


EFFECTS OF CONSTANT AND FLUCTUATING TEMPERATURES AND HUMIDITIES ON THE SURVIVAL OF SPODOPTERA FRUGIPERDA PUPAE (LEPIDOPTERA: NOCTUIDAE)

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ABSTRACT

Pupae of the fall armyworm, Spodoptera frugiperda (J. E. Smith), were maintained in the laboratory for emergence under selected constant and fluctuating temperatures and humidities. Temperatures ranged from 10 to 40°C, with a vapor pressure deficiency maintained constant at 8.5 mb in one study. No eclosion occurred at 10°C or at 40°C. Insects held at 15 and 35°C had low survival and a high percentage (39-62%) were deformed. The optimum rate of development occurred at 30 and 35°C, but a high percentage (58% of males, 39% of females) of the insects held at 35°C emerged deformed. In a comparison between the constant and fluctuating temperatures (the mean of the fluctuating temperature equalled the constant temperature treatment), survival was not affected, but development was generally faster with the fluctuating treatment. In another study, relative humidity ranged from 20 to about 100% (33.9 to about 0 mb) and was maintained at 30°C. Percentage survival, rate of development, or percent deformity were not affected by humidity. Weight loss was similar among insects held under different humidity treatments and was not affected by constant or fluctuating condition. Although survival was the same for the sexes, females developed at a faster rate and a smaller percentage emerged deformed as compared with males.

RESUMEN

Se mantuvieron pupas del cogollero del maíz, Spodoptera frugiperda (J. E. Smith) en el laboratorio a diferentes temperaturas y humedades para determinar su efecto en la emergencia. Las temperaturas fluctuaron desde 10 a 40°C, con una deficiencia de

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presion de vapor constante de 8.5 mb. No hubo eclosion a 10°C o a 40°C. Los insectos mantenidos a 15 y 35°C tuvieron una baja sobrevivencia y un alto porcentaje (39-62%) estaban deformados. La rata óptima de desarrollo ocurrió a 30 y 35°C, pero un alto porcentaje (58% de machos, 39% de hembras) de los insectos mantenidos a los 35°C de temperatura emergieron deformados. En una comparación entre las temperaturas constantes y fluctuantes (el promedio de la temperatura fluctuante era igual al de la temperatura constante), la sobrevivencia no fue afectada pero el desarrollo fue más rápido con el tratamiento de temperatura constante. En otro estudio, la humedad relativa tuvo un rango desde 20-100% (33.9 a 0 mb) y fue mantenida a 30°C. El porcentaje de sobrevivencia, rata de desarrollo, o porcentaje de deformidad no fueron afectados por la humedad. La pérdida de peso fue similar entre insectos mantenidos en varias humedades y no fue afectado por condiciones fluctuación constante. Aunque la sobrevivencia fue la misma para los dos sexos, las hembras se desarrollaron más rápidamente y un porcentaje menor mostró deformaciones comparadas con los machos.

The fall armyworm, *Spodoptera frugiperda* (J. E. Smith), is widely distributed throughout the Americas and Caribbean Basin. Each spring and summer, the moths migrate and reinfest areas which were unsuitable during the winter because of low temperature. Because of its wide distribution, the fall armyworm is subjected to much climatic diversity, namely, temperature and moisture, and soil type. Environmental factors influencing development and survival may contribute to the dynamics of the system in a given locale.

Differences in arthropod developmental times between constant and fluctuating temperature have been reported by numerous researchers. Hagstrum & Milliken (1991) listed 54 such examples by different researchers. Estimating insect development based on constant temperature generally underestimates the rate of development (Hagstrum & Milliken 1991).

Because the fall armyworm pupates from about 2 to 8 cm below the soil surface (Sparks 1979), it is subjected to the daily change in air temperature. Vickery (1929) reported that fall armyworm pupae can survive and emerge with a low temperature of 13.3°C, while living for 51 d; the pupae were first held for 4 d at 22.3°C. Lugnibill (1928) reported mortality of the pupal stage after 45 d under low field temperature. During the winter months in Brownsville, Texas, the pupal stage lasted 50-40 d (Vickery 1929).

In a more recent study (Wood et al. 1979), pupae held at 10°C lived for about 50 days but did not eclose. They concluded that the threshold for development must be above 10°C. In a field study, Wood et al. (1979) found that fall armyworm emergence was correlated with soil temperature at three locations in Florida. Also in their study, the temperature required for development of pupae was somewhat lower for laboratory-reared larvae than for field-reared larvae.

Moisture also has been known to affect the pupal stage. Vickery (1929) noted that “excessive dryness seemed to retard the emergence of the moth.” In laboratory observations, it appeared that fall armyworm larvae in notably dry media were more likely not to emerge, and those emerging later appeared to be more likely to be deformed.

