J. Entomol. Res. Soc., 26(2): 209-224, 2024 *Research Article*
Doi: 10.51963/jers.v26i2.2511 *Online ISSN: 2651-3579*

Fall Armyworm, *Spodoptera frugiperda* (J. E. Smith, 1797) may not be a Major Threat on Maize in South India: A Revelation Through its Life Table Studies

Begum Bennihalli RIYANA[1] Aralimarad PRABHURAJ[1*] Pramod KATTI[2]
Shivanand G. HANCHINAL[3] Yatagal Sharanappa AMARESH[4]

[1]Department of Agricultural Entomology, College of Agriculture, UAS, Raichur-584104, Karnataka, INDIA
[2]Nodal officer-ICAR, UAS, Raichur, Karnataka, INDIA
[3]AICRP on cotton, Main Agricultural Research Station, UAS, Raichur, Karnataka, INDIA
[4]Department of Plant Pathology, College of Agriculture, UAS, Raichur, Karnataka, INDIA
E-mails: [1]riyanabegum08@gmail.com, [1*]prabhusha2014@gmail.com, [2]pkatti2007@gmail.com [3]shanchinal@gmail.com, [4]ysama2008@rediffmail.com
ORCID IDs: [1]0009-0003-2248-6259, [1*]0000-0001-7703-4266, [2]0000-0001-7171-5706, [3]0000-0002-6162-6133, [4]0009-0008-0007-7071
[1*]Corresponding authors

ABSTRACT

Life table of *Spodoptera frugiperda* (J. E. Smith) on maize was studied in the laboratory set at 27 ± 1 ˚C to identify the key natural mortality factors. The net reproductive rate (R_o) was 389.88 females with a mean generation time (T) of 31.45 days. The intrinsic rate of increase (r_m) and daily finite rate of natural increase (λ) were 0.18 and 1.20 females/female/day, respectively, with weekly multiplication rate $(\lambda)^7$ of 3.58. The present study elucidates this pest as high-risk species capable of causing considerable economic loss to maize in coming years. However, the life table studies of field population recorded 18 mortality factors. The highest 'K' value (mortality rate) was observed in egg stage with maximum mortality (59.70%) followed by the late larval stages (25.23%). Generation survival was as low as 0.2577 with survivorship curve of type III typical to any invertebrate population which will have higher mortality in early developmental period and relatively lower mortality in surviving population. The higher egg and larval mortality is attributed to native egg and larval parasitoids belonging to Hymenoptera and Diptera Thus, it can be predicted that, in coming days, this pest can be managed effectively by conservation and exploitation of its natural enemies population along with other control methods.

Keywords: Fall armyworm, Invasive pest, mortality factors, natural enemies, life table.

Riyana, B.B., Prabhuraj, A., Katti, P., Hanchinal, S. G., & Amaresh, Y.S. (2024). Fall armyworm, *Spodoptera frugiperda* (J. E. Smith, 1797) may not be a major threat on maize in South India: A revelation through its life table studies. *Journal of the Entomological Research Society*, 26(2), 209-224.

Received: August 20, 2023 *Accepted: April 03, 2024*

INTRODUCTION

The fall armyworm (FAW), *Spodoptera frugiperda* (J. E. Smith, 1797) (Lepidoptera: Noctuidae), a crop pest native to tropical and subtropical regions of the America, was reported for the first time from South India during 2018 on maize (Sharanabasappa et al, 2018). The pest was believed to be migrated from African continent where it was first noticed in late 2016 covering 44 African nations (Goergen & Tarmo, 2016; Nagoshi et al, 2019; Rwomushana et al, 2018). After its invasion to India, reports of its occurrence in several parts of South India started appearing profusely (EPPO, 2018; Shylesha et al, 2018; Ganiger et al, 2018; Sharanabasappa et al, 2018). Simultaneously, its presence was also reported from other states viz., Andhra Pradesh (Venkateswarlu & Muralikrishna, 2018), Tamil Nadu (Srikanth et al, 2018), Chhattisgarh (Deole & Paul, 2018), Maharashtra (Chormule et al, 2019), Gujarat (Sisodiya et al, 2018), Odisha (Kerketta, Verma, Ayam, & Yadav, 2020) and West Bengal (Dhar et al, 2019).

Being a polyphagous pest, it is known to feed on more than 80 crop species (Goergen et al, 2016). However, maize is most preferred host and its infestation in Africa, India and Indonesia ranged from 6-100 per cent (Mallapur, Naik, Hagari, Prabhu, & Patil, 2018; Sari, Suliansyah, Nelly, & Hamid, 2021). It was estimated that, in the absence of suitable management practices, the FAW can cause yield losses in maize to the range of 8.3 to 20.6 Million tonnes per annum in African continent (Day et al, 2017). After its incursion to India, the total production of maize was reduced from 28,753 MT (2017-18) to 27,720 MT (2018-19) (Anonymous, 2019). In India, the pesticide expenditure to produce 100 kg of maize grains has increased from US$ 0.124 in 2017 to US$ 1.39 in 2020 due to the invasion of fall armyworm (Deshmukh et al, 2021).

The severity of FAW in terms of causing considerable yield losses in economically important agricultural crops was attributed to its wide host range, high dispersal ability, high fecundity rate and the absence of diapause (Knipling, 1980). The pest can migrate over 500 km before oviposition (Prasanna & Peschke, 2018).

For the successful establishment of an invasive pest, favourable environmental conditions akin to the place of its origin, high reproductive capacity and growth rate, stable resource availability and minimum/no biotic stress in the form of natural enemy are essential (Sallam, 2013).

In many cases, it has been observed that, many pests that are notorious in the regions of their origin failed to establish in invaded areas (Huber et al, 2002). At the same time, some of the insignificant or average pests in the areas of origin became highly pestiferous in the migrated regions (Kfir, 1997; Sallam, 2013). Fall armyworm has been successfully established in the invaded areas including India causing huge economic losses (Anonymous, 2019). However, whether the same trend continues in a longer run is the matter of concern and research. The biotic potential (the innate ability of survival and reproduction) and the environmental resistance (especially biotic resistance in the form of natural enemies and competition with other closely related species for food and space) are the key factors to decide the fitness of an organism in a long run (Choudhury, Rizvi, & Satpule, 2012).

