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Present status of new invasive pest fall armyworm, *Spodoptera frugiperda* in India: A review

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Abstract
The agricultural economy in India is vulnerable to threat from many potential bio weapons mainly invasive pests species. Invasive pest species are exotic, introduced, foreign, non-indigenous or non-native, is one that has been introduced by humans intentionally or otherwise through human agency or accidentally from one region to another. Invasive pest species have potential to rapidly established and spread in a new area cause major crop loss and can adversely affect food security. The spread of Invasive pest species is now recognized as one of the greatest threats to the biodiversity and economic well being of the country. The numbers of invasive insect pests species are introduced in India last 20th and 21st century by unintentionally or accidentally, recently, the fall armyworm, *Spodoptera frugiperda* have been reported in India. It was first noticed in mid-May 2018 in Shivamogga, Karnataka. The recent studies in India reported that the infestation of fall armyworm ranged from 2 to 35 per cent in maize. The new invasive pest has been spreading rapidly; the adult moths of FAW are highly migratory, capable of travelling up 500 km in a single season to find oviposition sites and capacity to fly over 100 km per night. It has potential threat to agriculture crop production as well as Indian economy.

Keywords: Invasive pest, fall armyworm and natural enemies

1. Introduction
The Fall Armyworm, *Spodoptera frugiperda* (J.E. Smith) (Insecta: Lepidoptera: Noctuidae) is a devastating pest of maize that is native to tropical and subtropical regions of the western hemisphere from the United States of America to Argentina [1]. The scientific name fall Armyworm, *Spodoptera frugiperda* is derived from the feeding habits of the larval life stage, *frugiperda* meaning "lost fruit" in Latin, as the pest can cause damage to crops resulting in severe yield loss. FAW is actually a caterpillar, not a "worm". As befits its name, which evokes an impression of marching masses of larvae akin to an army, wreaking havoc in its path [2]. FAW is polyphagous pest, known to attack more than 100 hosts. In addition, it is reported to cause major damage to economically important cultivated grasses such as rice, sorghum, and sugarcane as well as 23 horticultural crops like cabbage, beet, tomato, potato and onion besides cotton, pasture grasses, peanut, soybean, alfalfa and millets [3, 4, 5]. It threatens the food and nutritional security of millions of farming households in Africa [6, 7]. The adult moths of FAW are highly migratory in the Americas, capable of travelling up to 1,500-2,000 km per year in search of warmer climate, and can travel 500 km in a single season to find oviposition sites and capacity to fly over 100 km per night [1, 8]. Fall armyworm recently invaded India; here it rapidly spread throughout the country. Fall Armyworm could threaten the food security and livelihoods of millions of small-scale farmers in Asia as the invasive crop-eating pest is highly likely to spread further from India, with South East Asia and South China most at risk, warned FAO [9]. In this regard, present review we discuss the distribution status, damage severity, genetic similarity, natural occurring natural enemies of the fall armyworm in Indian.

2. Distribution of fall armyworm
2.1. World Distribution of Fall Armyworm
Fall Armyworm (FAW) native to the tropical regions of North and South America [10]. It was reported for the first time in the African continent in early 2016. Initial reports were from West

Africa: Nigeria, Benin, Togo and Sao Tome' and Principe [11, 12]. By May 2017 the pest has been reported in almost all Sub-Saharan African countries. In 2019 pest have been reached different new frontiers *viz*., Bangladesh, Myanmar, Sri Lanka, Thailand, China, Lao, Nepal, Viet Nam and, more recently, in the Republic of Korea in Asia [13]. The global distribution, is available on CABI's FAW portal (https://www.cabi.org/isc/datasheet/29810) and FAO's FAMEWS global platform (http://www.fao.org/fall-armyworm/monitoring tools/famews-global-platform/en/). The world map of areas affected by FAW presented in Figure-1.

