FALL ARMYWORM, *Spodoptera frugiperda* (J.E. Smith) MANAGEMENT STRATEGIES: A SYNOPSIS

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ABSTRACT

Fall armyworm (*Spodoptera frugiperda*) is a polyphagous pest with a host range, native to North and South America. This pest was formally reported for the first in January 2016 in Africa and in May 2018 in India. On 9 May 2019, this pest was first noticed in Nawalpur Nepal. 20-35% losses have been reported in maize crops. Since the outbreak of this pest from Africa, entomologists are working for their strategic management. This review aims to compile the fall armyworm (FAW) management works carried in the world and discuss their relevancy in Nepalese context. Of the various practices, chemical pesticides are one of the most commonly used tools followed by habitat management and other cultural practices. Insect pheromones are used for pest monitoring, and thereby to improve pest management decisions. Trap cropping, cover cropping, intercropping, maintaining floral diversity are some examples of habitat pest manipulation. Push-pull strategy uses Napier crop as a 'Pull' component and *Desmodium* crop as a 'Push' crop. . These agro-ecological strategies change the behavior of FAW and able to trap or manage them in a certain area or certain crop, where pest can be managed manually or using other non-insecticidal strategies. This review work will be useful for the academicians, extension workers and plant protectionist to design a sustainable FAW management protocol.

Keywords: *bio-pesticides, fall armyworm, integrated pest management, maize*

INTRODUCTION

Maize (*Zea mays*) is the third most important staple crop after rice and wheat in world (FAO, 2020). The global maize harvest for 2018 was 1,147 million tones with total area harvested of 193 million ha with slight decrease compared to the previous year (FAO, 2020). Cultivation practices, weather parameter, insect pest and diseases, weeds and several other reasons are crop production limiting factors (Assefa & Ayalew, 2019).

Fall armyworm, *Spodoptera frugiperda* (J.E. Smith) (Lepidoptera: Noctuidae), native to tropical and subtropical regions of America (Capinera, 2002), is the devastating insect of maize reported in several parts of world (Sharanabasappa et al., 2018). This pest can travel over 500 km/day (300 miles) before oviposition and 100 km/day in search of host (Johnson, 1987; Prasanna et al., 2018). It has almost 350 host species including cultivated and wild crops (Goergen et al., 2016; Roger et al., 2017). Larva stages of pest feed on the young leaf whorls, ears and tassels resulting significant damage on crop yield (De Almeida Sarmento et al., 2002). Globally, FAW damage is reported from 39% - 100% (Varshney et al., 2020).

The pest was accidentally introduced to Nigeria in 2016 (Goergen et al., 2016), reached to several African countries and made its way to Asia for the first time (India) on May 2018 (Kalleshwaraswamy, et al., 2018; Sharanabasappa et al., 2018). The pest got spread to several Asian countries including Bangladesh, Myanmar, Vietnam, Laos, China, Sri Lanka and Myanmar (CABI, 2019). The invasive pest reported in Nepal on May 9, 2019 (Bajracharya et al., 2019).

In Nepal, maize stands second in terms of area and production contributing an area of 900,288 ha with total production of 2300,121 mt and yield of 2555 mt/ha (MoAD, 2018). The productivity of the crop is less than potential due to presence of several insect pests while the loss varies place to place. Since the invasion of FAW in the country, maize farmers have faced an estimated yield loss of about 25-35% (PQPMC, 2019). It causes significant damage in several part of the world with great economic loss (FAO, 2017; GC et al., 2019), leading threat to food security and feed industry. FAO (2019) warned the threat and risk of invasion of FAW in Nepal since its invasion in India and believed the loss could reach 100% in maize crop. It has also been reported that there will be a greater risk of FAW if no management tactics are applied in Nepal (Bajrachharya et al., 2019; Gahatraj et al., 2020).

For the development of IPM programs for FAW, it is imperative to determine the magnitude of damage, extent of damage and effectiveness towards bio-pesticides. Several previous studies have explained about the invasion, distribution, life cycle and management of the pest (Bhusal & Bhattarai, 2019; Bhusal & Chapagain, 2020; Gahatraj et al., 2020; Gc et al., 2019). However, there are scanty literatures that explains about the efficacy of various management strategies that could been practiced for experimental research in Nepal (Bhusal & Bhattarai, 2019; Gahatraj et al., 2020). Findings from this review will be useful for the academicians, extension workers and plant protectionist to design a sustainable FAW management protocol. The general objective of this paper is to synthesize and summarize the findings from different studies carried out for FAW management across the globe. Specifically, this review aims to highlight different management strategies being practiced in different countries and discuss their relevancy in Nepalese context.