The life table is one of the important analytical tools in pest management as it reveals the most opportune periods, vulnerable stages of the insect species, thus providing detailed information on population dynamics to generate more informative statistics. Further, it also gives a comprehensive description of life history parameters, survivorship, expectation of life, key mortality factors and development of predictive model which can be tested against the natural population fluctuations (Harcourt, 1969; Bellows & Elkinton,1992; Kakde & Tayade, 2014). Life table studies of *S. frugiperda* have been initiated in India since its invasion and highlighted the biotic potential of the pest (Ashok et al, 2020). Therefore, the present study aimed to assess the biotic potential and the environmental resistance exerted by natural enemies on FAW through life table studies. The study also helps in assessing the performance of FAW as a serious pest in the coming years which helps in developing better management strategies.

MATERIALS AND METHODS

The investigations on life table study of FAW on maize were carried out during 2019-2020 at the Department of Agricultural Entomology, UAS, Raichur, India (16.2036° N latitude and 77.3300° E longitude).

Life table studies under laboratory conditions from laboratory reared population

Insect culture

The FAW culture was maintained in the laboratory on maize leaves and grains at 27 ± 1 °C with 75 ± 05% r.h. throughout the study period. Larvae were reared individually in glass vials (10 ml capacity) plugged with cotton wad. After completion of larval period, pre-pupal stage was allowed for pupation in the moist sand (10%). Emerging male and female moths were released into the insect cages (30 x 30 x 30 cm) and provided with potted maize seedlings (20-25 days old) for egg laying. In each cage, five pairs of adults were maintained. Cotton roll dipped in 10% honey solution was provided in the cage for adult feeding. Life table studies were initiated from 1-d-old batches of eggs laid by adult female during oviposition period.

Life table studies

A batch containing 100 one-d--old eggs was placed in a plastic vial (5.0 x 4.0 cm) with the help of camel hair brush. Immediately after hatching, larvae were individualized in a plastic vial (5.0 x 4.0 cm) and fed with bits of tender maize leaves for first three instars and with fresh corn seeds thereafter at 24 h interval till the completion of the larval period. A sub batch of 10 individuals was made for recording life table parameters. Once larval period was completed, pre-pupa was transferred to a vial containing sterilized moist (10%) sand to facilitate pupation. Throughout the developmental period from egg till the death of an adult moth, various observations such as survivability of each individual, duration of each stage, pre-ovipositional, ovipositional, post-ovipositional durations and fecundity of female moth was recorded daily.

Age-specific distribution life table

Age-specific distribution life table was constructed by partitioning its life cycle into distinct developmental stages viz., egg, larva, pupa and adult and evaluated the developmental time and survival or mortality for each of the developmental stages. The number of eggs hatched was counted immediately after hatching. Dead and malformed stages were recorded and removed as they occurred. The stable age distribution table was constructed as suggested by (Andrewartha & Birch, 1954; Atwal & Bains, 1974): x = pivotal age in days, Lx = stable age distribution (lx+(lx+1)/2) where lx = survival of individuals at different age interval, r_m = intrinsic rate of increase in number by solving equation Log_e Ro/T (Where e = 2.71828) and T = Mean generation time). Per cent distribution of each age group (x) was calculated by multiplying the Lx with $e^{-rm(x+1)}$. By combining, the percentage under each stage *viz*., egg, larva, pupa and adult, the expected per cent distribution was worked out.

Observation for above characters were recorded for two generations and used for constructing life table.

Age-specific fecundity life table

The total number of adults emerged on the same day were paired and each pair was placed in insect oviposition cage (30 x 30 x 30 cm) having 1 mm metal mesh on four sides separately with 10 per cent honey solution as food. Maize leaves were used as substratum for oviposition and were introduced daily in the cages. Observations on fecundity were recorded and continued upto the death of all female moths. As the sex ratio of majority of insects including noctuid moths is 1:1, the number of eggs obtained per female was divided by two to get the number of born females (mx).

The following parameters of fecundity life table are worked out as proposed by Howe (1953): lx = survival of female at age ‘x’, mx = age schedule for female births at age ‘x, Ro = Net reproductive rate (∑x.lx.mx), Pf =Potential fecundity (∑mx), lx.mx = Reproductive expectation, T = Mean length of generation (∑x.lx.mx/Ro), λ = Finite rate of increase in number (antilog e^{rm}), λ^7 = Weekly multiplication of population, DT = Doubling time ($\log_e$ 2/rm), $(Ro)^2$ = Hypothetical F_2 female.

Life expectancy

Life expectancy of *S. frugiperda* was worked out by using columns x, lx, dx, 100qx, Lx,Tx and ex. Where, lx = Number of survival at the beginning of the interval out of 100, dx = Number dying during ‘x’, 100qx = mortality rate per hundred alive at the beginning of the age interval (dx.100/lx), Lx = lx+(lx+1)/2 is alive between x and x+1, Tx = Number of individual’s life days beyond ‘x’, ex = expectation of further life (Tx/lx x 2).

Various population indices were included and computed in this study from the fecundity table as suggested (Howe, 1953; Birch, 1948).

Life table studies of field population under laboratory conditions

Egg sampling: The investigation was carried out to identify the key natural mortality factors of *S. frugiperda* in maize ecosystems of Raichur and Koppal district during 2019. These two districts grow maize as sole crop for two seasons (monsoon and post monsoon season) in a year. Since many farmers of these regions have small to marginal land holdings, they often do not take up any control measures. Samples were drawn from the field populations throughout the cropping season. Egg masses (containing 300-400 eggs) present on different plant parts were collected carefully, placed inside the polythene bags and brought to the laboratory. Each batch was transferred to a rearing container (ventilation size, 4mm) and incubated separately at 27 ± 1 °C to observe the egg mortality due to parasitization, infertility, desiccation or unknown reasons. Totally, 10 such batches were maintained for observation. In each batch, egg parasitoids if any emerged, were collected and preserved in 70 per cent ethanol for identification. The preserved egg parasitoids were sent for identification to National Bureau of Agricultural Insects Resources (NBAIR), Bengaluru based on morphological characteristics. The desiccated and other non-viable eggs due to unknown causes were discarded after recording their number and only hatched larvae were reared up to adult emergence.

