International Journal of Sciences: Basic and Applied Research (IJSBAR)

ISSN 2307-4531
(Print & Online)

http://gssrr.org/index.php?journal=JournalOfBasicAndApplied

Effect of Temperature and Relative Humidity on Development and Survival of Angoumois Grain Moth, *Sitotroga cerealella* (Olivier) (Lepidoptera: Gelechiidae) on Stored Maize

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Abstract

The effects of different rearing temperatures (26°C, 30°C, 32°C and 35°C) and of different relative humidities (55, 65, 70 and 85 per cent) on the development and survival of Angoumois grain moths, *Sitotroga cerealella* (Olive.) were investigated on maize under laboratory conditions during the period from May 2013 to January 2014. Temperature was the main factor affecting egg incubation period, larval-pupal development time, and adult survivorship. The highest number of eggs was laid at 30°C (172.50/female). The shortest incubation period occurred at temperatures of 32°C and higher, but they increased sharply as temperature decreased. Larval-pupal development time was shortest at 30°C. Survivorship was optimal at 30-32°C, but decreased sharply at 26 and 35°C. Male longevity was significantly more (7.17 days) at 26°C, and the least (4.17 days) was at 35°C; likewise, female longevity was significantly more (10.33 days) at 26°C, and the least (7.83 days) at 35°C. The relative humidity had no apparent effect on the duration of larval-pupal development; however, 70-85 per cent was optimal for hatching.

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Fecundity increased with increases up to 85 per cent RH, at which it was 167.7 eggs/female. The optimum conditions for development and survival of Angoumois grain moth on maize were 30-32°C and 70-85 per cent RH. The data will be useful for determining safe storage conditions for maize and for developing a computer model for simulating population dynamics of immature *S. cerealella.*

Keywords: Temperature; Relative humidity; *Sitotroga cerealella*; survivorship; Fecundity; Longevity; Stored maize grain

1. Introduction

Maize (*Zea mays* L.) is an important cereal crop in India after wheat and rice serving as source of food, feed and industrial raw material [1]. However, the use value of maize is hampered due to many biotic and abiotic factors both in the field and storage. Storage insect pests are the primary causes of loss for maize grains in storage. Losing crops to insect pests constitutes a great constraint to the realization of food security worldwide.

Among the stored grain pests Angoumois grain moth, *Sitotroga cerealella* (Gelechiidae: Lepidoptera) is one of the most serious pests of stored maize (both unshelled ears and shelled grains) at post harvest level. At the time of harvest the grain shows no sign of infestation usually, and the first adult emergence takes place after few weeks' of storage. A sizeable quantity of unshelled ears stored at farmer's level is badly damaged by Angoumois grain moth. It is an extremely efficient seed penetrator [2]. The Angoumois grain moth is one of the most dominant species in stored maize [3]. It is the number one pest on maize stored as unshelled cob. It not only infests the grains in storage, but also in field conditions. Despite the importance of this pest, quantitative data describing its life history over a range of environmental conditions at which it will develop are lacking. Such data can be used to define optimal storage conditions to reduce the level of infestation and damage by pests and to develop simulation models for optimizing pest management strategies [4]. High moisture content of grains (>12 per cent), high atmospheric temperature (25 to 35°C) and relative humidity (>60 per cent) during storage make the environment conducive for proliferation of storage pests.

In order to develop economical and effective control measures for *S. cerealella* , detailed and accurate knowledge of its bio-ecology is essential along with possible prediction of population levels and study of the various mortality factors affecting its abundance. The life cycle of this insect varies with temperature, relative humidity, and diet. The authors in [5] reported that total development time of this insect, from egg to adult, was completed in 25 days when reared on sorghum at 30°C and 70 per cent RH. Total development time was 28 days when the insects were reared on maize kernels mixed with some flour at 30°C and 80 per cent RH [6] and 36 days when the insects were reared in maize at ambient temperature and relative humidity [7]. Larval infestation leaves no visible symptoms on the grains. According to [8], total larval development of *S. cerealella* can be completed by 19 days at 30°C and 80 per cent relative humidity. Temperature limits the development at16°C & 35°C and humidity between 50 -90 per cent seems to have little effect on the rate of development. The authors in [6] concluded that 25 – 30°C and 80 per cent RH are most favourable for development, survival and reproduction of the Indian strain of *S. cerealella*. The maximum population increase of *S. cerealella* occurred at 30°C. High relative humidity and temperatures higher than 30°C are not suitable for development of this pest

[9]. Before pupation the larva constructs a chamber just under the grain seed coat, forming a small circular translucent window. Pupation takes places within the chamber inside a delicate cocoon. Adults fly well and cross-infestation occurs readily; but they are short-lived and generally survive only 5-14 days and in suitable stores breeding may be continuous throughout the year [8].

