

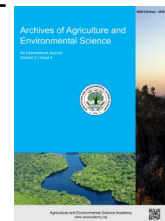


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REVIEW ARTICLE



Integrated pest management of fall armyworm infestations in maize fields in Nepal: A review

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ABSTRACT

Spodoptera frugiperda, commonly known as Fall Armyworm (FAW), is amongst the most terrifying pests of maize in Latin America, which unexpectedly appeared in Nepal in 2019 and spread expeditiously. Estimates of maize crop losses due to this pest are vital in order to compare the effect of these losses with the convenient of controlling FAW and suggest pertinent controlling technology and methods. Nepal is predominantly an agrarian nation thus, maize is grown substantially. However, climatic conditions of Nepal favor the outbreaks of pests such as FAW in many maize grown areas. On the grounds that most of the people of hill and mountainous regions depend on maize for their staple food, pests have appeared to be a great threat to cereal production. It causes considerable injuries to maize by feeding on leaf whorls, ears and tassel which often leads to total yield loss. Yet, agriculture is an economic activity, even among subsistence farmers in Nepal. Seeing high potential losses caused by FAW, different control methods have been proposed. This pest demands meticulous and stepwise plan for its management. This review emphasized on adoption of IPM methods of pests' control, which is the integration of biological, cultural, physical, chemical, and technological approaches. Meanwhile, early warning systems, though poorly developed in Nepal, can be highlighted for further studies and for further research work.

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INTRODUCTION

Fall armyworm, *Spodoptera frugiperda* (Lepidoptera; Noctuidae), a gluttonous agricultural pest has altered and declined the maize yield and other crops production of Gramineae family, mostly in tropical regions (Andrews, 1980). It is polyphagous in nature (Hoy, 2013) with host preference recorded more than 353 plants of 76 different families, majorly Poaceae (106), Asteraceae (31) and Fabaceae (31) (Montezano *et al.*, 2018). Due to its migratory performances, it has been categorized as the sporadic pest (Hardke *et al.*, 2015). The name is derived from the movement larva forming the military column and form *en masse*, feeding crops and leaving no vegetation (Casmuz *et al.*, 2012). Regardless of being cosmopolitan in distribution (Luginbill, 1928), it typically favors tropical region with annual

temperature ranging from 18 to 26°C and 500 to 700 mm annual precipitation (Early *et al.*, 2018). On account of its incapability to survive in freezing temperature, this pest migrates to warmer regions for overwintering (Sparks, 1979). It causes substantial loss to economically important crops like maize, sorghum, cotton, millet, rice, etc. by damaging young leaf whorls, ears and tassels (De Almeida Sarmiento *et al.*, 2002). Basically, there are two strains of fall armyworm, namely R-strain which attacks rice, bermuda grass and other members of gramineae family and C-strain which usually attack sorghum and maize (Pashley, 1986).

Next to rice, in Nepal, maize is the most cultivated crop in terms of acreage and production. In 2019, maize cultivation area accounts for 956,477 ha with total production of 2,713,635 tons (MoAD, 2020). Considering the fact of its diversified uses such

as animal feeds, poultry feeds, human consumption, and biofuel, the demand for maize, as compared to other cereal crops, is continually increasing. Greater part of the people, particularly in hill and mountainous regions are very much relied on maize for staple food (MoAD, 2020). In spite of having high genetic yield potential, corn plant is sensitive to insect pest infestation and other abiotic stresses. This voracious pest is becoming a havoc for successful maize production in Nepal and challenging to food security. IPM (Integrated Pest Management) approach is considered to be effective for many years. It is defined as "a decision-based process involving coordinated use of multiple tactics for optimizing the control of all classes of pests (insects, pathogens, weeds, vertebrates) in an ecological manner" (Prokopy, 2003). This technique focuses on use of locally available biological resources and minimal use of chemical pesticides. The aim of this review paper is to generate attention towards the eco-friendly, sustainable and cost-effective method to control incidence of fall armyworm. This work of review presents a clear insight into the knowledge that would encourage the maize growers to adopt the integrated pest management approach, which is effective and economical.

Methodology

Information related with management of fall armyworm on maize was collected from the available literature including problem identification, pest biology, pest monitoring, early warning system, and IPM measures. Relevant information was arranged systematically and findings from them are summarized. A secondary source of information was used such as journals, reports, articles, newspapers, etc. during the manuscript preparation.

Origin and distribution of Fall Armyworm

FAW is native to tropical and subtropical regions of Americas and migrates to different regions mainly in zone of maize planting (Mitchell et al., 1991). Its occurrence was first reported in West Africa on late 2016 (Goergen et al., 2016), which then spread across the continent due to unsafe quarantine measures (Abrahams et al., 2017). The plausible explanation for its quick spread is migratory behavior with the high dispersal capacity and adult moths with remarkable ability of flying 100 km in a single night (Johnson, 1987). Besides, this pest has numerous eggs laying capacity that increases species population in a very short time (Montezano et al., 2018). In Asia, the occurrence and prevalence of this pest was detected in Indian state of Karnataka at college of Agriculture, Shivamogga in May 2018 for the first time (Sharanabasappa et al., 2018a). Then, it spreads to different tropical states of India like Bihar, Chhattisgarh, Gujrat, Maharashtra, Odisha, West Bengal etc. causing devastating damage within short duration (CABI, 2020). Genetic homogeneity was found between FAW of India and South Africa with respect to the small number of COI and Tpi haplotypes suggesting their common source of origin (Nagoshi et al., 2019).

This pest migrated to different countries like Bangladesh, Sri Lanka and Thailand by December 2018 and other Asian countries like Myanmar, China, Indonesia, Philippines, Vietnam, Cambodia, The Republic of Korea and Japan by October 2019 (FAO, 2020). Geographical distribution of fall armyworm is shown in Figure 1.

Present status and threat of fall armyworm in Nepal

FAW was recorded in Nawalparasi district (N 27°42' 16.67" E 084°22'50.61") on 9th may 2019 for first time in Nepal (Bajracharya et al., 2019) and invasion of this voracious pest in Nepal was declared in the 19th meeting of Nepal Plant Protection Organization (NPPO) of Nepal (NPPO, 2019). Occurrence of this invasive pest in Chitwan district confirms the prevalence of this pest in Nepal indicating timely intervention (FAO, 2019). This menacing pest has spread across 58 districts of Nepal and has caused approximately 21% loss in maize production (Onlinekhabar, 2020). Growth, survival, multiplication and their distribution are significantly guided by environmental condition (Ramirez-cabral et al., 2017). Fall armyworm is the tropical pest that requires warm, humid growing season with heavy rainfall is required for survival of this pest (Stokstad, 2017). Climatological elements like temperature and precipitation are favorable for the introduction, establishment and multiplication of this pest (GC et al., 2019). Maize is widely cultivated in Nepal and ranks second in term of production this additionally adds the chance of fall armyworm spread. Crops like sorghum, millet, sugarcane, cotton and other cereal crops are mainly cultivated in Nepal and these crops attract this voracious pest in absence of maize as host (Bhusal and Chapagain, 2020). The larvae consume almost all the vegetation in their path and the major damage is due to the feeding on the foliage (Bista et al., 2020).