Larval sampling: Larvae of *S. frugiperda* were collected at monthly interval from the same fields where eggs were collected. The identity of the pest was established on the basis of typical feeding injury on leaf whorls and on the presence of fresh excrements (Sharanabasappa et al, 2019). Larval samples were grouped into three categories *viz*., early stage (1st and 2nd), mid stage (3rd and 4$^{th)}$ and late stage larvae (5th and 6th). Accordingly, the collected larvae were placed in a separate bread box (30 x 15 x 10 cm) containing bits of maize leaves (early stage larvae) and pieces of tender cobs (mid and late stage larvae). Later, larvae were placed individually in plastic vials along with food and maintained at 27 ± 1 °C to observe the mortality in each stage to record key natural mortality factors such as parasitization, diseases or unknown reasons. The parasitoids emerged from different growth stages (larval, prepupal and pupal) were collected and preserved in 70 per cent ethanol. Late instar larvae were placed in plastic vials containing sterilized wet sand to facilitate pupation. The observations were made daily basis on the number of malformed, diseased, mechanically damaged and incompletely developed larvae, prepupa, pupa and adult.

Construction of field life table

The different larval stages of *S. frugiperda* collected was referred as egg (N1) while constructing field life table as suggested by Morris and Miller (1954). After the construction of life table, the survivorship curves, mortality factors (K- factors) and relationship between mortality of *S. frugiperda* and K-values were worked out.

In the present study, the life table was constructed according to the method described by Morris and Miller (1954); x = Age or stage interval at which the sample was taken (egg, larva, pupa or adult), lx = The number surviving at the beginning of the stage noted in the 'x' column, dx = The number dying within the age interval stated in the 'x' column dxf = The mortality factors responsible for dx, 100qx = Mortality rate during stage 'x' (dx as percentage of lx), Sx = Survival rate within the stage mentioned in the x column K = Age specific key mortality. Key factor which is primarily responsible for increase or decrease in number from one generation to another was calculated. However, the total generation mortality was calculated by adding 'K' values of different life stages.

Age-specific survivorship and mortality

The survivorship curve was drawn by plotting the number of survivors in a given age (lx) against the age interval (x). The shape of the curve describes the distribution of mortality factors in relation to age (Slobodkin, 1980). Different mortality factors were identified and corresponding K- values were assigned for each of the mortality factors at different developmental stages and the relationship *S. frugiperda* mortality and K- values was calculated.

RESULTS

Life table studies under laboratory conditions from laboratory reared population

Survival of different developmental stages

The mean duration of different life stages viz., egg, larva and pupa of *S. frugiperda* was 3, 13 and 10 days, respectively. Out of 100 eggs observed, 92 eggs hatched into larvae of which 82 successfully completed their development, whereas, 72.5 succeeded to enter into pupal stage and same number of adults emerged. The cumulative mortality in egg, larval and pupal stages was 8, 18 and 27.5%, respectively (Table 1).

Table 1. Survival (%) of different developmental stages of *S. frugiperda* on maize.

Replication	No. of eggs	Egg stage (0 to 3 days)	Larval stage (4 to 16 days)	Pre pupa and Pupal stage (17 to 26)
1	10	10	8.5	6.5
2	10	8.5	8	6.5
3	10	10	7.5	6.5
4	10	10	10	9.5
5	10	8.5	8	8
6	10	9	8	7.5
7	10	8.5	8	7.5
8	10	10	8.5	7.5
9	10	8.5	7.5	7
10	10	9	8	6
Cumulative survivability (%)		92	82	72.5
Cumulative mortality (%)		8	18	27.5
Duration of growth stages in days	-	3	13	10

The mortality rate did not change significantly among the egg, larva and pupal stages of *S. frugiperda*, although numerically it was highest at larval (10%) followed by the pupa (9.5%) and egg (8%) Stage.

Age-specific distribution

Towards stable age distribution, eggs contributed to the tune of 56.91% followed by larvae (39.80%) and pupae (2.88%). The lowest contribution (0.39%) was made by adult stage.(Fig. 1).

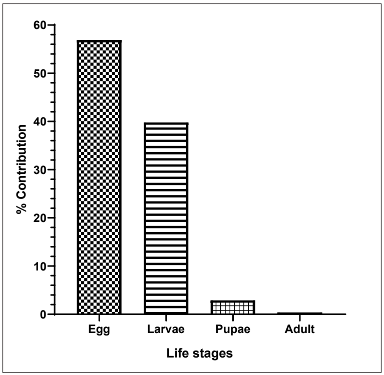

Figure 1. Contribution of different life stages of *S. frugiperda* to the stable age distribution.

Age-specific fecundity

The pre-oviposition period of *S. frugiperda* ranged from 26th to 28th day of pivotal age. Females started laying eggs on 29th day (mx = 145.73) and continued up to 37th day (mx = 7.47), with lx values of 0.315 and 0.195, respectively. The maximum number of offspring per female per day (mx = 307.73) was achieved in 31st day, whereas, the lowest number of progenies per female per day (mx = 7.47) was recorded on 37th day. The net reproductive rate (Ro) was 389.88 numbers. The mortality of first female within the cohort occurred on the 7th day after its emergence *i.e.*, on the 32nd day (lx = 0.31) and increased thereafter (R^2 = 0.41), indicating steady decrease in survival rate (lx) (Fig. 2).

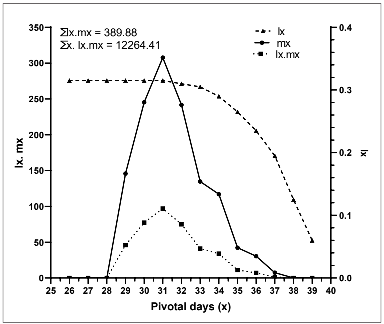

Figure 2. Age-specific fecundity of *S. frugiperda* on maize.

