Review Article

FALL ARMYWORM INCURSION IN NEPAL - WHAT CAN BE DONE WITH THE LESSONS FROM OTHER COUNTRIES

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ABSTRACT

Fall armyworm (FAW), *Spodoptera frugiperda* (J.E. Smith) (Lepidoptera: Noctuidae) is a polyphagous, transboundary pest. It primarily prefers maize crop, however; it is not that fastidious only to a few kinds of cereal. This pest was initially noticed in North America and later reported in many countries of Africa in early 2016. In Nepal, National Plant Protection Organization (NPPO) confirmed its first occurrence in Gaidakot, Nawalparasi in August 2019 with an estimated loss of about 10-15% in maize. It has the potential to impact the food security and livelihoods of the millions of smallholder farmers if coordinated actions are not initiated. The FAMEWS, FAW monitoring tool developed by FAO is found useful for tracking its movement. Besides chemical pesticides, habitat manipulation with the deployment of deterring crops 'push' such as desmodium (*Desmodium uncinatum*) and pest-attracting crop 'pull' such as Napier (*Pennisetum purpureum*) and Sudan grass (*Sorghum vulgare sudanense*) is suggested in a 'push-pull strategy in the maize field. Adoption of Integrated Pest Management (IPM) with field sanitation, use of azadirachtin 1500 ppm @ 5 ml per liter of water, hot pepper, *Artemesia, Xanthoxyllum*, sawdust, sand, and conserving pest natural enemies are suggested to limit the pest. Many literatures suggest the use of Spinetoram 11.7 SC @ 0.5 ml/liter of water, chlorantraniliprole 18.5% SC @ 0.4 ml/liter of water; spinosad 45%SC @ 0.3 ml/liter of water and emamectin benzoate 5% SG @ 0.4 g/liter of water are useful to control the larvae.

Key words: *Cosmopolitan, fall armyworm, invasive, integrated management, maize, transboundary.*

INTRODUCTION

The fall armyworm (FAW) *Spodoptera frugiperda* (J.E. Smith) (Lepidoptera: Noctuidae), is a moth (adult stage) with a damaging phytophagous stage called the larva or caterpillar, known to feed on several different crop species including maize (which it prefers), sorghum, millet, sugarcane, vegetable crops, and cotton. It is native to the tropical and subtropical Americas, where it has been known for several decades as an economic pest of many crop

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species, especially maize. It has a wide host range and feeds on more than eighty different crops including maize, sorghum, millet, sugarcane, vegetable crops, and cotton (FAO, 2018a). It is native to the Americas and was the first outbreak was reported in maize crop in Central and Western Africa in early 2016 (Goergen *et al.*, 2016).

Fig 1: Fall Armyworm distribution
(http://www.fao.org/fall-armyworm/en/for the status of FAW spread).

In the same year, the pest invaded through-out sub-Saharan regions threating livelihood of small-holder farmers and production loss lead to up to 20–50% (Early *et al.*, 2018). The adult moth has both a migratory habit and a more localized dispersal habit. In the former case, the moths can migrate over 500 km (300 miles) before oviposition. Because of its transboundary nature, now it has becoming a global pest marching across African continent in early 2016 (Early *et al.*, 2018)to Asia and the Pacific in 2020. It was first detected outside its native range in Central and Western Africa in early 2016. Within two years, it was reported to have invaded all of sub-Saharan Africa, except Lesotho. By July 2018, it was confirmed in Yemen in the Near East, and in India in the Asia region. By December 2018, it had been confirmed in Bangladesh, Sri Lanka, and Thailand. By October 2019, FAW has been confirmed in several more countries in the Asia region including Myanmar, China (including the Province of Taiwan), Indonesia, Philippines, Indonesia, Laos, Malaysia, Viet Nam, Cambodia, the Republic of Korea (South Korea) and Japan. In Nepal, National Plant Protection Organization (NPPO) confirmed its invasion in August 2019. In addition to the confirmation in Yemen in 2018, FAW has also been confirmed in Northern Africa and Egypt in 2019. Between January and March 2020, FAW reached Mauritania, Timor-Leste, and Australia (Fig. 1).

MATERIALS AND METHODS

The paper is based primarily on the review of the available literature and information as well as consultation with NPPOs. Works carried out in various parts of the world are linked with the current initiatives of FAW management in Nepal. The review includes the nature of the pests with their common hosts, losses, and some of the verified control options in different parts of the world which could be replicated in Nepal.

