



Bio-ecology and management of *Spodoptera frugiperda* (Lepidoptera: Noctuidae): A review

Muhammad Ramzan^{1,2*}, Muhammad Usman², Zulfurain Sajid³, Usman Ghani², Muhammad Abdul Basit⁴, Mohsin Razzaq², Waqas Shafee³ and Muhammad Rafiq Shahid⁵

¹State Key Laboratory for Biology of Plant Diseases and Insect Pests, Institute of Plant Protection, Chinese Academy of Agricultural Sciences, Beijing 100193, China

²Institute of Plant Protection, Muhammad Nawaz Sharif University of Agriculture, Multan, Pakistan

³Department of Entomology, University of Agriculture Faisalabad, Pakistan

⁴Department of Entomology, Pir Mehr Ali Shah Arid Agriculture University, Rawalpindi, Pakistan

⁵Institute of Agricultural Sciences, University of the Punjab Lahore, Pakistan

⁵Cotton Research Institute, Multan, Pakistan

*Corresponding author: Muhammad Ramzan (ramzan.mnsua@gmail.com)

Received: 2 September 2020

Accepted: 5 December 2020

Abstract: *Spodoptera frugiperda* (Lepidoptera: Noctuidae) locally known as fall armyworm is an emerging pest of various crops (maize, cotton, and sugarcane). It has polyphagous feeding nature and is distributed throughout the globe depending upon the climatic conditions. The cob of maize is its preferred food and is heavily damaged during the high pest population. Feeding of its larvae can cause a characteristic skeletonizing or 'windowing' effect with excessive fecal pellets in maize. Being holometabolous, complete metamorphic changes occur during its developmental process i.e., egg, larva, pupa, and adult. Among all stages, only the larval stage is very dangerous for crop production. At optimum climatic conditions, it completes its life cycle very quickly. Temperature and humidity play an important role in influencing the life cycle duration of the pest. Several control strategies have been adopted by small and large communities or researchers to control this notorious pest

all over the world like biological, chemical, botanical, physical, mechanical, and cultural operations. Due to the quick knockdown effect of insecticides, mostly farmers rely on the use of synthetic chemical pesticides, they are unaware that its use is a major threat to biodiversity and causes pest resistance to insecticides (Ali, et al., 2015). Keeping in view the drawback of chemical control, other alternative strategies such as mechanical, physical, botanicals, and biological can be promoted around the globe. *S. frugiperda* is an emerging pest in Pakistan since 2017, so biological control strategies should be devised. Among *Spodoptera* species, FAW (fall armyworm) *S. frugiperda* is different from others and closely resembles *S. litura* and implemented on a national scale that can control its growth, minimize its population and prevent the country from environmental pollution. © 2020 Department of Agricultural Sciences, AIOU

Keywords: Bio-pesticides, Emerging pest, Fall armyworm, Pakistan, *Spodoptera frugiperda*, *Trichogramma* spp.

To cite this article: Ramzan, M., Usman, M., Sajid, Z., Ghani, U., Basit, M. A., Razzaq, M., Shafee, W., & Shahid, M. R. (2020). Bio-ecology and management of *Spodoptera frugiperda* (Lepidoptera: Noctuidae): A review. *Journal of Pure and Applied Agriculture*, 5(4), 1-9.

Introduction

Genus, *Spodoptera* is a very big genus (Ramzan et al., 2019) with 25 different species. Among reported species, *S. exigua*, *S. ciliatum*, *S. pectin*, *S. litura* (Faiz et al., 2015; Faiz et al., 2019), and *S. frugiperda* (Naeem-Ullah et al., 2019) are a major threat for the horticultural and agricultural crops throughout the globe. The fall armyworm, *S. frugiperda* is an emerging and invasive pest of various countries including Pakistan (Naeem-Ullah et al., 2019). It is a migrant insect pest with more than 80-100 alternate host plants (Clark et al., 2007; Abrahams et al., 2017; Cock et al., 2017; Food and Agriculture Organization [FAO], 2018) and flight up to 100 km in one night (Centre for Agriculture and Bioscience International [CABI], 2017a; Gilal et al., 2020). It belongs to the order

Lepidoptera of the family Noctuidae (Naeem-Ullah et al., 2019).

Identification

S. exigua (Ramzan et al., 2019). The salient characteristics key of *S. frugiperda* has been described by Naeem-Ullah et al. (2019). On the forewing of adults, two white dots and an inverted Y-shaped dark yellow colored head of fully grown larvae have been reported by Niaz et al. (2018) similarly four black dots on the last body segments appear as a trapezium like structure (FAO, 2017).

Geographic distribution

It is mostly found in tropical and subtropical regions of the world (Abrahams et al., 2017; FAO, 2018; Prasanna et al., 2018). It has worldwide distribution including Brazil, USA (Prowell et al., 2004; Clark et al., 2007), Africa (Goergen et al., 2016), Pakistan (Niaz et al., 2018; Naeem-Ullah et al., 2019; Gilal et al., 2020), India (Sisodiya et al., 2018), Iran, China, Bangladesh, Thailand and Sri Lanka (FAO, 2019). Likewise, other insects, its food preference among host plants is also different throughout the world (Majid et al., 2017; Shahid et al., 2017; Day et al., 2017; Kumela et al., 2019) like in some areas its food is rice, maize (Belay et al., 2012; Sidana et al., 2018), sorghum, sugarcane (Abrahams et al., 2017; Sibanda, 2017; Prasanna et al., 2018; Harrison et al., 2019), soybean, and cotton (Pogue et al., 2002; Nagoshi, 2014). The distribution of FAW (fall armyworm) is influenced by climate conditions (Pashley et al., 1985; Pair et al., 1988). Feeding habits can be modified depending upon crop availability and temperature that allowed the pest to migrate from Florida and Mexico to Canada (Hernandez-Mendoza et al., 2008). It has a large number of cultivated plant species (Casmuz et al., 2010) but the greatest damage was observed on maize and sorghum (its main hosts) as well as on cotton and soybean (Hardke et al., 2015).