Population growth parameters

Mean generation time (T) of *S. frugiperda* was 31.45 days. The intrinsic rate of increase (rm) and finite rate of natural increase (λ) were 0.18 and 0.20 females/ female/day, respectively. Under a given set of conditions, FAW population doubled in 3.67 days with multiplication rate of 3.58 times per week. The hypothetical female population in F_2 generation was 152006.414 with a potential fecundity (Pf) of 1272.41 eggs per female (Table 2).

Table 2. Population growth parameters of *S. frugiperda* on maize.

Population growth parameters	Calculated value
Net reproductive rate (Ro)	389.88 numbers
Mean length of generation (Tc)	31.45 days
Innate capacity for increase in number (rm)	0.1895 females/female/day
Finite rate of increase in number (λ)	1.20 females/female/day
Arbitrary 'rm' (rc)	0.19
Weekly multiplication of population(λ)7	3.58 days
Doubling time (DT)	3.67 days
Potential fecundity (Pf)	1272.41
Hypothetical F2 female (Ro)2	152006.414 number

Life expectancy

The life expectancy (ex) of *S. frugiperda* declined gradually as the age advances. The life expectancy of newly deposited eggs was 19.61 days. However, the mortality rate (dx) was comparatively high on 33rd to 36th day of pivotal age when the expected further life was reduced from 19.61 days in the beginning to 0.5 day ($R^2 = 0.87$) (Fig. 3).

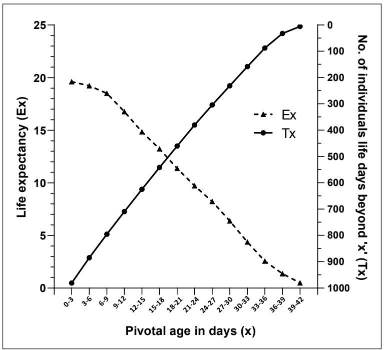

Figure 3. Life expectancy (Ex) of *S. frugiperda* on maize

Life table studies of field population under laboratory conditions

Life table studies: Among the 1785 eggs observed throughout their development period, the highest mortality was recorded in the egg stage (59.70%), followed by the late larval stage (25.23%), the pupal stage (10.96%), the mid larval stage (10.63%), the early larval stage (5.44%) and the adult stage (3.77%).

The egg parasitoids such as *Trichogramma* and *Telenomus* genera accounted to the tune of 9.8 and 30.43 per cent mortality, respectively. The factor of desiccation was of 19.46 per cent. During the early stage larval development, 5.33 per cent population died due to unknown reason, while hymenopteran parasitoids represented only 0.11 per cent. The mortality factors in the middle larval stage were mainly due to unknown reason (6.25%), hymenopteran parasitoid (3.05%), entomopathogenic fungi (1.21%) and dipteran parasitoid (0.12%). However, in the late stage larval development, the mortality rate increased considerably due to contribution of unknown factor (11.71%), entomopathogenic fungi (5.93%), hymenopteran parasitoids (4.58%) and dipteran parasitoids (3.01%). Among the various key mortality factors in larval stage, the unknown factor contributed to the highest percentage of mortality (23.29%) followed by hymenopteran parasitoids (7.74%), entomopathogenic fungi (7.14%) and dipteran parasitoids (3.13%).

Total mortality in the pre pupal stage was 9.04% of which 5.61% was due to dipteran parasitoids, followed by unknown factor (3.42%). In pupal stage, the total mortality recorded was 10.96% in which death due to unknown factor contributed 9.47% followed by dipteran parasitoids (1.49%). In the adult stage, a mortality rate of 3.77% was recorded due to the malformation.

The generation survival (SG) of *S. frugiperda* was 0.2577, indicating that only 25.77% of the population was able to survive and successfully complete the generation. The mortality of eggs due to egg parasitoids contributed high 'K' value of 0.4659. For larval stages, unknown factor contributed to high 'K' value (0.2437) followed by hymenopteran parasitoids, entomopathogenic fungi and dipteran parasitoids with 'K' values of 0.0788, 0.0732 and 0.0317, respectively (Table 3).

Survivorship curve

In the present investigation, the survivorship curve obtained fits to type III curve, which indicates the lowest age specific survival rate in the early stage of life and a high probability of survival for those passing through this bottleneck (Fig. 4). The highest rate of mortality was observed in the egg stage (59.70%) and thereafter it stabilizes in early and mid larval stages e. However, the survival rate dips further from late stage larva to prepupal stage (25.23%) and again stabilizes.

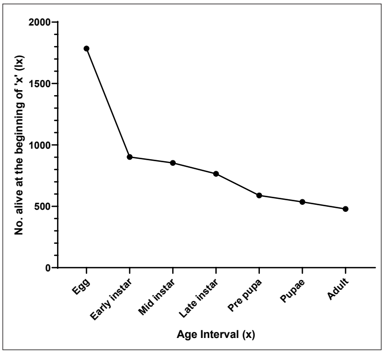

Figure 4. Type III survivorship curve of *S. frugiperda* on maize.

Mortality factors (K- factors)

A total of 18 mortality factors (K1 to K18) were identified. Some of the major identified mortality factors were hymenopteran egg (K1 and K2) and larval parasitoids (K4, K6 and K10), dipteran parasitoids (K7, K11, K14 and K16), entomopathogenic fungi (K8 and K12) and desiccation (K3). Other factors included adult malformation (K18) and death due to unknown reasons (K5, K9, K13, K15 and K17) (table 3). The relationship between mortality factors of *S. frugiperda* and K-value indicated that as the percentage mortality increases, K-values also increases (Fig. 5). Generally, K-values depict only the extent of mortality but not the nature of association.

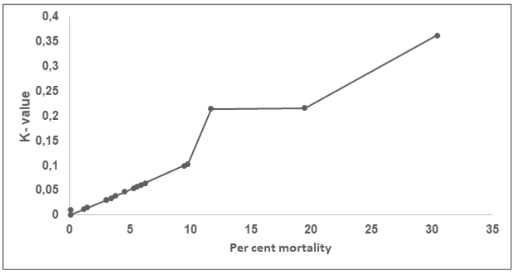

Figure 5. Relationship between mortality of *S. frugiperda* and K-value.