Common host crops and losses

Besides maize, it also attacks several other crops such as peanut (*Arachis hypogea* L.) and Bermuda grass (*Cynodon dactylon* (L.), Pers.) than the other favored hosts (Sparks, 1979). The temperature regime, vegetation, staggered and scattered planting of maize in Nepal is highly favorable for the pest to be established. Maize (the most preferable host of FAW) is the second-largest crop in terms of area of cultivation (954,158 ha) and quantity of production (2,555,847 MT). Maize is mainly the summer crop in Nepal through year-round cultivation of maize with irrigation facilities in the river basins and plain areas are increasing. The temperature regime during pre-monsoon, monsoon, and post-monsoon are highly favorable for FAW. Its infestation possesses a very high risk of food and seed insecurity especially in the mid-hill region of Nepal. As this is a polyphagous pest and not that fastidious only to the limited host crops, it can feed on more than 80 species and spreads rapidly in agro-ecological zones (Roel *et al*., 2010). In a different country, maize yield loss due to FAW was reported up to 20-34% when defoliation occurs around the flowering of Maize (FAO, 2018). The invasion of this pest in Nepal is somehow a new phenomenon and its systematic studies including losses before and after invasion are yet to be quantified. The pest has been reported from different maize production areas/districts, including Chitwan, Sindhupalchowk, Sindhuli, Ramechhap, Udayapur, Khotang, Okhaldhunga, Dolakha, Kavrepalanchowk, Lalitpur, Bhaktapur, Banke, Rolpa, Pyuthan, Salyan, Dailekh and so to manage the pest in time and minimize the economic loss (NPPO, 2019). As per the unpublished report of National Plant Protection Organisation (NPPO), Nepal about 20% losses has been reported in the maize field in Chitwan (NPPO, 2020). FAO, Nepal has reported sorghum is another crop attacked by this pest followed by maize.

Life cycle and its identification

It has a complete life cycle and is completed in about 30 days (at a daily temperature of ~28°C) during the warm summer months but may extend to 60–90 days in cooler temperatures (FAO, 2017). The life cycle of a female adult is 15-21 days. Generally, it has about 10 day's duration. The female moths start to lay eggs at the age of 3 - 4 days and continued until they become 3 weeks old. Adult moths are 20 to 25 mm long, with a wingspan of 30 to 40 mm. It has a kidney-shaped spot with fainted black lining, V-shape marking, an oval shape brown color spot, a distinct diagonal stripe, and a line of black dots at the periphery of the forewing. The forewings of female moths are less distinctly marked, ranging from a uniform grayish brown to a fine mottling of gray and brown. The hind wing is iridescent silver-white with a narrow dark border in both sexes. Adults are nocturnal and are most active during warm, humid evenings. The typical identification features of FAW are adult. The female moth is bigger than the males. Adults are either male or female with distinct forewings coloration respectively. After a preoviposition period of 3 to 4 days, the female moth normally deposits most of her eggs during the first 4 to 5 days of life, but some oviposition occurs for up to 3 weeks.

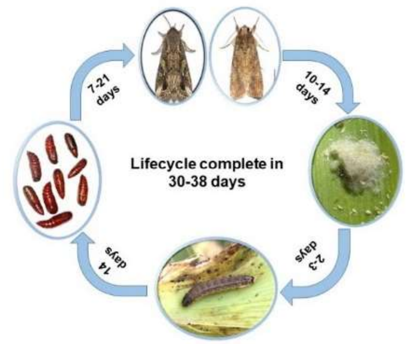

Fig. 2: The life cycle of FAW

After mating, they lay the eggs in the night time (Sparks, 1979). Adult females lay 100-200 eggs on the lower side of leaves and eggs are covered by protective scales rubbed off from the moth's abdomen. The female also deposits a layer of grayish scales between the eggs and over the egg mass imparting a furry or moldy appearance. It takes 4-5 days for egg hatching. Initially, larvae are green in color and later change to brown. It has six larval instars; 3-6 stages are more destructive compared with early instars. The larva has four dark spots forming a square on the second-to-last body segment and the larval head is dark red with pale upside-down Y-shaped marking on the front (Hardke, Jackson, Leonard, and Temple, 2015) (Fig. 2). Duration of the larval stage is 14–30 days depending on the prevailing temperature from warm to cooler. There are six larval stages with total larval duration is approximately 14 days. The matured caterpillar drops on the ground enter 2-8 cm below the soil and pupate inside it for 8-9 days. Pupation takes place in soil up to 2-8 cm below the grown surface and normally shiny brown. The pupal stage lasts for 8 to 9 days, and then an adult moth emerges. Pupation takes place in a loose oval cocoon, which is 20-30 mm in length. The duration of adult life is about 10 days, with a range of about 7-21 days. However, the FAW life cycle duration depends on prevailing weather conditions and food availability (Mello Da Silva *et al.*, 2017). The infestation of FAW has been associated with the region having similar climatic conditions as in native land (Early *et al*., 2018; FAO, 2018). The life cycle of FAW does not have the ability to diapause (a biological resting period), where conditions remain suitable (as in many sub-Saharan countries where there is no winter), and the populations are endemic. In non-endemic areas, migratory FAW arrives when environmental conditions allow and may have as few as one generation before they become locally extinct. Temperature and rainfall can affect the FAW migration and spread. The population dynamic and pest distribution are influenced by cold and wet weather *(Early et al.*, 2018). Its wider distribution has been mostly favored by its strong flying ability over 100 km in a single night along with other climatic factors and wider host range (Hardke, Lorenz and Leonard, 2015).