Biology

Females of *S. frugiperda* can lay eggs on the lower surface of leaves in a cluster up to 100-300 numbers. Eggs hatch within 2-10 days and young ones pass through six larval instars with the larval developmental period of 14-21 days. Pupae are reddish-brown in color and pupation took place 1-3' deep in the soil, between the leaves, or in an earthen cell with a period of 9-13 days, and adults emerged (CABI, 2017b). The mating of adults occur by releasing sex pheromone by female, and the life cycle of *S. frugiperda* is completed in 26-46 days depending upon the climatic conditions, however biological parameters regarding development differed concerning plant species they feed. The number of host plants reported for *S. frugiperda* is higher when compared to other congeneric species of agricultural importance such as *Spodoptera albula* (Walker) (65), *Spodoptera cosmioides* (Stoll) (126), *Spodoptera dolichos* (Fabricius) (94), and *Spodoptera eridania* (Stoll) (202) (Montezano et al., 2013; CABI, 2020).

Ecology and damage symptoms

Insect pests badly affect the yield productivity (Shahid et al., 2015) and quality of the product however, the mode of damage differs among plant species (Shahid et al., 2017). The preferred host plant of *S. frugiperda* is maize and its larvae damage the leaves and corn cob as shown in Fig. 1. Both temperature and humidity are very important

environmental factors that affect the growth and development of *S. frugiperda* under natural as well as artificial conditions (Du Plesis et al., 2020). The effect of different temperatures (32, 30, 26, and $22 \pm 1^\circ\text{C}$) on all stages of *S. frugiperda* demonstrated that the most favorable temperature for the growth and development of *S. frugiperda* was 26-30 °C with a minimum temperature threshold below 10 °C (Stokstad, 2017).

The temperature has a significant influence on the duration of *S. frugiperda*'s life cycle. Capinera (2002) reported that *S. frugiperda* completes its life cycle in about 30 days during the summer, 60 days in spring and autumn, and 80 to 90 days during the winter. The number of generations occurring in an area varies with the appearance of the dispersing adults. Up to eight generations per year can, however, occur in maize fields in tropical areas (Busato et al. 2005). According to Johnson (1987), *S. frugiperda* is a tropical pest that does not have the ability to diapause when temperatures decrease. It has, however, been reported that this species may survive mild winters (Johnson, 1987). The lower temperature for optimal growth was set to 25 °C as suggested by Valdez-Torres et al. (2012). The upper optimal temperature for growth was set to 30 °C (Simmons & Rogers, 1994), and the maximum temperature was set at 39 °C, near the threshold of 39.8°C reported by Valdez-Torres et al. (2012). Fall armyworm does not diapause and cannot survive the winters in temperate areas (Johnson, 1987). Diapause was therefore not included in this model. A temperature threshold model of Cold Stress was used, with a 12 °C threshold. With these settings, cold stress limits the potential range in the USA to the areas where *S. frugiperda* has been reported to survive winter months, in south-western Texas and southern Florida (Johnson, 1987). Heat stress parameters were set to allow persistence in all of the known locations from which it has been observed. The threshold of 39 °C is the same as the upper-temperature limit for development. The threshold annual heat sum required for population persistence (PDD) was set to 600 degree days above 12 °C, the lower temperature limit for development. Warm, humid growing seasons with heavy rainfall favor its survival and population buildup because it cannot develop at temperatures below about 10°C (Stokstad, 2017). Adults of FAW are nocturnal (CABI, 2017a). After a pre-oviposition period of three to four days, the female normally deposits most of her eggs during the first four to five days of life, but some oviposition occurs for up to three weeks (Prasanna et al., 2018). Duration of adult life averages about 10 days, with a range of about 7 to 21 days (Capinera, 2000) and due to the duration of the life cycle, 2 to 10 generations can be completed in each cropping cycle depending on climate. It is reproductively efficient in tropical areas, where the warmer temperature allows more generations per year compared to temperate areas that may have two or fewer generations in a year.

Economic importance of *S. frugiperda*

The larva is the damaging stage of *S. frugiperda*, its later instars can damage the whole leaf of the crop especially,

maize. As shown in Fig. 1, severe feeding of young larvae causes a characteristic skeletonizing or 'windowing' effect (Sisodiya et al., 2018; Chormule et al., 2019a) with excessive fecal material is the major symptom of its damage (Chormule et al., 2019b). The growing point of plant killing even 100% death of plants occurred. The corn ear can completely or partly be destroyed by the severe attack of larvae (RicBessin, 2004; Bokonon-Ganta et al., 2003), ears become susceptible to aflatoxin (FAO, 2017) and unfit for human consumption (Chimweta et al., 2020).

Integrated pest management

Across the globe different integrated pest management (IPM) strategies are being employed for the control of insect pests of economic crops. Integrated strategies include host plant resistance, cultural, physical, mechanical, biological, botanical, and chemical control tactics. Detail of the control methods for the management of *S. frugiperda* is given below:

Monitoring methods

It is an effective tool for the assessment of the insect pest (Shahid et al., 2019) and to control insect populations below economic injury level (Naharki et al., 2020). It can prove the best and effective tool to avoid *S. frugiperda* spread and establishment (Prasanna et al., 2018). The pest population can be minimized by using pheromones and light traps (Rajbhandari et al., 2019; Gebrezihher & Gebrezihher, 2020).

Host plant resistance

Host plant resistance also plays an important role in managing insect pest attacks (Shahid et al., 2012; Shahid et al., 2018). Morphological and biochemical traits of plants not only deter the attack of insect pest herbivory but also contribute to yield productivity (Rahman et al., 2013; Farooq et al., 2014).

Cultural control

Various cultural practices have been adopted by researchers to control *S. frugiperda* in the world, such as avoiding late crop sowing; intercropping; destruction of crop residues; crop plowing after crop harvesting to expose the larvae and pupae on the soil surface; early visual detection; and pest movement prevention from infested to non-infested areas (Shahid et al., 2014). The fall armyworm population can be decreased in various crops by adopting these cultural practices. Removal and destruction of egg masses and small gregarious larvae, burning of stubbles can reduce all stages of pests like adults, eggs, larva, and pupa in the field. The coming generation of pests survives even after harvesting reduces by the burning process (Assefa, 2018). The application of ash, sand, and soup directly to whorls can minimize the pest population.