Table 3. Life table studies of field collected population of *S. frugiperda* under laboratory conditions.

Age interval (x)	No. alive at the begging of x (lx)	Factors responsible for death (dxf)	K' s	No. of dying during x (dx)	Mortality per cent 100qx	Mortality d=dx/lx	Survival S=1-d	K' value (-ln(s))
Egg (N1)	1785	Trichogramma sp.	K1	175	9.80	0.0980	0.9020	0.1031
	1610	Telenomus sp.	K2	490	30.43	0.3043	0.6957	0.3628
	1120	Desiccation	K3	218	19.46	0.1946	0.8054	0.2164
		Sub total		883	59.70			0.6823
Early stage larvae	902	Hymenopteran parasitoids	K4	1	0.11	0.0011	0.9989	0.0011
	901	Unknown reasons	K5	48	5.33	0.0533	0.9467	0.0547
		Sub total		49	5.44			0.0558
Mid stage larvae	853	Hymenopteran parasitoids	K6	26	3.05	0.0305	0.9695	0.0309
	827	Dipteran parasitoids	K7	1	0.12	0.0012	0.9988	0.0012
	826	Entomopathogenic fungi	K8	10	1.21	0.0121	0.9879	0.0121
	816	Unknown reasons	K9	51	6.25	0.0625	0.9375	0.0645
		Sub total		88	10.63			0.1087
Late stage larvae	765	Hymenopteran parasitoids	K10	35	4.58	0.0458	0.9542	0.0468
	730	Dipteran parasitoids	K11	22	3.01	0.0301	0.9699	0.0305
	708	Entomopathogenic fungi	K12	42	5.93	0.0593	0.9407	0.0611
	666	Unknown reasons	K13	78	11.71	0.1171	0.8829	0.1245
		Sub total		177	25.23			0.2629
		Total larval mortality		314	41.30			
Pre pupa	588	Dipteran parasitoids	K14	33	5.61	0.0561	0.9439	0.0577
	555	Unknown reasons	K15	19	3.42	0.0342	0.9658	0.0347
		Sub total		52	9.04			0.0924
Pupa	536	Dipteran parasitoids	K16	8	1.49	0.0149	0.9851	0.015
	528	Unknown reasons	K17	50	9.47	0.0947	0.9053	0.0994
		Sub total		58	10.96			0.1144
Adults	478	Malformed adult	K18	18	3.77	0.0377	0.9623	0.0384
		Sub total		18	3.77			0.0384
		Total		1325	124.77		K-value =	1.3549
Normal females x 2(N2)	460							
Reproducing females x 2	230	Sex 50 % females						
Generation survival (N2/ N1)	0.2577							

DISCUSSION

Spodoptera frugiperda exhibited greater survivability with minimum mortality from egg to adult stage when reared under a given set of congenial conditions. In the present life table study of laboratory reared populations, the immature stages are vulnerable compared to the adult stage, as a result eggs and larvae contribute most to the stability of age distribution of the population which was not only observed by other researchers on *S. frugiperda* (Ashok et al, 2020) but also on other phytophagous pests (Bilapate, Pawar, & Thombre, 1980; Acharya & Patel, 2007; Gedia & Patel, 2008; Patil & Jat, 2014; Patil & Shitap, 2015; Deb & Bharpoda, 2016; Basavaraj & Shadakshari, 2018; Sunil & Hanchinal, 2019). In the adult stage, the fecundity of female moth increased as age advances reached a peak and starts declining. In case of age-specific survival rate, the survivability of the adults decreased with age (Fig. 2). (Singh & Yadav, 2009; Patil et al, 2014; Patil et al, 2015; Deb & Bharpoda, 2016; Basavaraj et al, 2018).

The overall life table studies on laboratory reared FAW clearly indicated its ability for quick multiplication (3.58 per week) and doubling rate in minimum days (3.67 days) which is a common observation made so far in FAW on maize (Rosa, Trecha, Alves, Garcia, & Goncalves, 2012; Omoto et al, 2016; Ashok et al, 2020) as well as other noctuid pests viz., *Spodoptera litura* (F.) on groundnut (Sunil et al, 2019; Gedia et al, 2008) and tobacco (Patil et al, 2014; Patil et al, 2015) and *Helicoverpa armigera* (Hubner) on chickpea (Dhabi & Patel, 2007; Singh & Yadav, 2009) and tomato (Deb & Bharpoda, 2016).

However, the life table studies of field populations of FAW gives a different picture in terms of population survival. A significant mortality was observed in all the developmental stages of FAW including adult stage. The major mortality factor was natural parasitisation by various hymenopteran and dipteran parasiotids followed by entomopathogens and unknown factor. Lepidopterans in general and noctuid pests in particular are attacked by innumerable hymenopteran parasitoids and *S. frugiperda* is no exception to that. Several species of hymenopteran/dipteran parasitoids and entomopathogens are known to attack egg, larval, and pupal stages of major noctuid pests such as *H. armigera* (Bisane, Khande, Bhamare, & Katole, 2009; Kaneria, Kabaria, Variya, & Bharadiya, 2018) and *S. litura* (Geetha & Jagadish, 2014; Kumar, Bharodia, & Acharya, 2015; Bhadane, Kumar, & Acharya, 2016) which are native to India.

In the present study, FAW was found to be vulnerable to different native hymenopteran and dipteran parasitoids at key developmental stages. The total parasitoid contribution to the mortality of FAW in the present study was accounted to the tune of 58.2% of which 40.23% was recorded in the egg stage alone. Several reports are also available in support of present study recording important egg parasitoids belonging to Trichogrammatidae and Platygastridae on FAW after its invasion in India (Shylesha et al, 2018; Dhar et al, 2019; Sharanabasappa et al, 2019; Gupta, 2019; Firake & Behere, 2020). Further, hymenopteran larval parasitoids belonging to Braconidae, Ichneumonidae, and Bethylidae were also found attacking FAW (Shylesha et al, 2018; Sharanabasappa et al, 2019; Gupta, 2019; Firake & Behere, 2020; Sagar et al, 2022). The dipteran parasitoid of the family Tachinidae was reported on larval and larval-pupal stages of FAW (Sharanabasappa et al, 2019; Firake & Behere, 2020).