2.2. Present status of Fall Armyworm in India

Fall Armyworm (FAW) continues to spread into new territory, moving further east and north in India. Severe incidences of fall armyworm were reported from across different Indian states. In India, it was first noticed in mid-May 2018 in Shivamogga, Karnataka by Sharanabasappa *et al*. 2018. So far, FAW is reported from Karnataka, Telangana, Andhra Pradesh, Maharashtra, Gujarat and Tamil Nadu. Massive surveys on war footing are undergoing. The area of infestation in India given inTable-1. The Indian states in which fall armyworm reported Figure-1 and Table-2.

3. Damage severity of fall armyworm

Fall Armyworm is found widely throughout the warmer parts of the New World. The damage results from the young larvae feed on the opened leaves by scraping and skeletonizing the upper epidermis leaving a silvery transparent membrane, later on the larvae enters into the whorl and start feeding between the leaves. The older larvae feed on the developing primordial shoot and tassel thus resulting in dead heart symptoms [14]. The larvae migrate to adjacent areas a large pest population can cause defoliation and resulting yield losses. The absence of natural biological control, fall armyworm can cause significant yield loss in maize and other crops [15]. The severity of damage varies from region to region. There are many variables to consider in determining the potential yield loss due to fall armyworm infestation. In general, how the crop responds to fall armyworm infestation is highly dependent on the population level of the pest and the timing of infestation, natural enemies and pathogen levels that can help to naturally regulate the populations, and the health and vigour of the maize. The maize infestation between 26.4 to 55.9 per cent and impact on yield of 11.57 per cent [16]. On leaf, silk and tassel damage levels ranged between 25 to 50 per cent and grain yield decrease of 58 per cent [17]. The per cent of infestation on maize fields ranged from 80 to 100 per cent and 82.2 to 100 per cent in Ethiopia and Kenya, respectively [18]. Average per cent of infested plants and damage severity (on a scale of 1 to 5) were the lowest 20.7 ± 7.4 per cent and 2.1 ± 0.1 respectively in the Sahelian regions and the greatest 69.0 ± 4.3 per cent and 3.1 ± 0.1 respectively in the Western Highlands of Cameroon [19]. Whereas, the information availability on the damage severity of fall armyworm in India is very less as pest is recently reported. Even though, some studies were find the damage severity in India and we presented here. The Infestation of fall armyworm ranged from 2 to 35 per cent in different crops. Among these, maximum cent per cent incidence was observed on sweet corn than maize, sorghum and sugarcane. The lowest per cent plant infestation was observed in sugarcane from Maharashtra [20]. The incidence ranged from 9.0 to 62.5 per cent at various locations in the Karnataka [14].