Some researchers have recommended fish soups that attract ants that eat the larvae of *S. frugiperda* (Murray et al., 2019). The maintenance of plant diversity in the field is a very important factor to control the pest population (Tippannavar et al., 2019; Tambo et al., 2020). It had been reported by many researchers that pest population increased through monocropping while decreased with intercropping with other crops such as leguminous (Harrison et al., 2019; Rajbhandari et al., 2019). Khan et al. (2018) reported that Napier grass (*Pennisetum purpureum*) proved the best attractant trap crop while Desmodium grass (*Desmodium spp.*) as a repellent to *S. frugiperda*. Push and pull strategy has proved the best approach against *S. frugiperda* (Midega et al., 2018).

Mechanical control

This technique is useful at a small level and farmers can manage the pest population by regular monitoring in the field. The early infestation can be controlled by the use of protective measures but later and high infestation of pests cannot be controlled until reaching the economic threshold level (Foster, 1989; Evans & Stansly, 1990; Dal Pogetto et al., 2012). These can be adopted to control pest populations such as fertilization (organic and inorganic manure and fertilizers), mulching, minimum tillage, intercropping, and reduce weed management. The locally available toxic substances such as sand, soil, lime, soaps, wood ash, and oils have been applied against larvae of *S. frugiperda* (Hruska, 2019) and gave the best control (Ebeling, 1971; Korunić, 2013).

Biological control

This is an effective and eco-friendly approach to control insect pests with a non-negative impact on humans, animals, biological fauna, and the environment (Shahid et al., 2007; Arif et al., 2011). Rodents, birds, ladybird beetles, bugs, ants, and flowers bugs are predators of *S. frugiperda* (Sana-Ullah et al., 2011; FAO, 2018; Farooq et al., 2018) in various crops like sorghum and maize (Cruz, 2007; Sueldo et al., 2010; Abrahams et al., 2017; Farooq et al., 2020). *Chelonus texanus*, *Cotesia marginiventris*, *Archytas marmoratus* and *Elenomus remus* are important parasitoids of different stages of *S. frugiperda* (Cave, 2000). *Orius insidiosus* has been reported as an egg and larval parasitoid of *S. frugiperda* (Isenhour et al., 1990). *Trichogramma* species have been distributed all over the world (Abrahams et al., 2017) and they are extensively used against various insect pests especially *Spodoptera* spp. like *S. frugiperda* of various horticultural and agricultural crops (apple, cotton, rice, corn). The population of parasitoids depends upon climatic conditions, availability of prey, and type of the crop (Parra et al., 2016). The entomopathogenic fungi (*Erynia radicans*, *Metarhizium anisopliae*, *Fusarium solani*, *Beauveria bassiana*, *Nomuraea rileyi*) (Rios-Velasco et al., 2011; Hernandez-Trejo et al., 2019), viruses (Nuclear polyhedrosis virus), and bacterium (*Bacillus thuringiensis*) have been reported as best and effective control against pest (Gardner et al., 1984; Lezama-Gutiérrez et al., 1996; Wraight et al., 2010; Faria et al., 2015; Liu et al., 2019; Li et al., 2020).

A study was conducted to check the efficacy of entomopathogenic nematodes (EPNs) such as Heterorhabdidae and Steinernematidae against *S. frugiperda* under laboratory conditions (Grewal et al., 2005; Zamora & Markelyn, 2019). They concluded that nematodes were found lethal and virulent against *S. frugiperda* (Andalo et al., 2012a). After 48 hours of post-treatment, EPNs were found more toxic with 65% mortality of larvae (Zamora & Markelyn, 2019). Another study was conducted to check the toxicity of entomopathogenic nematodes (*Heterorhabditis bacteriophora*) against prepupae and pupae of *S. frugiperda* under laboratory conditions. The study investigated 92% and 80% mortality of prepupae and pupae of *S. frugiperda*. The adult longevity (15-30%) and fertility (20%) of pests can be reduced by the infestation of ectoparasitic nematodes, *Noctuidonema guyanense* (Simmons & Rogers, 1994; Salazar-Gutiérrez et al., 2017). The complete list of natural enemies for different stages of *S. frugiperda* has been given in Table 1.

Botanical control

The pest resistance to insecticides can be minimized (Arain et al., 2018) by the application of plant materials (Khater, 2012). Botanical control has been widely used against insect pests in developed countries (Batista-Pereira et al., 2006) due to its availability, affordability, and also because it is safe for humans, animals, and biological fauna (Schmutterer, 1988). Many plant extracts such as *Milletia ferruginea*, *Azadirachta indica*, *Croton macrostachyus*, *Jatropha curcas*, *Chrysanthemum cinerariifolium*, and *Nicotina tabacum* are widely used plant extracts against *Spodoptera* species especially *S. frugiperda* in various countries (Schmutterer, 1988) and they give maximum larval mortality (Silva et al., 2015). The feeding and growth of larvae have been reduced by the application of *Argemone ochroleuca* extracts (Martínez et al., 2017).



Fig. 1 Damage of *Spodoptera frugiperda* (CABI, 2018)

Chemical control

The application of poisonous chemicals to control insect pests is a widely used method on a large scale all over the world. Different types of chemicals (insecticides) with a different mode of action and entry as ingestion and contact have been used for the management of *S. frugiperda* (de Albuquerque et al., 2006). According to Azevedo et al. (2004), seed treatment is not the best approach to control *S. frugiperda*. Various insecticides (lambda-cyhalothrin, Malathion, permethrin, and chlorpyrifos) have been used to check their effectiveness against *S. frugiperda* in the laboratory as well as in field conditions. Clothianidin and thiodicarb were found more effective and gave maximum larval mortality than thiamethoxam, fipronil, and chlorpyrifos (Camillo et al., 2005). Further studies depicted that Emamectin benzoate, Indoxacarb, Malathion, Flubendiamide, Methomyl, Chlorpyrifos, and Lufenuron gave better control against fall armyworm, *S. frugiperda* including; (Niaz et al., 2018).

Conclusion

The *S. frugiperda* has recently been becoming an invasive species and adopting the environmental conditions of

Pakistan. It is spreading in many areas of Pakistan, so urgent management options are needed to control this pest. There is also a need to provide awareness among the farming communities about pest scouting, understanding the right time of pest attack on which stage of the crop, right time of management application, and low-cost agronomic practices implementation for sustainable management of the *S. frugiperda*. Further trials should be conducted to check the host plants life cycle at different temperatures in Pakistan. Agriculture Research institutes and Academia should conduct experiments and Extension staff of the Government should timely transfer the result findings by educating the farming community about the pest. The plant population or diversity should be increased that can prove the best strategy in the enhancement of natural enemies. Intercropping is a very important strategy to control *S. frugiperda* such as maize with beans. The relationship of *S. frugiperda* with the weather (climate and temperature) is an important strategy for predicting *S. frugiperda* damage and distribution. A push-pull strategy like the cultivation of Napier grass and Desmodium grass with maize crop can prove the best management option of *S. frugiperda*. Biological fauna should be promoted and area-wise management would be the best option to control this pest.