Figure 1. Geographical distribution of fall armyworm (Source: FAO, 2020).

Insect biology and identification

FAW undergoes complete metamorphosis consisting of egg, 6-7 larval instars, pupa and adult (Luginbill, 1928). Time to complete its life cycle may vary seasonally i.e. 30 days in summer, 60 days in autumn and spring, and 80-90 days in winter (James and Engelke, 2010). Spherical shaped of about 0.75 mm diameter eggs in mass of 150-200 are laid by female in two to four layers on leaf surface (CABI, 2019). Egg develops in 2-3 days if favorable temperature of 20-30°C is provided. The larval stage of fall armyworm completes in six larval instar stages. First instar larva are greenish with black head while second instar are greenish brown in color that changes to brownish with three dorsal and lateral white lines in third instar larva. Fourth to sixth instar larvae are brownish black and have three white dorsal lines (Sharanabasappa et al., 2018b). Well-developed larva have inverted Y-shaped in yellow in head (Oliver and Chapin, 1981) and four black spots arranged in a square in last abdominal segment (CABI, 2019). The larval period is recorded to about 14-30 days (Pitre and Hogg, 1983). Larva stops feeding and turns greenish and the bright brown color after completion of sixth instar larval stage (Sharanabasappa et al., 2018b). Chapman et al. (2000) reported that two or fourth instar larvae exhibited cannibalistic behavior, accounting 40% mortality when maize plants were infested in field condition. Larvae forms protective covering called "cocoon" by webbing together leaf debris if the soil is too hard and pupal duration is 8-9 days in summer and 20-30 days in cooler season (Silva et al., 2017). Adult male has shaded forewing with gray and brown with triangular white patch at apical region whereas female has uniform grayish brown to a fine mottling of grey brown (Sharanabasappa et al., 2018b). Adult female is capable of laying around 1500 eggs which may increase up to 2000 during favorable environmental condition (Igyuve et al., 2018). The duration of adult life is estimated to average 10 days, with the range of 7-21 days (Sparks, 1979).

Nature of damage and yield loss

FAW larva is voracious feeder that consumes maize from seedling emergence to its maturity and defoliates the whole plant causing yield loss. This pest attacks leaves, stem and other reproductive part of host plant (Tefera et al., 2019). Earlier symptoms of fall armyworm resembles with other stem borer damage like window pan feeding and small holes (Deole and Paul, 2018). Window like structure appears on the developing leaf near the funnel and moist saw dust like fecal matter near feeding area is the symptom of fall armyworm larval feeding (Bateman et al., 2018). Skeletonized and scrapped leaf during vegetative stage of maize plant is due to larval feeding. Plant infested with fall armyworm in between first and second weeks after germination resulted yield reduction up to 22.6% while yield of plant infected three and four week after germination were intermediate without any particular trend (Evans and Stanly, 1990). Adult larvae feed on growing point of shoot and tassel thus results in 'dead heart' which ease back fruit formation (Bateman et al., 2018). Kernel number per ear is also reduces as the larva feeding on silk causes reduction in

pollination (Harrison 1984). This pest has troubled a number of farmers around the world due to its voracious feeding habit on different crops like maize, rice, sorghum, sugarcane, millet, cotton, vegetables like tomato and crucifers. Annual crop loss of more than US\$ 500 million in South-East United States and Atlantic coast is caused by this pest (Young, 1979). Current study from 12 African countries found that fall armyworm is able to cause annual yield loss of 4.1-17.7 million tons of maize (Rwomushana et al., 2018) that valued US\$ 2.5-6.2 billions (Conrow, 2018). Yield loss estimate due to fall armyworm is 22-67 percent in Ghana and Zambia (Day et al., 2017), 47 percent in Kenya (Kumela et al., 2018) and 9.4 percent in Zimbabwe (Baudron et al., 2019). Similarly, 80,000 hector of land is affected with this pest in Yunnan province of China (Gu and Woo, 2019) whereas in case of Sri Lanka 40,000 hectares of land has been infested by damaging 20% of its crop (UNNews, 2019). Similarly, fall armyworm can cause severe damage in Nepal due to the favorable climatic condition.

Integrated pest management

Integrated pest management comprises of modification of cultural practices, emphasis on biological control (use of predators, parasitoids, and entomopathogens), botanical extracts, pest monitoring, crop management practices, judicious use of chemicals etc. Management of fall armyworm through only one approach is unimaginable so, different methods should be used in an integrated way in order to control fall armyworm infestation (Bista et al., 2020). These practices should be used in sustainable and economic manner such that the risk caused by them to the environment and human being are minimal (Bateman et al., 2018).

Pest monitoring

Scouting, pheromones traps, and light traps are the effective pest monitoring technique and mass trapping of FAW (Abrahams et al., 2017). Scouting helps in understanding biology of organisms in the field and their ecology which is the basis for understanding and knowledge, better decision making for FAW management (FAO, 2018b). Pheromone trap is the insect trap that is usually used to attract male by the use of pheromone and it has been found as effective tool to control male population (Basista-Pereira et al., 2006). Adult male of fall armyworm can be captured by the standard unitrap with a green canopy, yellow funnel and white bucket (Meagher, 2001). Pheromone is chemical usually produced by female that attracts male for mating. *Spodoptera frugiperda* sex pheromone contains (z)-9-Tetradecenyl Acetate (Z-9-14: OAc) which is common to cabbage looper (*Trichoplusia Ni*), beet armyworm (*Spodoptera exigua*) and black cutworm (*Agrotis ipsilon exigua*) (Klun et al., 1996). Being nocturnal insect black light trap can be used to monitor both male and female insects (Haftay and Fissiha, 2020).

Cultural practices

Cultural practices include intercropping, trap cropping, crop rotation and other measures that alter environmental condition.