Further, in the present study, entomopathogens have contributed 7.14% mortality in the field population in support of similar such observations made in Indian FAW population (Shylesha et al, 2018; Mallapur et al, 2018a; Dhar et al, 2019; Sharanabasappa et al, 2019; Firake & Behere, 2020). In addition to biotic stress, other factors such as desiccation and unknown contributed 19.46 and 36.18%. This could be due to several factors of which prevailing environmental condition and the type of management practices that farmers' follow plays an important role (Sari, Suliansyah, Nelly, & Hamid, 2021). The overall trend indicated that, the high mortalities observed in the egg and late larval stages have a greater contribution in the reduction of the *S. frugiperda* population on maize. Similar observation was also made by other scientists on FAW (Dhar et al, 2019), *Spodoptera exigua* (Hubner) (Farhani, Naseri, & Talebi, 2011) and *S. litura* (Geetha & Jagadish, 2014; Kumar et al, 2015; Bhadane et al, 2016).

Overall, it could be summarized that, *S. frugiperda* though has high biotic potential and quick multiplication rate, but suffer heavy mortality due to biotic stress in the form of parasitoids and entomopathogens. This is an encouraging since; the native natural enemies are extending their host range to the exotic species. With the present result it can be predicted that, in coming days, the populations of FAW can be managed effectively on maize by exploiting the native natural enemy population. In addition to this, insecticide management generally followed will further decrease the population. Thus, it can be anticipated that, its infestation on maize may not pose a serious threat to economical yield loss. However, care should be taken if *S. frugiperda* expands its host range.

CONCLUSION

Fall armyworm has made a big negative impact on the production of maize in India since its invasion. However, the present life table studies on field populations has revealed its vulnerability to many of the native natural enemies. The study has reported highest egg and larval mortality due to hymenopteran and dipteran parasitoids which is highly encouraging. Conservation of natural enemies with judicious use of insecticides would be a wise approach in containing this pest in India.

ACKNOWLEDGEMENTS

The authors are profusely thankful to the Department of Agricultural Entomology, University of Agricultural Sciences, Raichur, Karnataka, India for necessary facilities and support and National Bureau of Agricultural Insect Resources (NBAIR), Bengaluru for insect identification service.

REFERENCES

Acharya, M.F., Vyas, H.J., Gedia, M.V., & Patel, P.V. (2007). Life table, intrinsic rate of increase and age-specific distribution of *Helicoverpa armigera* (Hubner) on cotton. *Annals of Plant Protection Sciences*, 15(2), 338-341.

Andrewartha, H.G. & Birch, L.C. (1954). *The distribution and abundance of animals*. University Chicago Press, Chicago. p 782.

Anonymous. (2019, December). *Indiastat*. Retrieved from https://www.indiastat.com.

Ashok, K., Kennedy, J.S., Geethalakshmi, V., Jeyakumar, P., Sathia, N., & Balasubramani, V. (2020). Life table study of fall armyworm, *Spodoptera frugiperda* (J. E. Smith) on maize. *Indian Journal of Entomology*, 82(3), 574-579.

Atwal, A.S. & Bains, S.S. (1974). *Applied animal ecology*. Kalyani Publishers, Delhi. p 245.

Basavaraj, K., Naik, M.I., & Shadakshari, Y.G. (2018). Studies on age specific fecundity life tables for *Helicoverpa armigera* (Hubner) (Lepidoptera: Noctuidae) on sunflower (*Helianthus annus* L.). *Journal of Entomology and Zoology Studies*, 6(2), 1364-1368.

Bellows, T.S., Driesche, R.G.V., & Elkinton, J.S. (1992). Life table construction and analysis in the evaluation of natural enemies. *Annual Review of Entomology,* 37, 587-612.

Bhadane, M., Kumar, N.N., & Acharya, M.F. (2016). Field life table of *Spodoptera litura* Fabricius on castor. *International Journal of Agriculture Innovations and Research*, 4(4), 2319-1473.

Bilapate, G.G., Pawar, V.M., & Thombre, V.T. (1980). Life tables and intrinsic rates of increase of *Spodoptera litura* (Fabricius) on sunflower. *Indian Journal of Agricultural Sciences*, 50(1), 273-277.

Birch, L.C. (1948). The intrinsic rate of natural increase of an insect population. *Journal of Animal Ecology*, 17(1), 15-26.

Bisane, K.D., Khande, D.M., Bhamare, V.K., & Katole, S.R. (2009). Life table studies of *Helicoverpa armigera* (Hubner) on chickpea. *International Journal of Plant Protection*, 2(1), 54-58.

Chormule, A., Shejawal, N., Sharanabasappa, Kalleshwaraswamy, C.M., Asokan, R., & Swamy, H.M. (2019). First report of the fall armyworm, *Spodoptera frugiperda* (J. E. Smith) (Lepidoptera: Noctuidae) on sugarcane and other crops from Maharashtra, India. *Journal of Entomology and Zoology Studies*, 7(1), 114-117.

Choudhury, R.A., Rizvi, P.Q., & Satpule, N.S. (2012). Stage specific life table of *Helicoverpa armigera* (Hubner) on chickpea. *Indian Journal Entomology*, 74(4), 310-314.

Day, R., Abrahams, P., Bateman, M., Beale, T., Clottey, V., Cock, M., Colmenarez, Y., Corniani, N., Early, R., Godwin, J., & Gomez, J. (2017). Fall armyworm: impacts and implications for Africa. *Outlooks Pest Management,* 28(5), 196-201.

Deb, S. & Bharpoda, T. (2016). Life-table parameters of fruit borer, *Helicoverpa armigera* (Hubner) Hardwick in tomato, *Lycopersicon copersicon*. *The Bioscan*, 11(1), 09-14.

