Research Article

Mortality Dynamics of Exotic Fall Armyworm, *Spodoptera frugiperda* (J.E. Smith) (Lepidoptera: Noctuidae)

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Abstract | *Spodoptera frugiperda* (J.E. Smith), commonly known as maize destructor is an exotic pest that has been migrated to Pakistan recently. In the present investigation, a total of 198 corn fields from different localities of Lahore and Kasur region of Pakistan, were surveyed after the published reports of fall armyworm presence in other parts of the country. Out of the total spots observed, the fall armyworm occurrence was spotted on ten variable locations. The highest level of infestation recorded was 19.39 % followed by 18.69 % while the lowest damage in percentage was 9.28. The present study was also directed to investigate the mortality factors in a lab-based experiment on the life table study of fall armyworm. A sub-lethal dose of 4µl of entomopathogenic NPV suspension containing 4×10^6 polyhedral inclusion bodies (PIB) was tested as a mortality factor against the late larval instars of *S. frugiperda* when natural mortality tends to decrease after each successive instar. The single-sex method was adopted in the construction of the life table. The ratio of mortality in the late instars (3rd to 5th) was greater than the early instars because of entomopathogenic treatment. The survivorship curve explicated that the 4th to 6th instar larvae, being more voracious, could be destructive for the maize crop if not managed properly. A large number of survivors could enhance the number of individuals in the next generation.

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1. Introduction

Maize is considered as Queen of cereals because of its excessive productive potential and lower productive cost as compare to other food grains. It appears as an important crop in agricultural economy as feed, food and organic matter for industrial impetus (Jaliya *et al.*, 2008). In Pakistan, sound climatic conditions and high yielding ability impart maize; a status of major income generating crop. It is the third most abundantly sown cereal crop in Pakistan after wheat and rice (Khan *et al.*, 2020). *Spodoptera frugiperda* (J.E. Smith) is a notorious insect pest of multiple crops, belongs to the order Lepidoptera and family Noctuidae. In many countries, it is locally known as Fall Armyworm (FAW) and has gained the status of invasive pest species.

Historically, the pest was captured, identified and named for the first time by Abbot and Smith (1797) as *Phaleana frugiperda*. Later on, the species was placed into another genus called *Laphygmain*. In 1958, the genus *Laphygma* was replaced by *Spodoptera*, since then, it is known as *S. frugiperda* (Luginbill, 1928). In different regions of America FAW damages different crops and is considered a polyphagous pest. The crops frequently damaged by FAW are maize, rice, cotton, alfalfa, forage grasses, soybeans and peanuts and hence it is called agricultural pest (Sisodiya *et al*., 2018). FAW has been recorded infesting over 350 different host plant species (Montezano *et al*., 2018). Although, FAW has a wide host range but prefers maize crop to feed on (Goergen *et al*., 2016).

In late 2016 first intercontinental spread of FAW was seen in West Africa where it started invading different parts of the continent rapidly. Currently, in forty-four of the African countries its presence has been reported (Prasanna *et al*., 2018). Before 2016, the pest was only confined to the new world damaging severely to the maize crops but after this year its ravage entered the old world too. In Africa, FAW caused up to 13 billion USD losses per annum to maize, sorghum and sugarcane crops (Liao *et al*., 2019). In the mid of 2018, the pest outbreak was reported from India as well (Sisodiya *et al*., 2018) and within a short period of six months, it was also found in Bangladesh, Sri-Lanka, Myanmar, Thailand and China (FAO, 2019a).

The female moth of fall armyworm is a strong flier that can fly up to 100 km per night (FAO, 2019b). Bordering areas are more likely to be attacked by FAW. Pakistan and India share a common boundary of hundreds of kilometers with a similar climate and cropping pattern. After the introduction of fall armyworm in India in 2018, public and private organizations closely monitored its proliferation as well as damage to the pest. Recently, some reports were published that fall armyworm has been reported in Pakistan (Naeem *et al*., 2019).

In ecological studies, life tables are influential and powerful tools for analyzing and understanding the survival, reproduction and population buildups of insect pests. Several methods have been developed to evaluate life tables which are widely adopted (Southwood, 1978). It is essential to understand the population fluctuations of a pest species before effective management.