Life history data for insects often do not include information on the effect of extreme conditions, where development or longevity is quite protracted or where survival is normally low. Often these two responses are linked. Properly stored commodities may seldom reach optimal conditions for insect growth. For example, corn stored in South Carolina was below 20^{o}C for 55-85 per cent of the year [10]. This may result in a situation where a computer model is being used to simulate growth for a considerable length of time under conditions for which little or no data were available to develop the model [11].This causes concern because simulation studies have shown that small changes in development or survival rates can have a large impact on the size of subsequent populations [12]. Several studies on the life history of *S. cerealella* have been reported [7, 6, 5]. However, these studies were carried out under various environmental and diet conditions and did not include some extreme environmental conditions and their combined effects.

Therefore, this study was conducted with the objective to determine development and survivorship of Angoumois grain moth reared on maize grain over the range of temperatures and relative humidities in order to identify favorable and unfavorable levels of temperature and humidity and also their interaction influencing populations of Angoumois grain moth.

2. Materials and Methods

2.1. Rearing of Sitotroga cerealella

The culture was reared on untreated and disinfested (free from live stages of any insects) grains of commercial maize variety, Pratap makka, in 2 L plastic jars in the laboratory of Entomology at Rajasthan College of Agriculture, Udaipur. The openings of the jars were covered with muslin cloth held in place by rubber bands. The moth culture was maintained by continuously releasing the insects on fresh disinfested grain. The culture was maintained at a temperature of 28 ± 1.0^{o}C and relative humidity of 65 ± 5 per cent and 12 h light: 12 h dark photoperiod in biological oxygen demand (B.O.D) incubator. Black paper strips were used to collect the eggs as described by the authors in [13]. After removing from the jars the papers were unfolded and cut into pieces and the eggs adhering to them were used for experimental purposes.

2.2. Observations on development and survivorship

Biological studies of *S. cerealella* were undertaken in the laboratory at four different levels of temperature (26^{o}C, 30^{o}C, 32^{o}C and 35^{o}C) and relative humidity (55, 65, 70 and 85%) in order to study their effect on development and survival of the insect. Fifty gram conditioned maize grains were taken in plastic jars (250 cm^{3}). Fifty one day old eggs of *S. cerealella,* after separating under binocular microscope were inoculated in each jar. These jars were kept in different biological oxygen demand (B.O.D.) incubators, which were adjusted at fixed temperatures of 26^{o}C, 30^{o}C, 32^{o}C and 35^{o}C with variable relative humidities and fixed humidity levels of 55, 65, 70 and 85% with variable temperatures. Observations were undertaken on fecundity, incubation period, per cent hatching, Larval-Pupal period, developmental period (egg to adult), adult longevity and survival percentage of adult moth as described here under:

Development time: Twenty days after the beginning of the experiments and every day thereafter, each jar was examined for emergence of adults. Development time was measured by recording the time between inoculations to adult emergence (in days) in each treatment.

Larval-pupal development time: Larval period was worked out by recording the date of hatching and date of emergence of window on the grain. The period between window formation and adult emergence was considered as pupal period.

Adult survival: per cent survival from egg to adult was calculated from eggs inoculated and adult emerged from these and are represent in per cent.

Fecundity/Number of eggs: The newly emerged adult moths from each treatment in the above experiment were transferred, one male and one female, into plastic vials to evaluate female fecundity. The vials were covered with muslin cloth held in place by rubber bands. A slit was made in the middle of the muslin cloth to allow the insertion of the oviposition paper. Black paper strips were used to collect the eggs as described by the authors in [13]. No food was provided. Each day the paper strips were removed and replaced with another one until the death of the females. In the mean time the longevity of mated male and female were recorded. The paper strips with the egg was carefully unfolded and the eggs were counted under a binocular microscope.

