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Review Article

Fall Armyworm (*Spodoptera frugiperda*) Invasive Pest of Agriculture and Their Biological Control: A Review

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Abstract

Spodoptera frugiperda is also known as fall armyworm, one of the important pests of agronomic and horticulture crops, and spread throughout the tropics and subtropics areas, threatening food security, economic advancement, and the lives of millions of cereal farmers. FAW is the world's major migratory pest, mainly damaging jade Rice, paddy rice, sorghum, sugarcane, cotton, pasture, and sugar beet more than 80 kinds of plants Although FAW has received extensive scientific attention in its home range in the Pakistan, chemical inputs play a key role in its mitigation, and biological control adoption is behind globally. Here, a quantitative review of the first report in Pakistan and different countries, potential risks of fall armyworm, collected and organized based on the monitoring, morphological, bio ecology, and geographical distribution of *S. frugiperda* invasive sites, further, the natural enemies of *S. frugiperda*, such as parasitic wasps, nematodes, pathogenic fungi, virus; Pheromones traps supporting technologies, Monitoring methods and suggestions, to study the potentially suitable areas of *S. frugiperda*. A risk assessment was carried out, the occurrence of this insect in Pakistan will affect my country's production industry Therefore, further develop relevant new technology research, strengthen the protection and utilization of natural enemies, and prevent the spread and disaster of *S. frugiperda* should be paid attention to in disaster-prone areas through the organic combination of biological control and chemical control.

Keywords

Spodoptera frugiperda, Geographical Regions, Pakistan, Biological Control Agents

1. Introduction

Spodoptera frugiperda belongs to the (Lepidoptera: Noctuidae) also known as fall armyworm, and is an omnivorous pest native to tropical and subtropical areas of America [1]. and world wild [2]. *S. frugiperda* has very Strong migratory flight ability if the weather conditions are suitable, the migratory flight distance is within 30 hours covering a distance up to 1600 km, and can be moved from the southern United States to the Caribbean, endangering local maize and grass crops harm [3, 4]. The " State of the World's Plants 2017" report [5] that FAW is the world's major migratory pest, mainly damaging jade Rice, paddy rice, sorghum, sugarcane, cotton, pasture, and sugar beet more than 80 kinds of plants

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such as potatoes e, t, c. *S. frugiperda* larvae mainly damage jade Rice, feeding on leaves can cause defoliation and subsequent transfer of damage; sometimes numerous larvae infest root cuttings, cutting off seedlings and young plants stems; larvae can burrow into the ears of booting plants and feed on the plant's Buds and growth points, and burrows into the fruit [2]. *S. frugiperda* was reported from Sindh, Pakistan, causing damage to maize crops, and it has been Colonized and multiplied, and spread continuously [6].

On May 15, 2019, the Pakistan Agricultural Research Council was informed of the existence of FAW in Pakistan. Later in 2020, Pakistan's Department of Plant Protection formally acknowledged the presence of fall armyworm [7].

2. Fall Armyworm Detection Worldwide

Before 2016 Lepidopteran pest, FAW, evolved in Brazil near Amazon, and later it was also detected in many other countries, different American states, Mexico, and the Caribbean, notorious pest was also found in West Africa [8], it quickly spread around Sub-Saharan Africa [9]. For the first time in Asia, this aggressive pest has been reported in Karnataka and Gujrat (India), [10, 11]. Further FAW has also been reported in other Asian countries, Siri Lanka, China, Bangladesh, and Thailand [12-14].

S. frugiperda is widely distributed in eastern and central North America and South America because they cannot survive in winter at temperatures below freezing as their biological characteristics [15], in the United States can only be found in the southernmost region, the problem in winter and spring in the southeastern states of the United States, and the summer and autumn seasons are very serious. throughout the eastern United States and southern Canada [15]. *S. frugiperda* invaded Africa in 1999, Saha was first discovered in Nigeria and reported in almost all regions of sub-Latin Africa, the African maize has wreaked havoc, with further spread and economic huge potential for damage, which has spread to Africa after 2 years into 44 countries [16]. In 2018, it started to spread widely in India [17], and invaded Myanmar, Yemen, Thailand and Sri Lanka. Invaded Myanmar in mid-December and formed an insect source base, Through the Sino-Myanmar border, it sporadically entered the territory of Yunnan in my country [18, 19]. This virulent insect pest can spread further from north to other Asian countries [20] and Europe [21].

3. Reported from Pakistan

As Pakistan and India are bordering countries sharing a common climate and habitat, it was a high chance that this notorious pest, which has the ability to fly 100 km at night [22], can be present in Pakistan [6]. After that, another study also confirmed that *S. frugiperda* is present in almost all corn, sorghum, and millet crops districts excluding Larkana, Shikarpur, and Jacobabad as described in Table 1 and Figure 1 [23]. Larvae collected from maize crops during October and November were reared to adult stage and their study had confirmed the presence of FAW in Faisalabad [24]. Moreover, FAW had been detected with an infestation rate of 5 out of 138 in Lahore and 5 out 60 in Faisalabad as described in Figure 2, Figure 3 and Table 2 [25]. Infestation of FAW was also observed from the samples taken from each tehsil of Multan [26]. Molecular work has provided the first evidence of the presence of Rice strain of FAW on maize in Sindh [27]. Further studies on FAW in Pakistan will help us to identify the total estimate distribution for the effective control strategies, Table 3.