This study was conducted to determine the effect of selected constant and fluctuating temperature and humidity regimes on survival and development of fall armyworm pupae.

**MATERIALS AND METHODS**

**Temperature Effects**

Fall armyworm larvae were reared in the laboratory according to Perkins (1979) using a colony which has been maintained in the laboratory since the fall of 1986. Upon
digging their pupal cell, larvae were removed and placed in individual plastic 30 ml cups with cap. Numerous ventilation holes were made along the side of the cup and in the cap. The insects (n = 30 per treatment) were held until pupation under 27°C and a vapor pressure deficit of 8.5 mb (80% RH). Within 24 h of pupation, the insects were moved to selected constant and fluctuating temperature regimes each under a constant dark condition. The selected constant temperatures were 10, 15, 20, 25, 30, 35, and 40°C. Fluctuating temperature regimes evaluated were: 10.8-17.5°C (mean = 15), 15.0 23.0°C (mean = 20), 19.9-28.3°C (mean = 25), and 23.5-33.9 °C (mean = 30). Each fluctuating temperature treatment was composed of 15 h of warmer and 9 h of cooler temperature. Humidity was adjusted in each environmental chamber to obtain a vapor pressure deficit of 8.5 mb for each temperature treatment. Hence, relative humidity varied for all constant temperature treatments as well as for each fluctuating temperature treatment.

Eclosion was checked daily, and the number of days from pupation to eclosion, percentage of eclosion, and any deformity (rated high or low) were recorded for each insect gender. Moths in the high deformity category were those whose wings were twisted or misshapen to the degree that the insect was unlikely to be capable of little, if any sustained flight. The gender of pupae which did not eclose was also recorded.

All statistical procedures were run on Statistical Analysis System (SAS Institute, 1985). Before any statistical analysis, percentage data were subjected to arcsine transformation. Means were compared using least significant difference and t-test procedures. A level of significance of P < 0.05 was used.

Humidity Effects

Larvae of the fall armyworm were handled as described above. Within 24 h of pupation, each pupa was weighed and confined in the cage described above and held at selected constant and fluctuating vapor pressure deficiencies. Vapor pressure deficit, which expresses moisture status independent of temperature, is biologically more meaningful than relative humidity (Ferro & Chapman, 1979). The selected constant vapor pressure deficits were: 33.9 (20% RH), 21.2 (50% RH), 8.5 (80% RH), and approximately 0 mb (approximately 100% RH). Temperature for each treatment was maintained at 30°C. The selected fluctuating vapor pressure deficiencies were: 30.40-36.06 mb (mean = 20% RH), 17.66-23.34 mb (mean = 50% RH), and 10.61-4.96 mb (mean = 80% RH). The lower level of each fluctuating vapor pressure deficit treatment was maintained for 15 h of a 15:9 cycle. Thirty pupae were tested per treatment. Emergence was checked daily. Upon eclosion, the moths were immobilized with CO₂ and weighed. The sex of all moths and any dead pupae were determined. Thirty additional pupae were held at 30°C, 8.5 mb and handled in the above described manner and the weight of the empty pupal case was determined. Vapor pressure deficit was regulated with humidifiers, humidistats, deshumidifiers, and deshumidistats and ranged + 10% RH. Data on weight loss was analyzed after log transformation. Other procedures were as noted above.

RESULTS

Temperature Effects

Fall armyworm pupae held at 10 and 40°C did not survive to the adult stage. However, some pupae held at 10°C lived for at least 62 days as indicated by movement when handled. An average of about 90% of each cohort eclosed at the other temperature values, except at 15°C, only 58 to 78% of the pupae eclosed (Fig. 1a,b). Although not statistically significant, the trend was for a higher percentage of males than females to
Fig. 1. Percent eclosion of *S. frugiperda* pupae under (A) fluctuating temperature; (B) constant temperature.

Eclose under both the constant and fluctuating temperature regimes (Fig. 1). Percent eclosion was not affected by either fluctuating or constant temperature regime.

Because the insects held at 15 and 35°C were near the threshold for development, they were subjected to heat and cold stress, and subsequently were adversely affected. A high percentage of pupae emerging near the lower and upper developmental thresholds (15 and 35°C) exhibited some physical deformity (Fig. 2a,b). Moreover, many
insects that emerged after being reared at 15 or 35°C constant temperature died within 24 h of emergence. At 15°C, 31% of the males and 18% of the females died, and at 35°C, 8% of the females but none of the males died within 24 h of emergence. Eclosing insects at other temperature regimes lived through the first 24 h after emergence. Deformity was generally low at other temperature regimes (Fig. 2a,b). Female moths were less likely than males to emerge deformed, but the percentage of deformed females was not

![Graph A](image)

![Graph B](image)

Fig. 2. Percent deformity of *S. frugiperda* pupae under constant temperature regimes; (A) percentage severely deformed; (B) total percentage deformed individuals across cohorts.
significantly different from males. Temperature had a significant (P = 0.0072) effect on deformity; notably, those under low temperature were more likely to emerge deformed (Fig 3a,b). Moreover, almost twice as many of the moths were deformed when held under fluctuating temperature $\bar{x} = 15^\circ$C (Fig. 3b) than when they were held under constant $15^\circ$C (Fig. 2b). In addition, 8% of the males died within 24 h of emergence.