Damage symptoms of *Spodoptera frugiperda* in maize

The pest can affect the crop at different stages of growth, from early vegetative to physiological maturity as they are voracious feeders (Harrison *et al.*, 2019). In maize crop, caterpillars damage the leaf, silk, tassel, and cobs (Chimweta *et al.*, 2019). Later larval instars chew larger holes, causing ragged whorl leaves, and produce sawdust-like larval droppings, while fresh feeding produces big lumps. The newly hatched young caterpillars feed superficially on the underside of leaves making semi-transparent patches on the leaves. By stage 3-6, the caterpillar reaches to leaf whorl where it does most damage resulting in ragged holes in leaves accompanied with excrements which appear like sawdust in dry condition (FAO, 2018). When an infestation occurs in the early stage of the crop or at the young plant, feeding can kill the growing point because of which no new leaf formation takes place and prevent cob development. At this stage, the larva becomes cannibalistic and found only one or two in a whorl (Chapman, 1999). If the plant is older and with cobs, caterpillars feed on young kernels through protective leaf bracts into the side of the cob (FAO, 2018). Damaged cobs may lead to fungal infection and aflatoxins, and loss of grain quality. When badly infested fields may look as if they have been hit by a severe hailstorm, they feed inside whorls and can destroy silks and developing tassels, thereby limiting fertilization of the ear. Larvae move to the ear zone and start feeding after tassel emergence because they are exposed to natural enemies.

Potential impacts of FAW

Maize is the second most important crop, in terms of area and production, after rice in Nepal (Subedi, 2016). Many efforts have been made to increase the productivity of maize, but the results are not encouraging. This crop is a major staple crop for people in mid-hill and a source of animal feed in Terai (KC *et al.*, 2016). The unprecedented damage due to FAW in Nepal is expected due to many reasons. FAW is a new pest to farmers and the agencies that support them, and this has posed challenges in effectively managing it. It is a highly destructive and economically significant pest. Because of its strong flight ability and wide host range, it multiplies and establishes quickly in the new environments. This makes FAW a major threat to rural livelihoods and areas that are already food insecure. It has invaded most part of the country and has already established in crop fields. It is causing significant damage in maize crops and has reduced the yields and potentially threatening food security, with multiple repercussions on livelihoods. The FAW does not distinguish between large-scale crop production and smallholder, subsistence production; however, most affected farmers are smallholder farmers growing maize, sorghum, millet, sugarcane, cowpea and certain vegetable crops. This is very apparent in Nepal as subsistence farming is dominant and control operations are hampered due to COVID-19, pandemic. These farmers have only limited access to information, tools, technologies and management practices to forecast, recognize and manage an infestation of FAW in their fields. Once their fields are infested, they neither have the financial means to cope the damage nor a management strategy to combat it. Apart from coordinated and committed interventions, FAW has made it difficult to achieve the Sustainable Development Goals (SDGs). One of the major challenges in dealing with the pest is the inadequate coordination among the farmers, among the communities, and among the organizations in applying recommended solutions based on integrated pest management (IPM). Yield losses in Nepal including Asia and Pacific region is yet to be estimated however, huge amount of financial losses is expected. CABI in 2017 estimated that FAW has the potential to cause maize yield losses of 8.3 to 20.6 million tons (which could feed 40.8 million to 101 million people) annually, valued at between USD 2.5 to USD 6.2 billion, in the absence of proper control methods, in 12 African maize-producing countries (Day *et al.*, 2017).

Integrated options of FAW management

FAO has developed a comprehensive guide on integrated management of the FAW. These options will be a useful tool to adopt in Nepal while managing this pest. The management of *S. frugiperda* is cumbersome as it has a wide host range, high rate of fecundity, with multiple generations within a year (Chormule *et al.*, 2019). Additionally, to develop FAW management strategies a good understanding of biology, ecology, and migration patterns is needed (Nagoshi *et al.*, 2012). Based on the available information and felt problem, the following tips are suggested for its possible management. Assessment of the suggested technology in a country-specific situation is also not ready at this moment. However, the technologies and outputs so far generated elsewhere in the world mainly in the new world- the Americas, and African countries will be better learning to Nepal. Following measures may be proposed at this stage.

Establish better coordination

The magnitude of the impacts of FAW at the national level needs to be established for carrying out sustainable control operations. Hence, a coordinated mechanism needs establishing, which is expected to be provided the policy support and technical support, approve the work plan, leveraging of the resources, solidarity in implementation of the action as well as coordination among the three tiers (federal, provincial and local) governance system. It will reinforce the coordination role in the country. This is what something has been felt necessary in most of the country where FAW has recently invaded. Several reasons are evident as FAW itself is a difficult transboundary invasive pest species, control in isolation is near to impossible. Fighting alone may not result in the desired result, hardly may limit the movement and reduction in the establishment of the pest in new area and crops. Coordinated actions in Nepal are important also to deal with the invasion of not only FAW but also other pests like locusts, fruit fly, and several other pests. In this regard, a fully operationalized unit for dealing with invasive pests can be formed with the involvement of the researcher, extension, academic, private sectors, and similar stakeholders. This may work as a rapid response platform where FAO, WFP, and similar UN and other agencies will have a significant contribution. This may provide early warning, diagnostic facility, and regulatory measures for preventing further dispersal.