Many of the entomologists recommend insecticide application to manage exotic *S. frugiperda*. The extensive use of insecticides causes ecological imbalances *viz*., non-target effects and food chain biomagnification (Kranthi *et al*., 2002). The resistance development against insecticides is another drawback associated with *S. frugiperda* management (Sisay *et al*., 2019). Hence, it is important to explore eco-friendly pest management options using bio-control agents providing similar efficacy against *S. frugiperda* as insecticides provide. The use of entomopathogens to keep the pest population under control has gained a prominent position in integrated pest management programs (Yang *et al*., 2012; Hu *et al*., 2007). Entomopathogenic virus, namely, Nuclear polyhedrosis virus (NPV) has been reported to effectively alleviate the population of lepidopterous insect pests (Escribano *et al*., 1999).

In the present study, the occurrence and intensity of damage by fall armyworm monitored for the first time in the Districts, Lahore and Kasur of Pakistan since its published reports from other parts of the country. Another attempt at a life table study of *S. frugiperda* was made in order to understand dynamics in the population of fall armyworm with reference to key mortality factors. The effect of entomopathogenic virus, nuclear polyhedrosis virus (NPV), was also tested as a mortality factor in the final instars.

2. Materials and Methods

2.1 Survey and damage assessment

A survey on the occurrence of *S. frugiperda* was conducted in the major maize growing areas of the Districts, Lahore and Kasur from August 2019 to Feb 2020. A total of 138 and 60 fields of maize crops were inspected during the study from Lahore and Kasur, respectively. 'W' shaped pattern was followed for pest scouting from each of the experimental units and GPS coordinates were taken also. Five spots were randomly selected from each field and from each spot 10 plants were monitored from top to bottom. Plants damaged by *S. frugiperda* were counted and percentage damage was assessed using specific methodology as mentioned by (Feng *et al*., 2014) who subjected organisms to life table study to assess population dynamics.

$$\textit{Percentage Damage} = (\textit{No. of Plants Infested / Total No. of Plants Inspected}) \times 100$$

2.2 Life table studies

A few individuals of the *S. frugiperda* were collected from the maize fields of Lahore and Kasur and brought to Integrated Pest Management Laboratory, IAGS, Punjab University, where they were subjected to rearing. The single-sex method was adopted for life table studies (Southwood, 1978). Introduced five pairs of males and females into five different wooden cages measuring (48cm x 44cm x 44cm) along with potted maize plants. Males and females were identified using forewings characteristics (Sylesha *et al*., 2018). The temperature of 26±2°C, 70±5% of RH and a photoperiod of 12 h light and 12 h night was maintained within the laboratory experiment (Pinto *et al*., 2019). The adult male and female moths were given complete freedom to mate and females were allowed to oviposit till their death. A thick layer of soil was provided in each of the wooden cages to assist pupation. The data, on oviposition, the number of hatchability, instar conversion, mortality by natural factors, or by NPV inoculations, were recorded precisely from eggs to adults. Newly emerged 3rd, 4th, 5th and 6th instar larvae were applied individually with 4µl of NPV suspension containing $4x10^6$ PIB (Polyhedral inclusion bodies) using micro-applicator. Following parameters were assumed for life table construction of *S. frugiperda*:

X= the pivotal age of class in units of time (days or intervals); lx= the surviving individuals at the beginning; Dx= the dying individuals during x interval; Dx*F= the factors responsible for mortality; K Value (-ln of S)= age-specific mortality, A key factor which determines the increase or decrease in number from one generation to another.

2.3 Statistical analysis

The infestation data acquired through survey, were subjected to ANOVA using a computer software, Statistics 8.1 while means were compared through Tukey's HSD test at $P = 0.05$.

3. Results and Discussion

3.1 Abundance and infestation level of S. frugiperda in maize

The incidence of FAW from South to North of Lahore was detected from five different maize fields against 138 inspected farm areas (Figure 1 and 2). The level of infestation was quite variable on all the spots observed; in Khawaja Faiq Pind 13.25 ± 0.78e % infestation was reported while the maize crop in Chappa Pind recorded infestation 18.74 ± 0.94b %. Both the villages were extremely North of Lahore; a few miles away from the Wahga border which is a corridor to Pakistan and India. Similarly, the levels of infestation recorded from two spots of Manga Mandi village were 15.21±0.78d% and 18.69±0.92c %, respectively. FAW was also reported from Farm Area of Punjab University, which is in the middle of the city, Lahore, where the statistically highest population was recorded 19.39±0.57a.

