Pectinophora Gossypiella (Lepidoptera: Gelechiidae) and *Heliothis Virescens* (Lepidoptera: Noctuidae): Moth Emergence from Hot and Cold Temperature Treated Larvae and Pupae

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ABSTRACT

We conducted studies to determine the effects on adult emergence following hot and cold temperature exposures of larvae and pupae of pink bollworm, *Pectinophora gossypiella* (Saunders) (PBW) and tobacco budworm, *Heliothis virescens* (F.) (TBW). PBW moth emergence was not affected by exposure of larvae or pupae to temperatures as high as 46ºC for 4 h. TBW moth emergence was reduced following exposure of larvae or pupae to 44ºC for 4 h. TBW pupae were more tolerant than PBW pupae to cold temperatures as low as 2ºC for 120 h. These results suggest high temperature tolerance for PBW compared with TBW and may partially explain the higher numbers of pheromone-baited trap catches of PBW from 1981 to 1988 and its long term economic pest status of cotton in Imperial Valley, California. TBW larvae and pupae were more susceptible to high temperature but more tolerant to colder temperatures.

RESUMEN

Se realizaron estudios para determinar los efectos que ocasionó la exposición de larvas y pupas a temperaturas calientes y frías sobre la emergencia de adultos del gusano cogollero rosado, *Pectinophora gossypiella* (Saunders) y del gusano de la yema del tabaco, *Heliothis virescens* (F.). La emergencia de la palomilla de *P. gossypiella* no se vio afectada por la exposición de larvas o pupas a temperaturas de hasta 46º C por 4 horas. La emergencia de las palomillas de *H. virescens* se redujo después de la exposición de las larvas y las pupas a 44º C por 4 horas. Las pupas de *H. virescens* fueron más tolerantes que las pupas de *P. gossypiella* a la exposición a temperaturas frías tan bajas como 2º C por 120 horas. Estos resultados indican que existe mayor tolerancia por parte de *P. gossypiella* a altas temperaturas en comparación con la que presenta *H. virescens* y puede explicar parcialmente las cantidades tan elevadas de captura de *P. gossypiella* durante 1981 a 1988 en trampas que usaron feromonas como atrayentes, así como su prolongado estatus como plaga de importancia económica del algodón en el Valle Imperial en California. Las larvas y pupas de *H. virescens* fueron más susceptibles a las temperaturas altas pero fueron más tolerantes a las bajas.

Key words. Cotton, pink bollworm, tobacco budworm, high temperature tolerance, pheromone-baited trap

The pink bollworm (PBW), *Pectinophora gossypiella* (Saunders), has been an economic pest of cotton in southern California since 1965, when it was first detected in Riverside and Imperial Counties (Noble 1969). Infestations spread rapidly and severe losses occurred by 1967 and have ranged from 8 to 79% of the crop value from 1966 to 1980 (Burrows et al. 1982). Since 1980, cotton production in the Imperial Valley has decreased dramatically (Natwick 1983). The PBW has been considered a major factor contributing to the reduction. Insecticidal control has been the principle method of reducing PBW damage but overuse has aggravated tobacco budworm (TBW), *Heliothis virescens* (F.) outbreaks (Watson 1980). TBW has been a sporadic cotton pest in Imperial Valley but an increasing level off insecticide resistance has complicated the problem when populations occur at damaging levels. Thus the PBW moth population was, as measured by male moth catches in pheromone-baited traps, often beyond 100/trap/night (Chu and Henneberry 1990) whereas TBW male moth catches during 1981-88 study period never reached 100 moths/trap/night.