Authors Contribution: M.R. wrote the manuscript. M.U., Z.S., U.G., M.A.B. and M.R. helped in write up. W.S. and M.R.S. critically reviewed the manuscript.

Conflict of interest: Authors have declared no conflict of interest.

References

- Abrahams, P., Beale, T., Cock, M., Corniani, N., Day, R., Godwin, J., Murphy, S., Richards, G., & Vos, J. (2017). Fall Armyworm Status Impacts and control options in Africa: preliminary evidence note. UK: CABI.
- Ali, Z., Shah, M., Nawaz, A., Nadeem, M., Shahid, M. R., & Farooq, M. (2015). Base line susceptibility of Bemisia Tabaci (Hemiptera: Aleyrodidae) to pyriproxyfen under lab conditions. *Gomal University Journal of Research*, 31(1), 1-8.
- Arain, M. S., Shakeel, M., Elzaki, M. E. A., Farooq, M., Hafeez, M., Shahid, M. R., Shah, S.A.H., Khan, F.Z.A., Shakeel, Q., Salim, A.M.A., & Li, G. Q. (2018). Association of detoxification enzymes with butene-fipronil in larvae and adults of Drosophila melanogaster. *Environmental Science and Pollution Research*, 25(10), 10006-10013.
- Arif, M. J., Gogi, M. D., Abid, A. M., Muhammad, I., Shahid, M. R., Sabir, H., & Muhammad, A. (2011). Predatory potential of some native coccinellid predators against *Phenacoccus solenopsis*, Tinsely (Pseudococcidae: Hemiptera). *Pakistan Entomologist*, 33(2), 97-103.
- Assefa, (2018). Status of fall armyworm (*Spodoptera frugiperda*), biology and control measures on maize crop in Ethiopia: A review. *International Journal of Entomological Research*, 6(2), 75-85.
- Azevedo, R. D., Grutzmacher, A. D., Loeck, A. E., da Silva, F. F., Storch, G., & Herpich, M. I. (2004). Effect of seed treatment and leaf spray of insecticides in different water volumes, on the control of *Spodoptera frugiperda* (JE Smith, 1797) (Lepidoptera: Noctuidae), in lowland corn and sorghum crops. *Revista Brasileira de Agrociencia (Brazil)*, 10(1), 71-77.
- Batista-Pereira, L. G., Stein, K., de Paula, A. F., Moreira, J. A., Cruz, I., Maria de Lourdes, C. F., Perri, J., & Corrêa, A. G. (2006). Isolation, identification, synthesis, and field evaluation of the sex pheromone of the Brazilian population of *Spodoptera frugiperda*. *Journal of Chemical Ecology*, 32(5), 1085-1099.
- Belay, D. K., Huckaba, R. M., & Foster, J. E. (2012). Susceptibility of the fall armyworm, *Spodoptera frugiperda* (Lepidoptera: Noctuidae), at Santa Isabel, Puerto Rico, to different insecticides. *Florida Entomologist*, 95(2), 476-478.
- Bokonon-Ganta, A. H., Bernal, J. S., Pietrantonio, P. V., & Setamou, M. (2003). Survivorship and development of fall armyworm, *Spodoptera frugiperda* (JE Smith) (Lepidoptera: Noctuidae), on conventional and transgenic maize cultivars expressing *Bacillus thuringiensis* Cry9C and Cry1A(b) endotoxins. *International Journal of Pest Management*, 49(2), 169-175.
- Busato, G. R., Grützmacher, A. D., Garcia, M. S., Giolo, F. P., Zotti, M. J., & Júnior, G. J. S. (2005). Biologia comparada de populações de *Spodoptera frugiperda* (JE Smith)(Lepidoptera: Noctuidae) em folhas de milho e arroz. *Neotropical Entomology*, 34(5), 743-750.
- Centre for Agriculture and Bioscience International [CABI]. (2017a). How to identify fall armyworm. A4 flyer. Plantwise. Retrieved from <http://www.plantwise.org/FullTextPDF/2017/20177800462.pdf>
- CABI, (2017b). Datasheet. *Spodoptera frugiperda* (fall armyworm). Invasive species compendium Retrieved from <http://www.cabi.org/isc/datasheet/29810>
- CABI (2018) Fall armyworm portal. Retrieved from <https://www.cabi.org/ISC/fallarmyworm>. Accessed November 2018
- CABI, (2019) Fall armyworm: Life cycle and damage. Retrieved from <https://www.cabi.org/isc/FullTextPDF/2019/20197800314.pdf>
- CABI, (2020). *Spodoptera frugiperda* (fall armyworm). Invasive Species Compendium. CABI. Retrieved from <https://www.cabi.org/isc/datasheet/29810> (Accessed 07 July 2020).
- Camillo, M. F., Di Oliveira, J. R. G., de Bueno, A. F., & Bueno, R. C. O. D. F. (2005). Seeds treatment on maize for *Spodoptera frugiperda* control. *Ecossistema*, 30(1/2), 59-63.
- Capinera, J. L. (2007). Fall Armyworm, *Spodoptera frugiperda* (J.E. Smith) (Insecta: Lepidoptera: Noctuidae). Document nr. EENY098. Department of Entomology and Nematology, UF/IFAS Extension. Retrieved from <http://edis.ifas.ufl.edu>. <http://edis.ifas.ufl.edu>.
- Casmuz, A., Juárez, M. L., Socías, M. G., Murúa, M. G., Prieto, S., Medina, S., Willink, E., & Gastaminza, G. (2010). Revisión de los hospederos del gusano cogollero del maíz, *Spodoptera frugiperda* (Lepidoptera: Noctuidae). *Revista de la Sociedad Entomológica Argentina*, 69(3-4), 209-231.
- Cave, R. D. (2000). Biology, ecology and use in pest management of *Telenomus remus*. *Biocontrol News and Information*, 21(1), 21-26.
- Chimweta, M., Nyakudya, I. W., Jimu, L., & Bray Mashingaidze, A. (2020). Fall armyworm [*Spodoptera frugiperda* (JE Smith)] damage in maize: management options for flood-recession cropping smallholder farmers. *International Journal of Pest Management*, 66(2), 142-154.
- Chormule, A., Shejawal, N., Sharanabasappa, C. M., Asokan, R., Swamy, H. M., & Studies, Z. (2019a). First report of the fall Armyworm, *Spodoptera frugiperda* (JE Smith)(Lepidoptera, Noctuidae) on sugarcane and other crops from Maharashtra, India. *Journal of Entomology and Zoology Studies*, 7, 114-117.