Deole, S. & Paul, N. (2018). First report of fall army worm, *Spodoptera frugiperda* (J. E. Smith), their nature of damage and biology on maize crop at Raipur, Chhattisgarh. *Journal of Entomology and Zoology studies*, 6(6), 219-221.

Deshmukh, S.S., Kalleshwaraswamy, C.M., Prasanna, B.M., Sannathimmappa, H.G., Kavyashree, B.A., Sharath, K.N., Pradeep, P., & Patil, K.K.R. (2021). Economic analysis of pesticide expenditure for managing the invasive fall armyworm, *Spodoptera frugiperda* (J. E. Smith) by maize farmers in Karnataka, India. *Current Science*, 121(11), 1487-1492.

Dhabi, M.V. & Patel, C.C. (2007). Life expectancy of *Helicoverpa armigera* on chickpea. *Journal of Semi-arid tropics Agricultural Research*, 5(1), 12-17.

Dhar, T., Bhattacharya, S., Chatterjee, H., Senapati, S.K., Bhattacharya, P.M., Poddar, P., Ashika, T.R., & Venkatesan, T. (2019). Occurrence of fall armyworm *Spodoptera frugiperda* (J. E. Smith) (Lepidoptera: Noctuidae) on maize in West Bengal, India and its field life table studies. *Journal of Entomology and Zoology Studies*, 7(4), 869-875.

EPPO (2018) EPPO Global Database: *Spodoptera frugiperda* (LAPHFR) https://gd.eppo.int/taxon/LAPHFR [Accessed on 08 December 2018].

Farhani, S., Naseri, B., & Talebi, A. A. (2011). Comparative life table parameters of beet armyworm *Spodoptera exigua* (Hubner) (Lepidoptera: Noctuidae) on five host plants. *Journal of the Entomological Research Society*, 13(1), 91-101.

Firake, D.M. & Behere, G.T. (2020). Natural mortality of invasive fall armyworm, *Spodoptera frugiperda* (J. E. Smith) (Lepidoptera: Noctuidae) in maize agroecosystems of north east India. *Biological Control*, 148, 104-303.

Ganiger, P.C., Yeshwanth, H.M., Muralimohan, K., Vinay, N., Kumar, A.R.V., & Chandrashekara, K. (2018). Occurrence of the New Invasive Pest, Fall Armyworm, *Spodoptera frugiperda* (J. E. Smith) (Lepidoptera: Noctuidae), in the Maize fields of Karnataka, India. *Current Science*, 115(4), 621-623.

Gedia, M.V., Vyas, H.J., Acharya, M.F., & Patel, P.V. (2008). Studies on life fecundity tables of *Spodoptera litura* (Fabricius) on groundnut. *Annals of Plant Protection Sciences*, 16(1), 74-77.

Geetha, S. & Jagadish, K.S. (2014). Field life table studies of *Spodoptera litura* (f.) infesting sunflower in Bengaluru conditions, Karnataka, India. *Global Journal of Biology, Agriculture and Health Sciences*, 3(4): 55-58.

Goergen, G., Kumar, P.L., Sankung, S.B., Togola, A., & Tamo, M. (2016). First report of outbreaks of the fall armyworm (*Spodoptera frugiperda* J. E. Smith) (Lepidoptera: Noctuidae), a new alien invasive pest in West and Central Africa. *PLoS One*, 11(10), 165-632.

Gupta, A. (2019). Taxonomic studies on parasitoids playing an unheeded yet unparalleled role in pest management. International Conference on Plant Protection In Horticultural: Advances and Challenges (ICPPH), Bengaluru, Karnataka, India. p 21.

Harcourt, D.G. (1969). The development and use of life tables in the study of natural insect populations. *Annual Review of Entomology*, 14(1), 175-196.

Howe, R.W. (1953). The rapid determination of intrinsic rate increase of an insect population. *Annals of Applied Biology*, 40, 134-155.

Huber, D.M., Hugh-Jones, M.E., Rustr, M.K., Sheffield, S.R., Simberloff, D., Taylorm, C.R., Gratz, N., Menge, J., & Thurston, H.D. (2002). *Invasive pest species: Impacts on Agricultural production, natural resources and the Environment.* Council of Agricultural Sciences and Technology (CAST), Ames, Iowa. p13.

Kakde, A.M, Patel, K.G., & Tayade, S. (2014). Role of life table in insect pest management - a review. *IOSR Journal of Agriculture and Veterinary Science*, 7(1), 40-43.

Kaneria, P.B., Kabaria, B.B., Variya, M.V., & Bharadiya, A.M. (2018). Field life table studies of *Helicoverpa armigera* (Hubner) infesting chickpea in Saurashtra conditions, Gujarat, India. *Journal of Entomology and Zoology studies*, 6(5), 2403-2406.

Kerketta, D., Verma, L.R., Ayam, G.P., & Yadav, R.S. (2020). First invasive report of fall armyworm, *Spodoptera frugiperda* (J. E. Smith) (Lepidoptera: Noctuidae) from Orissa, India. *Journal of Experimental Zoology*, 23(1), 465-468.

Kfir, R. (1997). Natural control of the cereals stemborers *Busseola fusca* and *Chilo partellus* in South Africa. *Insect Science and its application*, 17, 61-67.

Knipling, E.F. (1980). Regional management of the fall armyworm a realistic approach. *Florida Entomological Society*, 6(3), 468-480.

Kumar, N.N., Bharodia, R.K., & Acharya, M.F. (2015). Ecological life table of *Spodoptera litura* Fabricius on groundnut. *International Journal of Agriculture Innovations and Research*, 4(3), 2319-1473.

Mallapur, C.P., Naik, A.K., Hagari, S., Prabhu, S.T., & Patil, R.K. (2018). Status of alien pest fall armyworm, *Spodoptera frugiperda* (J. E. Smith) on maize in Northern Karnataka. *Journal of Entomology and Zoology studies*, 6(6), 32-436.

Mallapur, C.P., Naik, A.K., Hagari, S., Praveen, T., Patil, R.K., & Lingappa, S. (2018a). Potentiality of *Nomuraea rileyi* (Farlow) Samson against the fall armyworm, *Spodoptera frugiperda* (J. E. Smith) infesting maize. *Journal of Entomology and Zoology Studies*, 6(6), 1062-1067.