Fig. 3. Percent deformity of *S. frugiperda* pupae under fluctuating temperature regimes; (A) percentage severely deformed; (B) total percentage deformed individuals across cohorts.
under the 15°C fluctuating regime, whereas moths lived through 24 h under the three other fluctuating temperature regimes.

Pupae held under 30 and 35°C had the fastest rate of development (Table 1). Females developed at significantly (P = 0.0001) less time than males. In the fluctuating temperature regimes averaging 15, 20, and 25°C, the rate of development was faster than under respective constant temperature regimes, but development was slower under 30°C. Under constant temperature, males and females required a mean of 39.0 and 34.4 d, respectively, at 15°C and 6.0 and 5.2 d, respectively, at 35°C to complete the pupal stage.

Humidity Effects

Humidity had no significant effect on time of eclosion nor on deformity incidence. Although pupae required significantly more time to develop at 20% RH (7.3 d) than at 50% RH (6.4 d), 80% RH (6.5 d), or 100% RH (6.6 d), no pattern indicating a humidity effect on rate of development was evident. Perhaps one reason no humidity effect was seen at 30°C may be because vapor pressure deficiency effects tend to occur with interactions at high temperatures.

Although humidity had a significant (P = 0.0076) effect on weight loss, no trend was apparent among the humidity levels. The combined weight of pupal cases plus weight lost via desiccation, for each humidity level, were as follows: 96.9 mg, 50% RH; 98.0 mg, 80% RH; 106.4 mg, 20%; and 107.3 mg, 100% RH. The weight of pupal case and weight loss via desiccation was significantly (P = 0.0001) greater for males (110.4 mg) than for females (92.7 mg).

CONCLUSION

Temperature near the upper and lower threshold for pupal development had the most adverse effects on pupal developmental rate, eclosion, initial survival after eclosion, and level of deformity. Henneberry & Clayton (1991), working with *Heliothis virescens* (F.), reported that mating frequency decreased with the duration of exposure

## TABLE 1. Percent development per day for pupal stage of *S. frugiperda* held under selected constant and fluctuating temperature regimes.

<table>
<thead>
<tr>
<th>Temp. (°C)</th>
<th>Constant Temp.</th>
<th>Fluctuating temp.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Male</td>
<td>Female</td>
</tr>
<tr>
<td>10</td>
<td>NE</td>
<td>NE</td>
</tr>
<tr>
<td>15</td>
<td>39.00(3.13)</td>
<td>35.41(2.94)</td>
</tr>
<tr>
<td>20</td>
<td>20.07(0.76)</td>
<td>17.58(1.38)</td>
</tr>
<tr>
<td>25</td>
<td>9.90(0.73)</td>
<td>8.92(0.44)</td>
</tr>
<tr>
<td>30</td>
<td>6.50(0.63)</td>
<td>5.92(0.49)</td>
</tr>
<tr>
<td>35</td>
<td>6.00(0.00)</td>
<td>5.73(0.47)</td>
</tr>
<tr>
<td>40</td>
<td>NE</td>
<td>NE</td>
</tr>
</tbody>
</table>

NE indicates no eclosion.  
Dash ( ) indicates not tested.
of pupae to low temperature, while mating, oviposition, and egg hatch decreased with increased temperature. It is not known if egg production and mating behavior of the fall armyworm may be affected by the exposure of pupae to low or high temperature. Simmons & Marti (1992) reported that only occasionally did the fall armyworm mate in the laboratory when held at 10°C. Thus, the effect of low temperature on mating coupled with the adverse effect of low temperature on pupal survival and development affects the population dynamics. Depending on location, the range of daily fluctuation and magnitude of temperature and humidity in the field will differ. In this study, fluctuation was moderate in the controlled humidity and temperature tests. Fluctuating humidity or temperature, as compared with constant regimes, had little affect on survival, developmental rate, or adult deformity.

Pathogens, soil type and porosity, and compaction may also influence fall armyworm pupal emergence. Because of the wide distribution of the fall armyworm, pupation occurs in many soil conditions.

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REFERENCES CITED