***Table 1.** Incidence of FAW in different location of Pakistan and their infestation.*

Location	Host	% infestation	Reference
Multan district	Maize leaves	early as well as old instars larvae feed on the maize leaves and even cause 100% defoliation	[28]
Faisalabad	natural diet		[24]
Punjab, Sindh and Khyber Pakhtunkhwa IN 32 district	Maize fields	12 out of 536 fields were positive in Punjab (2.10% average incidence); no out of 55 fields in KPK; Out of 338, 198 felds were found positive in Sindh (56.12% average incidence)	[29]
Sargodha	five varieties of wheat (Dilkash-20, Fakhar-E-Bhakkar-17, Subhani-21, Faisalabad-08, and Akbar-19), and one variety of maize (NK-6654)	nutritional physiology of *S. frugiperda* was satisfactory on maize and some wheat varieties as well	[30]
Bahawalpur	maize, castor bean, cotton, cabbage, okra and sugarcane	The proximate compositions and mineral contents of the tested host plants showed a significant difference (p<0.5)	[31]
Sargodha	maize wheat, rice, and sorghum	Larval diets had a significant varying effect on the finite and intrinsic increase rates, reflecting that maize was the	[32]

Location	Host	% infestation	Reference
		most suitable diet.	
Multan	Fresh leaves of maize	The damage infestation was recorded 15-50% on maize. The damage pattern was also observed in the laboratory conditions.	[26]
Multan	maize leaves under laboratory conditions	Duration of egg, larva, pupa, and adult of a noctuid moth, S. frugiperda	[28]

Table 2. FAW infestation level on fodder and grain corn crop at different locations in 2020 [23].

Location	Field Visited	Infestation level (percentage)	Infestation means (percentage)
Ghotki	5	0-12	4.80±2.33
Hyderabad	47	0-60	12.49±1.69
Jacobabad	12	0	0
Jamshoro	1	20	20.00±0.00
Khairpur	20	0-9	0.90±0.54
Larkana	13	0	0
Matiari	53	0-35	11.85±1.32
Mirpur Khas	19	0-50	8.05±2.51
Naushaharo Feroze	38	0-5	0.87±0.28
Shaheed Benazirabad	9	0-100	13.33±11.06
Shikarpur	10	0	0
Sukkur	15	0-11	1.93±0.91
Tando Allahyar	18	0-70	15.17±4.09
Thatta	10	0-10	1.70±1.05
Umer Kot	19	0-40	8.47±2.74

Source: [23]

Table 3. August 2019 - February 2020 FAW Incidence report Source: [25].

Sr. No.	District	Village	Crop	Variety	Level of infestation (%) & S. E
1	Lahore	Khawaja Faiq Pind	Maize	P3939	13.25 ±0.78
2	Lahore	Chappa Pind	Maize	Neelum	18.74 ±0.94
3	Kasur	Rao Khan Wala	Maize	Neelum	12.82 ±0.56
4	Kasur	Orarra	Maize	Agaiti	09.28 ±0.52
5	Kasur	Jamalpur Khuddian Khaas	Maize	Pearl	10.32 ±0.82
6	Kasur	Raja Jang	Maize	P3939	13.26 ±0.78
7	Kasur	Kumharan Wala	Maize	Agaiti	11.94 ±0.79
8	Lahore	Farm Area, Punjab University	Maize	Agaiti	19.39 ±0.57
9	Lahore	Warra Gillan Ala, Manga Mandi	Maize	Sahiwal Gold	15.21 ±0.78

Sr. No.	District	Village	Crop	Variety	Level of infestation (%) & S. E
10	Lahore	Sardar Umer Da Dera, Manga Mandi	Maize	Sahiwal Gold	18.69 ±0.92