RESULTS AND DISCUSSION

Distribution and status of FAW in Nepal

Major Terai districts and mid-hills have already been faced the devastating damage from FAW infestation (NPPO, 2020). The pest was even reported from 1700 masl in Kavre of Dolakha district of Nepal which suggests FAW has wide geographical distribution from alpine to tropical region (Gahatraj et al., 2020). Despite its geographical coverage, systematic studies on the loss assessment are still non-existence, probably due to its recent invasion and insufficient research and management initiatives in the country.

Management strategies for FAW

Control and management of FAW is crucial in the present scenario in Nepal (Rijal, 2019). The economic threshold level should be assessed before adopting any management strategy (FAO, 2017). Fifty percent damage threshold is reported at seedling to early whorl stage (3-4 weeks after emergence) of maize (Firake et al., 2019).

Regular monitoring and scouting

Monitoring is the foremost phase of pest management. Monitoring information can help to develop the protocol for the area wide pest management including several other pest management strategies (Gahatraj et al., 2020). Monitoring and scouting data can be used to make a decision for pesticidal management practices (Deshmukh et al., 2020). Three methods are popular for monitoring i.e., scouting, pheromone traps and light traps (Abrahams et al., 2017). FAO (2020) suggested scouting guideline is ‘W’ from side in field as soon as maize seedling emerges. The scout walks in field about 5m (avoiding the border rows of the field to avoid edge effects), stops at 5 locations such that zigzag forms. At each location, the scout assesses 10-20 plants looking for signs of FAW feeding (Figure 1.a). However, for densely planted maize at tassel stage or beyond may be difficult thus alternative pattern i.e., Ladder (Figure 1.b) can be used. In ladder pattern, A-E are used as alley to transverse field in semi-systemic manner. The action threshold level is 5%, 10% and 20% at early (3-4 weeks after emergence), mid (5-7 weeks after emergence) and late whorl stage respectively. The suggested number of pheromone trap is 5 per acre for regular monitoring (Firake et al., 2019). Similarly, for monitoring, pheromone traps are reported more effective for adult FAW (FAO, 2018).

FAO has also developed an android based mobile application- "Fall Armyworm Monitoring and Early Warning System (FAMEWS)" and successfully implemented in African countries through Farmer Field Schools (FSS) and Community- based forum (FAO, 2018). Likewise, application can be developed for use in Nepalese context too.

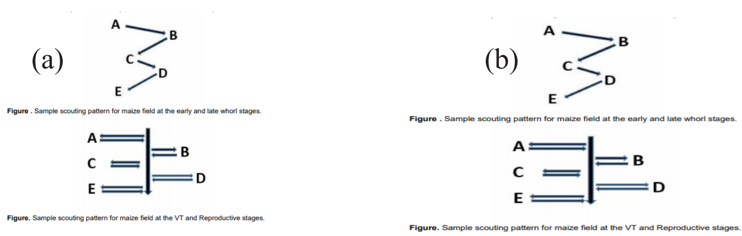

Figure 1. Sample scouting pattern for maize field at (a) the early and late whorl stages and (b) the Vegetative and Reproductive stages (Source: FAO)

Cultural methods

Healthy plants are less susceptible to insect and pathogen attack so, cultural interventions can promote the growth of healthy plants (Prasanna et al., 2019).

a) **Intercropping with beans** *(Phaseolus vulgaris):* Semio-chemicals released by the companion crops repeals the insects from the main crop or attracts the pest and ultimately reduces the main crop infestation (Khan et al., 2010). Novel flavonoid compound present in bean root exudates can disrupt the pupating phase of FAW life cycle in soil and alter pest ecology (Day et al., 2017). Severity of infestation can be reduced by intercropping beans with maize with significantly higher cob length and 1000 grain weight of 30.7 cm and 1.1 g compared to control (no input) of 24.7 cm and 0.9 g respectively (Tanyi et al., 2020). Similarly, less infestation was reported in bean intercropped maize with 65% compared to sole maize 95% (Hailu et al., 2018). Bean crop also provides the ecological niche for FAW larvae (Chamberlain et al., 2006; Day et al., 2017). Intercropping of maize with leguminous crop shows higher reduction of larva per plant at early growth stages of maize (up to tasseling) (FAO, 2018; Hailu et al., 2018).