This enables FAW to attack less economic important crops. Intercropping of leguminous crop i.e. Soybean, Groundnut, bean etc. with maize protects crop from FAW as compared to that when it is mono cropped (Hailu et al., 2018). Deep ploughing before showing will expose FAW pupa to predators. Push-pull technology is the habitat management strategy that involves intercropping maize with repellent plants i.e. Desmodium (push plant) which repels FAW and planting trap crop like Napier grass (pull plant) are shown in the maize field 3-4 rows and spraying with 5% NSKE or Azadirachtin 1500 ppm when trap crops show symptom of FAW damage (Firake et al., 2019; Khan et al., 2011). Spraying of sugar solution in the maize field caused parasitism on fall armyworm (11.38%) as compared to water sprayed (6.38%); however, it does not reduce pest population (Bortolotto et al., 2014). Cover crops like mucuna, lalab beans, sun hemp etc. provide shelter to natural enemies of fall armyworm like spider, beetle ants, etc. (Altieri et al., 2012). Climate adapted push-pull technology reported significant reduction in larval population and plant damage along with 2.7 times higher yield compared to maize grown as sole crop (Midega et al., 2018). Selection of resistant variety and genetically modified seed play vital role in controlling fall armyworm (Burtet et al., 2017). Bt-maize was reported resistant in Africa but in some case of America, it has overcome Bt-maize (FAO, 2018a). Fall armyworm larval growth was significantly decreased by 33-kD proteinase which is naturally produced by some sweet corn (Pechan et al., 2000). In Latin America, In Nepal, GMO is not practiced for commercial purpose. Cultivation of maize hybrid with tight husk if found to be effective to reduce FAW damage (Firake et al., 2019). Infestation on plant can be reduced by planting early maturing variety as they are less exposed to FAW (Harrison et al., 2019). Conservation tillage is also beneficial to control fall armyworm infestation in Americas as it promotes crop diversification and provides favorable habitat for predatory species (Rivers et al., 2016).

Mechanical control

Egg masses and neonate larva are hand-picked and destroyed by crushing or immersing in kerosene water (Firake et al., 2019). Application of dry sand and wood ashes into the whorl of effected maize plant soon after observation of FAW incidence is also very effective mechanical method to control fall armyworm infestation (Abate et al., 2000). Volunteer plants, infected crop

residue, weeds, etc. are host for the pest so they should be removed from field. Removing larva of fall armyworm during vegetative stage of plant reduces the number of insecticidal spray required during the silking period (Foster, 1989). As the adult female moth of fall armyworm lays eggs in cluster underneath of leaves, this allows easy destroying of eggs manually or by natural enemies (Wightman, 2018).

Biological control

Use of natural enemy of the pest is the main theme of biological management of pest. IPM concept mainly focuses in biological control as this method is environment friendly and sustainable. Biological management of FAW involves the use of predatory insect and mites which feed their prey, parasitoids which are free living in adult stage and parasitic in larval stage and entomopathogens like fungi, bacteria, viruses and nematodes that cause lethal infection (FAO, 2018b).

Parasitoid

They lay eggs on egg masses, larva and adult of fall armyworm and cease their growth by growing on them. Egg parasitoids are considered as most important among other biological control as they prevent any damage to crop and they can be easily grown in huge amount (Prasanna et al., 2018). Recently, Nepal Agriculture Research council has reported fall armyworm egg parasitoids and the specimen were almost identical to multiple specimens in Gene Bank (GC et al., 2020). *Cotesia icipie* is very important larval parasitoids which has potential to kill over 60% of fall armyworm (ICIPE, 2018). Table 1 shows different parasitoids of the fall armyworm.

Predators

Predators are the natural enemies that destroy eggs, caterpillars, pupa or adult of the fall armyworm during their lifecycle either as larva or adults (FAO, 2018b). Ants, wasps and spiders are also most important predators of FAW eggs, larvae or pupa. Similarly, vertebrate predator like birds, skunks and rodents around the maize field is also beneficial as they feed larva as well as pupae of fall armyworm (Capinera, 2000). Mostly fall armyworm reside inside whorl of maize where predatory earwig, *Doru luteipes* occurs throughout the life span of maize whose nymphs feed 8-12 larva daily and adult one consumes 10-21 larva daily (Reis et al., 1988). Different predators of FAW along with description is presented in Table 2.

Table 1. Parasitoids of Fall Armyworm.

S.N.	Natural enemy	Nature
1	<i>Trichogramma pretiosum</i>	Females are egg parasitoids.
2	<i>Telenomus remus</i> (Nixon)	Females are egg parasitoids.
3	<i>Chelonus insularis cresson</i>	Females are egg/larval parasitoids.
4	<i>Campoletis flavicincta</i> (Cameron)	Females are larval parasitoids.
5	<i>Cotesia icipie</i>	Females are larval parasitoids.
6	<i>Habrobracon hebetor</i>	Females are larval parasitoids.
7	<i>Winthemia trinitatis</i>	Females are larval parasitoids.
8	<i>Lespesia archippivora</i>	Females are larval/pupal parasitoids.
9	<i>Archytas marmoratus</i>	Females are larval/pupal parasitoids.

Source: (Prasanna et al., 2018)

Table 2. Predators of FAW.

S.N.	Predators	Scientific name	Description
1	Ladybird beetles	<i>Coleomegilla maculate</i> <i>Olla v-nigrum</i> <i>Cycloneda sanguinea</i> <i>Hippodamia convergens</i> <i>Eriopis connexa</i>	Both adults and larvae of ladybugs feed on eggs and young larvae of Lepidoptera including FAW.
2	Ear wigs	<i>Doru luteipes</i> <i>Euborellia annulipes</i>	They are recognized as egg and larval predator of FAW.
3	Ground beetle	<i>Calosoma granulatum</i>	They show predatory habit both as adult or larvae feeding on young FAW caterpillar.
4	Assassin bugs	<i>Zelus longipes</i> <i>Zelus leucogrammus</i> <i>Zelus armillatus</i>	They feed on immature of FAW.
5	Flower bugs	<i>Orius insidiosus</i>	They are predators of <i>lepidopteran</i> eggs.
6	Pirate bugs	<i>Nabis rugosus</i>	They are predators of small <i>lepidopteran</i> larvae.
7	Big-eyed bugs	<i>Geocoris punctipes</i>	They feed on immature of FAW.
8	Spined soldier bug	<i>Podisus maculiventris</i>	Nymphs and adults mainly feed on <i>lepidopteran</i> larvae.

Source: (Prasanna et al., 2018; FAO, 2018b)

Entomopathogens

Generally, plant pathogen (viruses, fungi, protozoa, bacteria and nematodes) are harmful to the crops and play vital role in reducing crop yield but some of them regulate FAW population in the field (Assefa and Ayalew, 2019). Nuclear Polyhedrosis Viruses (NPVs) can be the useful and effective method against fall armyworm (de Romero et al., 2009). FAW is naturally affected by Nuclear Polyhedrosis Viruses (NPVs) such as the Spodoptera Frugiperda Multicapsid Nucleopolyhedrovirus (SfMNPV), fungi like *Metarhizium anisopliae*, *Metarhizium rileyi*, *Beauveria bassiana*, Protozoa and bacteria like *Bt bacteria* (FAO, 2018b).

