared to China from southern India.

Rainfall significantly affects the population of FAW in the field as it dislodges egg masses and young larvae from the plants. Dry and warm weather favors population increase. According to Suby et al (2020) FAW may not establish in places where the temperature drops below 10^{o}C and raises above 40^{o}C.

Economic damage

Even though over 350 host plant species have been recorded for this pest, the population established in Asia prefers maize. Maize is the third most important crop in Asia after rice and wheat (Prasanna et al., 2021). Food and Agriculture Organization (FAO) cautioned that FAW can cause a loss of 80 million tonnes of maize worth \$18 billion annually, impacting 600 million people in Africa, Asia-Pacific, and the Near East countries (FAO 2020). Day et al. (2017) predicted FAW to cause 21 – 53% annual loss in maize production in Africa but Harrison (1984) estimated 14.3 – 22.7% yield reduction in the Americas. In India, Suby et al (2020) estimated the damage to be 5 – 10% leading to a reduction in maize output by 37,000 – 75,000 tonnes. The annual loss of FAW attack is at least \$300 million for farmers in the U.S., and billions of dollars around the globe (Barnard, 2022).

Management

Fall armyworm is a polyphagous migratory pest but the strain that invaded Africa and Asia prefers maize as its primary host. The management option is to identify and develop compatible and effective technologies, and incorporate them in the Integrated Pest Management program for maize ensuring that these technologies to complement rather than disrupt technologies included for management of other maize pests and diseases in the regions. Different management options available for consideration are: scouting and use of pheromone traps for monitoring, mechanical control, cultural control, resistant varieties, GMOs, biological control including natural enemies and bio- and botanical pesticides, mating disruption, and use of chemical pesticides.

Scouting and use of pheromone traps for monitoring: McGrath et al. (2021) have reviewed scouting, action thresholds, and monitoring for FAW. While scouting is common in developed countries, its adoption is minimal among the small-scale farmers in developing countries. Several private companies, both in developed and developing countries produce pheromone lures and traps for FAW and their use has become popular in Asia. FAW being a highly mobile insect and it can migrate from one region to another depending on the intensity and direction of the wind (Day et al., 2017), and its preference to maize, setting up pheromone traps in the fields immediately after sowing and monitoring will lead to immediate recognition after its occurrence. Scouting for egg masses soon after observing the first moth in the trap will further confirm its establishment in the field however it is not mandatory.

Mechanical control: Squashing egg masses and handpicking larvae in Kenya and Ethiopia in the early years after FAW invasion in 2017 under panic conditions was carried out, however, it is labor intensive and not economical. Additionally, this activity results in killing parasitoids in the already parasitized eggs leading to negating early establishment of the parasitoids in the field. Placing of sand and ash in the whorls to kill larvae was also practiced in some African countries during the same period (Hruska 2019) which was a desperate attempt to save the crop in the absence of availability of other management tactics.

Cultural control: Van Huis (1981) in Nicaragua and Hailu et al. (2018) in Uganda found intercropping maize with beans reduced incidence of FAW. Midega et al. (2018) reported push-pull system using *Desmodium* *uncinatum* (Leguminaceae) and Napier grass (*Pennisetum purpureum*) or *Brachiaria* sp. (Poaceae) in maize fields to be effective in reducing FAW incidence and plant damage caused by it.

Host plant resistance: Prasanna et al. (2021) have reported progress made in genetic and transgenic breeding for resistance to FAW in Africa and Asia. A few lines have been identified for resistance but the resistance need to be incorporated in locally accepted varieties for widespread adoption. Transgenic maize varieties are available but currently accepted to be cultivated only in the Philippines and Vietnam in Asia.

Chemical Control: McGrath et al. (2021) have reviewed chemical pesticides and their safe use for FAW control. There is concern for some of the chemicals being recommended for Asia and Africa such as Flubendiamide, whose registration has been cancelled in the U.S.A. in 2016 (Fitchette 2016). USAID has prepared a Pesticide Evaluation Report and Safe Use Action Plan (PERSUAP) listing pesticides authorized for use in management of FAW which is the most reliable among recommendations currently exist. https://ipmil.cired.vt.edu/wp-content/uploads/2022/09/Pages-from-USAID_2019_PERSUAP_GLOBAL_FALL_ARMYWORM_MANAGEMENT_4.pdf