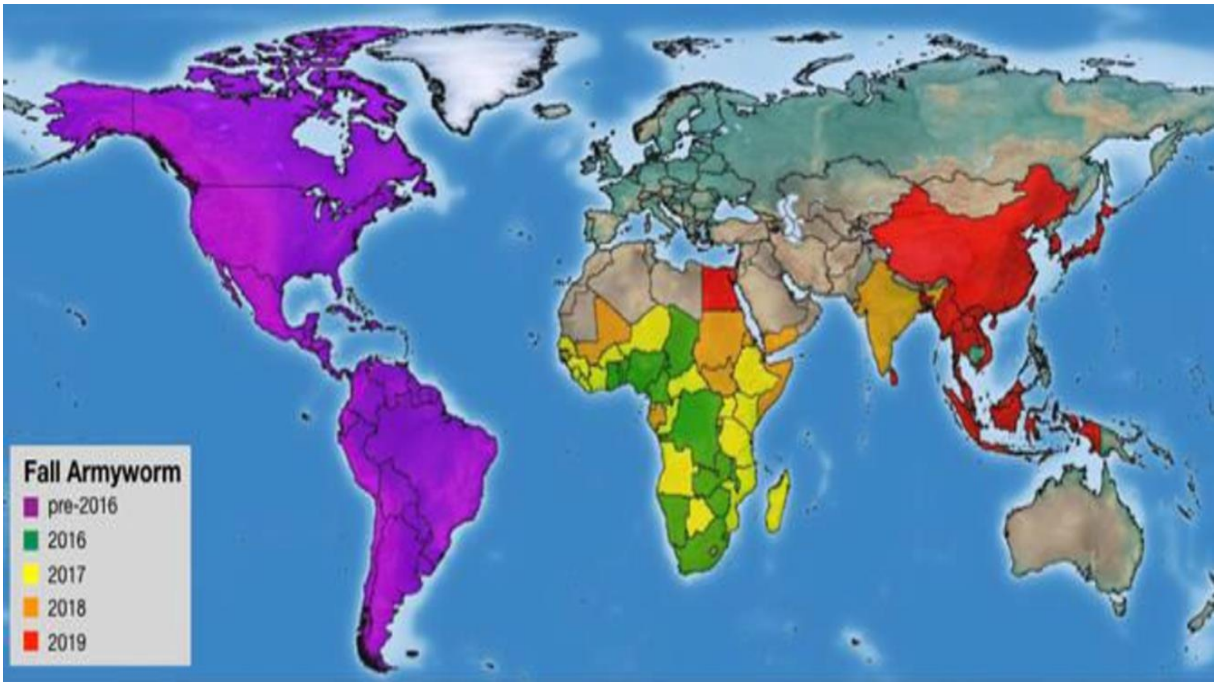

Fig 1: World map of areas affected by fall armyworm

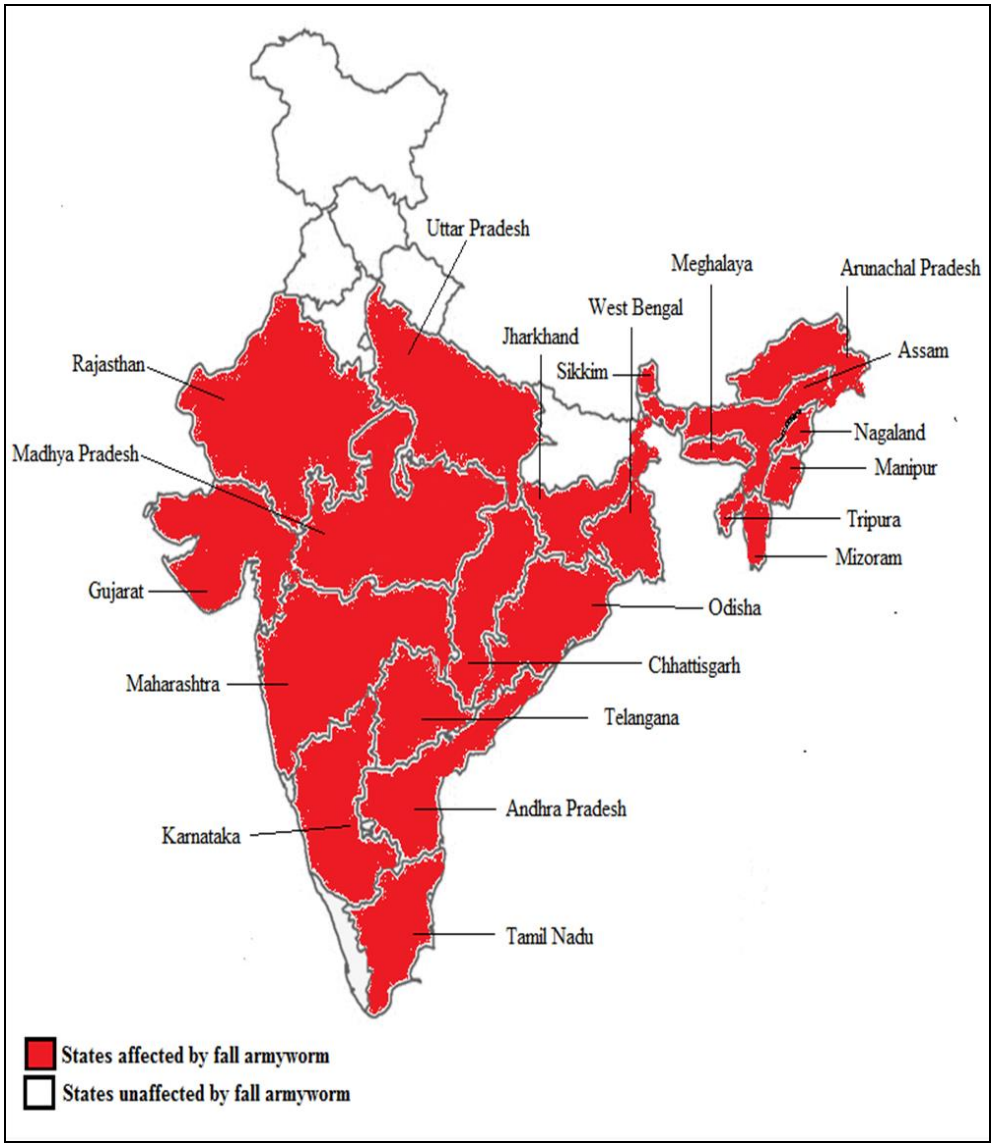

Fig 2: India states affected by fall armyworm

Table 1: Details of area affected due to fall armyworm during the last two years [29, 30]

Sl. No.	State	Details of area affected due to Fall Armyworm during Last two years (area in ha.)	
		2018-19	2019-20 (up to 2019)
1	Chhattisgarh	1539	1007.74
2	Andhra Pradesh	2538	137
3	Madhya Pradesh	-	110
4	Gujarat	70	14
5	Karnataka	211300	140000
6	Uttar Pradesh	-	2
7	Sikkim	-	376
8	Mizoram	-	1877.29
9	Manipur	-	4341.64
10	Nagaland	-	4553.29
11	Meghalaya	-	40
12	Tripura	-	7.08
13	Assam	-	27.65
14	Telangana	24288.40	-
15	West Bengal	-	485
16	Arunachal Pradesh	-	250
17	Tamil Nadu	315	200
18	Odisha	60	-
19	Jharkhand	-	7.08
20	Maharashtra	5144	2000
21	Rajasthan		59,000

Table 2: Fall Armyworm infestation in Indian states

Name of the Indian states	Host plant	Month and Year	References
Karnataka	Maize	May 2018	[24, 31]
Chhattisgarh	Maize	August 2018	[32]
Gujarat	Sweet corn	September 2018	[33]
Tamil Nadu	Sugarcane	November 2018	[34]
Maharashtra	Sugarcane	September 2018	[20]
Odisha and West Bengal	Maize	2018	[30]
Andhra Pradesh	Sugarcane	March, 2019	[26]
Mizoram, Nagaland, Tripura, Manipur and Meghalaya	Maize	May 2019	[35]
Arunachal Pradesh	Maize	June 2019	[36]
Telangana	Maize	2019	[37]
Madhya Pradesh, Uttar Pradesh, Assam, Sikkim, Rajasthan and Jharkhand	Maize	2019	[29, 38]