Efforts of the Technical Committee on FAW management in Nepal

In an attempt to control the FAW, Nepal has better established a national response team headed by high-level officials supported by a technical committee. The committee has actively engaged in coordination with provinces, local municipalities, and research, and other non-governmental institutions. It has developed three important documents namely, surveillance protocol for Fall armyworm, *Spodoptera frugiperda* for Maize in Nepal, an action plan for the management of Fall armyworm in Nepal, and protocol for Integrated Pest Management of Fall armyworm in Nepal. These documents were endorsed by the NPPO, Ministry of Agriculture and Livestock Development, Government of Nepal in December 2019 (NPPO, 2019). Planned and coordinated activities are also presented by the FAW Focal Person and outlined against the FAW management in Nepal.

Reduce crop yield losses caused by FAW

Integrated pest management (IPM) is an eco-friendly method of pest management where all compatible options such as cultural, mechanical, pheromones, biological can be integrated, and chemical pesticides can be used when pests cross the economic threshold level (Day *et al.*, 2017). This approach is equally important for managing knowledge and better communication. Awareness raising and implementation of national action plans are very crucial. At the same time, the establishment of national monitoring and early warning systems, which includes scouting, testing of ecosystem-based IPM, and their scaling up through training and dissemination through farmer field schools are carried out. Pesticide increases the resistance level for almost all pests including FAW and it has also developed resistance for several major classes of insecticides such as carbamates, organophosphate, and pyrethroid insecticides (Yu *et al*., 2003). Given the complexity of the serious threat that the FAW represents, collective farmers' action in the community is needed. It also implies among the neighboring countries. Farmers and technical actors need to be informed not only about the entry of the pest but also about its biology and behavior along with the guided actions, whether the neighbor has adopted the control measures. Within FAO's program for action on the sustainable management of the fall armyworm, the information and knowledge sharing are coordinated normally through global, regional, and national committees. Therefore, FAO together with government counterparts is establishing such groups and collaborating networks. FAMEWS, a FAW monitoring tool, and audio-video materials are developed by FAO, which can be used in ranges of options. Access to information and knowledge to the farmers is considered as the key to the success of control of this pest. Technical extension leaflets targeting farmers and extension workers on FAW management decisions specifically on identification, prevention, monitoring, and direct control are very much crucial.

Reduce the risks to further introduction and spread

It is necessary to activate the national response team such as National Task Force (NTF) and Technical Task Force (TTF) needs. They can be activated for preparing the guidance on the prevention of the further spread of FAW in the new crops and area. Implementation of standards for inspection and surveillance can be carried out with the support of the International Plant Protection Convention (IPPC) and Asia Pacific Plant Protection Committee (APPPC) secretariats. Imparting innovation and knowledge is ensured through the collaborative efforts of regional and national training workshops to minimize the spread of FAW. Innovative technologies such as new digitalization tools for area-specific strategies needs applied for monitoring and early warning; prevention and control; surveillance and diagnoses. Before adopting any pest management strategies, the economic threshold level has to be assessed (FAO, 2017b). Regular surveillance and monitoring of pests should be followed to evaluate the pest's threshold level in maize fields. If the pest has not entered into a new locality, intra- or inter-quarantine strategies should be strictly followed. Farmers should be familiar with the damage symptoms, identification of larvae, early detection, etc. (Day *et al*., 2017).

Apply control measures at critical maize growth stages

The right-planting date is crucial for successful crop production. Maize generally goes through several growth stages, divided into vegetative stages (V) and reproductive stages (R). Therefore, ensuring a healthy and vigorous crop by timely planting, use of fast-maturing varieties, use of quality seeds, and optimum use of fertilizers and manure will ensure that the maize crop is healthy and can either escape the FAW attack, withstand the FAW attack or recover the following attack. A farmer who ensures a healthy crop from the outset is more likely not to suffer from the effects of a FAW attack on his or her field, and to reduce the costs that would have been incurred in applying FAW control methods. While FAW can damage maize plants in nearly all stages of development, it will concentrate on the late-planted plant that has not yet silked. FAW can only be effectively controlled while the larvae are small (before the third instar). Controlling larger larvae (fourth to sixth instars), typically after they are hidden under the frass, is much more difficult and costly. Based on the critical growth stages of the maize, early control operations and uniform plantation in the community are crucial which is represented in the following Fig. 3.