Incubation period and hatching percentage: The egg hatching period was studied by collecting egg samples from each treatment. A sample of 50 eggs from each treatment was taken to evaluate egg hatching. The eggs were placed in the vials. Paper strips were removed daily from vials and the number of egg hatched was recorded. Hatching period was noted as interval in days from inoculation to 1st instar larval emergence. The percentage of egg hatching was calculated by counting number of larvae from 50 eggs and expressed in per cent.

All the biological parameters were studied in the experiments laid out as Completely Randomized Design with three replications for two consecutive seasons.

2.3. Statistical analysis

The data on recorded parameters of *S.cerealella* were subjected to statistical analysis by using PROC GLM [4]. Data obtained were transformed using arcsine transformation (for percentage data) before analysis of variance. Treatment means were separated using Students Newman Keuls test at 5% level. Back transformed means are presented in the tables.

3. Results

3.1. Larval-pupal development time:

Analysis of pooled data for two years showed that duration of larval-pupal development significantly varied with temperature and interaction of temperature by relative humidity, but not with relative humidity (Table 1, 2 and Fig. 1). So, we described larval-pupal development period as a function of temperature. At 26°C the laval-pupal period took longer time of 33.83 days for their development, whereas larval-pupal development was completed in 26.31 days at 30°C (Table 1). Regarding the combined effect of temperature and relative humidity, it was observed that at 26°C and 55 per cent RH the time required for completion of larval-pupal period was longer (34.35 days) and significantly different from all other combination except at interaction of 26°C and 70 per cent RH (33.17 days), whereas only 22.33 days were required to complete the larval-pupal development at 30°C and 70 per cent RH (Fig. 1).

3.2. F_1 adult emerged and survival percentage:

The maximum survival (63.50 per cent) was recorded at 30°C and minimum (37.00 per cent) at 35°C (Table 1). The data recorded on the effect of relative humidity showed that 85 per cent RH was most favourable for survival of Angoumois grain moth. On the contrary, the lowest survival percentage (30.50 per cent) could be obtained at 55 per cent RH (Table 2). The combined effect of temperature and relative humidity revealed that interaction of 30°C by 70 per cent RH resulted in maximum adult emergence (32.6) and survival (65 per cent) of the pest from eggs. The same trend was also observed with the interaction of 30°C by 85 per cent RH. The minimum (4 and 5 per cent) survival were obtained at 35°C by 55 per cent RH and 35°C by 70 per cent RH, respectively (Table 3).

3.3. Adult development Period:

From Table 1, 2 and 3, we observed that moth development period was varied significantly in different levels of temperature, relative humidity and their interaction. The maximum developmental period (39.67 days) of *S. cerealella* was at the lowest temperature 26°C which was statistically different from other different levels of temperature and closely followed by the temperature of 35°C (35.50 days). The minimum developmental period (31.26 days) of *S. cerealella* was found from 30°C temperature (Table 1). At 26°C moth emergence was prolonged by 8.41 more days than at 30°C. Optimum temperatures for development were 30 and 32°C. Data on effect of relative humidity showed that longest development period (37.67) of moth was found from the lowest (55 per cent) RH, which was statistically different from all other humidity levels. The shortest development period (31.33 days) was recorded at 85 per cent RH. There were no significant differences among the remaining two levels of RH. But with the increase of relative humidity moth development time decreased significantly (Table 2). The combined effect of temperature and relative humidity on development period is presented in Table 3. The longest development period (41.85 days) of adult moth was recorded at combination of 26°C and 55 per cent RH, which was significantly different from all other combinations. The shortest development time (27.33 days) was observed at 30°C under 70 per cent relative humidity (Table 3).

3.4. Longevity of adult moth:

The maximum adult longevity (7.17 days for male and 10.33 days for female) was observed at 26°C while the minimum (4.17 days for male and 7.83 days for female) was recorded at 35°C (Table 1). The observations recorded on the effect of relative humidity revealed that the adult male and female could survive up to 7.50 and 12.50 days, respectively at 70 per cent RH. Minimum adult longevity of 4.67 days for male and 7.50 days for female were recorded at 55 per cent RH (Table 2). The combined effect of temperature and relative humidity indicated that the combination of 30°C and 85 per cent RH resulted in maximum longevity of male and female moths (6.83 and 8.50 days, respectively), whereas it was minimum at 35°C with 55 per cent RH followed by 35°C with 70 per cent RH (Fig. 2).