Low rainfall, low relative humidity and high temperature extremes characterize the cotton growing seasons in Arizona and southern California and may account for some of the differences in population development of PBW and TBW. For example, Butler et al. (1979) proved that TBW larvae did not survive at a constant 35ºC and adults did not emerge from pupae exposed to 38ºC. TBW also entered into pupal estivation in the summer when the maximum temperature exceeded 32ºC

(Butler et al. 1985). In contrast, PBW larvae survived and developed at 35ºC and pupae survived exposure to 38ºC (Butler and Hamilton 1976). Fye and Poole (1971) showed that the fecundity, fertility and longevity were not affected when PBW and TBW larvae and pupae were exposed at 35ºC for 8 h or 40ºC for 4 h. Further evidence of PBW larval tolerance to high temperatures is the high percentage (95%) of larval survival in green cotton bolls of temperatures ranging from 44º to 46ºC for 5 h (Chu and Bariola 1987) and to 33% of the larvae surviving in green bolls at a constant temperatures of 50ºC for 8 h (Chu and Bariola 1988).

Low winter temperatures in the cotton growing areas of Arizona and southern California appear to have little affect on survival of PBW diapause larvae and subsequent emergence of adults from pupae the following spring. Wright (1977) found that mortality of diapausing PBW larvae exposed to 5ºC for 8-week, was less than 5%. Also exposures to 6 and 9ºC, did not induce diapause larval mortality that was appreciably greater than mortality of diapause larvae exposed to 21ºC.

The objectives of our studies were to provide additional information on tolerances of PBW and TBW larval and pupal stages to hot and cold temperatures in laboratory and field studies and to explain the pheromone-baited trap catches of both pests conducted from 1981 to 1988.

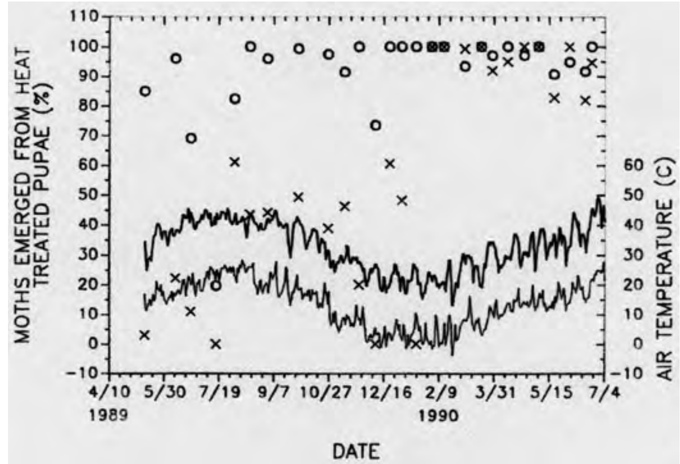

Fig. 1. Percentages of moth emergence from heat treated pink bollworm (o) *Pectinophora gossypiella* Saunders and tobacco budworm (X) *Heliothis virecens* F. pupae under outdoor insectary conditions in 1989-1990 at Brawley, CA. Upper and lower lines were maximum and minimum air temperatures, respectively.

MATERIALS AND METHODS

General. PBW and TBW larvae and pupae used in the studies were obtained from the insectary at the Western Cotton Research Laboratory, Phoenix, AZ. PBW were reared on the wheat germ diet as described by Bartlett and Wolf (1985) and TBW on the modified wheat germ diet from that of Henneberry and Kishaba (1966). In all experiments, moth emergence was considered successful if the moth was completely free or two wings were completely free of the pupal case. Moth emergence was considered partially successful if one wing was completely free of the pupal case. In all other instances, mortality was considered as occurring in the pupal stage. All temperature exposure experiments were conducted in completely randomized experimental designs.

Moth emergence from heat treated PBW and TBW larvae and pupae under controlled conditions. PBW or TBW larvae and pupae were treated at 44.3, 46.2, 47.5ºC (± 0.2ºC) or room temperature (control, 27 ± 0.5ºC) for 4 h. The treatments were replicated three and four times for larvae and paupe, respectively. Ten 4th instar PBW or TBW larvae and 3-4 d old pupae each were placed in 100 x 15 mm petri dishes without food supply. A 90 mm diameter filter paper wetted with 1 ml of distilled water was placed at the bottom of each petri dish to maintain moist condition. The petri dishes were sealed with adhesive tape. Insects were treated with designated temperatures in a controlled temperature cabinet. The temperatures were determined using a copper-constantan thermocouple. Thermocouples were placed in petri dishes (which also contained moist filter paper) in the temperature cabinet that were adjacent to petri dishes containing PBW or TBW larvae or pupae. The thermocouples were connected to a micrologger (Model CR21, Campbell Scientific, Inc., Logan, UT) described by Chu and Bariola (1988). The micrologger was programmed to read and record temperatures every 6 min. After 4 h exposures, treated larvae or pupae of each species and controls were transferred to a constant 28±0.2ºC temperature cabinet for moth emergence under 14/10 h day/night

