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The Pharma Innovation

ISSN (E): 2277- 7695
ISSN (P): 2349-8242
NAAS Rating: 5.23
TPI 2021; SP-10(11): 715-719

www.thepharmajournal.com
Received: 13-09-2021
Accepted: 15-10-2021

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Effect of temperature on the development of fall armyworm (*Spodoptera frugiperda*) (J.E. Smith) under laboratory condition

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Abstract
From past three years (i.e. 2018) lepidopteran pest Fall armyworm *Spodoptra frugiperda* (J.E. Smith) became severe on maize crop in India which was earlier reported in Africa for the first time on late 2016. The distribution and abundance of Fall Armyworm are largely influenced by the relationship between development rate which is dependent and temperature which is independent. A change in temperature influences the developmental rate of insects as development of insects occurs within a specific temperature. Temperature also influences the duration of life cycle and ultimately the survival rate and mortality. The experiment was conducted on "Effect of temperature on the development of Fall Armyworm- *Spodoptera frugiperda* (J.E. Smith) under laboratory condition" Agricultural Entomology Section, College of Agriculture, Pune, during the year of 2020-21. The influence of temperature was studied at the temperature range of 18, 22, 26, 30, 32 ^{0}C ±2 ^{0}C and 65 ± 10% relative humidity with a 14:10 h (L: D) in BOD incubator.

Keywords: fall armyworm**,** temperature dependent, life history study, survival rate

1. Introduction
Maize (*Zea maize* L.) is one of the widely grown cereal for seed, fodder and seed purpose and ranks third next to wheat and paddy in production in India. In India, it is gaining significant importance on account of its growing demand for diversified uses, human consumption (sweet corn) and especially as animal feed and industrial uses like corn syrup, corn oil, extraction of dextrose and starch form food processing (Mallapur *et al.,* 2018). In India maize has three growing seasons namely *Kharif, Rabi* and Spring. *Kharif* season covers around 80 percent of the total area of maize in India and become the most important season covering. Maize is traditionally grown in *Kharif*- monsoon season, which is accompanied by high temperature (<35°c) and rainfall. In India, first time Fall Armyworm was reported on maize from the Indian sub-continent in Shivamoga, Hassan, Devanagere, Chikkaballapur, and Chitradurga districts of Karnataka in 2018 by several workers. After observing different reports from several states of India, it is indicated that it primarily targets maize in all the initial points of entry and moving to other hosts like sweet corn and sorghum subsequently. Development in insects occurs within a specific temperature range, a change in temperature will influence the developmental rate, the duration of the life-cycle and also the survival and mortality of the insect. If ambient temperature increases to near the thermal optimum of the insects, it can cause an increase in their metabolism and their activity also. The thermal optimum is the temperature at the temperature at which a species develops, reproduces and survives optimally is known as thermal optimum temperature and temperatures lower or higher than the optimum temperature leads to a decrease in the development rate of the insect. Temperature influences the duration of each instar, as well as the number of instars also which go up to the adult stage (Plessis *et al.* 2020) [11]. This research is to determine the development rate of *S. frugiperda* at different temperature to calculate the period for each stage to complete its development. It will be helpful to the scientists for developing successful pest management strategies as well as it will be helpful for the farmers in growing maize crop in future.

2. Materials and Methods
The culture of *S. frugiperda* larvae were collected from the maize fields around Pune and reared on maize plant under laboratory conditions for studying the life history studies of Fall Armyworm under different constant temperature.

The equipment used were compoun microscope, Vernier caliper, ocular micrometer, lenses, BOD incubator, humidifier, various containers, oviposion cage, plastic container, petri plates, cotton, vessels, tubes and food etc. used for raring of Fall Armyworm and the facilities were provided by All India Coordinated Research project Biological Control Laboratory, Agriculture Entomology Section, College of Agriculture Pune. Fall Armyworm were raised for one generation to enable the field stock to acclimatize to laboratory condition. The larvae were reared on fresh maize leaves in a separate plastic jars of (10x12 cm) and provided with sufficient food and space for avoiding the overcrowding and cannibalism. The jar was covered tightly with clean white muslin cloth by rubber band for preventing the larval escaping but with proper supply of oxygen. Everyday fresh and tender leaves were collected from the field at morning and evening hours. Maize leaves were washed in sterilized water before feeding. Fresh leaves were given to the larvae daily two times (i.e. morning and evening) until pupation. Larval plastic jars were cleaned every day for two times. Larva were transferred from one jar to another with the help of camel brush by dipping into the water. Sanitary conditions were maintained nicely by cleaning the partially eaten leaves, dried leaves and larval excreta to avoid the bacterial and fungal contamination in the plastic jar. The pupae were transferred into another petri plate and adults emerged from that pupa were collected daily. The pair of adults were releases in wooden cage of 30x30cm for mating. The male and female adults were determined by observing the shape, pattern and color of wings. Potted maize plant along with young leaves were placed inside the oviposition cage for the egg laying purpose. A swab of cotton dipped in 5 percent honey solution was kept inside the cage as food for adult and the cotton changed daily for escaping from ants. Female moth started laying eggs on underside of the maize leaves and these eggs were counted as F1 generation and used for further studies.