- Chormule, A., Shejawal, N., Nagol, J., & Brown, M. E. (2019b). American fall armyworm (*Spodoptera frugiperda*): alarming evidence of infestation in sugarcane, maize and jowar. *Journal of Sugarcane Research*, 8(2), 195-202.
- Clark, P. L., Molina-Ochoa, J., Martinelli, S., Skoda, S. R., Isenhour, D. J., Lee, D. J., Krumm, J. T., & Foster, J. E. (2007). Population variation of the fall armyworm, *Spodoptera frugiperda*, in the Western Hemisphere. *Journal of Insect Science*, 7, 5. doi: 10.1673/031.007.0501
- Cock, M. J., Beseh, P. K., Buddie, A. G., Cafá, G., & Crozier, J. (2017). Molecular methods to detect *Spodoptera frugiperda* in Ghana, and implications for monitoring the spread of invasive species in developing countries. *Scientific Reports*, 7(1), 1-10.
- Cruz, I. (2007). Alternativas para o controle da lagarta-do-cartucho, *Spodoptera frugiperda* e principais cuidados no uso de milho transgênicos resistentes a insetos. *Milho: fatores determinantes da produtividade. Piracicaba, USP-ESALQ*, 79-105.
- Dal Pogetto, M. H. F. A., Prado, E. P., Gimenes, M. J., Christovam, R. S., Rezende, D. T., Aguiar Junior, H. O., Costa, S. I. A., & Raetano, C. G. (2012). Corn yield with reduction of insecticidal sprayings against fall armyworm *Spodoptera frugiperda* (Lepidoptera: Noctuidae). *Journal of Agronomy*, 11(1), 17-21.
- Day, R., Abrahams, P., Bateman, M., Beale, T., Clotley, V., Cock, M., & Gomez, J. (2017). Fall armyworm: impacts and implications for Africa. *Outlooks on Pest Management*, 28(5), 196-201.
- de Albuquerque, F. A., Borges, L. M., Iacono, T. D. O., Crubelati, N. D. S., & Singer, A. D. C. (2006). Efficiency of insecticides applied in seed treatment and pulverization, in the control of maize initial pests. *Revista Brasileira de Milho e Sorgo*, 5(1), 15-25.
- Du Plessis, H., Schlemmer, M. L., & Van den Berg, J. (2020). The effect of temperature on the development of *Spodoptera frugiperda* (Lepidoptera: Noctuidae). *Insects*, 11(4), 228.
- Ebeling, W. (1971). Sorptive dusts for pest control. *Annual Review of Entomology*, 16(1), 123-158.
- Evans, D. C., & Stansly, P. A. (1990). Weekly economic injury levels for fall armyworm (Lepidoptera: Noctuidae) infestation of corn in lowland Ecuador. *Journal of Economic Entomology*, 83(6), 2452-2454.
- Faiz, A. H., FI-Abbas, Z., & Zahra, L. (2015). Avifaunal diversity of Tolipir National Park Azad Jammu And Kashmir Pakistan. *Journal of Animal and Plant Sciences*, 25, 404-409.
- Faiz, A. H., Hassan, M. U., Bagaturov, M. F., Tariq, G., & Faiz, L. Z. (2019). Diversity of Moths in some Selected Areas of District Bagh, Azad Jammu & Kashmir (Pakistan). *Journal of Bioresource Management*, 6(1), 27-35.
- Food and Agriculture Organization [FAO]. (2018). Integrated management of the Fall Armyworm on maize: A guide for Farmer Field Schools in Africa, 1-139.
- FAO. (2017). Fall armyworm continues to spread in Ethiopia's maize fields. Facilitates national awareness training for key partners and field offices. Retrieved from <http://www.fao.org/food-chain-crisis/howwe-work/plant-protection/fall-armyworm/en/>
- FAO. (2019). Fall Armyworm (FAW); Q & A. Retrieved from <http://www.fao.org/3/a-i7471e.pdf>
- Faria, M., Lopes, R. B., Souza, D. A., & Wraight, S. P. (2015). Conidial vigor vs. viability as predictors of virulence of entomopathogenic fungi. *Journal of Invertebrate Pathology*, 125, 68-72.
- Farooq, J., Anwar, M., Riaz, M., Farooq, A., Mahmood, A., Shahid, M. T. H., Shahid, M.R., & Ilahi, F. (2014). Correlation and path coefficient analysis of earliness, fiber quality and yield contributing traits in cotton (*Gossypium hirsutum* L.). *Journal of Animal & Plant Sciences*, 24(3), 781-790.
- Farooq, M., Shakeel, M., Iftikhar, A., Shahid, M. R., & Zhu, X. (2018). Age-stage, two-sex life tables of the lady beetle (Coleoptera: Coccinellidae) feeding on different aphid species. *Journal of Economic Entomology*, 111(2), 575-585.
- Farooq, M., Zhu, X., Shakeel, M., Iftikhar, A., Shahid, M. R., Saeed, N., & Arain, M. S. (2020). Comparative analysis of the demographic parameters of seven spotted ladybird beetle (Coleoptera: Coccinellidae) reared on various host aphid species. *PeerJ*, 8, e8313. doi: 10.7717/peerj.8313.
- Foster, R. E. (1989). Strategies for protecting sweet corn ears from damage by fall armyworms (Lepidoptera: Noctuidae) in southern Florida. *Florida Entomologist*, 146-151.
- Gardner, W. A., Noblet, R., & Schwehr, R. D. (1984). The potential of microbial agents in managing populations of the fall armyworm (Lepidoptera: Noctuidae). *Florida Entomologist*, 67(3), 325-332.
- Gebrezihier, H. G., & Gebrezihier, F. G. (2020). Effect of integrating night-time light traps and push-pull method on monitoring and deterring adult fall armyworm (*Spodoptera frugiperda*). *International Journal of Entomology Research*, 5(1), 28-32.
- Gilal, A. A., Bashir, L., Faheem, M., Rajput, A., Soomro, J. A., Kunbhar, S., Mirwani, A. S., Mastoi, G. S., & Sahito, J. G. M. (2020). First record of invasive fall armyworm (*Spodoptera frugiperda* (Smith))(Lepidoptera: Noctuidae) in corn fields of Sindh, Pakistan. *Pakistan Journal of Agricultural Research*, 33(2), 247-252.
- Goergen, G., Kumar, P. L., Sankung, S. B., Togola, A., & Tamò, M. (2016). First report of outbreaks of the fall armyworm *Spodoptera frugiperda* (JE Smith)(Lepidoptera, Noctuidae), a new alien invasive pest in West and Central Africa. *PLOS ONE*, 11(10), e0165632. doi: 10.1371/journal.pone.0165632