Table 1. Effect of different temperature levels on developmental parameters of *S. cerealella (*Mean±S.E)

Temperature levels	Larval-pupal period (days)	No. of Adult emerged	Survival percentage	Development time (days)	Longevity of adult (days)	
					Female	Male
26°C	33.83±0.60	20.50±0.43	41.00±0.85	39.67±0.21	10.33±0.67	7.17±0.16
30°C	26.31±0.60	31.83±0.48	63.50±0.88	31.17±0.30	9.50±0.42	6.50±0.42
32°C	28.00±0.97	29.50±0.42	59.00±0.81	33.17±0.70	8.50±0.43	5.33±0.33
35°C	31.17±0.60	18.67±0.98	37.00±1.96	35.50±0.76	7.83±0.54	4.17±0.47
C.D. at 5%	1.20	1.90	3.70	1.35	1.68	1.18
C.V. (%)	3.29	6.15	6.00	3.15	15.10	16.56

Table 2. Effect of different relative humidity levels on developmental parameters of *S. cerealella* (Mean±S.E)

Relative Humidity levels	Larval- pupal period (days)	No. of Adult emerged	Survival percentage	Development time (days)	Longevity of adult (days)	
					Female	Male
55%	30.33±1.25	15.33±1.05	30.50 ±2.06	37.67±0.88	7.50±0.56	4.67±0.49
65%	27.17±1.13	28.83±0.47	57.50 ±0.95	34.21±0.96	9.83±0.30	5.67±0.33
70%	28.67±1.33	29.83±0.47	59.50 ±0.88	33.50±1.05	12.50±0.42	7.50±0.42
85%	28.33±0.80	33.33±0.98	66.50 ±1.99	31.33±1.14	7.67±0.33	4.83±0.30
C.D. at 5%	ns	2.12	2.60	3.51	1.38	1.28
C.V. (%)	10.75	6.42	4.49	8.06	11.94	18.32

"ns" represent non-significant

Table 3. Interaction effect of different levels of temperature and relative humidity on developmental parameters of *S. cerealella* (Mean±S.E)

Temperature X RH	No. of Adult emerged	Survival percentage	Development time (days)
26°Cx55%	11.83±0.40	23.50 ±0.81	41.85±0.85
26°Cx70%	22.17±0.31	44.00 ±0.57	38.50±1.16
26°Cx85%	31.00±0.57	62.00 ±1.15	38.30±0.60
30°Cx55%	16.83±0.30	34.00 ±0.57	32.00±0.42
30°Cx70%	32.67±0.21	65.00 ±0.36	27.33±0.55
30°Cx85%	32.00±0.25	64.00 ±0.51	32.02±0.00
35°Cx55%	2.17±0.31	4.00 ±0.57	38.17±0.74
35°Cx70%	2.50±0.22	5.00 ±0.36	34.36±0.55
35°Cx85%	3.50±0.42	7.00 ±0.85	32.43±0.51
C.D. at 5%	0.96	1.59	1.61
C.V. (%)	4.79	4.02	3.44