2.1 Experimental details

The experiment was carried out at 65 ± 10% relative humidity and a 14:10 h (L: D) in BOD incubator.

Treatment Details

Treatment No.	Temperature
T_1	18±2°C
T_2	22±2°C
T_3	26±2°C
T_4	30±2°C
T_5	32±2°C

2.2 Formulation of life history of Fall Armyworm *S. frugiperda* under laboratory condition

In order to construct the life history of Fall Armyworm under different temperature, 50 eggs and 30 larvae were kept in BOD at each temperature. Every day maize leaf feeding was done twice in a day till before pupation and leftover larvae and exuviae were removed. At each temperature 30 larvae were kept singly at each plastic container (10 × 12 cm) in BOD incubator at 18, 22, 26, 30, 32 ^{0}C ±2 ^{0}C with 14h L :10h D. Immediately after hatching freshly laid 50 egg were collected from the stock colony within 12 hours of oviposition with the help of wet camel air brush and individually eggs were placed on maze leaf bits and kept in plastic container covered with ventilated lid. The plastic containers were kept in BOD incubator. The eggs were checked daily twice until they hatched and the egg development were recorded daily. The eggs that hatched successfully were counted as hatched eggs and eggs that failed to hatched by the end of experiment were counted as dead. The number of eggs hatched, the duration of incubation period and hatching percentage were calculated. After hatching, 30 neonate larvae (10 larvae in each replication) were collected and transferred to the plastic container with maize leaf bits and covered by a ventilated lid and again kept them at the temperature range of 18, 22, 26, 30, 32 ^{0}C ±2 ^{0}C in the BOD incubator. On daily basis larval development and mortality were studied from I instar to VI instar under the same condition of temperature and photoperiod on the basis of exuviae. Daily observations of the larvae were taken before the molting. The pupa were collected from the soil and leaf debris and examined their color, shape and size. The sex was examined by their size i.e. male being smaller in size and female being longer. Pupal development was checked in all the constant temperature ranges until the emergence of the moths. The number of days to emergence of moth was recorded.

3. Result and Discussion

3.1 Life history of Fall Armyworm *S. frugipera* at constant temperature under laboratory conditions

3.1.1 Incubation and hatching percentage of Fall Armyworm

The observations on incubation period and hatching percentage of eggs of *S. frugiperda* was carried out at five different constant temperature viz., 18 ±2 ^{0}C, 22±2 ^{0}C, 26±2 ^{0}C, 30±2 ^{0}C and 32±2 ^{0}C in controlled laboratory conditions and are presented in table 1. Maximum incubation period (7.08 ± 1.3) days was observed when eggs of Fall Armyworm were kept at 18±2 ºC temperature, while minimum period was recorded i.e. 3.54 ± 0.76 days at 30±2 ºC. The egg incubation period was 5.54± 0.76, 4.58 ± 0.71 and 3.54 ± 0.76 days at 22±2 ºC, 26±2 ºC and 30±2 ºC temperatures, respectively. The incubation period was decreased for 7.08 ± 1.3 to 3.54 ± 0.76 days as the temperature increased from 18±2 ºC to 30±2 ºC. But 30 ºC temperature, it was observed that incubation again increased up to 3.58± 0.71 days. While 18±2 ºC temperature, the hatching percentage of the egg stage of Fall Armyworm was minimum and it was only 48.00 per cent at 18 ±2 ^{0}C, while maximum hatching percentage (88.00%) was recorded at temperature 30±2 ^{0}C. The hatching percentage of egg was 62.00, 82.00 and 84.00 per cent at 22±2 ^{0}C, 26±2 ^{0}C and 32±2 ^{0}C, respectively. According to observations, the incubation period of eggs of Fall Armyworm decreased while hatching percentage increased as the temperature increased up to 30 ºC.