b) **Intercropping with *Desmodium* surrounded by Napier** (*Pennisetum purpureum*) or Brachiaria grasses (*Brachiaria spp.*) (Push-pull): Midega et al. (2017) and Hailu et al. (2018), on research in intercropping of Desmodium with maize reported that average larvae of FAW per plant were reduced compared to control with significantly higher yield. They reported the technology to be superior in reducing FAW infestation and plant damage rates. In conventional push-pull farming system: Silver leaf Desmodium repels (push) the pest while Napier Grass (*Pennisetum purpureum*) attracts the pest (pull) and thus significantly reduce the pest damage in maize crop (Dively, 2018; Samal & Sahu, 2020).

Similarly, under climate smart push pull farming system: two drought- tolerant species, Greenleaf Desmodium (*Desmodium intortum*) as push crop and Brachiaria grass (*Brachiaria cv mulato* II) as pull crop was found effective. 80% stem borer larvae do not survive on these plants as they are not suitable plants for development of FAW (Scheidegger et al., 2021). Likewise, reduction of 82.7% in average number of larvae per plant and 86.7% in plant damage per plot were observed in climate smart push pull farming system compared to maize monocrop plots with significantly higher (2.7 times) maize grain size (Midega et al., 2018).

c) **Field sanitation:** Sanitation of field, clean cultivation and removal of debris reduces the host availability of the pest thus reduces the pest population (Gahatraj et al., 2020).

d) **Use of healthy seed and seed treated with insecticides:** Seed treated with Imidacloprid 48 %FS @4ml/ kg seed have been reported to control the pest infestation until 3 weeks of old crop (NPPO, 2018). Seed treatment with cyantraniliprole 19.8%+ Thiamethoxan 19.8% @ 4ml per kg seed is reported to be effective for about 2 to 3 weeks after germination of maize seed (Firake, 2019). Healthy plants can invest more in defense, thereby increasing the likelihood of escaping serious damage (Chapin, 1991).

e) **Adjustment in planting date:** Successful production always relies on right planting date. Late planted and late maturing hybrid crops are more likely to infestation (GC et al., 2019). Timely sowing interrupts the continuous availability of host plants (Bhusal & Chapagain, 2020). Infestation on plant can be reduced by planting early maturing variety as they are less exposed to FAW (Harrison et al., 2019).

f) **Crop variety:** Selection of the crop variety plays important role for FAW management. Matova et al. (2020) and ISAAA (2017) reported that a transgenic maize MON89034, introduced in 2010 by Bayer Company, contains stack of insect resistant traits and was found to be resistant to FAW, African Busseola fusca, Chilo partellus maize stalk borer and spotted stalk borer, making it more preferred maize event in controlling FAW in South Africa. Research conducted in two consecutive years (2016 and 2017) in Florence, South Carolina reported, across both years, the highest recorded infestation rates in Bt hybrids P_{1319}HR, P_{1319}YHR, and P_{1319}VYHR were 15.2%, 5.1%, and 0.96% respectively while non-Bt hybrids P_{1319}R and DKC6_{427}R reached maximum infestation of 81% and 68.3% respectively (Bilbo et al., 2020). Bt- Maize are found to be resistant to FAW in African countries, however, FAW has already overcome Bt- Maize in some part of American countries (FAO, 2018).

In Nepalese context, GMO is not yet practiced for commercial purposes. Cultivation of maize hybrid with tight husk was found to be effective to reduce FAW damage (Firake et al., 2019). While the introduction of existing GMO varieties that are FAW resistant can be an option, but field scale experiments and other management aspects should also be considered. Field experiments on screening the genotypes and hybrids available in Nepal against the infestation of FAW can help find local varieties that may potentially be resistant or less susceptible.