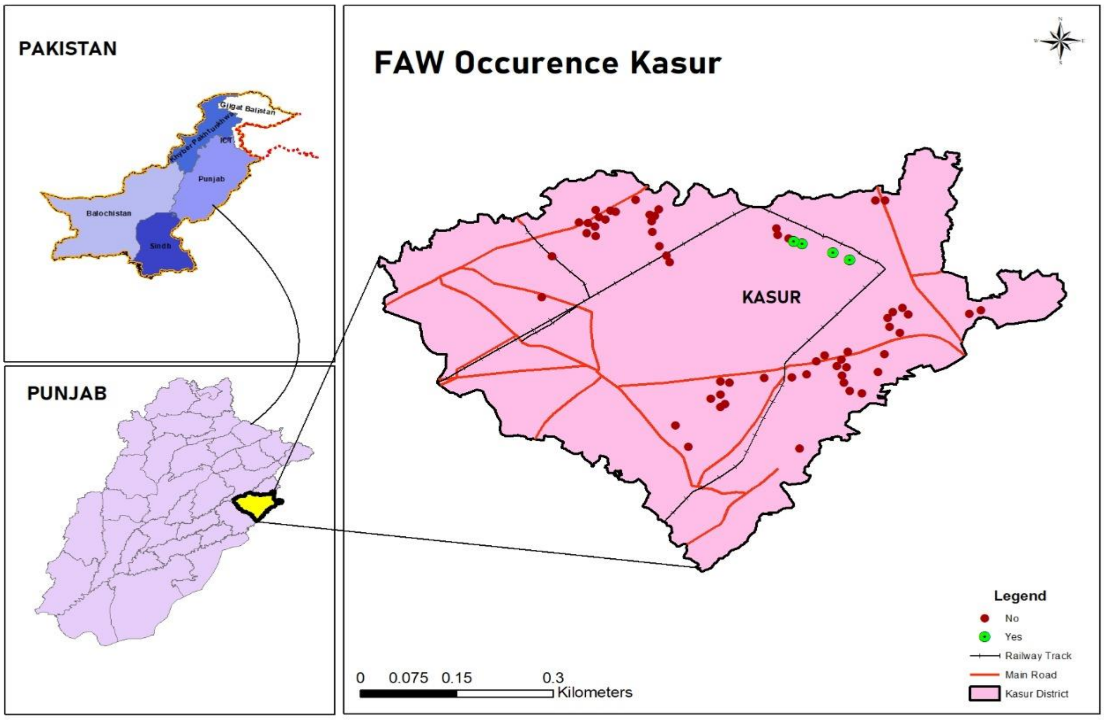

Figure 1. *Graphical representation of Survey and Prevalence at Kasur Source: [25].*

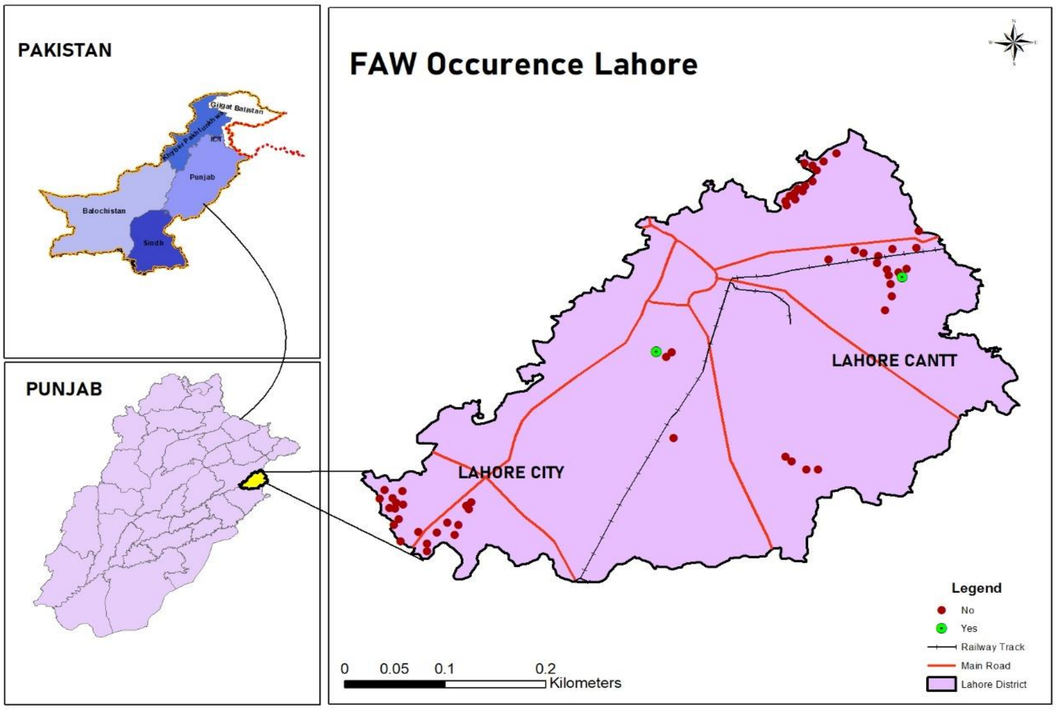

Figure 2. *Graphical representation of Survey and Prevalence at Lahore Source: [25].*