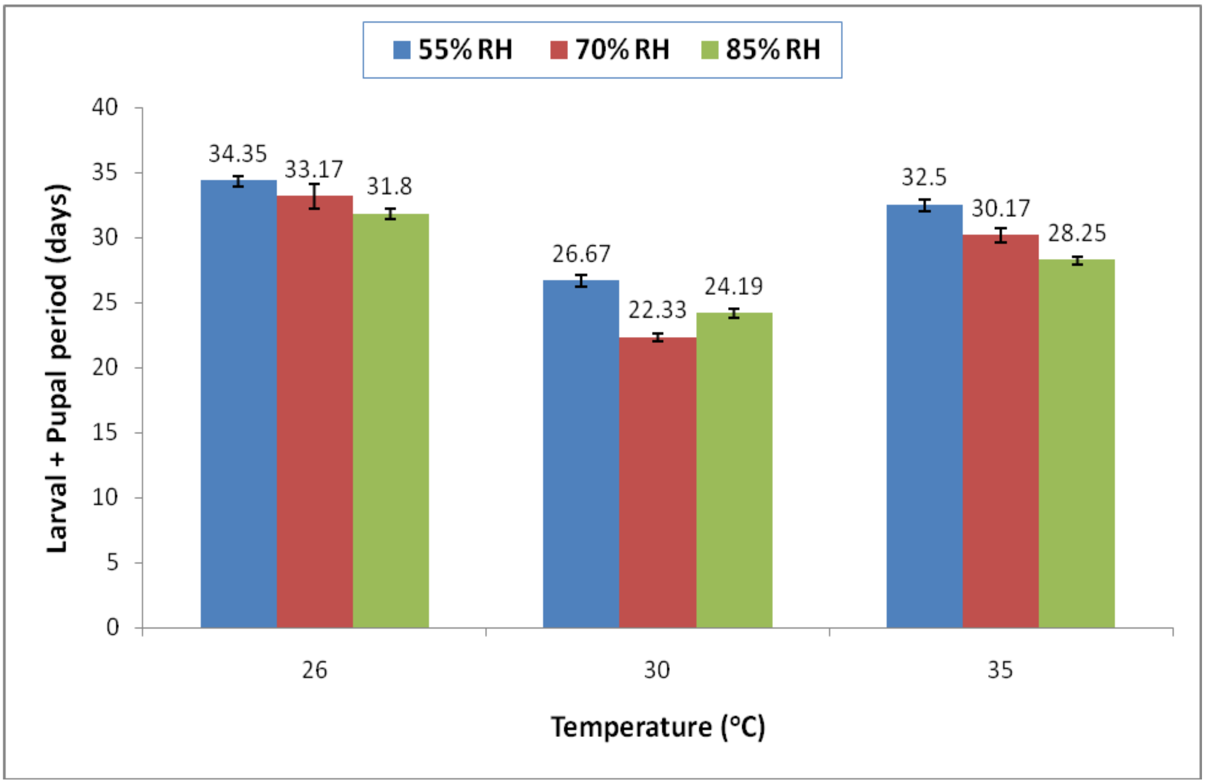

Figure 1. Interaction effect of different levels of temperature and relative humidity on larval+pupal period of *S. cerealella* (Mean ± S.E)