- Grewal, P. S., Koppenhöfer, A. M., & Choo, H. Y. (2005). Nematodes as biocontrol agents. In P. S., Grewal, R. U., Ehlers, & D. I. Shapiro-Ilan (Eds.), *Lawn, turfgrass and pasture applications* (pp. 115-146). doi: 10.1079/9780851990170.0115
- Hardke, J. T., Lorenz III, G. M., & Leonard, B. R. (2015). Fall armyworm (Lepidoptera: Noctuidae) ecology in southeastern cotton. *Journal of Integrated Pest Management*, 6(1), 10; doi: 10.1093/jipm/pmv009
- Harrison, R. D., Thierfelder, C., Baudron, F., Chinwada, P., Midega, C., Schaffner, U., & Van Den Berg, J. (2019). Agro-ecological options for fall armyworm (*Spodoptera frugiperda* JE Smith) management: providing low-cost, smallholder friendly solutions to an invasive pest. *Journal of Environmental Management*, 243, 318-330.
- Hernandez-Mendoza, J. L., López-Barbosa, E. C., Garza-González, E., & Mayek-Perez, N. (2008). Spatial distribution of *Spodoptera frugiperda* (Lepidoptera: Noctuidae) in maize landraces grown in Colima, México. *International Journal of Tropical Insect Science*, 28(3), 126-129.
- Hernandez-Trejo, A., Estrada-Drouaillet, B., López-Santillán, J. A., Rios-Velasco, C., Rodríguez-Herrera, R., & Osorio-Hernández, E. (2019). Effects of Native Entomopathogenic Fungal Strains and Neem Extract on *Spodoptera frugiperda* on Maize. *Southwestern Entomologist*, 44(1), 117-124.
- Hruska, A. J. (2019). Fall armyworm (*Spodoptera frugiperda*) management by smallholders. *CAB Reviews*, 14, 1-11.
- Isenhour, D. J., Layton, R. C., & Wiseman, B. R. (1990). Potential of adult *Orius insidiosus* [Hemiptera: Anthocoridae] as a predator of the fall armyworm, *Spodoptera frugiperda* [Lepidoptera: Noctuidae]. *Entomophaga*, 35(2), 269-275.
- Johnson, S. J. (1987). Migration and the life history strategy of the fall armyworm, *Spodoptera frugiperda* in the Western Hemisphere. *International Journal of Tropical Insect Science*, 8(4-6), 543-549.
- Kandel, S., & Poudel, R. (2020). Fall Armyworm (*Spodoptera Frugiperda*) in Maize: An Emerging Threat in Nepal and its Management. *International Journal of Applied Sciences and Biotechnology*, 8(3), 305-309.
- Khan, Z. R., Pittchar, J. O., Midega, C. A., & Pickett, J. A. (2018). Push-pull farming system controls fall armyworm: lessons from Africa. *Outlooks on Pest Management*, 29(5), 220-224.
- Khater, H. F. (2012). Prospects of botanical biopesticides in insect pest management. *Pharmacologia*, 3(12), 641-656.
- Korunić, Z. (2013). Diatomaceous earths: Natural insecticides. *Journal Pesticides and Phytomedicine*, 28(2), 77-95.
- Kumela, T., Simiyu, J., Sisay, B., Likhayo, P., Mendesil, E., Gohole, L., & Tefera, T. (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.
- Lezama Gutierrez, R., Alatorre Rosas, R., Bojalil Jaber, L. F., Molina Ochoa, J., Arenas Vargas, M., Gonzalez Ramirez, M., & Rebolledo Dominguez, O. (1996). Virulence of five entomopathogenic fungi (Hyphomycetes) against *Spodoptera frugiperda* (Lepidoptera: Noctuidae) eggs and neonate larvae. *Vedalia Revista Internacional de Control Biologico (Mexico)*.
- Li, Y., Wang, Z., & Romeis, J. (2020). Managing the Invasive Fall Armyworm through Biotech Crops: A Chinese Perspective. *Trends in Biotechnology*, 39(2), doi: 10.1016/j.tibtech.2020.07.001
- Liu, H., Hu, X., Wang, Y., Yang, P., Shu, C., Zhu, X., Zhang, J., Sun, G., Zhang, X., & Li, Q. (2019). Screening for *Bacillus thuringiensis* strains with high toxicity against *Spodoptera frugiperda*. *Chinese Journal of Biological Control*, 35(5), 721-728.
- Majid, M. A., Shahid, M. R., Ahmad, S., Ishtiaq, M., Akram, M., Mahmood, A., Abass, Q., & Hussain, M. (2017). Diet predilection of jassid on advanced cultivars of cotton under laboratory and field conditions. *Pakistan Entomologist*, 39(2), 13-18.
- Martínez, A. M., Aguado-Pedraza, A. J., Viñuela, E., Rodríguez-Enríquez, C. L., Lobit, P., Gómez, B., & Pineda, S. (2017). Effects of ethanolic extracts of *Argemone ochroleuca* (Papaveraceae) on the food consumption and development of *Spodoptera frugiperda* (Lepidoptera: Noctuidae). *Florida Entomologist*, 100(2), 339-345.
- Midega, C. A., Pittchar, J. O., Pickett, J. A., Hailu, G. W., & Khan, Z. R. (2018). A climate-adapted push-pull system effectively controls fall armyworm, *Spodoptera frugiperda* (JE Smith), in maize in East Africa. *Crop Protection*, 105, 10-15.
- Montezano, D. G., Specht, A., Bortolin, T. M., Fronza, E., Sosa-Gomez, D. R., Roque-Specht, V. F., Pezzi, P., Luz, P. C., & Barros, N. M. (2013). Immature stages of *Spodoptera albula* (Walker) (Lepidoptera: Noctuidae): Developmental parameters and host plants. *Anais da Academia Brasileira de Ciências*, 85(1), 271-284.
- Murray, K., Jepson, P. C., & Chaola, M. (2019). Fall armyworm management by maize smallholders in Malawi: an integrated pest management strategic plan. Retrieved from <http://hdl.handle.net/10883/20170>
- Naeem-Ullah, U., Ashraf Ansari, M., Iqbal, N., & Saeed, S. (2019). First authentic report of *Spodoptera frugiperda* (JE Smith)(Noctuidae: Lepidoptera) an alien invasive species from Pakistan. *Applied Sciences and Business Economics*, 6(1), 1-3.
- Nagoshi, R. N., Adamczyk, J. J., Meagher, R. L., Gore, J., & Jackson, R. (2014). Using stable isotope analysis to examine fall armyworm (Lepidoptera: Noctuidae) host