Mechanical management

Hand picking, collection and destruction of infested plants, collection and killing of the eggs and larvae, placing sand or wood-ash in whorls of maize plants, drenching plants with tobacco extracts can be effective method for FAW management (Kumela et al., 2001; Matova et al., 2020). Hand picking and destroying egg masses and larvae or dropping larvae in hot water prevents immediate crop damage along with reduce appearance of more than 1,500-2000 new caterpillars within less than 4 weeks (FAO, 2020). Similarly, Huska (2019) reported egg squashing and larvae picking satisfactorily controlled 337,000 ha and 402,000 ha in 2017 and 2018 in Kenya and Ethiopia respectively. However, mechanical management might be impractical for a large area of field and later stage of infestation.

Biological management

Some of the potential predators of the pest are earwigs, ground beetles, assasian bugs, ants, flowers bugs, spider, insectivorous birds and bats, predatory wasp (Harrison et al., 2019). *Bacillus thuringensis* (Bt), Baculovirus and *Beauveria bassiana* were also found as effective biological control agents against FAW (FAO, 2018). Egg parasitoids, *Trichogramma chilonis* and *Telenomus remus* @ 50,000 per acre at weekly interval were revealed as the effective biocontrol against FAW in Nepal (Elibarikin, 2019). Similarly, *Telenomus remus* was reported to cause 69.3% egg parasitism in FAW egg in Kenya (Sisay et al., 2019). Nymph of *Doru luteipes* consumes 8-12 larvae daily, while in adult stage they consume 10-21 larvae of FAW (Reis et al., 2018). Augmentative biological control can be implemented to suppress FAW in Nepal.

Non-insecticidal management

Soap solution has been also reported as effective to a certain extent against FAW larvae. However, its mode of action arenot been clearly understood. Apart from soap, wood ash and soil have been used to control FAW for long time by several small holder farmers in America (Wyckhuys et al., 2007). CABI (2019) suggested the use of "Fawligen", a baculovirus biopesticides to manage FAW among small holder farmers in South Sudan and 63% yield gain on average was observed compared to untreated maize fields.

Botanical pesticides

Neem-based pesticides

Neem based pesticides have shown effectiveness against FAW in laboratory and field condition (Babendreier et al., 2020; CABI, 2020; GC et al., 2019). Azadirachtin (a neem-based pesticide) acts as antifeedant, repellent and growth inhibitor to pest while low toxic to non-target pest (Brahmachari, 2004). Babendreier et al. (2020) reported that neem-based pesticides show equal effect to control FAW damage with respect to Emamectin benzoate, which is widely used as safe chemical pesticides for the control of pest. Azadirachtin 1% resulted in reduced damage (48.67%) compared to untreated control plot (69.92%) (Kumar & Mohan, 2019). Higher efficacy and lower cost benefit ratios were achieved with neem-based pesticides indicating a good scope of its use at farmers' level (G.C et al., 2019). Tanvares et al. (2010) under laboratory experiment reported 80% larval mortality after exposure to 0.25% Neem oil extract. Likewise, plant oil extract from clove and palmarosa have potential to control first instar larvae whereas, plant oil extract from turmeric, clove and palmarosa have pronounced effects to control second instar of FAW larvae (Barbosa et al., 2018).

Integrated Pest Management (IPM)

In this method, all possible management options such as cultural, mechanical, pheromones, biological organisms are integrated with each other and use of chemical pesticides should be practiced with care. (Day et al., 2017). Chlorantraniliprole, Emamectin benzoate and Spinetoram can be used as components of integrated pest management

(Deshmukh et al., 2020). Different management strategies have been proposed to control FAW at different stage of infestation (Table 1).

Table 1. Integrated management strategies for control of FAW according to the stage of damage

Stage of FAW damage	Integrated management strategies
First Window (Seedling to early whorl stage) to control FAW larvae	5% Neem Seed Kernel Extract or Azadirachtin 1500 ppm@ 5ml/lit (1 lit/acre) water
Second window (Mid whorl to late whorl stage) to manage 2nd and 3rd instar larvae at 10-20% damage	Spinetoram 11.7%SC @0.5 ml/lit of water or Chlorantraniliprole 18.5% SC @ 0.4ml/lit water
Poison baiting for late instar larvae of second window	Keep mixture of 10 kg rice bran + 2 kg Jaggery with 2-3lit of water for 24 hours to ferment. Half an hour before application, add Thiodicarb. Application of bait should be in the whorl of the plant.
Third Window (8 weeks after emergence to tasseling and post tasseling)	Insecticide management is not cost effective at this stage. Hand picking of the larvae is a wise strategy.