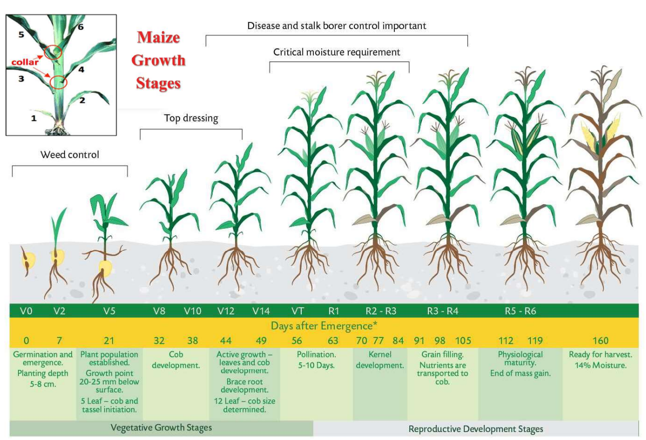

Fig. 3: Maize growth stages [VE to V6 (early whorl stage), V7 to VT (late whorl stage), R1 to R3 (tasseling and silking)]

The population density as well as the onset of the arrival is known through scouting which is usually expressed as a percentage (percentage) of infested plants. For this, the commonly used approach is the "W" pattern in the field. The scout walks into the field about five meters (avoiding the border rows of the field is important to avoid the edge effects). The scout then zigzags the field, stopping at five different locations. At each of these locations, the scout assesses 10-20 plants looking for signs of FAW feeding. The percentage of damaged plants is recorded, and the scout moves to the next checkpoint.

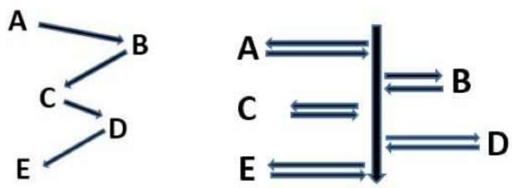

Fig. 4: Sample scouting pattern late whorl stages (left) and Reproductive stage (right).

Use of pheromone traps

Collection and destruction of infected plants; collection and killing of eggs and larvae and use of FAW lure are important mechanical methods of FAW management (Kumela *et al.*, 2019). Pheromone traps may be used as an additional tool for insect monitoring. The pheromone attracts (usually) male insects. Because pheromones can travel by air over very long distances, their use is very useful for monitoring FAW presence. However, some pheromone lures also attract a limited number of non-target moths. The universal bucket trap is normally used (FAO and CABI, 2019). Adult moths will be attracted to the pheromone and will be stuck on the sticky pad when they enter the trap. Pheromones should be replaced about every four weeks.

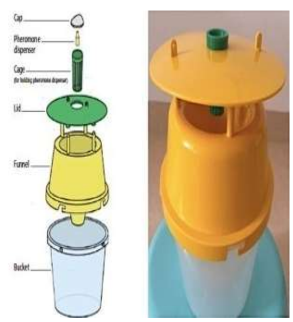

Fig. 4: Bucket trap

Use of natural enemies

Many natural enemies of FAW have been reported from around the globe. Earwigs, ladybird beetles, ground beetles, assassin, flower bugs, and predatory wasps were reported to be a predator for FAW. Likewise, wasps were found as parasitoids of the FAW. Similarly, the Nuclear polyhedrosis virus (NPVs) and *Spodoptera frugiperda* multi capsid nucleopolyhedrosis virus (SfMNPV) are reported as lethal to the FAW. *Bacillus thuringenesis* (Bt), *Beauveria bassiana* and Baculovirus were found effective against controlling FAW (FAO, 2018b). Different natural enemies effective to FAW include earwigs, ground beetles, assassin bugs, ants, flower bugs, spiders, insectivorous birds and bats, predatory wasp are the potential predators of this pest (Harrison *et al.*, 2019).

Similarly, Ichneumonids (*Campoletis grioti* Blanchard, *Campoletis sonorensis* Cameron), and braconids (*Aleiodes laphygmae* Viereck) are common parasitoids which are reported to be effective against FAW (Gabriela Murúa *et al*., 2009; Molina *et al.*, 2004; Wyckhuys and O'Neil, 2006). In the laboratory study, viruses such as Nuclear Polyhedrosis Virus (NPVs) and Baculovirus (Barreto *et al*., 2005; Figueiredo *et al*., 2015; Rowley *et al*., 2010), fungus such as *Metarhizium anisopliae*, *M. rileyi*, and *Beauveria bassiana* (Carneiro *et al.*, 2008; Rios-Velasco *et al*., 2011), bacteria such as *Bacillus thurigensis* Bt, nematodes such as *Hexamermis* sp. and *Neoaplectana carpocapsae* Weiser (Gardner and Fuxa, 1980; Salvadori *et al.*, 2012) are reported to be successfully used to control this pest. Conservation of these agents with minimum use of chemical pesticides should be encouraged. Biocontrol demonstrates an environmentally friendly, economical, culturally acceptable solution. Two natural enemies that attack the eggs of the pest – *Telenomus remus* and *Trichogramma* have shown great promise so far, the research done in NARC (Nsami *et al.*, 2020). The two natural enemies are local to both Africa and Asia, and the technique used to mass-multiply and release them is easily transferrable. Nepal Agriculture Research Council (NARC), Entomology Division may continue laboratory work and shuttle release can be done with the help of public and private ventures at provincial, federal, and local levels.