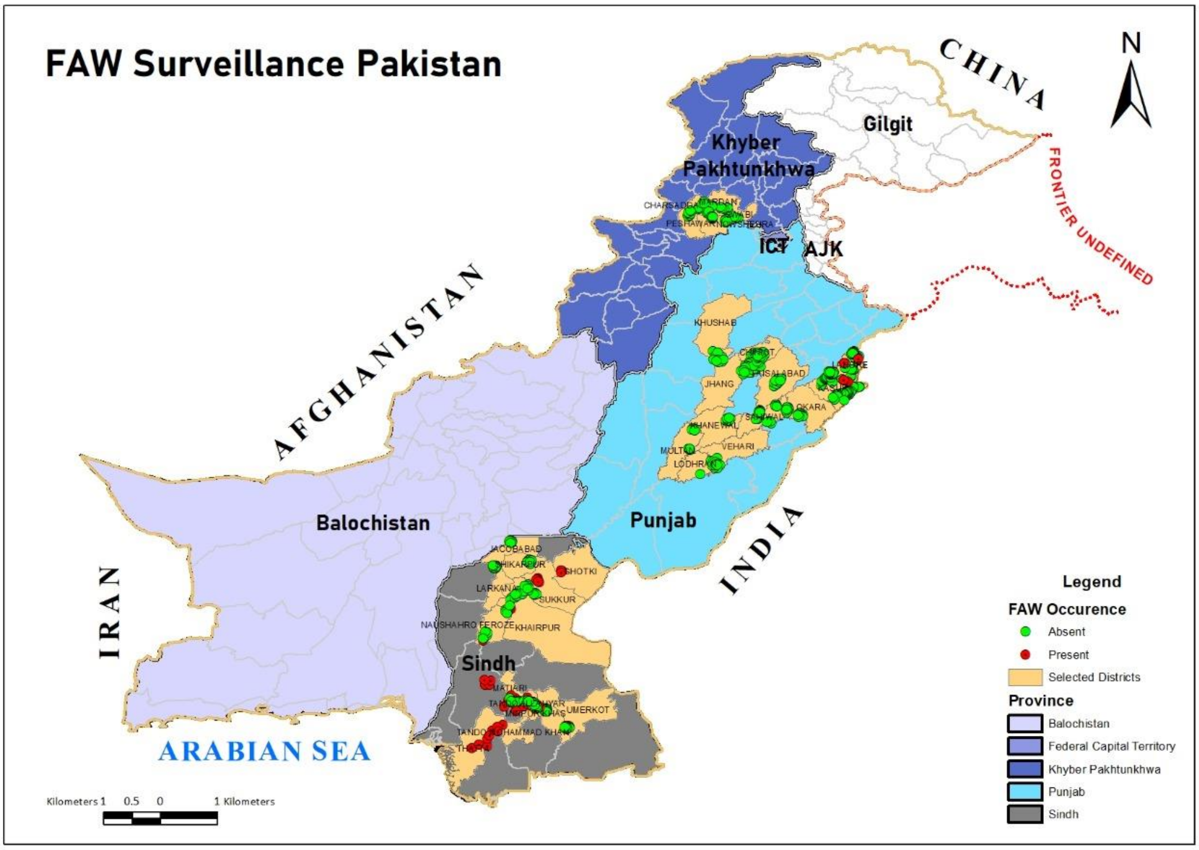

Figure 3. *S. frugiperda surveillance in Sindh, Punjab and Khyber Pakhtunkhwa, Pakistan. There was no prevalence in Khyber Pakhtunkhwa, a low prevalence in Punjab, and a high prevalence in many parts of Sindh. Source: [27].*

4. Potential Risk of Fall Armyworm

Cereals like Maize, Wheat, and Rice have an important role in world food security and hunger mitigating programs [33]. After wheat and rice, maize is widely cultivated all over Pakistan for food, silage, and feed respectively for human consumption, domestic animals, and birds. According to the Pakistan bureau of statistics in 2018, every year around 1.34 million hectares of land is cultivated with maize [34]. FAW has become a threat to global food security and animal feed [35]. FAW damage the maize crop, other cereals, and fodder production all over the world because of its incredible movement, lack of diapause, high reproductive ability, diverse host range and, worldwide unmonitored trade [22, 10, 36, 37, 38]. Thus, in 2017 Centre for Agriculture and Biosciences International included the FAW in the top 10 devastating pests [39].

FAW being a polyphagous insect has 353 larval host plant ranges of 76 families [36]. Such a wide host range provides alternative hosts to survive and multiply all over the year. According to the current study, FAW is the primary pest and risk to the maize crop, causing significant financial losses [28]. This aspect made FAW a voracious pest and posed a hurdle to applying integrated pest management. For this reason, it caused 500 million USD in losses annually in the Atlantic and USA either damaging the crop or management costs [40]. All staple crops (sorghum, millet, and maize) and the livelihood of many small farmers in Africa are at risk as those crops are the favorite host plants for FAW larvae to chew and grow [41].

From the early days of FAW spread in Asia and Africa, many farmers are trying to manage this invasive pest through synthetic insecticides which reduces crop losses for the time being by putting the environment at stake. Such as, in China (Yunnan) during the emergence of *S. frugiperda* 71-95% of growers used pesticides to maintain crops below the threshold level due to which management costs soared up from $81 to $276 USD per hectare [42]. Although, in Pakistan, FAW has invasive status and is less damaging at present many farmers are managing this pest like other *Spodoptera* pests by applying pesticides such as Lufenuron, Chlorantraniliprole, Emamectin benzoate, and Spinetoram. [7]. At this rate, pesticide use will exaggerate the production cost, small farmers' income, and environmental sustainability. Additionally, the overuse of chemical pesticides will disrupt the ecosystem, kill natural enemies, and cause a negative impact on animals' and humans' health.

Like all other insects, biotic and abiotic factors also impact FAW development, reproduction, and dispersal. It was reported that with day by day increase in climate change has impacted the FAW to have more generations per year [43, 44, 45]. Under the use of (the Shared Socioeconomic Pathway) SSP5-8.5 multi-model ensemble, it has projected the highest FAW propagation and infiltration risk by 2050 and 2070 as there is a surge (4.49-8.33%) in its habitat suitability (Figure 5) all over the world [46].