Table 1. Mean percentages (± SE) of moth emergence following 4 h heat treatments of *Pectinophora gossypiella* and *Heliothis virescens* larvae and pupae.

	% Moth emergence[z]			
	Larvae		Pupae	
Temperature	PBW	TBW	PBW	TBW
ºC				
27.0[y]	95.0 ± 1.5 a	87.8 ± 3.3 a	92.8 ± 2.4 a	90.0 ± 2.6 a
44.3	95.0 ± 2.9 a	15.0 ± 15.0 c	83.3 ± 8.8 a	40.0 ± 23.1 b
46.2	92.5 ± 2.9 a	0.8 ± 0.8 c	71.1 ± 12.4 a	0.0 ± 0.0 c
47.5	47.5 ± 22.6 b	0.0 ± 0.0 c	26.7 ± 14.5 b	0.0 ± 0.0 c

[z]Means of moth emergence from larvae or pupae of the two species not followed by the same letters are significantly different (Student-Neuman-Keul's Multiple Range Test, $P = 0.05$).
[y]Untreated control.

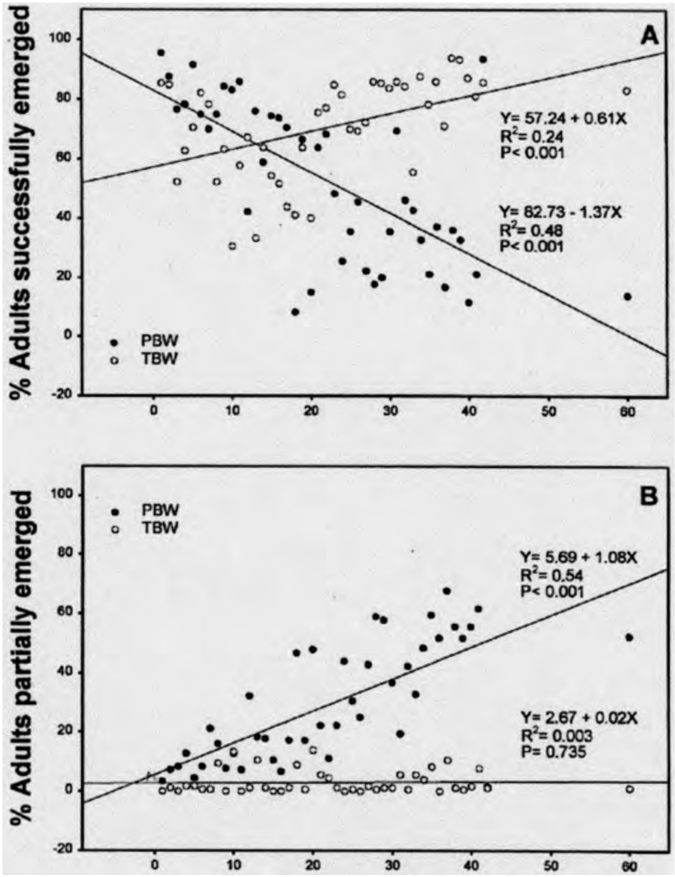

Fig. 2. Effects of durations of exposure to -2.2ºC temperature on the percentages of successful (A) and partial (B) adult moth emergence from treated pink bollworm (•) *Pectinophora gossypiela* Saunders and tobacco budworm (o) *Heliothis virecens* F.

photoperiod and 30±10% relative humidity. After two week incubations, numbers of emerged moths were recorded (Bartlett and Wolf 1985).