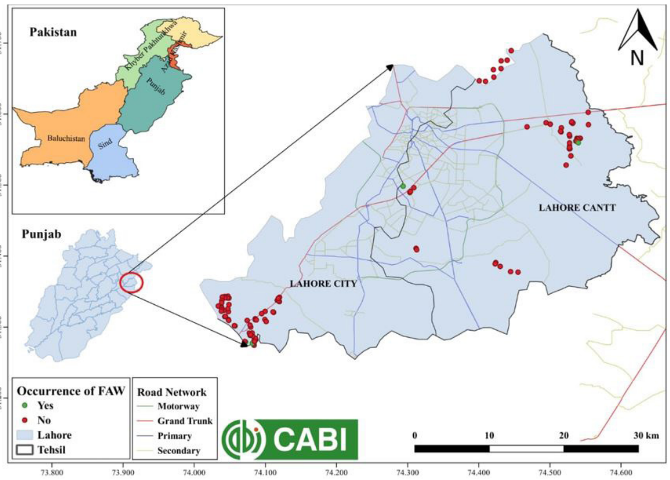


Figure 1: Graphical Representation of field Survey and Prevalence of Fall armyworm in District Lahore.

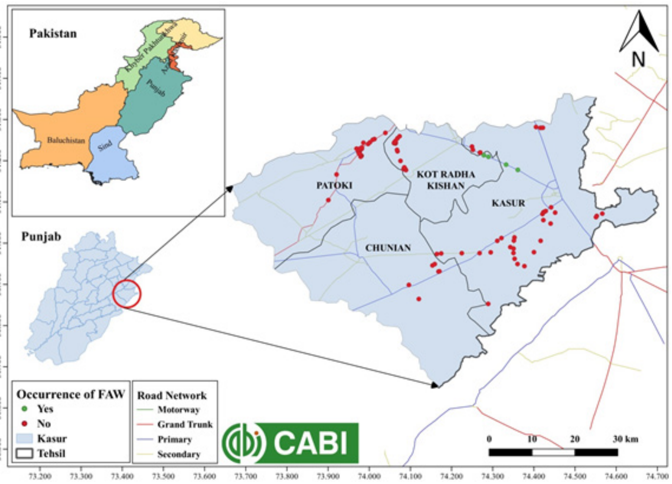


Figure 2: Graphical Representation of field Survey and Prevalence of Fall armyworm in District Kasur.

Similar to Lahore, Kasur is another District of Punjab which shares its boundary with India. A total of 60 maize fields were surveyed, again spotted the pest on five different patches but the level of FAW infestation in the Kasur region was fairly low. The levels of pest damage to the villages Jamalpur, Rao Khan, Orarra, Raja Jang and Kumharan wala were 11.94 ± 0.79g %, 12.82 ± 0.56f %, 9.28 ± 0.52i %, 13.26 ± 0.78e % and 10.32 ± 0.82h %, respectively (Table 1).

3.2 Nature of damage

The FAW incidence was relatively more severe upon the young corn plants. Mostly, larvae were found in the central whorl called the funnel of the plants. The damage spotted from each location, was in patches, without a uniform distribution inside the field. The pest damage is evident from Figures 3a and 3b.

Figure 3: Visible FAW damage on leaves and inflorescence.

3.3 Life table studies of S. frugiperda

The factors of mortality and number of deaths were detected at different developmental stages of fall armyworm i.e. at eggs, early instars, late instars and pupal stages. The cumulative mortality shown by late larval instars (3rd to 5th instars) was a maximum of 87.52 % followed by early instars i.e., 1st and 2nd stages (43.92 %). The relative mortalities in egg and pupal stages were 12.63 % and 8.33 % (Table 2). The factors responsible for egg mortality were infertility and the un-hatchability of the eggs. The early two instars recorded 43.92 % mortality due to natural factors since these are considered as the most vulnerable instars to the natural death in the lepidopterous insects. The highest mortality in the late instars was mainly due to entomopathogenic viral infections. NPV viral entities were inoculated at the rate of 4 x 10^6 PIB which caused maximum cumulative mortality in the late instar. In the 6th larval instar, 16.16 % mortality was recorded due to two factors; NPV treatment and cannibalism. *S. frugiperda* is highly cannibalistic at its last larval instar (Andow *et al*., 2015). The cause of death in the pupal stage was merely the deformation of the pupal cocoons.