Botanical pesticides

Botanical pesticides are derived from different plant species of different plant family for pest control. Botanical pesticides are environment friendly, less harmful to farmer and consumer and safe to natural enemies of pest. The seeds or leaves of the plants of the Meliaceae family (*Azadirachta*) and Asteraceae family (*Pyrethrum*) can be use in order to manage fall armyworm (FAO, 2018b). Application of 0.25% Neem oil extract under laboratory condition showed 80% larval mortality (Tavares et al., 2010). (Maredia et al., 1992) reported that Neem seed powder was very effective to control fall armyworm that can cause over 70% larval mortality in his laboratory. Hexane and ethanol extracts of seeds of *Aglai cordata* Heirn showed 100% larval mortality under laboratory condition (Mikolajczak et al., 1989). Botanical extracts from *Azadirachta indica*, *Schinus molle*, *Phytolacca dodecandra* caused maximum larval mortality (>95%) after 72 hours of application (Sisay et al., 2019). The seed cake extract of *Azadirachta indica* (Silva et al., 2015) and methanol extract of roots and other areal parts of *Myrtillocactus geometrizans* (Cespedes et al., 2005) have shown larvicidal property due to decrement in feeding and eased back larval growth. 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 fall armyworm larvae (Barbosa et al., 2018). The aqueous extracts from leaves of the neem and spraying adjuvants has lethal effect upto 100% on the neonate larvae of

fall armyworm after three day of application and ceases the larval development (Viana and Prates, 2003). Ethanol extracts of *Argemone ochroleuca* shows larvicidal property as this extracts reduces the feeding ability of larva (Martinez et al., 2017).

Chemical pesticides

Chemical pesticides are the synthetic chemical compound that is used to kill or repel insect and pest which are which are invasive and causes damage to crop. Different insecticides and pesticides are reported to be effective against FAW. However, use of pesticide is not central idea of IPM but in severe condition chemical pesticide is used. Its judicious use is recommended so that risk caused by them is minimal to environment and human beings. Pesticides provide higher level of crop protection which other approaches cannot provide but they should be under the economic threshold. Soybean seed treated with Chlorantraniliprole and Cyantraniliprole caused reduction need for foliar spray against fall armyworm (Trash et al., 2013). Some of the synthetic chemical pesticides like Methomyl, Cyfluthrin, and Methyl parathion can be used to control the invasion of fall armyworm (Tumma and Chandrika, 2018). Pesticides should be used in judicious level due to their toxicity, persistence and tendency of accumulation and bio-magnification. Methomyl, Chlorpyrifos, Carbosulfan, Beta-cypermethrin, Spinetoram, Emamectin benzoate, Indoxacarb, Cartap hydrochloride, Lufenuron, Diflubenzuron, Chlorantraniliprole, etc. are widely used in South Africa to control fall armyworm in maize, cotton, sorghum, potatoes, crucifers and other vegetables (IRAC, 2018). More than 90% larval mortality occurs by the use of Spinosad and 39% yield loss occurs by the larval damage if insecticide is not used in right time (Cruz et al., 2012). Emamectin benzoate 5 SG showed highest acute toxicity, followed by Chlorantraniliprole 18.5 SC and Spinetoram 11.7 SC by leaf-dip bioassay method whereas, Chlorantraniliprole 18.5 SC, 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 are effective by field efficacy for 2 planting dates (Jun and Sept shown crop) for control of second instar larvae of fall armyworm (Deshmukh et al., 2020).

Early warning system

With climate changes, the world is striving to encounter and adapt to inevitable, possibly profound, alteration. Farmers can employ systems such as light traps, pheromone traps, and sticky traps to spot any severe pest outbreaks. It is suggested that they conduct such kind of scouting activity at least twice a week. In addition to this early detection, maize growers can further check the incidence of pests, as well as diseases, through crop rotations. An early warning system is needed to inform farmers of future possible threats. It has four parts: Risk knowledge, Monitoring and Predicting, Information dissemination, and Response.

Risk knowledge: Risk evaluation provides crucial information to set priorities for pest mitigation and prevention strategies and designing early warning systems.

Monitoring and predicting: Approaches with monitoring and predicting potentialities provide timely estimates of the possible risk faced by the farmers.

Information dissemination: Communication systems are required for passing warning messages to the highly affected farmers. The messages need to be reliable, synthetic and simple to be understood by authorities and the public.

Response: Coordination, effective governance and suitable action plans are important points in good early warning. Similarly, public awareness is a critical aspect of pest management.

The most fundamental idea behind early warning system is that the earlier farmers are able to anticipate potential hazards associated with pests and crops, the more likely they will be able to manage and mitigate a disease's impact on crops and environment. It empowers farmers to take action prior to a loss. Effective early warning systems include the following aspects: risk analysis; monitoring and predicting the intensity of the

diseases and pests; communicating alerts to farmers and to those potentially affected; and responding to the pest infestations. This system requires an effective communication channel. Many communication networks are currently available for warning dissemination, like Short Message Service (SMS), email, radio, TV, and web service. ICT is an important element in early warning, which plays a crucial role in disease management and disseminating information to farmers (UNEP, 2012). These are systems that provide answers to such questions as 'what if the pests attack the crops?' or 'what if there's immediate disease outbreak?' To be effective these plans need an early warning system to alert people of impending threats to tackle problems and reduce risk. Early warning systems make contingency strategies and evacuation procedures more precise and help farmers to improve their way of farming. In Nepal, there is a high degree of vulnerability to biological risk in crop productions such as pests infestation, particularly among the poor households and those located in rural areas. Communication to such farmers through an early warning system can help mitigate disease risk by improving preparedness and giving greater protection. Figure 2 displays the elements of an early warning system.

Monitoring and predicting is just a part of the early warning process which provides the input information for the early warning procedures that needs to be disseminated to farmers whose responsibility is to respond. This warning gives the possibility of responding to take mitigation or security measures before pest infestations occurs. When monitoring and predicting systems are connected with communication channels and response plans, they are considered early warning.

Conclusion

Fall armyworm is a voracious pest of maize. It has recently been introduced in Nepal due to favorable temperature and precipitation regime. For several years, it has become a pest of major economic importance causing up to 100% yield reduction as warned by FAO. For this reason, this pest demands immediate action. Intercropping with leguminous crops, removal of alternate host, volunteer hosts, push-pull crop like Napier grass and Desmodium, use of plant-based pesticides, biological control measures like use of predators, parasitoids are some measures that can be adopted for effective pest management. Nevertheless, the use of entomopathogens in Nepal is not appropriate and successful. Regular monitoring and scouting should be done for mass trapping and control of pest. For effective control, there is a need of proper quarantine regulation in Indo-Nepal border and in non-invaded areas. Different synthetic chemicals like Emamectin benzoate, Chlorantraniliprole, Spinetoram, Flubendiamide, indoxacarb, novaluron etc. are recorded effective against FAW but they should be use below threshold level. Future research work should be based on ecological methods of pesticides application, non-toxicological approach of insect pest management and environmental plus crop-friendly based of pest control.