Moth emergence from heat treated PBW and TBW pupae under field insectary conditions. PBW or TBW pupae were treated at 45±0.2ºC for 4 h. The untreated PBW and TBW under room temperature (27±0.5ºC) were used as control. The treatments were replicated 18 times. Ten pupae of each species were placed, in each of 18 petri dishes, as described previously and treated in a constant temperature cabinet. After treatment, dishes with pupae, were held in an outdoor (screen) insectary for six or more weeks when the numbers of adults that emerged were counted. Air temperatures during the period were obtained from a weather station 0.5 km from the screen insectary. This experiment was repeated at 2-week intervals for a total of 27 times from 12 May 1989 to 27 June 1990 so that the heat treated pupae were exposed to year round outdoor climatic conditions.

Moth emergence from cold treated PBW and TBW pupae under controlled conditions. PBW or TBW pupae were treated at 2.2±0.2ºC for 1 to 42 h. The untreated PBW and TBW under room temperature (27±0.5ºC) were used as control. The treatments were replicated 18 times. Ten 3-4 d old pupae of each species were placed in each of 18 petri dishes and exposed to -2.2±0.2ºC for 1 to 42 h and at hourly intervals and in one experiment for 60 h. In another experiment, ten pupae of each species were placed in each of ten petri dishes and treated at 2.1±0.2ºC for 120 h. Untreated controls were ten petri dishes with pupae of each species held under room temperature (27±0.5ºC). The treated pupae and untreated control pupae in dishes were placed in a constant 27±0.2ºC temperature cabinet for moth emergence under 14/10 h day/night photoperiod and 30 ± 10% relative humidity. Moth emergence was recorded after two weeks.

PBW and TBW male moth trap catches in pheremone-baited traps. Pheromone-baited traps were used to compare PBW and TBW population densities in cotton in each growing season from 1981 to 1988. PBW live traps (Lingren et al. 1980) were baited with gossyplure (0.1 mg) in methylene chloride on rubber septa (Flint et al. 1974). The trap installation was described earlier (Chu and Henneberry 1990). Briefly, PBW traps were installed each year at the edge of cotton fields at the Irrigated Desert Research Station, Brawley, CA. Trap catches were counted daily, except weekends, and numbers of male PBW moths caught were recorded. Trapping began as early as 9 March (1982) and as late as 13 May (1981). Trapping was terminated as early as 1 September (1987) or as late as 12 November (1982). The number of traps installed each year ranged from 6 (1982) to 24 (1988) and averaged 11.5 traps per year, or about one trap each year for each acre of planted cotton.

Six TBW cone traps (Hartstack et al. 1979) baited with 1.61cm^2 plastic laminate virelure dispensers (Z-11 hexadecenal and Z-9 tetradecenal at 16:1 and 80 mg/6.45 cm^2, Hercon Division, Health-Chem Corp., South Plainfield, N.J.) were installed at the edge of cotton field each year during the same time trap periods for PBW. Trap catches were counted daily, except weekends, and numbers of male TBW moths were recorded. Air temperatures during the period were obtained from a weather report provided by the Imperial Irrigation District, Imperial, CA.

Data analyses. Percentages of moth emergence from larvae or pupae exposed to heat or cold temperatures were arcsin transformed and analyzed using ANOVA for the appropriate experimental design (Anonymous 1989). Means were separated with Student-Neuman-Keul's Multiple Range Test. PBW and TBW male moth catches were averaged for each 2-week sample period from May through August for each year (1981-1988). Average numbers of moth caught/trap/night for each 2-week sample period were plotted on three dimensional scales for each species. Mean air temperatures for each month during the period were also plotted.