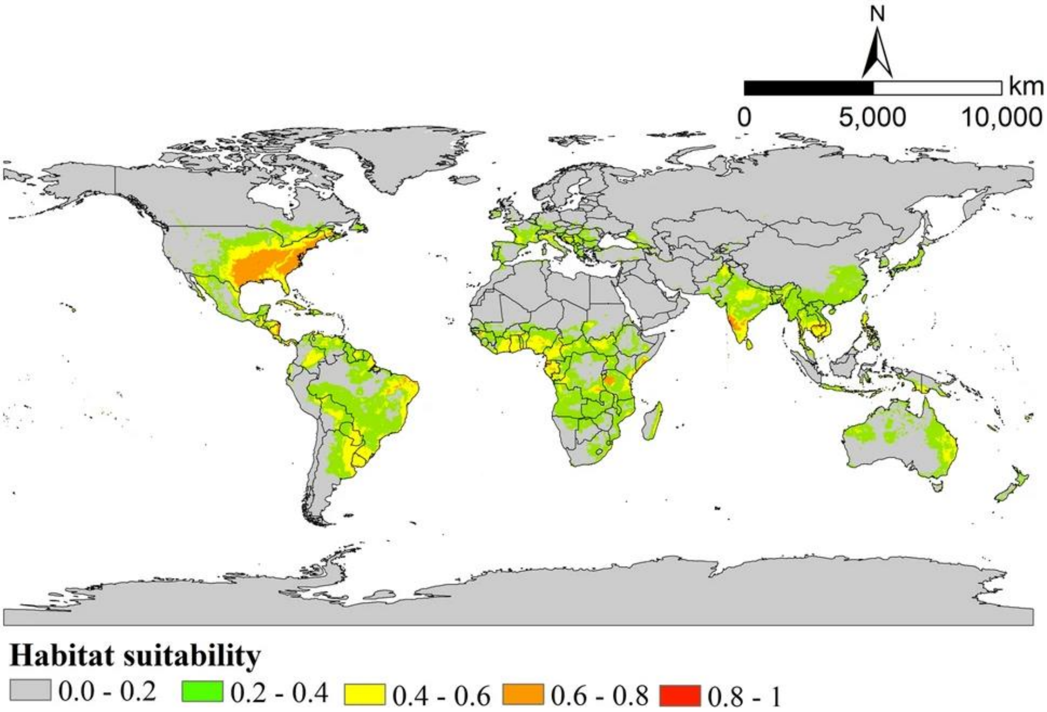

Figure 4. *Current potential distribution of S. frugiperda. Grey = unable to serve as habitat, green = low suitable habitat, yellow = medium suitable habitat, orange = optimum habitat, and red = highly suitable habitat. (Source: [46].*

5. The Damage of Spodoptera Frugiperda

Hazards and Losses

S. frugiperda damage is serious in African corn-producing areas threats to European food security. According to Africa's 12 main maize producing countries report that in the absence of control measures, grassland-reduced corn yield 8.3-20.6 million t/year, of the noctuid moth reaches and the value is estimated at 2.5-6.2 billion US dollars/year, plus other crops face risk, with losses worth more than $13 billion/year [41].

S. frugiperda is regarded as a key defoliator pest, and it resulted in a 34% decrease in global maize grain production in tropical and subtropical regions [47, 48]. In Brazil, annually FAW damaged maize crops worth 400 million USD [49]. In Africa, severe larval attacks have reduced maize output by 8-20 million tons per year [41]. Pakistan is a country that grows a wide range of main agricultural crops like cotton, wheat, paddy, sugarcane, sunflower, fruits, and vegetables. Studies in Pakistan have revealed that this pest mostly targets fodder maize and reported that 100% damage to fodder maize occurred in Shaheed Benazir Abad [23], but it can be devastating for agricultural crop plants in this country [26]. because of its diverse host range [36].

FAW larval stage is the most destructive [28], and it feeds on vegetative and reproductive parts of maize and other host crops [8, 50]. During the cropping season of 2021, FAW significantly reduced the yield of maize, both at the 3-5 leaf stage and at the cob stage [23]. FAW larvae eat on leaves and make sporadic holes, and scruffy edges on them, and maybe the presence of frass in the whorl [2], and damage can be seen in figure 6. It also reported that FAW preferred both the stems and the leaves of maize, with the stems performing similarly well in terms of population and biological traits [23]. While feeding on maize, larvae can transfer saprotrophic and pathogenic fungi, which further contaminates and lowers the grain quality [51].