- strains in a cotton habitat. *Journal of Economic Entomology*, 100(5), 1569-1576.
- Naharki, K., Regmi, S., & Shrestha, N. (2020). A Review on invasion and management of fall armyworm (*Spodoptera Frugiperda*) in Nepal. *Reviews in Food and Agriculture*, 1(1), 6-11.
- Niaz, U., Khan, A., & Javed, M.U. (2018). Fall armyworm *Spodoptera frugiperda* (Lepidoptera: Noctuidae) a well known quarantine pest and its global IPM strategies. *Journal of Agricultural Science and Botany*, 2(3), 1-4.
- Parra, J. R. P., Alves, G. R., Diniz, A. J. F., & Vieira, J. M. (2016). *Tamarixia radiata* (Hymenoptera: Eulophidae) *Diaphorina citri* (Hemiptera: Liviidae): mass rearing and potential use of the parasitoid in Brazil. *Journal of Integrated Pest Management*, 7(1), 1-11.
- Pair, S. D., Raulston, J. R., Rummel, D. R., Westbrook, J. K., Wolf, W. W., Sparks, A. N., & Schuster, M. F. (1988). Development and production of corn earworm and fall armyworm in the Texas high plains: evidence for reverse fall migration. *The Southwestern Entomologist (USA)*, 12(2), 89-99.
- Pashley, D. P., Johnson, S. J., & Sparks, A. N. (1985). Genetic population structure of migratory moths: the fall armyworm (Lepidoptera: Noctuidae). *Annals of the Entomological Society of America*, 78(6), 756-762.
- Pogue, Pogue, G., Pogue, M. G., Pogue, M., Pogue, G. M., Pogue, G. M., Pogue, G., Pogue, M. G., Pogue, M. G., Pogue, M. G., Pogue, M. G., Pogue, M. G., Pogue, M. G., Pogue, M. G., Pogue-Geile, M., & Pogue, G. (2002). A world revision of the genus *Spodoptera* Guenée (Lepidoptera: Noctuidae). *The Memoirs of the Entomological Society of Canada*, 111, S108.
- Prasanna, B. M., Huesing, J. E., Eddy, R., & Peschke, V. M. (2018). Fall armyworm in Africa: A guide for integrated pest management. Retrieved from <https://repository.cimmyt.org/bitstream/handle/10883/19204/59133.pdf?sequence=1&isAllowed=y>
- Prowell, D. P., McMichael, M., & Silvain, J. F. (2004). Multilocus genetic analysis of host use, introgression, and speciation in host strains of fall armyworm (Lepidoptera: Noctuidae). *Annals of the Entomological Society of America*, 97(5), 1034-1044.
- Rahman, S. A., Iqbal, M. S., Riaz, M., Mahmood, A., Shahid, M. R., Abbas, G., & Farooq, J. (2013). Cause and effect estimates for yield contributing and morphological traits in upland cotton (*Gossypium hirsutum* L.). *Journal of Agricultural Research*, 51(4), 393-398.
- Rajbhandari, R., Shah, L., Acharya, M., Subedi, R.S., & Bajracharya, A.B., (2019). American Fall Armyworm in maize crop: In Nepalese Language. Plant Quarantine and Pesticide Management Centre and Plantwise. Retrieved from: <https://www.cabi.org/isc/FullTextPDF/2019/20197800519.pdf>
- Ramzan, M., Murtaza, G., Javaid, M., Iqbal, N., Raza, T., Arshad, A., & Awais, M. (2019). Comparative Efficacy of Newer Insecticides against *Plutella xylostella* and *Spodoptera litura* on Cauliflower under Laboratory Conditions. *Indian Journal of Pure Applied Biosciences*, 7(5), 1-7.
- RicBessin, (2004), Fall Armyworm in Corn. ENTFACT-110: Fall Armyworm in Corn. Extension Entomologist University of Kentucky College of Agriculture.
- Rios-Velasco, C., Gallegos-Morales, G., Cambero-Campos, J., Cerna-Chávez, E., Del Rincón-Castro, M. C., & Valenzuela-García, R. (2011). Natural enemies of the fall armyworm *Spodoptera frugiperda* (Lepidoptera: Noctuidae) in Coahuila, México. *The Florida Entomologist*, 94(3), 723-726.
- Salazar-Gutiérrez, J. D., Castelblanco, A., Rodríguez-Bocanegra, M. X., Teran, W., & Sáenz-Aponte, A. (2017). *Photorehabdus luminescens* subsp. *akhurstii* SL0708 pathogenicity in *Spodoptera frugiperda* (Lepidoptera: Noctuidae) and *Galleria mellonella* (Lepidoptera: Pyralidae). *Journal of Asia-Pacific Entomology*, 20(4), 1112-1121.
- Sana-Ullah, M., Arif, M. J., Gogi, M. D., Shahid, M. R., Adid, A. M., Raza, A., & Ali, A. (2011). Influence of different plant genotypes on some biological parameters of cotton mealybug, *Phenacoccus solenopsis* and its predator, *Coccinella septempunctata* under laboratory conditions. *International Journal of Agriculture and Biology*, 12, 125-129.
- Schmutterer, H. (1988). Potential of azadirachtin-containing pesticides for integrated pest control in developing and industrialized countries. *Journal of Insect Physiology*, 34(7), 713-719.
- Shahid, M. R., Akram, M., Ahmad, S., Sadiq, M. A., Farooq, M., Shakeel, M., Ahmad, S., Kanwal, S., & Mahmood, A. (2019). Assessment of natural incidence of *Phenacoccus solenopsis* on different host plants under core and non-core cotton zone of Punjab, Pakistan. *Pakistan Entomologist*, 41(1), 21-26.
- Shahid, M. R., Arif, M. J., Abid, M., Muhammad, A., Gogi, M. D., & Farrukh, E. (2012). Comparison of resistance among different cultivars of cotton against *Thrips tabaci* under unsprayed conditions. *Pakistan Entomologist*, 34(1), 83-85.
- Shahid, M. R., Arif, M. J., Gogi, M. D., & Javed, N. (2017). Host-plant-preference and mortality analysis of *Phenacoccus solenopsis* in association with biochemical traits of different plant species. *International Journal of Agriculture and Biology*, 19, 211-218.
- Shahid, M. R., Farooq, J., Mahmood, A., Iqbal, M. S., Mahmood, K., & Abbas, H. G. (2015). Economic yield, fiber trait and sucking insect pest incidence on advanced genotypes of cotton in Pakistan. *Cercetari Agronomice in Moldova*, 48(1), 51-56.