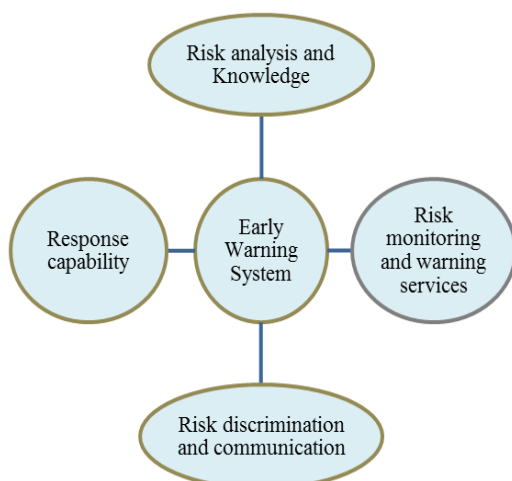


Figure 2. The elements of an early warning system. Source: (OpenLearn, 2018).

Suggestion for future research work

The authors suggest that future research endeavors should include an in depth studies on the biology, ecology, and management techniques of different hazardous insects, such as fall armyworm. Precedence should be given on the conductance of different IPM related programs, incentives for pest control, and awareness programs for disease control. We suggest further following works to be focused:

The investigations should be repeated to confirm the present results.

- Efficient predators and parasitoids should be identified and utilized for the management of *Spodoptera frugiperda* in maize crop.
- Suitable Integrated Pest Management strategies are needed to be applied for the management of *S. frugiperda*.
- Studies on the pheromones of *S. frugiperda* should be conducted.
- Efficacy of botanical insecticides against *S. frugiperda* should be studied.

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REFERENCES

Abate, T., Van Huis, A. and Ampofo, J. (2000). Pest management strategies in traditional agriculture: An African perspective. *Annual Review of Entomology*, 45(1): 631-659, <https://doi.org/10.1146/annurev.ento.45.1.631>

Abrahams, P., Bateman, M., Beale, T., Clotey, V., Cock, M. and Colmenarez, Y. (2017). Fall Armyworm: Impacts and Implications for Africa. UKaid and CABI.

Africa, I.S. (2018). Integrated Pest Management (IPM) and Insect Resistance Management (IRM) for Fall Armyworm in South African Maize. Retrieved from <https://www.irc-online.org/documents/ipm-irm-for-fall-armyworm-in-s-african-maize/>

Altieri, M., Funes-Monzote, F. and Peterson, P. (2012). Agroecologically efficient agricultural systems for smallholder farmers: contributions to food sovereignty. *Agronomy for Sustainable Development*, 32(1): 1-13, <https://doi.org/10.1007/s13593-011-0065-6>

Andrews, K.L. (1980). The Whorlworm, *spodoptera frugiperda*, in Central America and Neighboring Area. *The Florida Entomological Society*, 63: 456-467, <https://doi.org/10.2307/3494530>

Assefa, F. and Ayalew, D. (2019). Status and control measures of fall armyworm (*Spodoptera frugiperda*) infestations in maize fields in Ethiopia: A review. *Congent Food and Agriculture*, 5(1), <https://doi.org/10.1080/23311932.2019.1641902>

Bajracharya, A.S., Bhat, B., Sharma, P., Shashank, P., Meshram, N. and Hashmi, T. R. (2019). First record of fall army worm *Spodoptera frugiperda* (J. E. Smith) from Nepal. *Indian Journal of Entomology*, 81: 635-639, <https://doi.org/10.5958/0974-8172.2019.00137.8>

Barbosa, M., Dias, B., Guerra, M. and Haralampidou da Costa Vieira, G. (2018). Applying plant oils to control fall armyworm (*Spodoptera frugiperda*) in corn. *Australian Journal of Crop science*, 12(04): 557-562, <https://doi.org/10.21475/ajcs.18.12.04.pne822>

Basista-Pereira, L., Stein, K., Paula, A., Moreira, J., Cruz, I. and Figueiredo, M. (2006). Isolation, identification, synthesis and field evaluation of sex pheromone of the Brazilian population of *Spodoptera frugiperda*. *Journal of Chemical Ecology*, 32(5): 1085-1099, <https://doi.org/10.1007/s10886-006-9048-5>

Bateman, M.L., Day, R.K., Luke, B., Edgington, S., Kuhlmann, U. and Cock, M.J. (2018). Assessment of potential biopesticide options for managing fall armyworm (*Spodoptera frugiperda*) in Africa. *Journal of Applied Entomology*, 142(9): 805-819, <https://doi.org/10.1111/jen.12565>

Baudron, F., Zaman-Allah, M., Chaipa, I., Chari, N. and Chinwada, P. (2019). Understanding the factors influencing fall armyworm (*Spodoptera frugiperda* J.E. Smith) damage in African smallholder maize fields and quantifying its impact on maize yield. A case study in Eastern Zimbabwe. *Crop Protection*, 120: 141-150, <https://doi.org/10.1016/j.cropro.2019.01.028>

Bhusal, S. and Chapagain, E. (2020). Threats of fall armyworm (*Spodoptera frugiperda*) incidence in Nepal and its integrated management-A review. *Journal of Agriculture and Natural Resources*, 3(1): 345-359, <https://doi.org/10.3126/janr.v3i1.27186>

Bista, S., Thapa, M.K. and Khanal, S. (2020). Fall armyworm: Menace to Nepalese farming and the integrated management approaches. *International Journal of Environment, Agriculture and Biotechnology*, 5(4): 1011-1018, <https://doi.org/10.22161/ijeab.54.21>

Bortolotto, O., Menezes Junior, A., Hoshino, A., Carvalho, M., Pomari-Fernandes, A. and Salgado Neto, G. (2014). Sugar solution treatment to attract natural enemies and its impact on fall armyworm *Spodoptera frugiperda* in maize field. *Interciencia*, 416-421.

Burtet, L., Bernardi, O., Melo, A., Strahl, T. and Guedes, J. (2017). Managing fall armyworm, *Spodoptera frugiperda* (Lepidoptera: Noctuidae) with Bt maize and insecticides in southern Brazil. *Pest Management Science*, 73(12): 2569-2577, <https://doi.org/10.1002/ps.4660>

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

CABI. (2019). *Spodoptera frugiperda*. Retrieved from Invasive Species Compendium: <https://www.cabi.org/isc/datasheet/29810>

CABI. (2020). *Spodoptera frugiperda* (fall armyworm). Invasive Species Compendium. Retrieved from <https://www.cabi.org/isc/datasheet/29810>

Capinera, J. (2000). Fall Armyworm, *Spodoptera frugiperda* (J E Smith) (Insecta: Lepidoptera: Noctuidae). UNIVERSITY OF FLORIDA IFAS EXTENSION.

Casmuz, A., Juarez, L., Socias, M., Mueua, M., Prieto, S. and Medina, S. (2012). Revisión de los hospederos del gusano cogollero del maíz, *Spodoptera frugiperda* (Lepidoptera: Noctuidae). *Revista de la Sociedad Entomologica Argentina*, 69: 209-231.