Figure 5. *FAW damage on Maize. A. Long, ragged holes in the leaves B. Outer leaves with signs of shot holes C. a larva eating a corn cob. Source: D. Adult of S. frugiperda [52].*

6. *Spodoptera frugiperda*

6.1. Morphological Characteristics

Male moths are 16-18 mm in length and 10.5-15 mm in forewing length. Male moths have gray-brown forewings, with yellowish, oval wings on the wings Ring-shaped spots with a white wedge-shaped pattern on the lower corners of the ring-shaped spots, the outer edge of the wings There is a distinct nearly triangular white spot; female moths are slightly larger and longer 18~20 mm, forewing length 11~18 mm, female forewings are mostly gray, Brown, or gray and brown variegated, without obvious markings. The larvae are 6 instars, occasionally 5, and the young larvae are green Colored or brown, very similar to other noctuid larvae, difficult to Identify morphologically; older larvae are distinct [53], make the head area white or light yellow inverted "Y" pattern and the first 8 Four large dark spots arranged in a square in the abdominal segments are used for its identification. typical characteristics. Eggs are dome-shaped, with a distinct round point in the center of the top. Flat bottom, about 0.4 mm in diameter and 0.3 mm in height; The pupa is oblong, 14-18 mm long, 4.5 mm wide at breast height, The first pupation is white, then turns reddish brown.

6.2. Biological Characteristics

Reproductive power is strong the life cycle of *S. frugiperda* in summer completed in 30 days, 60 days in spring and autumn; in winter, the life cycle of some caterpillars lasts about 80–90 days [54]. The number of spawning varies by climate, with females typically producing about 1500 eggs [54]. Destructive power. *S. frugiperda* can feed on leaf sheaths, leaves, Growing point, vegetative. *S. frugiperda* young stage requires very little food, later food needs are about the same as earlier 50 times [55], due to this rapid change in feeding pattern, until at the presence of larvae after almost all of their hosts have been destroyed overnight.

6.3. Flight

Move fast adult worms can use wind at altitudes of several hundred meters conduct long-range directional migratory flights of up to 100 km per night; usually It can migrate up to 500 km [22].

6.4. Host

S. frugiperda exhibits a very broad host range, order More than 80 species of plants have been previously recorded [8]. Common harmful plants are Corn, sweet corn, sorghum, and grass weeds such as crabgrass (Digitaria spp.). Other crops are also frequently infested, including alfalfa, barley, bermudagrass, buckwheat, cotton, clover, Corn, oats, millet, peanuts, rice, ryegrass, sorghum, Beets, Sudan grass, soybeans, sugar cane, tobacco and wheat, even Vegetables (solanaceous crops such as tomatoes) and fruits (apples, grapes, oranges, papayas, peaches, strawberries). Spodoptera frugiperda may currently Differentiate into 2 lines: the rice line and maize line, due to differences in habitat (preferably host plants) and reproductive behavior [2].

7. Research on Biological Control Technology

7.1. Parasitic Wasps and Flies

Comparative study on biological control technology of *S. frugiperda* abroad most of them is concentrated on parasitic natural enemies, moth native to the Americas and the Caribbean, parasitizing its eggs, and larvae, More than 150 natural enemies of pupae and adults have been recorded, respectively there are 13 families, including 9 families in Hymenoptera and 4 families in Diptera. there are 36 species and 28 species of wasps in the middle respectively; There are 55 species of Parasitoid [56].

In the Americas, the predominant parasitic wasp in North United States America is Egg Wasp *Telenomus remus* (Nixon) *Cotesia marginiventris* (Cresson), net borer wasp *Chelonus texanus* (Cresson) C. *insularis* (Cresson) and *Euplectrus platyhypenae* (Howard), the pupal parasitoid was *Diapet imorpha introita* (Cresson), and *Archytas marmoratus* (Townsend) [57]. Mexican Lord in Central America parasitic wasps for Braconite *C. insularis*, Braconidae *Rogas vaughani* (Muesebeck) and *R. laphygmae* (Viereck), Parasitic flies are *A. marmoratus* and *Lespesia archippivora* (Riley) [58]; Honduras, Central America, the main parasitic wasp is Braconidae *C. insularis*, *Aleiodes laphygmae* (Viereck) and *Campoletis sonorensis* (Cameron) [59]; In South America, the most common parasitic wasps are *C. insularis*, *Meteorus laphygmae* (Viereck), *Cam poletis grioti* (Blanchard) and *Ophion sp.*, The parasitic flies are *Archytas incertus* (Macquart) and *A. mar moratus* [57]. In Argentina, the parasitic rate of parasitic wasps can be as high as 39.4% [60], these, *C. insularis* is the most widespread in America's natural distribution.

In Africa, Sisay et al. [9] conducted a study on Spodoptera frugiperda in Ethiopia. surveys of native predators in Asia, Kenya, and Tanzania, A total of 5 common parasitic natural enemies were found in eggs and larvae, including 4 species of Hymenoptera and 1 species of Diptera. in Ethiopia, *Cotesia icipe* is the predominant larval parasitoid with a parasitic rate of Between 33.8% and 45.3%; in Kenya, *Palexorista zonata* is the main parasitic fly with a parasitic rate of 12.5%; *Charops ater* and *Coccygidium luteum* are the most common in Kenya and Tanzania The parasitic wasps seen were 6%-12% and 4%-8.3%, respectively.