RESULTS AND DISCUSSION

Moth emergence from heat treated PBW and TBW larvae and pupae under controlled conditions. PBW moth emergence from 4th instar larvae or pupae exposed for 4 h to 44.3 or 46.2ºC was not significantly different compared with emergence from untreated larvae or pupae (Table 1). However, moth emergence from larvae or pupae exposed to 47.5ºC for 4 h was reduced to 47.5 and 66.1%, respectively compared with

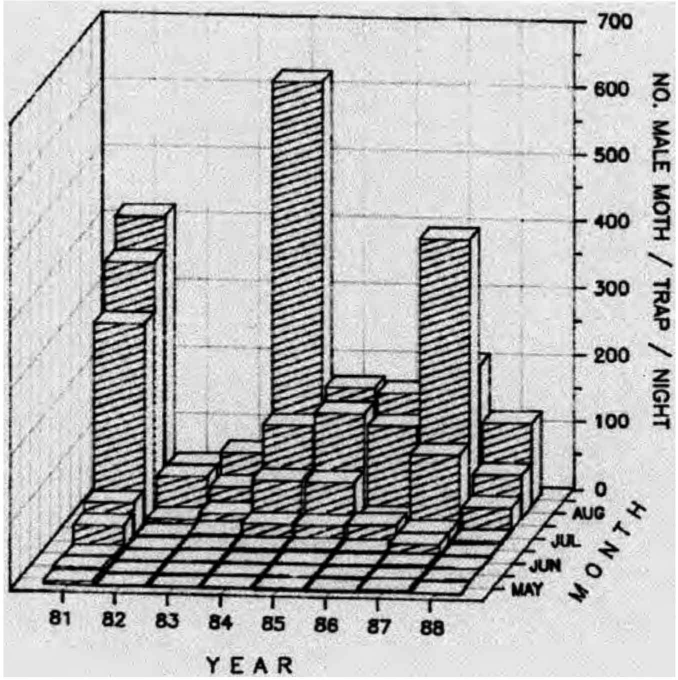

Fig. 3. Average numbers of male pink bollworm (*Pectinophora Gossypiella* Saunders) moths caught per trap per night in gossyplure-baited traps from May through August each year from 1981 to 1988.

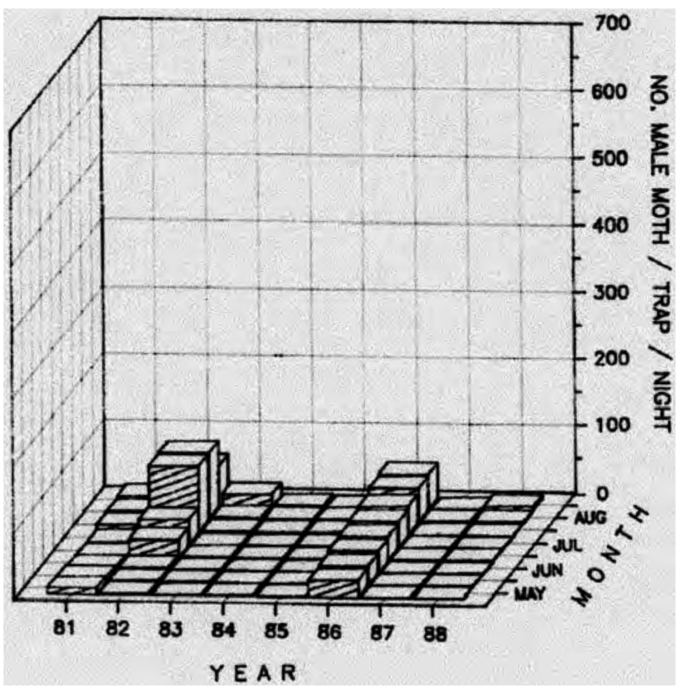

Fig. 4. Average numbers of male tobacco budworm *Heliothis virescens* F. moths caught per trap per night in virelure-baited traps from May through August each year from 1981 to 1988.

emergence from untreated larvae or pupae. Percentages of TBW moth emergence after exposure of larvae to 44.3ºC or higher for 4 h were reduced 72.8 to 100%. Adult emergence from pupae exposed to 44.3ºC or higher for 4 h was reduced to 50 to 100% in each case, compared with untreated larvae or pupae.