3.1.2 Larval period, pupal period and larval mortality of Fall Armyworm

The larvae of Fall Armyworm *S. frugiperda* were kept at five different constant temperature viz., 18 ±2 ^{0}C, 22±2 ^{0}C, 26±2 ^{0}C, 30±2 ^{0}C and 32±2 ^{0}C in controlled conditions till to pupation. The period taken by each larva for completion of instar was recorded and finally total larval period calculated and larval mortality in each temperature also calculated. After pupation, the same pupae were kept at same temperature up to adult emergence and pupal period was recorded and presented in table 3.

3.1.2.1 At 18±2 ^{0}C temperature

The data presented in the table 3 revealed that larval stage of Fall Armyworm required 6.54 ± 0.48 days period for completion of first instar at 18±2 ^{0}C with range of 6.00 to 7.16 days. 4.01 ± 0.33 days period required for second instar larval stage with the range of 3.16 to 4.16 days. Larva of *S. frugiperda* completed its 3rd, 4th, 5th and 6th larval stages within 4.49 ± 0.48 days with the range of 4.00 to 5.08 days, 4.38 ± 0.44 days with the range of 4.00 to 5.00 days, 5.09 ± 0.07 days with the range of 5.00 to 5.16 days and 6.64 ± 0.47 days with the range of 6.08 to 7.16 days, respectively. The total larval period was 31.15 ± 0.42 days at 18±2 ^{0}C with the range of 30.56 to 31.56 days. The pupal period of Fall Armyworm was 18.39 ± 0.45 days with the range of 18.00 to 19.08 days at18±2 ^{0}C under laboratory condition.

3.1.2.2 At 22±2 ^{0}C temperature

The data presented in the table 3 revealed that the first instar larvae of Fall Armyworm required 5.08 ± 0.06 days at 22 ºC with range of 5.00 to 5.16 days and second instar larval stage required 4.08 ± 0.07 days with the range of 4.00 to 4.16 days, third instar larval stage required 2.64 ± 0.44 days with the range of 2.00 to 3.08 days, fourth instar larval stage required 3.24 ± 0.32 days with the range of 3.08 to 4.00 days, fifth instar period required 3.6 ± 0.46 days with the range of 3.00 to 4.08 days while sixth instar period required 5.42 ± 0.43 days with the range of 5.08 to 6.00 days. The larval period was 24.06 ± 0.59 with the range of 22.24 to 24.56 days and pupal period was 16.65 ± 0.48 days with the range of 16.08 to 17.16 days at 22±2 ^{0}C temperature.

3.1.2.3 At 26±2 ^{0}C temperature

According to the data presented in the table 3 it was observed that the larval stage completed with mean average period of 24.06 ± 0.59 days and was in the range of 22.24 to 24.56 days at 26±2 ^{0}C. 1st, 2nd, 3rd, 4th, 5th and 6th larval instars of Fall Armyworm required 3.06 ± 0.06, 2.05 ± 0.05, 2.07 ± 0.06, 2.32 ± 0.39, 2.39 ± 0.41 and 3.83 ± 0.42 days period at 26±2 ^{0}C, respectively. First instar was completed in the range of 3.00 to 3.16 days while 2nd, 3rd, 4th, 5th and 6th instars larval stage completed with the range of 2.00 to 2.16 days, 2.00 to 2.16 days, 2 to 3.08 days, 2.08 to 3.00 days and 3.16 to 4.16 days, respectively. The pupal period of fall armyworm was 16.65 ± 0.48 days with the range of 16.08 to 17.16 days 26±2 ^{0}C.

3.1.2.4 At 30±2 ^{0}C temperature

The data presented in the table 3 revealed that the first instar larvae of Fall Armyworm required 2.09 ± 0.07 days period when kept at 30 ºC with range of 2.00 to 2.16 days. The second instar larval stage required 1.87 ± 0.38 days with the range of 1.08 to 2.16 days. In case of third instar larval stage required 1.1 ± 0.06 days with the range of 1.00 to 1.16 days, fourth instar larval stage required 1.09 ± 0.06 days with the range of 1.00 to 1.16 days. While fifth instar larval stage required 1.99 ± 0.29 days with the range of 1.16 to 2.16 days and sixth instar larval stage required 2.35 ± 0.4 days with the range of 2.08 to 3.00 days. The total larval period at 30 ºC was 10.49 ± 0.52 with the range of 9.40 to 11.56 days. The total pupal period was 8.15 ± 0.24 days with the range of 8.00 to 9.00 days.