Table 3: Natural enemies of *Spodoptera frugiperda* in India ecosystem

S. No.	Scientific name	Family	Host stage	References
1	*Telenomus* sp.	Hymenoptera: Platygastridae	Egg parasitoid	[14]
2	*Trichogramma sp*	Hymenoptera: Trichogrammatidae	Egg parasitoid	
3	*Glyptapanteles creatonoti* (Viereck)	Hymenoptrea: Braconidae	Larval parasitoid	
4	*Forficula sp.*	Dermaptera: Forficulidae	Larval predator	
5	*Coccygidium melleum* (Roman)	Hymenoptera: Braconidae	Endo larval parasitoid	[27]
6	*Campoletis chlorideae* Uchida	Hymenoptera: Ichneumonidae	Endo larval parasitoid	
7	*Eriborus* sp	Hymenoptera: Ichneumonidae	Endo larval parasitoid	
8	*Odontepyris* sp.	Hymenoptera: Bethylidae	Larval parasitoid	
9	*Exorista sorbillans* (Wiedemann)	Diptera: Tachinidae	Endo larval parasitoid	
10	*Forficula* sp.	Dermaptera: Forficulidae	Predator	
11	*Harmonia octomaculata* (Fabricius)	Coleoptera: Coccinellidae	Predator	
12	*Coccinella transversalis* Fabricius	Coleoptera: Coccinellidae	Predator	
13	*Nomuraea rileyi* (Farlow) Samson	Ascomycota: Clavicipitaceae	Entomo-pathogen on larva	
14	Nucleopolyhedrovirus (NPV)	Baculoviridae	Virus on larva	[28]

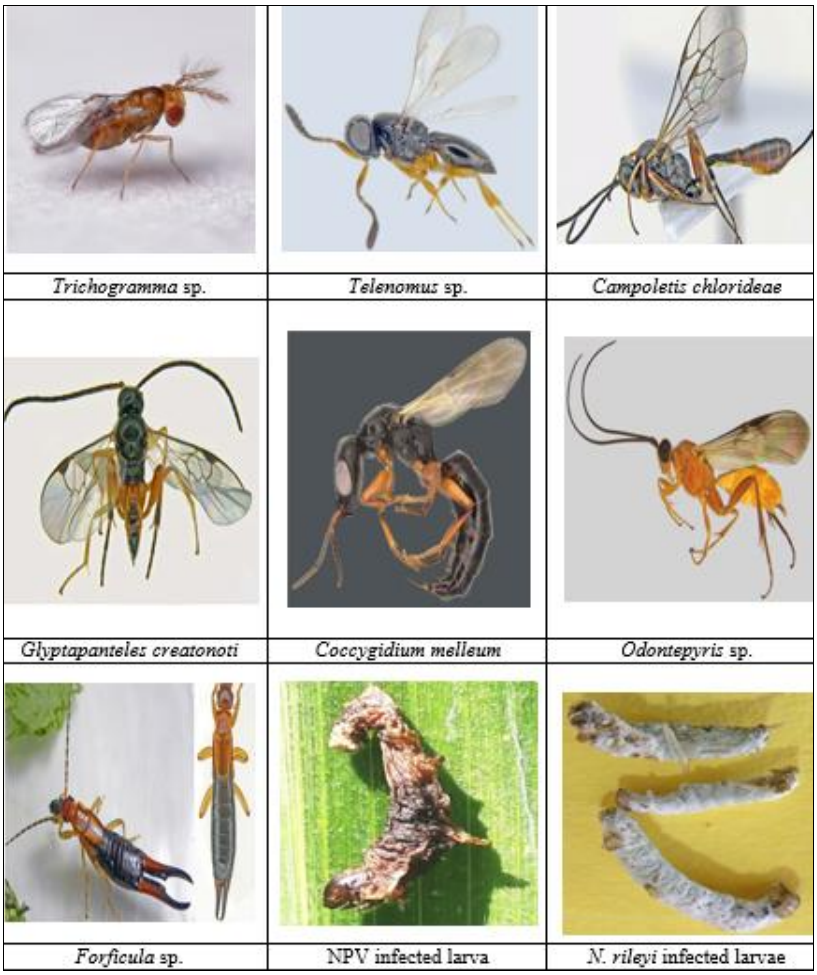

Fig 3: Natural enemies of Fall Armyworm in India (Photos credited to authors of previously published research articles, names of these authors mentioned in this review citations and acknowledged)