The trend-index value (I) from (Table 3) is positive which means the fall armyworm population will be much higher in the consecutive generation since each egg from the first generation will contribute a 67.15 % increase in egg production further on to the next generation. The survivorship curve in Graph 1 is more or less a type III curve which indicates that the final instars are fairly good survivors. In short, final larval instars could be destructive for the crop plants while early instars are more vulnerable and critical for pest management. Additionally, a large number of survivors could enhance the number of individuals in the next generation.

Table 1: Incidence of *S. frugiperda* on maize in District Lahore and Kasur.

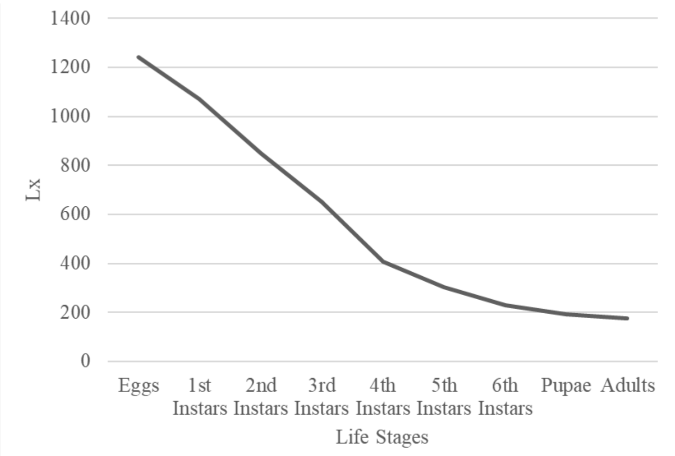
Sr. No.	District	Village	Crop	Variety	GPS coordinates	Age of crop	Level of infestation (%) + S. E	Homogeneous groups
1	Lahore	Khawaja Faiq Pind	Maize	P3939	31.559584 74.539957	V6	13.25 ± 0.78	e
2	Lahore	Chappa Pind	Maize	Neelum	31.277185 74.536188	V5	18.74 ± 0.94	b
3	Kasur	Rao Khan Wala	Maize	Neelum	31.1904683 74.3324993	V8	12.82 ± 0.56	f
4	Kasur	Orarra	Maize	Agaiti	31.1777419 74.3609991	V5	09.28 ± 0.52	i
5	Kasur	Jamalpur Khuddian Khaas	Maize	Pearl	31.0055787 74.3111010	V6	10.32 ± 0.82	h
6	Kasur	Raja Jang	Maize	P3939	31.2133483, 74.2783740	V8	13.26 ± 0.78	e
7	Kasur	Kumharan Wala	Maize	Agaiti	31.2095701 74.2895444	V4	11.94 ± 0.79	g
8	Lahore	Farm Area, Punjab University	Maize	Agaiti	31.498356 74.293647	R1	19.39 ± 0.57	a
9	Lahore	Warra Gillan Ala, Manga Mandi	Maize	Sahiwal Gold	31.279048 74.072219	V9	15.21 ± 0.78	d
10	Lahore	Sardar Umar da Dera, Manga Mandi	Maize	Sahiwal Gold	31.277185 74.081582	V9	18.69 ± 0.92	c

Table 2: Life table for *S. frugiperda* under laboratory conditions.

Age interval	Number alive at the beginning of x	Factors responsible for mortality F	Number dying during x	Mortality %age	Mortality	Survival	K Value
X	Lx	Dx*F	Dx	M%=Dx/Lx	M	S= 1-d	(-ln of S)
Eggs	1240	Infertility, and Un-hatching	169	12.63	0.1263	0.8737	0.058
1st instars	1071	Natural Mortality	221	20.63	0.2063	0.7937	0.231
2nd instars	850	Natural Mortality	198	23.29	0.2329	0.7671	0.265
3rd instars	652	Sublethal Dosses Inoculation of NPV	246	37.73	0.3773	0.6227	0.474
4th instars	406		103	25.37	0.2537	0.7463	0.293
5th instars	303		74	24.42	0.2442	0.7558	0.280
6th instars	229	NPV Plus Cannibalism	37	16.16	0.1616	0.8384	0.176
Pupa	192	Deformation	16	8.33	0.0833	0.9167	0.087
Adults	176 91-Female, 85-Males		Sex ratio= M: F=1: 0.93				

Table 3: Interpretation of the life table data.