Cespedes, C., Salazar, J., Martinez, M. and Aranda, E. (2005). Insect growth regulatory effects of some extracts and sterols from *Myrtillocactus geometrizans* (Cactaceae) against *Spodoptera frugiperda* and *Tenebrio molitor*. *Phytochemistry*, 66(20): 2481-2493, <https://doi.org/10.1016/j.phytochem.2005.07.010>

Chapman, J., Williams, T., Castillo, A., Cisneros, J., Caballero, P. and Cave, R. (2000). Does cannibalism in *Spodoptera frugiperda* (Lepidoptera: Noctuidae) reduce the risk of Predation? *Behavioral Ecology and Sociobiology*, 48(4): 321-327, <https://doi.org/10.1007/s002650000237>

Conrow, J. (2018). Destructive fall armyworm now invading India. Retrieved from <https://allianceforscience.cornell.edu>

Cruz, I., de Lourdes Correa Figueiredo, M., da Silva, R., da Silva, F., de Souza Paula, C. and Foster, J. (2012). Using sex pheromone trap in the decision-making process for pesticide application against fall armyworm (*Spodoptera frugiperda* [Smith] [Lepidoptera: Noctuidae]) larvae in maize. *International Journal of Pest Management*, 58(1), <https://doi.org/10.1080/09670874.2012.655702>

Day, R., Abrahams, P., Bateman, M., Beale, T., Clotey, V., Cock, M. and Gomez, J. (2017). Fall armyworm: impacts and implication for Africa. *Outlooks on Pest Management*, 28(5): 196-201, https://doi.org/10.1564/v28_oct_02

De Almeida Sarmiento, R., de Souza Aguiar, R., Vieira, S., de Oliveira, H. and Holtz, A. (2002). Biology review, occurrence and control of *Spodoptera frugiperda* (Lepidoptera, Noctuidae) in corn in Brazil. *Bioscience Journal*, 18: 41-48.