In Asia, Wykhuys et al. [60] investigated grasslands in southern India. The parasitic natural enemies of *S. frugiperda*, among which egg parasitoids are black egg wasp Genus *Telenomus* sp. and *Trichogramma sp*., young parasitoid wasp *Glyptapanteles creatonoti* (Viereck) and *Campoletis chlorideae* (Uchida), a larval-pupa parasitoid was found in a species of the family Agiopidae, *G. creatonoti* is the main parasitic control of *S. frugiperda* enemies.

The parasitic natural enemies, the current prevention and control effect is relatively good and extensive the distribution mainly includes the *Telenomus remus* (Nixon), belonging to the family Scelionidae, order, Hymenoptera, is a species of various Lepidoptera important natural enemies of moth pests [62, 63], the most important the egg parasitoid, *T. remus* can destroy the insect in the egg stage, thus effective control of its damage to crops in the larval stage. *T. remus* (Nixon) [64], for the first time *T. remus* was described in Ulugunbak, Kuala Lumpur, Malaysia; [64]. *T. remus* has a high parasitic the study by [65] showed that at 19-28 ℃, *T. remus* had higher parasitic potential and emergence rate, and *S. frugiperda* the noctuid moth is suitable as a host for the mass reproduction of *T. remus*.

The first study on the control of *S. frugiperda* by *T. remus* began in the Americas, due to high parasitism rates, *T. remus* was It has been successfully used as a biological control for parasitic wasps [62, 66]. Under experimental conditions, *T. remus* can be mass-produced in *S. frugiperda* or other hosts and released in the field [67]. Females lay an average of 270 eggs in their lifetime; Usually spawned individually in each host egg to avoid over-parasites [68], while being able to parasitize the entire egg mass; in cornfields, release *T. remus* 5000~8000 heads/hm2, the parasitic rate can reach 78% to 100%, can completely control *S. frugiperda* [69]. Currently, The use of *T. remus* to control fall armyworm is becoming more and more mature, Brazil, Mexico, Venezuela and other Latin American countries [67-71]. Significant results have been achieved, and large-scale use of *T. remus* to control. The main challenge for *S. frugiperda* is how to produce hosts on a large scale and the development of artificial feeds for hosts [72]. [73] also reported in Africa *T. remus* has been discovered, and this bee has been studied as a parasitoid for Biological control of *S. frugiperda*.

7.2. Brass spp. and *B. insularis*

Molina-Ochoa et al. [57] Survey of sweet corn in 3 southern Florida counties the most common parasitic wasps are the wasp. These two parasites were found in 23 and 18 of the 25 sampling points, respectively. Raw bees. *C. marginiventris* is native to the Americas (order formerly throughout South and Central America), mainly parasitizing 1st and 2nd instar juveniles worms [74], and facultative parasitism of eggs-larval has also been reported [75]. Host population is low Under the density, *C. marginiventri* has the phenomenon of host alternation [76], however, when the population of its best host, such as *S. frugiperda*, increases, it will direct selection for *S. frugiperda* parasitism. *C. insularis* is an important parasitic natural enemy, which are parasitic wasps across egg-larval stages, and parasitic of *S. frugiperda* can also parasitize armyworm, African armyworm, lawn sticky Insects, and other Lepidoptera insects [54]. *C. insularis* through the host Initiating host physiological factors after internal spawning, even when parasitism does not occur Development can also lead to premature cocooning of host larvae [77].

7.3. Nematodes

Noctuidonema guyanense (Remillet & Silvain) it is the most important ectoparasitic nematode of *S. frugiperda* [56]. at the earliest In 1988, [78] found that *N. guyanense* can control the growth of *S. frugiperda*, life cycle and host range. [79] found that *N. guyanense* infects 25 species of noctuid moth family of insects, *S. frugiperda* is the most frequently infested species, and indeed The distribution and prevalence of this nematode have been determined [80], *Neoaplectana carpocapsae* (Weiser) which mainly occurs in northern Southern America, Central America, Caribbean countries, and Northern South America and Colombia [81] also has a certain control effect on *S. frugiperda*, but There is no commercial product yet. [59] found that, the nematode *N. guyanense* had a low field parasitism rate of only 3.8%.

7.4. Pathogenic Fungi

Entomopathogenic fungi alone are difficult to control *S. frugiperda* larvae, which do not cause significant mortality even at high doses rate [82]. Carneiro et al., [83] found that only 4 of the 24 *Beauveria bassiana* strains Pairs of 2-year-old Meadowlands Soaked in Aqueous Conidial Suspension Moth larvae were lethal. Thomazoni et al., [84] found that 49 strains of coccidioides none of the *B. bassiana* strains caused greater mortality in 3rd instar larvae over 44.9%. Rivero - Borja et al., [85] by combining chlorpyrifos ethyl, multi-kill the combination of Bacteriocin, *B. bassiana* and *Metarhizium anisopliae* the fungal sporogenesis to increase *S. frugiperda* mortality. In terms of pseudo parasitism, although the result of pseudo parasitism will not increase the next generation of parasitoids, but increases pest larval mortality.

Illustrating that a combination of chemical pesticides and entomopathogenic fungi can improve true bacterial infectivity, while reducing field doses of pesticides and reducing negative effects on the environment, grass can be controlled using specific combinations Spodoptera. (Shylesha et al., [61] found a large number of *Nomuraea rileyi* (Farlow) can infect grassland night moth.