Source: Samal & Sahu, 2020

For spraying the formulations mentioned in Table 1, the spray solution should be directed towards the whorls of the crop and sprayed either in early hours of the day or in the evening time. Apart from this methods, awareness and capacity building is equally important for promoting IPM strategies.

Chemical management

Use of the chemicals for the pest control should be the last resort (FAO, 2018). Pest develops resistance towards regular used pesticides with time and thus becomes difficult to control with same pesticides in future (Gahatraj et al., 2020; Yu et al., 2003). Several experiments have been run under laboratory conditions to examine the effectiveness of different control methods for FAW in different countries. Study conducted in laboratory with several insecticides for FAW larvae using direct spray over third instar showed more than 80% mortality in Chlorantraniliprole, Flubendamide, Spinosad, Indoxacarb and Fenvalerate treatments after application (Belay et al., 2012). Similar laboratory result was reported by ICAR (2019) where second and third instar larvae were significantly controlled by application of Chlorantraniliprole. In diet incorporated assays, the LC50 values of Chlorantraniliprole (0.068 μgm/L) and Spinetoram (0.066 μgm/L were significantly lower than LC 50 of Indoxacarb (0.392 μgm/L and Flubendamide (0.930μgm/L) (Harde et al., 2011). However, higher values of LC were found with Indoxacarb and Lambda-Cyhalothrin in the research conducted by Deshmukh et al. (2020) in India.

Research conducted to find the field efficacy of several commercial insecticides to control FAW in India revealed that the Chlorantraniliprole 18.5 SC was the most effective followed by Emamectin benzoate 5 SG, Spinetoram 11.7 SC, Flubendiamide 480 SC, Indoxacarb 14.5 SC, Lambda-cyhalothrin 5 EC, and Novaluron 10 EC (Deshmukh et al., 2020). Similar result was also reported by Hardke et al. (2011) where Chlorantraniliprole provided effective reduction in pest population by 2.5-fold times than that in the non-treated control. Kumar and Mohan (2019) recorded the reduced larval population in the plot treated with Spinetoram (97.32%) in their both researches conducted in Rabi and Kharif season in India followed by Novaluran (93.09%) and Chlorantraniliprole (90.43%). Worku and Ebabuye (2019) recorded the maximum larval mortality with Chlorpyriphos Ethyl (48.99%) followed by Profenaphos + Lambdacyhalothrin (44.99%) under field conditions. Similar result was reported by Sisay et al. (2019) where FAW was effectively controlled using Spinetoram followed by Chlorantraniliprole, Spinosad and Lambda-cyhalothrin.

Since the recent invasion of FAW, haphazard application of unregistered pesticides is being practiced by farmers. PQPMC (2019) suggested to apply soft insecticides i.e., Spinetoram 11.7 SC @1ml/2lit of water, Chlorantraniliprole 18.5% SC @ 1ml/ 2.5lit of water and Spinosad 45 % SC@1ml/3lit of water for the control of FAW. However, further field experiments are required to evaluate their effectiveness across varied climatic and field conditions and come out with appropriate recommendation rates.

CONCLUSION

Despite of the short period of invasion in Nepal, significant devastation of FAW have been observed around the country. Therefore, development of appropriate management strategies to control FAW is warranted before it is too late. Eco-friendly and sustainable management of FAW should be focused as it has been evident that the damage and infestation of the pest is unavoidable. Generating awareness among the farmers about the different stages of the pest and adverse impacts of unbridle use of pesticides can be suggested. Preservation of natural enemies, sowing at right time, use of botanicals such as neem-based extracts and low-cost soft insecticides as last resort can potentially be incorporated in designing successful FAW management. Regulations for strict quarantine measures on imported seed is recommended to regulate further entry of pests. The summary of several studies carried out in different parts of the world presented in this study can provide a roadmap for setting up effective experiments in both field and laboratory conditions. Extensive research on FAW management under local growing conditions of Nepal should be carried out to understand the efficacy of potential management strategies as discussed in the paper. The review suggests for a comprehensive and collaborative work between agriculture universities, research and extension centers and government bodies to carry out research and provide effective recommendation to farmers for timely, economical and environment friendly management of FAW.

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