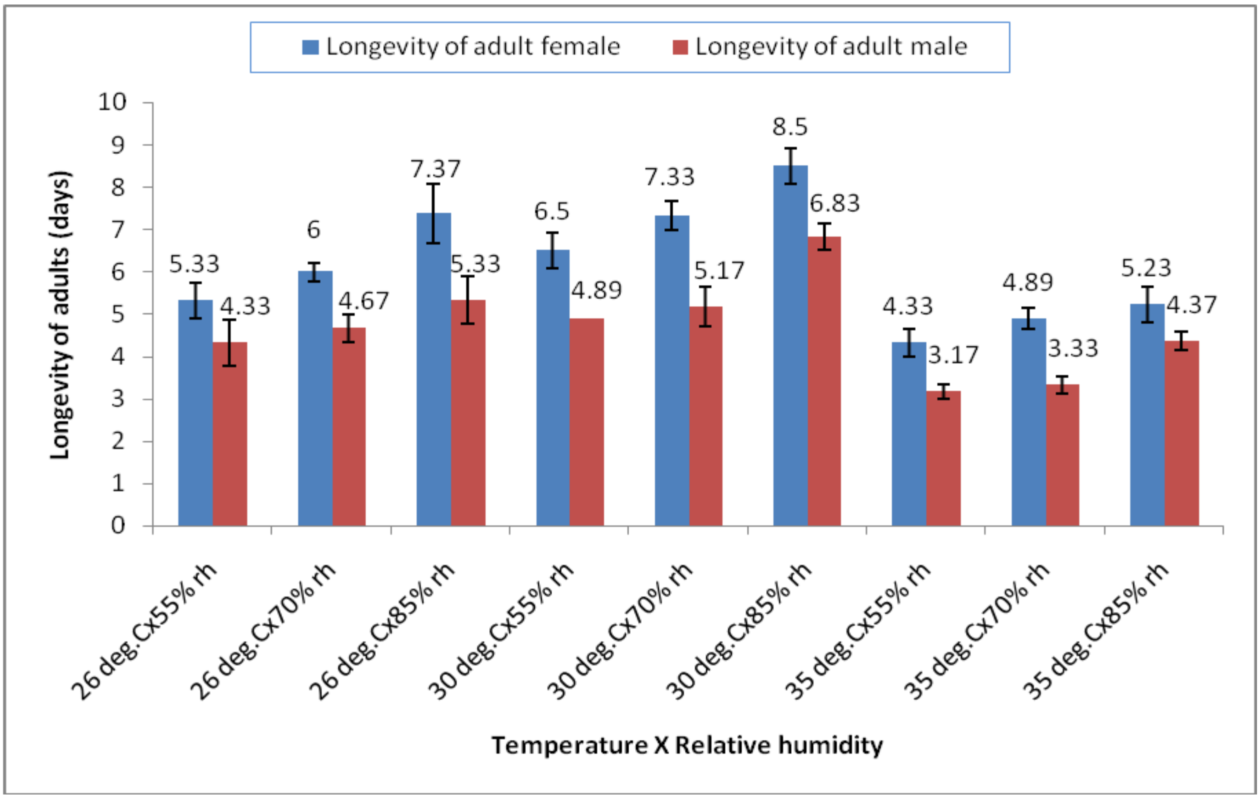

Figure 2. Interaction effect of different levels of temperature and relative humidity on longevity of adults *S. cerealella* (Mean ± S.E)

3.5. Fecundity:

The data on the effect of temperature, relative humidity and interaction of both the factors on the fecundity of *S. cerealella* are presented in Table 4, 5 and 6. It is evident from the data that mean number of eggs laid per female moth was maximum (172.50) at 30^{o}C and followed by that at 26^{o}C (170.17) which were statistically at par. High temperature (35^{o}C) reduced the fecundity of the insect. The average number of eggs laid per female at 35^{o}C was 94.50 which was significantly lower than all other levels of temperature (Table 4). Maximum (167.67) number of eggs per female moth was found at 85 per cent relative humidity while the lowest number of eggs (118.50) was laid at 55 per cent relative humidity (Table 5). The interaction effect of temperature and relative humidity has been shown in Table 6. The result showed that the combination of 30^{o}C and 70 per cent RH was optimum for egg laying, where 176.67 eggs were laid by a single female followed by the combination of 30^{o}C and 85 per cent RH, where the eggs laid by a single female were 164.17. Under the combined effect of 35^{o}C and 55 per cent RH the lowest (98.17) eggs/female were produced which is significantly different from all other combinations (Table 6).

3.6. Incubation period:

Duration of the egg hatching varied significantly with temperature, relative humidity and the interaction (Table 4, 5 and 6). The longest incubation periods (5.33 and 4.50 days) occurred at 26^{o}C and 30^{o}C, respectively, while the shortest incubation periods occurred at 32 and 35^{o}C, and incubation period increased as temperatures decreased below 30°C (Table 4). Similar trends were observed in case of relative humidity. Longest incubation period (9.00 days) was observed at 55 per cent RH which was significantly different from all other levels of RH. Higher levels of relative humidity *viz.*, 70 and 85 per cent resulted in shorter hatching period of 4.83 and 4.17 days, respectively, and were statistically at par (Table 5). Regarding the combined effect of temperature and relative humidity, it was observed that at 26°C and 55 per cent RH and 26°C and 85 per cent RH, the egg hatching period was lengthened up to 6.50 days, whereas minimum egg hatching period of 3.83 days was observed at 35°C and 85 per cent RH (Table 6).

3.7. Number of larvae emerged and egg hatching percentage:

Maximum larval emergence and hatching was recorded at 26°C and 30°C, where 45.83 & 45.33 larvae emerged and 91.50 & 90.50 per cent eggs hatched, respectively, and were statistically at par. While, the minimum hatching (72.00 per cent) was observed at 35°C (Table 4).