3.1.2.5 At 32±2 ^{0}C temperature

The data presented table 3 revealed that first instar larvae of Fall Armyworm required 2.08 ± 0.06 days period when kept at 32±2 ^{0}C with range of 2.00 to 2.16 days, second instar larval stage required 1.68 ± 0.45 days with the range of 1.16 to 2.08 days. In case of third instar larval stage required 1.86 ± 0.37 days with the range of 1.16 to 2.08 days, fourth instar larval stage required 1.09 ± 0.06 days with the range of 1.00 to 1.16 days. While fifth instar larval stage required 1.73 ± 0.46 days with the range of 1.16 to 2.16 days and sixth instar larval stage required 2.88 ± 0.38 days with the range of 3.00 to 3.16 days. The total larval period at 32 ºC was 11.31 ± 0.57 days with the range of 10.56 to 12.48 days. The total pupal period was 7.82 ± 0.43 days with the range of 7.16 to 8.16 days.

3.1.3 Effect of constant temperature on larval survival of Fall Armyworm *S. frugiperda* under laboratory conditions

The larvae of Fall Armyworm *S. frugiperda* reared at five different constant temperatures viz., 18 ±2 ^{0}C, 22±2 ^{0}C, 26±2 ^{0}C, 30±2 ^{0}C and 32±2 ^{0}C to study the effect of temperature on growth and survival and presented in table 13.7.

The survival of larval stage of Fall Armyworm was lowest i.e. 64 per cent at 18 ±2 ^{0}C and it was 87.40 and 86.77 per cent at 22±2 ^{0}C and 26 ±2 ^{0}C temperature, respectively while 100 per cent larvae of Fall Armyworm survived and kept at 30±2 ^{0}C. But again at 32 ºC±2 ^{0}C temperature, 80.00 per cent population survived.

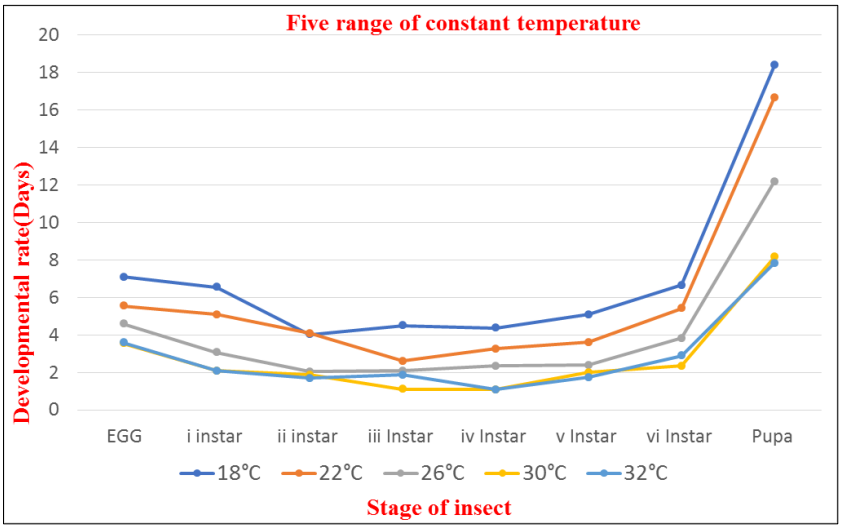

Fig 1: Development of Larval Instars of Fall Armyworm at different constant temperature under laboratory condition.

Table 1: Incubation and hatching percentage of Fall Armyworm *S. frugiperda* at constant temperature under laboratory conditions

Sr. No.	Temperature	Incubation Period (Days)	Hatching (%)
1.	18±2 ^{0}C	7.08±1.30	48.00
2.	22±2 ^{0}C	5.54±0.76	62.00
3.	26±2 ^{0}C	4.58±0.71	82.00
4.	30±2 ^{0}C	3.54±0.76	88.00
5.	32±2 ^{0}C	3.58±0.71	84.00

Table 2: Survival of larva of Fall Armyworm *S. frugiperda* at constant temperature under laboratory condition.