Moth emergence from heat treated PBW and TBW pupae under field insectary conditions. Under outdoor insectary conditions, daily fluctuating maximum or minimum air temperatures did not appear to affect PBW or TBW moth emergence from pupae pre-exposed to 45ºC for 4 h (Fig. 1). Percentages of moths emerged from heat-treated-pupae of each species were lower in 1989 compared with 1990. The reason remains unexplained but higher ambient temperature during the test period in 1989 compared with 1990 may partially explain the results. In 1989, moth emergence was significantly higher from heat treated PBW pupae (87.5±5.5%) compared with TBW pupae (30.1±5.8%) ($P < 0.001$). In 1990, however, the differences in PBW and TBW moth emergence were not significant (97.0±1.0% vs. 95.5±1.9%). For the overall experimental period from 10 April 1989 to 4 July 1990, the average moth emergence from heat treated PBW pupae was higher (77.4±4.2%), compared with TBW moth emergence (36.9±5.7%) from heated treated pupae. For untreated control pupae, overall moth emergence was 82.8±3.7% and 59.1±5.6% for PBW and TBW, respectively.

Moth emergence from cold treated PBW and TBW pupae under controlled conditions. Percentages of successful moth emergence from PBW pupae decreased with increasing length of exposure from 1 to 60 h at 2.2ºC (Fig. 2A). Percentages of partially emerged moths from PBW pupae were from 0 to 60% and were positively related to the duration of exposure to 2.2ºC while moth emergence of TBW was 0 to 10% and did not show any relation to duration of exposure (Fig. 2B). Percent successful emergence over all exposure periods was 52.3±4.1% and 70.7±2.6% for PBW and TBW, respectively. Average percents of partially emerged moths over all exposure durations was 29.6±3.0% for PBW compared with 3.0±0.6% for TBW. Average percent of total (successfully and partially) moth emergence over all 2.2ºC exposures were 81.9% and 73.7% for PBW and TBW, respectively.

Moth emergence from PBW pupae exposed to 2.1ºC for 120 h averaged 13±12% compared with 94±7% for untreated control pupae. TBW moth emergence from pupae exposed to 2.1ºC for 120 h was 46±10% compared with 76.0±14% for untreated control pupae. These differences were statistically significant ($P < 0.001$). TBW pupae appear more tolerant to below freezing temperatures compared with PBW pupae.

PBW and TBW male moth trap catches in pheromone-baited traps at cotton field edges. In each year from 1981 to 1988, numbers of male PBW moths caught per trap per night in gossylure-baited traps increased gradually in May and June and more abruptly (50 to over 600 per trap per night) in July and August (Fig. 3, Chu and Henneberry 1990). In 1982, PBW male moth catches were extremely low because all cotton fields in the Imperial Valley were treated with a minimum of four applications of slow-release formulated gossyplure in a state mandated PBW control program (Natwick 1983). Gossyplure applications prevent orientation of male moths to gossyplure-baited traps (Gaston et al. 1977). The low male moth catches in 1983 may have occurred because the pheromone behavior control program resulted in low overwintering populations in 1982. The numbers of male TBW moths caught per virelure-

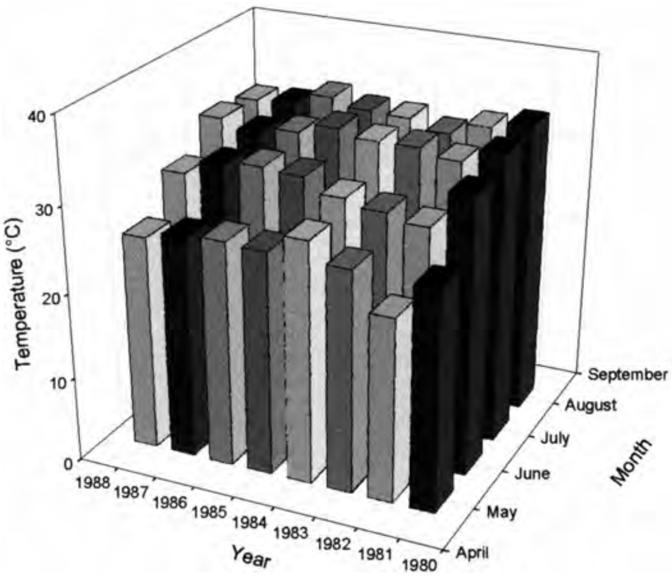

Fig. 5. Mean air temperature from May to August from 1981 to 1988.

baited trap per night were low (less than 14 per trap per night) during May through August in the same trapping periods, except for 1982 and 1986 when trap catches ranged from 42 to 99 per trap per night in July and August (Fig. 4).