Push-pull strategy and physical control

A popular pest management method 'push-pull' technology could be an important management tool to keep the FAW larva away from the maize field. In this technology, Desmodium can be deployed in the maize field as an intercrop to deter or 'push' the FAW from the maize field and Napier grass in field edges can be used as an attractant or to trap or 'pull' the FAW (Khan *et al.*, 2001). This is feasible at the farmer level. Handpicked larvae can be crushed in small-scale farming. Neem based botanicals can be used with local preparation. These production techniques at the community, the level needs encouraging rather than costlier production.

Way forward

Use of local Azadirachtin 1500 ppm @ 5 ml per liter of water, hot pepper, *Artemisia*, *Xanthoxyllum*, sawdust, sand is recommended against larvae. Similarly, spinetoram 11.7%SC (Delegate) @ 0.5 ml/liter of water or chlorantraniliprole 18.5%SC @ 0.4 ml/liter of water or spinosad 45%SC @ 0.3 ml/liter of water or emamectin benzoate 5% SG @ 0.4 g/liter of water are recommended based on the research done in other country situation. To promote them in Nepalese agriculture, it is always advisable for their verification by the national research system. Highly hazardous chemical pesticides are used in different situations, but they pose a problem to humans, animals, aquatic life, and environmental health. In the end, the use of chemical pesticides needs discouraging with the use of alternative compounds. In many cases, chemical pesticides have been found ineffective for control of FAW. Farmers are using different chemical pesticides at higher doses leading to environmental and human contamination. The use of neem-based pesticides has been found effective to protect crops from FAW (Constanski *et al.*, 2016). Several synthetic pesticides were reported to be effective against FAW. They are methomyl, acephate, cyfluthrin, benfuracarb, chlorpyrifos, cyfluthrin, diazinon and methyl parathion.

FAW's economic impact has yet to fully reach Nepal, and neither has the spread of COVID-19. However, a coordinated cautious approach is needed to control both. By activating the National Fall Armyworm Working Group led by Ministry of Agriculture and Livestock Development (MoALD), Nepal Agriculture Research Council (NARC), Agriculture University, Food, and Agriculture Organization (FAO), USAID, iDE, private sectors, and others, Nepal can protect crops threatened by the merging influx of FAW. Control options supported by enhanced awareness followed by surveillances are advisable. Facilitating supplies such as seeds, fertilizers, pheromones, both bio- and chemical- pesticides, and other inputs to farmers is also crucial to maintaining a vibrant supply chain. Continued production of natural enemies of fall armyworm and ensuring their release is pertinent so that farmers do not lose time in mitigating the spread of the pest in their fields. Existing coordinated mechanisms among three tiers of governance system along with virtual hubs such as Facebook and WhatsApp that foster networks of farmers interested in IPM and other crop protection services will also help combat FAW. Many food-exporting countries will probably impose restrictions amidst the rise of COVID-19 –hence, locally maintained food production by suppressing pest infestation in Nepal could have a major impact in preventing food insecurity.

NPPOs are actively engaged and have a mandate in pest reporting, survey, and surveillance. In Nepal, NPPO played a crucial role in notifying and management ever since its occurrence. Since then, it has been actively engaged in planning, coordination, and management with the engagement of multi-stakeholder organizations. Within the frame of the National FAW response team, Nepal Agriculture Research Council (NARC), iDE, Agricultural Institutes, and private sectors have formed the national working group. It has been rolling out different activities in the country through the involvement of provincial as well as local government. Despite the efforts, technical know-how and do-how for its systematic control measures are largely needed, which can be back up through the capacity building to the farmers and technical staffs working at various institutions. At present, FAO Regional Office, Bangkok has launched the Technical Cooperation Project (TCP) on FAW management in Nepal. Within the broader framework of this project, it is expected its backstopping role to fill these voids and capacity building of the NPPO. NPPO can play a greater role in coordination, training, and sharing of the latest innovations in FAW management

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LITERATURE CITED

Barreto, M. R., C.T. Guimaraes, F.F. Teixeira, E. Paiva and F.H. Valicente. 2005. Effect of Baculovirus spodoptera isolates in *Spodoptera frugiperda* (J.E. Smith) (Lepidoptera: Noctuidae) larvae and their characterization by RAPD. Neotropical Entomology. 34(1):67-75. https://doi.org/10.1590/s1519-566x2005000100010

Carneiro, A.A., E.A. Gomes, C.T. Guimarães, F.T. Fernandes, N.P. Carneiro and I. Cruz. 2008. Molecular characterization and pathogenicity of isolates of *Beauveria* spp to Fall armyworm. Pesquisa Agropecuaria Brasileira.43(4):513–520. https://doi.org/10.1590/S0100-204X2008000400010

CABI. 2017. *Spodoptera frugiperda*. Retrieved from Invasive Species Compendium: https://www.cabi.org/isc/datasheet/29810

Constanski, K.C., J. Zorzetti, P.H. Santoro, A.T. Hoshino and P.M. Neves., 2016. Inert powders alone or in combination with neem oil for controlling *Spodoptera eridania* and *Spodoptera frugiperda* (Lepidoptera: Noctuidae) larvae. Semina: Ciências Agrárias (Londrina). 1801-1810.