- Shahid, M. R., Mahmood, A., Farooq, J., Shahid, M. T. H., Asif, M., Ramzan, M., Akram, M., & Iqbal, M. S. (2014). The impact of sowing dates and varieties on the incidence of *Oxycarenus laetus* and *Dysdercus koingii* on cotton. *Comunicata Scientiae*, 5(4), 412-418.
- Shahid, M. R., Shakeel, M., Farooq, M., Arain, M. S., Hanif, C. M. S., Yin, H., Akram, M., & Ahmad, S. (2018). Earliness index deters *Pectinophora gossypiella* incidence on advanced cultivars of Bt cotton. *Arthropod-plant Interactions*, 12(2), 303-309.
- Shahid, M. R., Suhail, A., Arif, M. J., Gogi, M. D., Shahzad, M. A., & Hussain, S. (2007). Effectiveness of *Trichogramma chilonis* (ishii) (Hymenoptera: Trichogrammatidae) against sugarcane stem borer (*Chilo infuscatellus* Snellen) (Lepidoptera: Pyralidae). *Pakistan Entomologist*, 29(2), 141-146.
- Sibanda, Z. (2017). Training Manual on Fall Armyworm. R. T. J. Mulila-Mitti, S. Luchen, L. Hove (Ed.). FAO, Rome, Italy. Retrieved from www.fao.org
- Sidana, J. A. S. M. E. E. N., Singh, B. I. K. R. A. M., & Sharma, O. (2018). Occurrence of the new invasive pest, fall armyworm, *Spodoptera frugiperda* (JE Smith) (Lepidoptera: Noctuidae), in the maize fields of Karnataka, India. *Current Science*, 115, 621-623.
- Silva, M. S., Broglio, S. M. F., Trindade, R. C. P., Ferreira, E. S., Gomes, I. B., & Micheletti, L. B. (2015). Toxicity and application of neem in fall armyworm. *Comunicata Scientiae*, 6(3), 359-364.
- Simmons, A. M., & Rogers, C. E. (1994). Effect of an ectoparasitic nematode, *Noctuidonema guyanense*, on adult longevity and egg fertility in *Spodoptera frugiperda* (Lepidoptera: Noctuidae). *Biological Control*, 4(3), 285-289.
- Sisodiya, D. B., Raghunandan, B. L., Bhatt, N. A., Verma, H. S., Shewale, C. P., Timbadiya, B. G., & Borad, P. K. (2018). The fall armyworm, *Spodoptera frugiperda* (JE Smith) (Lepidoptera: Noctuidae); first report of new invasive pest in maize fields of Gujarat, India. *Journal of Entomology and Zoology Studies*, 6(5), 2089-2091.
- Sparks, & Alton, N. (1979). A review of the biology of the fall Armyworm" (<https://www.jstor.org/stable/3494083>). *The Florida Entomologist*, 62(2), 82-87.
- Stokstad, E. (2017). New crop pest takes Africa at lightning speed. *Science*, 356, 473-474.
- Sueldo, M. R., Bruzzone, O. A., & Virla, E. G. (2010). Characterization of the earwig, *Doru lineare*, as a predator of larvae of the fall armyworm, *Spodoptera frugiperda*: a functional response study. *Journal of Insect Science*, 10(1), 38. doi: 10.1673/031.010.3801
- Tambo, J. A., Day, R. K., Lamontagne-Godwin, J., Silvestri, S., Beseh, P. K., Oppong-Mensah, B., Phirif, N. A., & Matimelo, M. (2020). Tackling fall armyworm (*Spodoptera frugiperda*) outbreak in Africa: An analysis of farmers' control actions. *International Journal of Pest Management*, 66(4), 298-310.
- Tippannavar, P. S., Talekar, S. C., Mallapur, C. P., Kachapur, R. M., Salakinkop, S. R., & Harlapur, S. I. (2019). An outbreak of Fall Armyworm in Indian subcontinent: A new invasive pest on maize. *Maydica*, 64(1), 1-10.
- Valdez-Torres, J. B., Soto-Landeros, F., Osuna-Enciso, T., & Báez-Sanudo, M. A. (2012). Phenological prediction models for white corn (*Zea mays* L.) and fall armyworm (*Spodoptera frugiperda* JE Smith). *Agrociencia (Montecillo)*, 46(4), 399-410.
- Wraight, S. P., Ramos, M. E., Avery, P. B., Jaronski, S. T., & Vandenberg, J. D. (2010). Comparative virulence of *Beauveria bassiana* isolates against lepidopteran pests of vegetable crops. *Journal of Invertebrate Pathology*, 103(3), 186-199.
- Zamora, R., & Markelyn, J. (2019). Caracterización de aislados nativos de nematodos entomopatógenos y uso potencial contra *Spodoptera frugiperda*. Diss Universidad Nacional Agraria. Retrieved from <https://repositorio.una.edu.ni/3830/>