- de Romero, M., Romero, E., Gomez, D. and Willink, E. (2009). Evaluación de aislamientos de baculovirus para el control de *Spodoptera frugiperda* (Smith, 1797) (LEP.: Noctuidae), plaga clave del maíen el noroeste argentino. *Revista Industrial y Agrícola de Tucumán*, 86(2): 7-15.
- Deole, S. and Paul, N. (2018). First report of fall armyworm, *Spodoptera frugiperda* (J.E. Smith), their nature of damage and biology on maize crop at Raipur of Chhattisgarh. *Journal of Entomology and Zoology Studies*, 6(6): 219-221.
- Deshmukh, S., Pavithra, H., Kalleshwaraswamy, C., Shivanna, B., Maruthi, M. and Mota-Sanchez, D. (2020). Field Efficacy of insecticides for Management of Invasive Fall Armyworm, *Spodoptera frugiperda* (J.E. Smith) (Lepidoptera: Noctuidae) on Maize India. *Florida Entomologist*, 103(2): 221-227, <https://doi.org/10.1653/024.103.0211>
- Early, R., Gonzalez-moreno, P., Murphy, S.T. and Day, R. (2018). Forecasting the global extent of invasion of the invasion of the cereal pest *Spodoptera frugiperda*, the fall armyworm. *NeoBiota*, 40, 25-50, <https://doi.org/10.3897/neobiota.40.28165>
- Evans, D. and Stanly, P. (1990). Weekly Economic Level For Fall Armyworm (Lepidoptera: Noctuidae) Infestation of Corn in Lowland Ecuador. *Journal of Economic Entomology*, 83(6): 2452-2454.
- FAO. (2018a). Briefing note on FAO actions on fall armyworm. Rome: Food and Agricultural Organization (FAO) of the United Nations.
- FAO. (2018b). Integrated Management of Fall Armyworm on maize A Guide for Farmer Field School in Africa . Rome: Food and Agriculture Organization of the United Nation.
- FAO. (2019). *Spodoptera frugiperda* (Fall Armyworm). Retrieved from <http://www.ippc.int/en/countries/nepal/pestreports/2019/08/spodoptera-frugiperda-fall-armyworm/>
- FAO. (2020). The Global Action for Fall Armyworm Control: Action framework 2020-2022. Working together to tame the global threat. Rome: Food and Agriculture Organization of United Nation.
- Firake, D.M., Behere, G.T., Babu, S. and Prakash, N. (2019). Fall Armyworm: Diagnosis and Management (An Extension Pocket Book). Umiam-793 103, Meghalaya: ICAR Research Complex For NEH Region.
- Foster, R. (1989). Strategies for protecting sweet corn ear damage by fall armyworms (Lepidoptera: Noctuidae) in Southern Florida. *Florida Entomologist*, 72(1): 146-151, <https://doi.org/10.2307/3494981>
- GC, Y., Dhungel, S., Ghimire, K., Devkota, S. and GC, A. (2019). Fall Armyworm: Global status and potential threats for Nepal. *The Journal of Agriculture and Environment*, 20: 10-20, <https://doi.org/10.3126/aej.v20i0.25002>
- GC, Y., Ghimire, K. and GC, A. (2020). Assessment of Bio-Pesticides against Fall Armyworm Management in Nepal. *Advances in Agriculture, Horticulture and Entomology*, 2020(02).
- Goergen, G., Sankung, S., Togola, A., Tamo, M. and Kumar, L. (2016). First Report of Outbreaks of Fall Armyworm *Spodoptera frugiperda* (JE 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>
- Gu, H. and Woo, R. (2019). Crop invaders: China's small farmers struggle to defeat armyworm. Retrieved from <https://www.google.com/amp/s/mobile.reuters.com/article/amp/idUSKCN1UZ0LL>
- Haftay, G. and Fissiha, G. (2020). Effect of integrating night-time light trap and push-pull method on monitoring and deterring adult fall armyworm (*Spodoptera frugiperda*). *Journal of Entomology Research*, 5(1): 28-32.
- Hailu, G., Niassy, S., Zeyaur, K.R., Ochatum, N. and Subramanian, S. (2018). Maize-Legume Intercropping and Push-Pull for Management of Fall Armyworm, Stemborers and Striga in Uganda. *Agronomy Journal*, 110(6): 2513-2522, <https://doi.org/10.2134/agronj2018.02.0110>
- Hardke, J.T., Lorenz III, G. and Leonard, B. (2015). Fall armyworm (Lepidoptera: Noctuidae) ecology in southeastern cotton. *Journal of Integrated Pest Management*, 6(1), <https://doi.org/10.1093/jipm/pmv009>
- Harrison, F. (1984). Observations on the infestations on corn bt fall armyworm (Lepidoptera: Noctuidae) concerning plant maturity. *Florida Entomologist*, 67: 333-335, <https://doi.org/10.2307/3494709>
- Harrison, R., Thierfelder, C., Baudron, F., Chinwada, P., Midgea, C. and Schaffner, U. (2019). Agro-ecological options for fall armyworm (*Spodoptera frugiperda* JE Smith) management: providing low-cost, smallholder friendly solution to an invasive pest. *Journal of Environmental Management*, 243: 318-330, <https://doi.org/10.1016/j.jenvman.2019.05.011>
- Hoy, M. (2013). Insect Population ecology and Molecular Genetics. In M. Hoy, *Insect Molecular Genetics* (Third Edition) (pp. 591-659). Academic Press.
- Hunt, T., Highley, L., Witkowski, J., Young, L. and Hellmich, L. (2001). Dispersal of adult European corn borer (Lepidoptera: Crambidae) within and proximal to irrigated and non-irrigated corn. *Journal of Economic Entomology*, 94(6): 1369-1377, <https://doi.org/10.1603/0022-0493-94.6.1369>
- ICIPE. (2018). Retrieved from Combating the fall armyworm in Africa- The European Union (EU) provides new funding to icipe: <http://www.icipe.org/news/combating-fall-armyworm-africa-%E2%80%93-european-union-eu-provides-new-funding-icipe>
- Igyuve, T., Ojo, G., Ugbaa, M. and Ochigbo, A. (2018). Fall Armyworm (*Spodoptera frugiperda*); Its Biology, Impacts and Control on Maize Production in Nigeria. *Nigerian Journal of Crop Science*, 5: 70-79.
- James, R. and Engelke, M. (2010). resistance in *Zoysia* grass (*Zoysia spp*) to the Fall Armyworm (*Spodoptera frugiperda*) (Lepidoptera: Noctuidae). *Florida Entomologist*, 93(2): 254-259, <https://doi.org/10.1653/024.06-93.0216>
- Johnson, S. (1987). Migration and the life history strategy of the fall armyworm. *Journal of Tropical Insect Science*, 8: 543-549.
- Khan, Z., Midgea, C., Jimmy, P., Pickett, J. and Bruce, T. (2011). Push-Pull technology: a conservation agriculture approach for integrated management of insect pests, weeds and soil health in Africa. *International Journal of Agricultural Sustainability*, 9(1): 162-170. <https://doi.org/10.3763/ijas.2010.0558>
- Klun, J., Potts, W. and Oliver, J. (1996). Four species of noctuid moth degrade sex pheromone by a common antennal metabolic pathway. *Journal of Entomological Science*, 404-413, <https://doi.org/10.18474/0749-8004-31.4.404>
- Kumela, T., Simiyu, J., Sisay, B., Likhayo, P., Mendesil, E., Gohole, L. and Tefera, T. (2019). Farmer's knowledge, perceptions and management practices of 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>
- Luginbill, P. (1928). The Fall Army Worm. U.S. Dept. of Agriculture: Wasington D.C.
- Maredia, K., Segura, O. and Mihm, J. (1992). Effects of neem, *Azadiracta indica* on six species of maize insect pests. *Tropical Pest Management*, 38(2): 190-195, <https://doi.org/10.1080/09670879209371682>
- Martínez, A.M., Aguado-Pedraza, A.J., Viñuela, E., Rodríguez-Enriquez, C.L., Lobit, P., Gómez, B. and Pineda, S. (2017). Effects of ethanolic extracts of *Agrimone ochroleuca* (Papaveraceae) on the food consumption and the development of *Spodoptera frugiperda* (Lepidoptera: Noctuidae). *Florida Entomologist*, 100(2): 339-345, <https://doi.org/10.1653/024.100.0232>
- Meagher Jr, R. (2001). Collection of fall armyworm (Lepidoptera: Noctuidae) adults and nontarget Hymenoptera in different colored unitraps. *Florida Entomologist*, 84(1): 77-82, <https://doi.org/10.2307/3496666>
- Midega, C., Pittchar, J., Pickett, J., Hailu, G. and Khan, Z. (2018). A Climate-adapted push-pull system effectively controls fall armyworm, *Spodoptera frugiperda* (J E Smith), in maize in East Africa. *Crop Protection*, 105: 10-15, <https://doi.org/10.1016/j.cropro.2017.11.003>
- Mikolajczak, K., Zikowski, B. and Bartelt, R. (1989). Effect of meliaceous seed extracts on the growth and survival of *Spodoptera Frugiperda*. *Journal of Chemical Ecology*, 15(1): 121-128.
- Mitchell, E.R., McNeil, J.N., Westbrook, J.K., Silvain, J.F., Lalanne-Cassou, B., Chalfant, R.B. and Proshold, F.I. (1991). Seasonal periodicity of fall armyworm, (Lepidoptera: Noctuidae) in the caribbean basin and northward to Canada. *Journal of Entomological Science*, 26(1): 39-50, <https://doi.org/10.18474/0749-8004-26.1.39>
- MoAD. (2020). Statistical Information on Nepalese Agriculture 2018/19. Kathmandu: Ministry of Agriculture, Land Management and Cooperatives.
- Montezano, D.G., Specht, A., Sosa-Gómez, D.R., Roque-Specht, V.F., Sousa-Silva, J.C., Paula-Moraes, S.D. and Hunt, T.E. (2018) Host plants of *Spodoptera frugiperda* (Lepidoptera: Noctuidae) in the Americas. *African Entomology*, 26 (2): 286-300, <https://doi.org/10.4001/003.026.0286>
- Nagoshi, R.N., Dhanani, I., Asokan, R., Mahadevaswamy, H.M., Kalleshwaraswamy, C.M. and Meagher, R.L. (2019). Genetic characterization of fall armyworm infesting South Africa and India indicate recent introduction from a common source of population. *PLoS One*, 14(5): 1-16, <https://doi.org/10.1371/journal.pone.0175076>
- NPPO. (2019). NPPO Nepal Declares the INVASION of American Fall Armyworm (*Spodoptera frugiperda*) in Nepal. Retrieved from <http://www.npponepal.gov.np/noticedetail/20/2019/82947178>
- Oliver, A. and Chapin, J. (1981). Biology and illustrated key for the identification of twenty species of economically important noctuid pests. Louisiana Agricultural Experiment Station Bulletin, No. 733.
- Onlinekhabar. (2020). Fall armyworms have spread across 58 districts of Nepal so far: Agriculture Ministry. Retrieved from <https://english.onlinekhabar.com/fall-armyworms-have-spread-across-58-districts-of-nepal-so-far-agriculture-ministry.html>