Sr. No.	Temperature	Survival of Fall Armyworm larva (%)
1.	18 ±2 ^{0}C	64.00
2.	22 ±2 ^{0}C	84.40
3.	26 ±2 ^{0}C	86.77
4.	30 ±2 ^{0}C	100.00
5.	32 ±2 ^{0}C	80.00

Table 3: Life history of immature stages Fall Armyworm *S. frugiperda* at different constant temperature under laboratory condition

Temperature/ Fall Armyworm stage	18±2 ºC	22 ±2 ºC	26±2 ºC	30±2 ºC	32±2 ºC
Incubation period (Days)	7.08 ± 1.30	5.54 ± 0.76	4.58 ± 0.71	3.54 ± 0.76	3.58 ± 0.71
I instar (Days)	6.54 ± 0.48	5.08 ± 0.06	3.06 ± 0.06	2.09 ± 0.07	2.08 ± 0.06
II instar (Days)	4.01 ± 0.33	4.08 ± 0.07	2.05 ± 0.05	1.87 ± 0.38	1.68 ± 0.45
III instar (Days)	4.49 ± 0.48	2.64 ± 0.44	2.07 ± 0.06	1.10 ± 0.06	1.86 ± 0.37
IV instar (Days)	4.38 ±0.44	3.24 ± 0.32	2.32 ± 0.39	1.09 ± 0.06	1.09 ± 0.06
V instar (Days)	5.09 ± 0.07	3.6 ± 0.46	2.39 ± 0.41	1.99 ± 0.29	1.73 ± 0.46
VI instar (Days)	6.64 ± 0.47	5.42 ± 0.43	3.83 ± 0.42	2.35 ± 0.40	2.88 ± 0.38
Larval period (Days)	31.15 ± 0.42	24.06 ± 0.59	15.72 ± 0.45	10.49 ± 0.52	11.31 ± 0.57
Pupal period (Days)	18.39 ± 0.45	16.65 ± 0.48	12.17 ± 0.45	8.15 ± 0.24	7.82 ± 0.43

Plate 1: Oviposion cage of Fall Armyworm studies

Plate 2: B.O.D for temperature

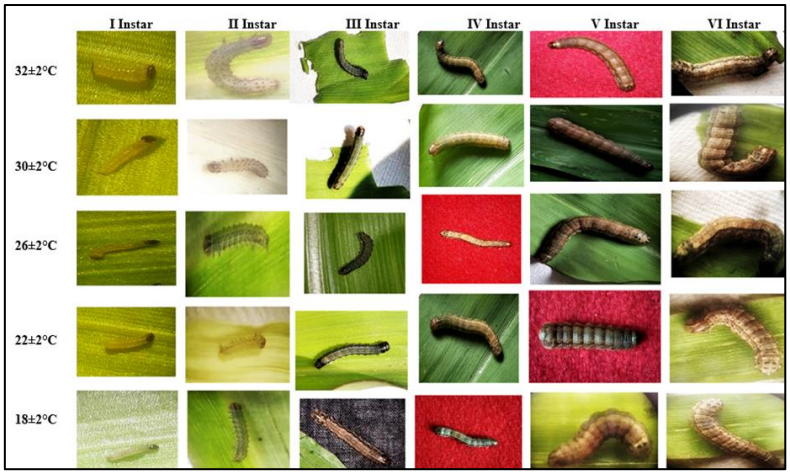

Plate 3: Development of larval instars of Fall Armyworm at different constant temperature under Laboratory Condition

4. Conclusions

The Fall Armyworm, *S. frugiperda* has potential to grow on all six different temperatures i.e. 18, 22, 26, 30, 32 ± 2 ºC but the most favourable temperature for growing was 30 ºC. Egg incubation, larval and pupal growth of Fall Armyworm was faster and shorter at 30±2 ºC and 3.54 ± 0.76 days incubation period, 10.49 ± 0.52 days larval period and 8.15 ± 0.24 days pupal period recorded. While growth and development of Fall Armyworm was recorded very slow and maximum period i.e. 7.08 ± 1.30, 31.15 ± 0.42 and 18.39 ± 0.45 days required for completion of egg incubation, larval and pupal stage at 18±2 ºC. Period from egg stage to pupation was decreased when the temperature increased from 18±2 ºC to 30±2 ºC.

5. Acknowledgements

The authors are thankful to Head and Faculty members, Department of Entomology Section, College of Agriculture Pune for their valuable suggestions, assistance and encouragement.

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