Seasonal reproduction rate	(Number of emerged females/total number of eggs in the first generation) * 100	7.34 %
Mean Cohort's fecundity	mean number of eggs produced by a female * number of females in a single generation (where mean fecundity is 915) (Dhar *et al.*, 2019)	83,265
Trend-index (I)	Mean Cohort's fecundity/total number of eggs in the first generation	67.15
Generational survival	Total number of females and males emerged/number of individuals at first instar	0.164



Graph 1: The survivorship curve of the individuals of *S. frugiperda*.

Fall armyworm has a rapid spread rate in South Asian countries which putting food security under threat with millions and millions of losses in maize production (Chhetri and Acharya, 2019). The present investigation discusses the trans-boundary movement of *S. frugiperda* i.e., from Indian territories to Pakistan. Lahore and Kasur cities of Pakistan share a common boundary with the Indian Punjab Province where the pest has been reported and characterized several times (Suby *et al.*, 2020). Although the infestation rate is quite low at the beginning, the damage statistics of the pest in the neighboring countries cannot be ignored. The situation could be worse in case if it were not be addressed.

The life-table analysis is one of the most powerful analytical tools in evaluating the success of a regulating factor in the population dynamics of an insect pest. Several studies have been made to understand the changes in populations depending on mortality factors of a particular-species (Tuan *et al.*, 2014) and the impact of entomopathogens on an insect-pest species (Akutse *et al.*, 2019). Egg unviability is considered an important source of mortality in insects. As per Murúa *et al.* (2008) findings, the mean percentage of egg unviability is flexible and may range from 10 to 68% in natural FAW populations. A similar study performed by Busato *et al.* (2005) using lab-reared insects disclosed that 5 to 28% of FAW eggs were found not viable. Indeed, in this study, egg masses that were kept in the laboratory to assess egg viability showed, on average, 12.63% of egg unviability.

The current study observed a higher mortality ratio in lateral instars (3rd to 5th) than the earlier ones because of entomopathogenic treatment. The survivorship curve provided that if a greater number of caterpillars will undergo the final stages they could be devastating for the maize crop since lateral instars are more voracious in terms of feeding. For larval mortality, Zalucki *et al.* (2002) found up to 90% Lepidopteron larval mortality during early stages by natural enemies, dispersal or establishment, weather, or host-related factors. Fall armyworm larvae also can also die by cannibalism, although cannibalistic behavior is less frequent among early instars (Beirne, 1970).

Rios-Velasco *et al*. (2012) revealed first to six instars of *S. frugiperda* to unnatural diet injected with different NPV applications while eggs were nursed slightly with variable applications of virus entities. Bioassay absorption on egg piles caused the highest mortality rate persuade by the first instar larvae. But in present study a single dose of NPV at the rate of $4*10^6$ PIB was inclined to late larval instars independently which give rise to progressive mortality of 87.52% from 3rd to 5th instar larvae.

Conclusions and Recommendations

Global maize production is under suffering from the huge losses caused by the fall armyworm. Developing countries are struggling to manage the pest through traditional ways. Proper management strategies are needed to tackle the menace, integrated pest management is the novel option for that purpose. From the standpoint of pest management, a life table study on a particular pest is quite useful to know when and why a pest population suffers higher mortality. This is the time when it is the most vulnerable in its life span. After knowing such vulnerable pest stages from the life table, we can make time-based applications of the controlling strategies, to conserve the natural parasitoids and predators and reduce environmental pollution.

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Novelty Statement

The use of entomopathogens in pest management could be an innovative approach in integrated pest control.

Author's Contribution

The life-table study was performed by Muhammad Arslan Ibrahim and Hafiz Muhammad Zahid Anwar. Mr. Mansoor Ahmad provided logistic support to visiting sites. And lastly, Muhammad Arslan Ibrahim and Aneeqa Aleem finalized the manuscript.

Conflict of interest

The authors have declared no conflict of interest.

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