Chapman, J.W. 1999. Fitness consequences of cannibalism in the fall armyworm, *Spodoptera frugiperda*. Behavioral Ecology.10(3):298-303. https://doi.org/10.1093/beheco/10.3.298

Chimweta, M., I.W. Nyakudya, L. Jimu and A. Bray Mashingaidze. 2019. Fall armyworm [*Spodoptera frugiperda* (J.E. Smith)] damage in maize: management options for flood-recession cropping smallholder farmers. International Journal of Pest Management. https://doi.org/10.1080/09670874.2019.1577514

Chormule, A., S. Deshmukh, N. Shejawal, C. Kalleshwaraswamy, R. Asokan and H. Mahadeva Swamy. 2019. First report of the fall armyworm, *Spodoptera frugiperda* (J.E. Smith) (Lepidoptera, Noctuidae) on sugarcane and other crops from Maharashtra, India. Journal of Entomology and Zoology Studies. 7(1):114-117. Retrieved from https://www.researchgate.net/publication/330185271

Day, R., P. Abrahams, M. Bateman, T. Beale,V. Clottey, M. Cock and A. Witt. 2017. Fall armyworm: Impacts and implications for Africa. Outlooks on Pest Management. 28(5):196-201. https://doi.org/10.1564/v28_oct_02

Early, R., P. González-Moreno,S.T. Murphy and R. Day. 2018. Forecasting the global extent of invasion of the cereal pest Spodoptera frugiperda, the fall armyworm. NeoBiota.40:25-50. https://doi.org/10.3897/neobiota.40.28165

FAO.2017a. Fall armyworm (*Spodoptera frugiperda*): Identification, biology and ecology. Fall Armyworm. https://doi.org/10.5962/bhl.title.123807

FAO. 2017b. Sustainable management of the Fall armyworm in Africa. Food and Agriculture Organization of the United Nations F, (October). 1-34.

FAO. 2018a. Integrated management of the Fall Armyworm on maize A guide for Farmer Field Schools in Africa. FAO. Retrieved from http://www.fao.org/3/I8665EN/i8665en.pdf

FAO.2018b. FAO launches mobile application to support fight against Fall Armyworm in Africa. Retrieved from News Article: http://www.fao.org/news/story/en/item/1106850/icod

FAO and CABI. 2019. Community based Fall Armyworm (*Spodoptera frugiperda*) Monitoring, Early Warning and Management. Training of Trainer Manual (1st ed.). Food and Agriculture Organization of the United Nations and CAB International. 106p.

Figueiredo, M. L.C., I. Cruz, A.M.P. Dias and R.B. Silva. 2015. Interaction between Baculovirus spodoptera and natural enemies on the suppression of *Spodoptera frugiperda* (J.E. Smith) (Lepidoptera: Noctuidae) in Maize. Revista Brasileira de Milho e Sorgo. 8(3):207–222. https://doi.org/10.18512/1980-6477/rbms.v8n3p207-222

Gabriela Murúa, M., J. Molina-Ochoa and P. Fidalgo. 2009. Natural distribution of parasitoids of larvae of the Fall armyworm, *Spodoptera frugiperda*,in Argentina. Journal of Insect Science. 9(20):1–17. https://doi.org/10.1673/031.009.2001

Gardner, W.A. and J.R. Fuxa. 1980. Pathogens for the suppression of the fall armyworm (*Spodoptera frugiperda*). Florida Entomologist.

Goergen, G., P.L. Kumar, S.B. Sankung, A. Togola andM. Tamò. 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. 11(10). https://doi.org/10.1371/journal.pone.0165632

Hardke, J.T., R.E. Jackson, B.R. Leonard and J.H. Temple. 2015. Fall armyworm (Lepidoptera: Noctuidae) development, survivorship, and damage on cotton plants expressing insecticidal plant-incorporated protectants. Journal of Economic Entomology108(3):1086-1093. https://doi.org/10.1093/jee/tov092

Hardke, J.T., G.M. Lorenz, and B.R. Leonard. 2015. Fall armyworm (Lepidoptera:

Noctuidae) ecology in Southeastern cotton. Journal of Integrated Pest Management.6(1). https://doi.org/10.1093/jipm/pmv009

Harrison, R.D., C. Thierfelder, F. Baudron, P. Chinwada, C. Midega, U. Schaffner and J. van den Berg. 2019. Agro-ecological options for fall armyworm (*Spodoptera frugiperda* J.E. Smith) management: Providing low-cost, smallholder friendly solutions to an invasive pest. Journal of Environmental Management.243:318-330. https://doi.org/10.1016/j.jenvman.2019.05.011

KC, G., T.B. Karki, J. Shrestha and B.B. Achhami. 2016. Status and prospects of maize research in Nepal. Journal of Maize Research and Development.1(1):1-9. https://doi.org/10.3126/jmrd.v1i1.14239