Morris, R.F. & Miller, C.A. (1954). The development of life tables for the spruce budworm. *Canadian Journal of Zoology*, 32(4), 283-301.

Nagoshi, R.N., Dhanani, I., Asokan, R., Mahadevaswamy, H. M., Kalleshwaraswamy, C.M., & Meagher, R.L. (2019). Genetic characterization of fall armyworm infesting South Africa and India indicate recent introduction from a common source population. *PLoS One*, 14(5): 1-16.

Omoto, C., Bernardi, O., Salmeron, E., Sorgatto, R., Dourado, P.M., Crivellaari, A., Carvalho, R.A., Willse, A., Martinelli, S., & Head, G.P. (2016). Field-evolved resistance to Cry 1Ab maize by *Spodoptera frugiperda* in Brazil. *Pest management Science*, 72(9), 1727-1737.

Patil, R.A., Ghetiya, L.V., Jat, B.L., & Shitap, M.S. (2015). Life table evaluation of *Spodoptera litura* (Fabricius) on bidi tobacco, *Nicotiana tabacum*. *The Ecoscan*, 9(1&2), 25-30.

Patil, R.A., Mehta, D.M., & Jat, B.L. (2014). Studies on life fecundity tables of *Spodoptera litura* Fabricius on tobacco *Nicotiana tabacum* Linnaeus. *Entomology, Ornithology and Herpetology,* 3(1), 1-5.

Prasanna, B.M., Huesing, J.E., Eddy, R., & Peschke, V.M. (2018). *Fall armyworm in Africa: a guide for integrated pest management*. p109.

Rosa, A.P.A., Trecha, C.O., Alves, A.C., Garcia, L., & Goncalves, V.P. (2012). Biology and fertility life table of *Spodoptera frugiperda* (J. E. Smith) in strains of corn. *Arquivos do Instituto Biologico*, 79(1), 39-45

Rwomushana, I., Bateman, M., Beale, T., Beseh, P., Cameron, K., Chiluba, M., Clottey, V., Davis, T., Day, R., Early, R., Godwin, J., Gonzalez-Moreno, P., Kansiime, M., Kenis, M., Makale, F., Mugambi, I., Murphy, S., Nunda, W., Phiri, N., Pratt, C., & Tambo, J. (2018). *Fall armyworm: impacts and implications for Africa*.

Sagar, D., Suroshe, S.S., Keerthi, M.C., Poorani, J., Gupta, A., & Chandel, R. K. (2022). Native parasitoid complex of the invasive fall armyworm, *Spodoptera frugiperda* (J. E. Smith) from Northern India. *International Journal of Tropical Insect Science*, 42(3), 2773-2778.

Sari, S.P., Suliansyah, I., Nelly, N., & Hamid, H. (2021). The occurrence of *Spodoptera frugiperda* attack on maize in West Pasaman District, West Sumatra, Indonesia. In *IOP Conference Series: Earth and Environmental Science*, 741(1), 012020.

Sallam, M.N. (2013). INSECT DAMAGE: Damage on Post-Harvest, (Ed.) D. *Mejia and B. Lewis (Rome: Food and Agriculture Organization of the United Nations)*.

Sharanabasappa, Kalleshwaraswamy, C.M., Asokan, R., Mahadeva swamy, H.M., Maruthi M.S., Pavithra, H.B., Hegde, K., Navi, S., Prabhu, S. T., & Goergen, G. (2018). First report of the fall armyworm, *Spodoptera frugiperda* (J. E. Smith) (Lepidoptera: Noctuidae), an alien invasive pest on maize in India. *Pest Management in Horticultural Ecosystem*, 24(1), 23-29.

Sharanabasappa, Kalleshwaraswamy, C.M., Poorani, J., Maruthi, M.S., Pavithra, H.B., & Diraviam, J. (2019). Natural enemies of *Spodoptera frugiperda* (J. E. Smith) (Lepidoptera: Noctuidae), a recent invasive pest on maize in South India. *Florida Entomological Society*, 102(3), 619-623.

Shylesha A.N., Jalali, S.K., Gupta, A., Varshney, R., Venkatesan, T., Shetty, P., Ojha, R., Ganiger, P.C., Navik, O., Subaharan, K., Bakthavatsalam, N., & Ballal, C.R. (2018). Studies on new invasive pest *Spodoptera frugiperda* (J. E. Smith) (Lepidoptera: Noctuidae) and its natural enemies. *Journal of Biological Control*, 32(3), 145-51.

Singh, S.K. & Yadav, D.K. (2009). Life table and biotic potential of *Helicoverpa armigera* (Hubner) on chickpea pods. *Annals of Plant Protection Sciences*, 17(1), 90-93.

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* (J. E. 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.

Slobodkin, L. B. (1980). *Growth and regulation of animal populations* (2nd ed.). Dover Publications, New York, USA.

Srikanth, J., Geetha, N., Singaravelu, B., Ramasubramanian, T., Mahesh, P., Saravanan, L., Salin, K.P., Chitra, N., & Muthukumar, M. (2018). First report of occurrence of fall armyworm *Spodoptera frugiperda* in sugarcane from Tamil Nadu, India. *Journal of Sugarcane Research*, 8(2), 195-202.

Sunil, K., Katti, P., Nadagouda, S., & Hanchinal, S.G. (2019). Life table evaluation of *Spodoptera litura* (Fabricius) (Lepidoptera: Noctuidae) on groundnut. *International Journal of Current Microbiology and Applied Sciences*, 9, 1-12.

Venkateswarlu, U., Johnson, M., Narasimhulu, R., & Muralikrishna, T. (2018). Occurrence of the fall armyworm, *Spodoptera frugiperda* (J. E. Smith) (Lepidoptera: Noctuidae), a new pest on bajra and sorghum in the fields of agricultural research station, Ananthapuramu, Andhra Pradesh, India. *Journal of Entomology and Zoology Studies*, 6(6), 811-813.