Table 4. Effect of different temperature levels on reproductive attributes of *S. cerealella* (Mean±S.E)

Temperature levels	Fecundity (eggs/female)	Incubation period (days)	No. of larvae emerged	Egg hatching percentage
26°C	170.17±0.60	5.33±0.55	45.83±0.60	91.50± 1.14
30°C	172.50±1.17	4.50±0.42	45.33±0.33	90.50 ±0.61
32°C	101.00±0.81	3.83±0.30	40.33±0.71	80.50 ±1.45
35°C	94.50±1.82	4.17±0.31	36.00±0.73	72.00 ±1.46
C.D. at 5%	2.73	1.22	1.97	3.34
C.V. (%)	1.65	18.27	3.83	4.06

Table 5. Effect of different relative humidity levels on reproductive attributes of *S. cerealella* (Mean±S.E)

Relative Humidity levels	Fecundity (eggs/female)	Incubation period (days)	No. of larvae emerged	Egg hatching percentage
55%	118.50±0.99	9.00±0.57	33.33±0.76	66.50 ±1.54
65%	152.33±1.35	5.67±0.55	40.67±0.80	81.50 ±1.66
70%	162.17±0.94	4.83±0.30	41.17±0.87	82.50 ±1.66
85%	167.67±1.89	4.17±0.31	37.83±1.13	75.50 ±2.21
C.D. at 5%	4.19	1.30	2.43	3.24
C.V. (%)	2.27	17.82	5.16	4.30

The results obtained on the effect of different levels of relative humidity showed that the most favourable levels of RH required for maximum egg hatching were 70 and 65 per cent, which resulted in 82.50 and 81.50 per cent egg hatching, respectively and not significantly different from each other. At 55 per cent RH lowest larval and egg hatching percentage (66.50 per cent) were observed (Table 5). The data on combined effect revealed that the combination of 26^{o}C and 85 per cent RH was optimum for egg hatching, where 97.00 percent hatching was recorded. It was followed by the combination of 26^{o}C and 70 per cent RH, where the egg hatching percentage was 90.50 per cent. On the contrary the minimum egg hatching percentage (48.00 per cent) was observed at combination of 35^{o}C and 85 per cent RH (Table 6).

Table 6. Interaction effect of different levels of temperature and relative humidity on reproductive attributes of *S. cerealella* (Mean±S.E)

Temperature X RH	Fecundity (eggs/female)	Incubation period (days)	No. of larvae emerged	Egg hatching percentage
26^{o}Cx55%	140.17±0.60	6.50±0.43	43.00±0.25	86.00 ±0.57
26^{o}Cx70%	146.67±0.55	4.83±0.30	45.33±0.21	90.50 ±0.34
26^{o}Cx85%	153.83±0.94	6.50±0.42	48.33±0.21	97.00 ±0.36
30^{o}Cx55%	135.17±0.30	5.33±0.33	39.00±0.25	78.00 ±0.57
30^{o}Cx70%	176.67±0.55	4.00±0.25	43.83±0.40	87.50 ±0.71
30^{o}Cx85%	164.17±0.31	5.83±0.31	40.33±0.21	81.00 ±0.36
35^{o}Cx55%	98.17±0.47	4.67±0.55	27.33±0.33	54.50 ±0.71
35^{o}Cx70%	109.17±0.60	4.17±0.30	31.17±0.30	62.00 ±0.57
35^{o}Cx85%	117.00±0.81	3.83±0.31	24.00±0.36	48.00 ±0.57
C.D. at 5%	1.73	1.07	0.85	1.29
C.V. (%)	1.07	18.04	1.92	1.78

4. Discussion

Temperature is an important component of the environment and the rate of metabolism, growth, development, reproduction, general behaviour and distribution of insect pests are largely controlled by it. The effect of relative humidity on the development of storage pest is almost intimately associated with that of temperature and operates indirectly through the moisture content of grains. Below a certain minimum threshold temperature insects do not complete development from egg to maturity and the pest population cannot increase. At temperatures only slightly above their threshold, say within 4-5°C, mortality rates are extremely high for virtually all stages of development. Most species do not multiply fast enough to become a pest until temperature is somewhere between 3-6°C above the minimum threshold for development.