Khan, Z. R., J.A. Pickett, L. Wadhams and F. Muyekho. 2001. Habitat management strategies for the control of cereal stemborers and striga in maize in kenya. Insect Science and Its Application. 21(4):375-380. https://doi.org/10.1017/S1742758400008481

Kumela, T., J. Simiyu, B. Sisay, P.Likhayo, E. Mendesil, L. Gohole and T. Tefera. 2019. Farmers' knowledge, perceptions, and management practices of the new invasive pest, fall armyworm (*Spodoptera frugiperda*) in Ethiopia and Kenya. International Journal of Pest Management. 65(1):1-9. https://doi.org/10.1080/09670874.2017.1423129

Mello Da Silva, D., A. De, F. Bueno, K. Andrade, C. Dos, S. Stecca and M.C. Neves De Oliveira. 2017. Biology and nutrition of *Spodoptera frugiperda* (Lepidoptera: Noctuidae) fed on. Sci. Agric.74(1):18-31. https://doi.org/10.1590/1678-992X-2015-0160

Molina, J., J.E. Carpenter, R. Lezama, J.E. Foster, M. González, C.A. Angel and J. Farías. 2004. Natural distribution of hymenopteran parasitoids of *Spodoptera frugiperda* (Lepidoptera: Noctuidae) larvae in Mexico. Florida Entomologist. 87(4):461-472. https://doi.org/10.1653/0015-4040(2004) 087[0461:NDOHPO]2.0.CO;2

Nagoshi, R.N., R.L. Meagher and M. Hay-Roe. 2012. Inferring the annual migration patterns of fall armyworm (Lepidoptera: Noctuidae) in the United States from mitochondrial haplotypes. Ecology and Evolution. 2(7): 1458-1467. https://doi.org/10.1002/ece3.268

NPPO. 2019. Surveillance protocol for fall armyworm, *Spodoptera frugiperda*for maize in Nepal. National Plant Protection Organization.Ministry of Agriculture and Livestock Development, Government of Nepal

NPPO. 2020. Fall armyworm status and its management in Nepal. National Plant Protection Organization. Report submitted to FAO, Regional Office, Bangkok, June, 2020.

Elibariki, N.,A.S.R. Bajracharya, B. Bhat, T. Tefera, J.L. Mottern, G. Evans, R. Muniappan, Y.D. G C, B. Pallangy and P. Likhay 2020. Candidates for augmentative biological control of *Spodoptera frugiperda* in Kenya, Tanzania and Nepal.Indian Journal of Entomology, Review Article (2020). Online published (Preview) in www.entosocindia.org Ref. No. 20107 (pp.1-3). https://ipmil.cired.vt.edu/wp-content/uploads/2020/05/Candidates-for-Augmentative-Biological-Control-of-Spodoptera-Frugiperda.pdf

Rios-Velasco, C., G. Gallegos-Morales, J. Cambero-Campos, E. Cerna-Chávez,M.C.Del Rincón-Castro andR. Valenzuela-García. 2011.Natural enemies of the fall armyworm *Spodoptera frugiperda* (Lepidoptera: Noctuidae) in Coahuila, México . Florida Entomologist. 94(3):723-726. https://doi.org/10.1653/024.094.0349

Roel, A., D. Dourado, R. Matias, K. Porto, A. Bednaski and R. da Costa. 2010. The effect of sub-lethal doses of *Azadirachta indica* (Meliaceae) oil on the midgut of *Spodoptera frugiperda* (Lepidoptera, Noctuidae). Revista Brasileira de Entomologia. 54(3). doi:10.1590/S0085-56262010000300024

Rowley, D.L., R.R. Farrar, M.B. Blackburn and R.L. Harrison. 2010. Genetic and biological variation among nucleopolyhedrovirus isolates from the fall armyworm, *Spodoptera frugiperda* (Lepidoptera: Noctuidae). Virus Genes. 40(3):458-468. https://doi.org/10.1007/s11262-010-0462-y

Sparks, A.N. 1979. A review of the biology of the fall armyworm. The Florida Entomologist. 62(2):82. https://doi.org/10.2307/3494083

Subedi, S. 2016. A review on important maize diseases and their management in Nepal. Journal of Maize Research and Development. 1(1):28-52. https://doi.org/10.3126/jmrd.v1i1.14242

Wyckhuys, K.A.G. and R.J. O'Neil. 2006. Population dynamics of *Spodoptera frugiperda* Smith (Lepidoptera: Noctuidae) and associated arthropod natural enemies in Honduran subsistence maize. Crop Protection. 25(11): 1180-1190. https://doi.org/10.1016/j.cropro.2006.03.003

Yu, S. J., S.N. Nguyen and G.E. Abo-Elghar. 2003. Biochemical characteristics of insecticide resistance in the fall armyworm, *Spodoptera frugiperda* (J.E.Smith). Pesticide Biochemistry and Physiology.77(1):1-11. https://doi.org/10.1016/S0048-3575(03)00079-8