4. Genetic similarity of Indian fall armyworm

The first and foremost important step in pest management system is correct identification of the pest. Using diagnostic morphological keys requires microscopic examination of adult male genital structures, a tedious procedure when screening large numbers, and one that requires substantial sample preparation and undamaged specimens [4, 21]. Development of molecular systematics using nucleotide sequences along with the conventional taxonomy would enhance the species identification, which is not limited by species polymorphism, sex and stage. Elucidation of genetic variation in geographical populations is an important aspect to study the pest populations and their management. Within an ecosystem, the extent of genetic variation between geographical populations depends on several factors; including gene flow between populations, host range and climatic factors [22, 23]. In this context, present section we discuss the genetic similarity of the *Spodoptera frugiperda* in India with other countries. BLASTn search of DNA barcodes from Indian S. *frugiperda* specimens revealed 98-99% nucleotide sequence identity with S. *frugiperda* voucher specimens of USA, Ghana, Nigeria, Uganda and Canada in maize field population [24]. The genetic homogeneity observed between the South Africa and India collections with respect to the small number of COI and Tpi haplotypes strongly suggests that each arose from a common source. The majority haplotype was identical in the sequenced segment to the most common corn-strain fall armyworm sequence found in the Western Hemisphere (CS01, HM136586), which was present in 94% and 93% of the South Africa and India specimens tested, respectively. The South Africa and India collections showed nearly identical haplotype profiles with fall armyworm from Kenya and Tanzania, suggesting a close relationship and recent interactions between these populations [25]. It has been reported that the 99 per cent genetic similarity between the 'R' strain population from Vizianagaram, AP, India to Mexico haplotypes of 'C' strain [26].

5. Natural occurrence of fall armyworm natural enemies in India

The common management strategy for the control of FAW in infested regions of across the world has been use of insecticide sprays. However, currently in agricultural pest control, the adverse effects of the use of insecticides are leading scientists to search for alternatives to chemical control of insect pests. Biological control has been used for pest management for many years and it has gained renewed interest because they are safe to environment, ecosystem and human health. In this regard, there is an urgent need to understand, promote and maximize the effectiveness of indigenous populations of natural enemies against the fall armyworm. The occurrence and parasitism rate of FAW larval parasitoids varies considerably between localities, regions, crop practices, plant stage, and environmental characters [18]. This information is needed to assess the potential value of the existing larval parasitoid fauna in controlling FAW on different host plants in India. The natural occurrence of *S. frugiperda* natural enemies in different maize growing areas of Karnataka and Tamil Nadu, recorded 5 larval parasitoids, 3 predators, and 1 entomopathogenic fungus, of which larval parasitoid, namely *Coccygidium melleum* (Roman), *Eriborus* sp. (Hymenoptera: Ichneumonidae) and *Odontepyris* sp. (Hymenoptera: Bethylidae) were reported for the first time on *S. frugiperda* in the world. The extent of parasitism by *C. chlorideae* was 2 to 3% on maize. They also suggested that the native parasitoids of other *Spodoptera* spp. in India, such as *C. chlorideae* and *E. argenteopilosus*, may also adapt to *S. frugiperda* in due time [27]. The natural occurrence of Nucleopolyhedrovirus (NPV) infection on *S. frugiperda* larvae were found on maize fields of Gujarat [28]. The natural enemies list of *Spodoptera frugiperda* in India ecosystem presented in Figure-3 and Table-3.

6. Conclusion

Fall armyworm has been reaching new frontiers with rapid pace. FAO already warned the food and nutritional security of world population due to recent pest outbreak in Asia. In this regard, adoption of suitable management strategy is a key criterion for the management of the fall armyworm. Fall armyworm already well known pest in western hemisphere, the knowledge previously present regional pest management strategies need to valuate in the newly infested regions. Further, it is easy to identification pest with molecular characterization of the species within the region and across the world; it enables the adoption of similar management strategies related to the region. For eco-friendly management of pest population, further information on the occurrence and rates of parasitism of indigenous natural enemies is of paramount importance in designing a biological control program for fall armyworm, either through conservation of native natural enemies or the introduction of new species for augmentative release. It would be worthwhile to evaluate indigenous parasitoids that known to be effective in India against *S. frugiperda*.

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