- OpenLearn (2018). Early warning systems. <https://www.open.edu/openlearncreate/mod/oucontent/view.php?id=79974andsection=6.1>
- Pashley, D.P. (1986). Host-associated Genetic Differentiation in Fall Armyworm (Lepidoptera: Noctuidae): a sibling Species Complex? *Annals of Entomological Society of America*, 79(6): 898-904, <https://doi.org/10.1093/aesa/79.6.898>
- Pechan, T., Ye, L., Chang, Y.M., Mitra, A., Lin, L., Davis, F.M. and Luthe, D.S. (2000). A Unique 33-kD Cysteine proteinase Accumulates in response to Larval Feeding in Maize Genotypes Resistant to Fall armyworm and Other Lepidoptera. *The Plant Cell*, 12(7): 1031-1041, <https://doi.org/10.1105/tpc.127.1031>
- Pitre, H.N. and Hogg, D.B. (1983). Development of the Fall armyworm on cotton, soybean and corn. *Journal of the Georgia Entomological Society*, 18: 187-194.
- Prasanna, B., Huesing, J.E., Eddy, R. and Peschke, V.E. (2018). Fall Armyworm in Africa: A guide for Integrated Pest Management, First edition. Mexico: CDMX: CIMMYT.
- Prokopy, R.J. (2003). Two decades of bottom-up ecologically based pest management in a small commercial apple orchard in Massachusetts. *Agriculture Ecosystems and Environment*, 94(3): 299-309, [https://doi.org/10.1016/S0167-8809\(02\)00036-1](https://doi.org/10.1016/S0167-8809(02)00036-1)
- Ramirez-cabral, N., Kumar, L. and Shabani, F. (2017). Future climate scenarios project a decrease in the risk of fall armyworm outbreaks. *The Journal Agricultural Sciences*, 155(8): 1219-1238, <https://doi.org/10.1017/S0021859617000314>
- Reis, L., Oliveira, L. and Cruz, I. (1988). Doru Luteipes Biology and potential in Spodoptera control. *Brazilian Agricultural Research*, 23: 333-342.
- Rivers, A., Barbercheck, M., Govaerts, B. and Verhulst, N. (2016). Conservational agriculture affects arthropod community composition in a rainfed maize-wheat system in central Mexico. *Applied Soil Ecology*, 100: 81-90, <https://doi.org/10.1016/j.apsoil.2015.12.004>
- Rwomushana, I., Bateman, M., Beale, T. and Beseh, P. (2018). Fall Armyworm: impacts and implications for Africa: Evidence Note Update, October 2018. Retrieved from <https://www.invasive-species.org/Uploads/InvasiveSpecies/FAW%20Evidence%20Note%20October%202018.pdf>
- Sharanabasappa, D., Kalleshwaraswamy, C., Maruthi, M. and Pavithra, H. (2018a). First report of Fall Armyworm, *Spodoptera frugiperda* (J.E. Smith) (Lepidoptera; Noctuidae), an alien invasive pest on maize in India. *Pest Management in Horticultural System*, 24(1): 23-29.
- Sharanabasappa, D., Kalleshwaraswamy, C., Maruthi, M. and Pavithra, H. (2018b). Biology of invasive fall armyworm *Spodoptera frugiperda* (J.E. Smith) (Lepidoptera: Noctuidae) on maize. *Indian Journal of Entomology*, 80(3): 540-543, <https://doi.org/10.5958/0974-8172.2018.00238.9>
- Silva, D., Bueno, A., Andrade, K., Stecca, C., Neves, P. and Oliveira, M. (2017). Biology and nutrition of *Spodoptera frugiperda* (Lepidoptera: Noctuidae) fed on different food sources. *Scientia Agricola*, 74(1): 18-31, <https://doi.org/10.1590/1678-992x-2015-0160>
- Silva, M., Broglio, S., Trindade, R., Ferreira, E., Gomes, I., and Micheletti, L. (2015). Toxicity and application of neem in fall armyworm. *Communicate Scientiae Horticultural Journal*, 6(3): 359-364, <https://doi.org/10.14295/cs.v6i3.808>
- Sisay, B., Tefera, T., Wakgari, M., Ayalew, G. and Mendesil, E. (2019). The efficacy of Selected Synthetic Insecticides and Botanicals against Fall Armyworm, *Spodoptera frugiperda*, in Maize. *Insects*, 10(2): <https://doi.org/10.3390/insects10020045>
- Sparks, A.N. (1979). A Review of Biology Of the Fall Armyworm. *The Florida Entomologist*, 62(2): 82-87, <https://doi.org/10.2307/3494083>
- Stokstad, E. (2017). New crop pest takes Africa at lightning speed. *Science*, 356(6337): 473-474, <https://doi.org/10.1126/science.356.6337.473>
- Tavares, W., Costa, M., Cruz, I., Silveira, R., Serrao, J. and Zanuncio, J. (2010). Selective effects of Natural and Synthetic insecticides on mortality of *Spodoptera frugiperda* (Lepidoptera: Noctuidae) and its predator *Eriopis connexa* (Coleoptera: Coccinellidae). *Journal and Environmental Science and Health PartB*, 45: 557-561, <https://doi.org/10.1080/03601234.2010.493493>
- Tefera, T., Goftishu, M., Ba, M. and Muniappan, R. (2019). A Guide to Biological Control of Fall Armyworm in Africa Using Egg Parasitoids. First Edition, Nairobi, Kenya. Retrieved from <http://34.250.91.188:8080/xmlui/handle/123456789/1001>
- Thrash, B., Adamczyk, J.J., Lorenz, G., Scott, A.W., Armstrong, J.S., Pfannenstiel, R. and Taillon, N. (2013). Laboratory Evaluation of Lepidoptera-Active Soybean Seed Treatment on Survivorship of Fall Armyworm (Lepidoptera: Noctuidae) Larvae. *Florida Entomologist*, 96(03): 724-728, <https://doi.org/10.1653/024.096.0304>
- Tumma, M. and Chandrika, K. (2018). Fall Armyworm. Retrieved from <http://vikaspedia.in/agriculture/crop-production/integrated-pest-management/fall-armyworm-faw>
- UNEP (2012). Early Warning Systems: A State of the Art Analysis and Future Directions. Division of Early Warning and Assessment (DEWA), United Nations Environment Programme (UNEP), Nairobi. https://na.unep.net/siouxfalls/publications/Early_Warning.pdf
- UNNews. (2019). 'Growing alarm' over Fall Armyworm advance, with cash crops 'under attack' across Asia. Retrieved from <https://news.un.org/en/story/2019/03/1035071>
- Viana, P. and Prates, H. (2003). Larval development and mortality of *Spodoptera frugiperda* fed no corn leaves treated with aqueous extracts from *Azadiracta indica* leaves. *Bragantia*, 62(1): 69-74, <https://doi.org/10.1590/S0006-87052003000100009>
- Wightman, J. (2018). Can lessons learned 30 years ago contribute to reducing the impact of the fall armyworm *Spodoptera frugiperda* in Africa and India? *Outlooks on Agriculture*, 47: 259-269, <https://doi.org/10.1177/0030727018814849>
- Young, J.R. (1979). Fall Armyworm: Control with Insecticides. *Florida Entomological Society*, 62(2): 130-133, <https://doi.org/10.2307/3494089>