Our results in the present study is in close agreement with the findings of the author in [15] who reported the maximum developmental period of *S. cerealella* at the lowest temperature of 20^{o}C and 24^{o}C while the minimum developmental period (17.42 days) of *S. cerealella* was at 32^{o}C. With the increase in temperature moth development duration also decreased significantly. The authors also reported that the longevity of females was more than that of males which is also confirmed in the present study. According to the author in [8], total larval development of *S. cerealella* can be completed in 19 days at 30^{o}C and 80 per cent relative humidity. The authors in [6] concluded that 25 – 30°C and 80 per cent RH are most favorable for development, survival and reproduction of the Indian strain of *S. cerealella*. The maximum population increase of *S. cerealella* occurred at 30°C. High relative humidity and temperatures higher than 30°C are not suitable for development of this pest [9]. The authors in [16] reported that the duration of the egg stage was negatively correlated with temperature (the optimum for hatching being at 27°C), as was the duration of the preoviposition, oviposition and postoviposition periods and the adult life-span for *S. cerealella* reared on wheat grain . According to these Authors the maximum number of eggs was also laid at 27 °C (155/female). These notions are in close agreement with the current finding..

The authors in [6] reported on duration of immature development on corn at five levels of temperature and three levels of relative humidity, but they used corn kernels mixed with flour. In our study the duration of egg and immature development was somewhat slower. The study by the authors in [5] on sorghum also indicates longer immature development times than reported by the authors in [6]. In the study by authors in [5], the optimum conditions for immature development were also found to be 25-30°C and 60-80 per cent RH. In another similar study the authors in [17] reported life history of immature Angoumois grain moths, *S. cerealella,* on dent corn at seven temperature levels and four different relative humidities. According to these authors temperature was the main factor affecting egg incubation period, larval-pupal development time, and larval-pupal survivorship. Duration of development for both egg and larval-pupal stages was a bit faster in our study across all levels of temperature and relative humidity as compared with results from their study. For example, at 30°C and 55 per cent RH, it took 6.8 and 31.1 days in their study compared with 5.3 and 26.7 days in our study for duration of development of the egg and larval-pupal stages, respectively. They reported that the most suitable environmental conditions for development from egg to adult occurred at 25°-30°C and 80 per cent RH (28.1 days). Similarly, our results indicated that the best conditions for development occurred at 30°C and 70 per cent RH (33.33 days). Survival at 30°C and 55 per cent RH during both the egg stage and through immature development was lower in our study (78 and 34 per cent, respectively) compared with their data (83 and 50 per cent, respectively). In general at both temperature and humidity levels longevity of female moth was more than that of male. So, these slight differences between the present results and some of previous studies may be due to the reasons that environmental conditions, food, and genetics of the insect populations varied among studies.

The average incubation period on rice was 5.5 ± 0.03 days [18], but in summer season incubation period was from 2 to 3 days and in winter season it ranged from 5 to more (overall, incubation period depends on temperature and relative humidity). Egg hatching was reported to take 11 days at 27.3°C temperature and 68.3 per cent RH [19]. The results obtained in the present study were in close agreement with these findings. The author in [7] reported that the incubation period of eggs and the duration of the larval-pupal period of *S. cerealella* varied with the maturity of the corn used. The authors in [20] showed that the number of eggs laid, duration of immature development and the weight & number of progeny produced by *S. cerealella* was correlated with the protein, sugar, and fat content of the corn on which the insect is reared. Thus, the differences in immature development and survivorship observed by different scientists might have been related to differences in the rearing media and strains used.

5. Conclusion

In the present study, the temperature and relative humidity of the microclimate produced effects similar to those measured in the macro-environment. Under natural condition *S. cerealella* (Olivier) is more or less active throughout the year but less active during the period from mid December to first part of March. During July to August the population of the pest reaches its peak. Moth development stage duration also varied for different temperatures. With the increased of temperature it also decreased. The present study showed that a temperature of 30 – 32^{o}C and 70 – 85 per cent RH were optimum for larval-pupal development and survivorship. The combination of 32^{o}C with 70 and 85 per cent RH were optimum and favourable for the insect development and survival. Temperature had the greatest effect on development and survivorship of immature Angoumois grain moths. Although the effect of relative humidity was sometimes statistically significant, this effect was minimal and usually most pronounced at extreme temperatures. This indicates that the effect of relative humidity is most important when the insect is already stressed because of adverse temperatures. Larval-pupal development was not significantly affected by humidity; therefore, humidity would not be closely controlled once the cribs were bagged. So, we described larval-pupal development period as a function of temperature.

Acknowledgements

The authors are grateful to Department of Entomology, RCA and Indian Council of Agricultural Research (ICAR) for financing this study. We are indebted to Dr. N.K Bajpai for his kind cooperation in providing B.O.D. incubators.

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