Biological control: In the Americas, native range of FAW, over 150 natural enemies have been recorded (Molina-Ochoa et al., 2003). Of these, the promising ones identified for augmentative control of FAW were the native egg parasitoids, *Trichogramma pretiosum*, (Hymenoptera: Trichogrammatidae) and the introduced egg parasitoid from Asia, *Telenomus remus* (Hymenoptera: Playgastridae). *Telenomus remus* was described from Malaysia in 1937 and it is a native to peninsular Malaysia and Papua New Guinea. In 1963 it was introduced to India from Papua New Guinea for biological control of castor semilooper, *Achaea janata* (Lepidoptera: Noctuidae) (Sankaran 1974). Later, it was sent to Israel from India in 1969 (Rao et al., 1971). It was introduced to Australia in 1982 from Southeast Asia and Dominican Republic and to New Zealand from Pakistan (Waterhouse and Norris, 1987). Cave (2000) reviewed its introduction to Barbados in 1971-1972 and other Caribbean Islands, Central and South America and Florida for control of FAW resulting in a classic example of supporting theory of New Association proposed by Hokkanen and Pimentel (1984). Currently it is being used in augmentative control of FAW in Central and South American countries (Cave, 2000). Recently it has been found to occur fortuitously in most of the countries in Africa (Kenis et al., 2019) and Asia (Elibariki et al., 2020; Liao et al., 2019; Muniappan, Pers. Obser.).

In Asia, several natural enemies of FAW have been identified with China leading in this list with more than three dozen organisms, followed by India about two dozen and others actively surveying for natural enemies. The common natural enemies considered for augmentative biological control in Asia are *Tr. pretiosum* and *T. remus*. In Bengaluru, India, *Bracon brevicornis* (Hymenoptera: Braconidae) was reported to attack fourth and fifth instar larvae of FAW and 54% average reduction in infestation after its release in the field (Ghosh et al., 2022) and in Hyderabad, India under laboratory conditions, *Bracon hebetor* (Hymenoptera: Braconidae) attacked larvae of FAW but it preferred *Corcyra Cephalonia* (Lepidoptera: Pyralidae) first followed by *Helicoverpa armigera* (Lepidoptera: Noctuidae) and then FAW (Sree Latha et al., 2019). However, studies in Bangladesh showed *Habrobracon hebetor* (syn. *Bracon hebetor*) to sting, host feed and kill the larvae of FAW but no parasitoid progenies were produced (Alam et al., 2021). Based on these studies it could be speculated that there are three different species of *Bracon* occurring in the subcontinent which need to be determined through molecular studies. The egg parasitoid *Trichogramma chilonis* (Hymenoptera: Trichogrammatidae) currently mass reared and field released for FAW control in Kenya, Nepal and other countries is a poor choice as it is not an effective parasitoid of FAW. Instead *Tr. pretiosum* should be considered. Predators such as *Eocanthecona furcellata* (Hemiptera: Pentatomidae) and earwig *Euborellia annulata* (Dermaptera: Carcinophoridae) are also being studied and evaluated.

IPM for maize incorporating management of FAW

1. Select varieties that are resistant to pests and diseases and locally acceptable, if available.
2. Treat seeds with *Trichoderma* sp. and a systemic insecticide. *Trichoderma* sp. provides protection against soil borne fungal diseases and also induces resistance in plants. Systemic insecticide normally provides protection of the young crop up to two to three weeks against caterpillar pests (caterpillars/larvae emerged from the eggs laid on the treated plants will die when they feed on the leaves but the eggs of the moths are unaffected).
3. Set up a FAW pheromone trap in the field one week after sowing seeds.

4. Survey the field for FAW egg masses once a moth is found in the pheromone trap, but not mandatory.
5. Release egg parasitoids *T. remus* and *Tr. pretiosum* in the field when FAW moths are noted in the trap (and egg masses are found in the field). Absence of the need for chemical sprays to control larval stages of FAW in the first three weeks of the crop due to seed treatment with a systemic insecticide, presence of live FAW eggs in the field laid by the invading populations of FAW, and early inoculation with egg parasitoids leads to establishment of a healthy population of natural enemies.
6. Avoid treating with chemical pesticides when window damage is noted on leaves as the maize plants overcome and compensate this damage and also leads to protect existing natural enemies in the field.
7. Release late larval instar attacking parasitoids *B. hebetor* or *B. brevicornis*, when whorl damage is observed.
8. Treat only the whorls not the whole plant with bio- or botanical pesticides to kill the late instar larvae. Use a safe chemical insecticide for whorl treatment as a last resort.
9. Spraying chemical pesticides when the plants are above two feet in height is not recommended under Asian small holder farm conditions as most farmers lack access to personal protective clothing and are not prepared for safe application of these pesticides.
10. Follow USAID approved PERSUAP (Pesticide Evaluation Report and Safe Use Action Plan) as some of the published literature lack thorough scrutiny of approved pesticides in their recommendations.
11. Use bio- or botanical pesticides for treating plants at the tasseling stage, if needed.

Future priorities

To implement the IPM package for maize incorporating FAW management activities, countries should register one of the safe systemic insecticide that could provide protection for early stages of the crop. Set up public and private laboratories for rearing and release of egg parasitoids *Tr. pretiosum* and *T. remus* and larval parasitoids *B. hebetor* or *B. brevicornis*. Observe conservation biological control to preserve natural enemies in the field. Follow the IPM package template for maize crop.

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