7.5. Viruses Disease

Granulosis Virus (GV) use can safely and effectively control noctuid pests [86], Columbia Studies in Asia and Brazil suggest that SfGV is a coeliac virus, a Slow-killing beta baculovirus, better against *S. frugiperda* control [87]. Pidre et al., [88] identified a species native to the new isolation of *S. frugiperda* granulosis virus from central Argentina, named SfGV ARG, and it was observed that juveniles infected with this virus. The color of the worm is yellow, the body is swollen, and finally, the abdomen shows a clear death due to apparent damage. Although SfGV does not stand alone as biological the best method of control, when used with virus mixtures for control, it can enhance the infection of nuclear polyhedrosis virus (Nuclear Polyhedrosis Virus, NPV) [89].

7.6. Pheromones and Supporting Technologies

Mitchell et al., [90] did research and found that the trapping effect, the traps composed of multiple colors was stronger than monochromatic traps, indicating that *S. frugiperda* has a certain effect on color. (Malo et al., [91] studied the effect of trap size, and color effect on *S. frugiperda*, found that homemade kettle traps lure better than commercial traps (scentry heliothis) and water bottle traps, yellow traps catch significant numbers of *S. frugiperda* higher than blue and black traps; Response Research in chemical ecology studies, electrogenesis of pheromone by male adults of *S. frugiperda* in India [85].

Cruz-Esteban et al., [92] identified *S. frugiperda* 3 compounds released by female moths: (Z)-9-tetradecenyl acetate, (Z)-7-dodecenyl acetate, and (Z)-11-hexadecenyl acetate, The first 2 compounds elicited an antenna response in adults, however, the contents and relative proportions of each component in the field varied among different populations. Determine the difference, the sex pheromone lure of the same formula induces in different regions.

7.7. Monitoring Methods and Suggestions

It is very difficult to control the fall armyworm with chemical pesticides. resistance develops rapidly [93], which can lead to high doses or multiple pesticides mixed application can reduce its number, and also affect natural enemies, pollution contaminate soil and water, causing environmental and human health risks; through Bt Insecticides can control pests, but *S. frugiperda* have developed resistance [94], so new control methods need to be found. Biological control is an effective way to control *S. frugiperda*. Except for the above in addition to methods, such as the use of bacterial pesticides [94, 95] (such as Bacillus thuringiensis) and Bacillus, etc.), predatory natural enemies [61] (such as spiders, centipedes, bugs, wasps and earwigs, etc.), plant extracts [96], (such as yellow ketones and limonin, etc.) will play a certain role in prevention and control. Target Before, research on biological control of *S. frugiperda* were carried out in Pakistan. The use of parasitic natural enemies (such as the noctuid black larvae and braconid wasps) undoubtedly is the most important item in the biological control of *S. frugiperda*.

In Pakistan for control of FAW Different biological controlling strategists are used as shown in Table 4.

Table 4. *Different bio control strategies used to control FAW in vitro.*

Study area	Biological control	locations	Reference
Sargodha	*Rhazya stricta* Decne, *Sophora mollis*, Baker and *Withania somnifera*) extracts was affective against FAW	Vitro	[97]
District Multan	Predator (Black ants, ladybird beetles, and spiders)	VITRO	[98]
Multan	*Beauveria bassiana*, and *Metarhizium anisopliae*	vitro	[99]
Sargodha	*Beauveria bassiana*, *Metarhizium anisopliae*	vitro	[100]
Sargodha	-*M. anisopliae* and *B. bassiana* Four combinations of plant extracts with synthetic insecticide (chlorantraniliprole) and EPF (Synergized toxicity of EPF isolates and plant Extracts)	vitro	[97]
Islamabad, Chak Shahzad, and NARC	(*Beauveria bassiana*, *Trichoderma* spp. and *Metarhizium anisopliae*	Vitro	[101]

8. Conclusion and Recommendation

It is recommended to further develop relevant new technology research, strengthen the protection and utilization of natural enemies, and prevent the spread and disaster of *S. frugiperda* should be paid attention to in disaster-prone areas through the organic combination of biological control and chemical control. Specifically, the following should be Strengthen prevention and control in several aspects: (1) Government plant protection departments should strengthen publicity Communication and training, for quarantine personnel, technical personnel, and personnel of Nonfan units training on FAW identification and control techniques for staff and growers; Do a good job in pest monitoring and information release; prepare for long-term prevention and control, Reserve emergency prevention and control materials for different season; establish a unified defense and governance mechanism, Especially the linkage mechanism different District; (2) Strengthening Monitoring, using advanced technologies such as insect radar, remote monitoring systems, etc. means to monitor the migratory dynamics of *S. frugiperda* in a timely and efficient manner, regularly Fixed-point investigation of *S. frugiperda* on rice, corn, cotton, Sorghum and other crops are damaged; (3) Strengthen scientific research reserves and rely on Scientific research units jointly tackle key problems and carry out basic biology, ecology and research on Green Prevention and Control Technology.

Conflicts of Interest

The authors declare no conflicts of interest.

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