In May and early June of each year, numbers of male moths caught/trap/night were similar for PBW and TBW in 7 out of the 8 years studied (Figs. 3 and 4). Numbers of TBW moths caught in May and June in 1986 were higher than the numbers of PBW trap caught. However, numbers of PBW moths caught in July and August were much higher than the numbers of TBW trap caught. Mean air temperatures during the period ranged from 21.6-28.3, 29.1-32.5, 32.1-34.1, and 32.1-34.4ºC for May, June, July, and August, respectively (Fig. 5).

The results of these studies indicate that the PBW is tolerant to high temperatures. This may partially explain its role as a key pest of cotton in Imperial Valley, California before the implementation of short-season cotton management system in 1989 (Chu et. al. 1996). TBW undergoes summer (in July-August in our study) and high temperature (over 32ºC for mean air temperature) pupal diapause (Butler et al. 1985) that may reduce the number of generations each year in the Imperial Valley. Additionally, our results show that TBW larvae and pupae are less tolerate to high temperatures resulting in reduced adult emergence. This phenomenon may also be true in Arizona. In addition to cotton, other cultivated crops such as alfalfa (*Medicago sativa* L.), lettuce (*Lactuca sativa* L.), and tomato (*Lycopersicon esculentum* L.), as well as many spring annual weeds in the Imperial Valley (Pearson et al. 1988) may serve as TBW host plants (Graham and Robertson 1970). Also, about 43 plant species found in the Southwestern United States have been reported as host plant for PBW (Noble 1969). Both TBW and PBW have potential sources of host material year round in the Imperial Valley, California. However, little information is available on occurrence, development or survival of these insects on host plants other than cotton, particularly under adverse temperature conditions.

REFERENCES

Anonymous. 1989. A microcomputer program for the design, management, and analysis of agronomic research experiments, version 1.2. Michigan State University, East Lansing, MI.

Bartlett, A. C., and W. W. Wolf. 1985. *Pectinophora gossypiella*, pp. 415-430. *In* R. F. Moore and P. Singh (eds.), Handbook of insect rearing, Vol 2. Elsevier Amsterdam.

Burrows, T. M., V. Sevacherian, H. Browning, and J. Baritelle. 1982. History and cost of the pink bollworm in the Imperial Valley. Bull. Entomol. Soc. Am. 28: 286-290.

Butler, G. D. Jr., and A. G. Hamilton. 1976. Temperature-dependent development rates for four strains of *Pectinophora gossypiella*. Ann. Entomol. Soc. Am. 69: 450-452.

Butler, G. D., Jr., A. G. Hamilton, and F. I. Proshold. 1979. Developmental times of *Heliothis virescens* and H. Subflexa in relation to constant temperature. Ann. Entomol. Soc. Am. 72: 263-266.

Butler, G. D. Jr., L. T. Wilson, and T. J. Henneberry. 1985. *Heliothis virescens* (Lepidoptera: Noctuidae): Initiation of summer diapause. J. Econ. Entomol. 78: 320-324.

Chu, C. C., and L. A. Bariola. 1987. Survival of pink bollworm, *Pectinophora gossypiella* (Saunders), larvae in green bolls at high internal temperatures. Southwest. Entomol. 12: 271-277.

Chu, C. C., and L. A. Bariola. 1988. Effect of cotton boll temperatures on larval mortality of pink bollworm *Pectinophora gossypiella* (Saunders). Southwest. Entomol. 13: 185-189.

Chu, C. C., and T. J. Henneberry. 1990. Pink bollworm seasonal distribution, yearly variation, and male moth trap catch relationships to population increases in cotton. Southwest. Entomol. 15: 273-280.

Chu, C. C., T. J. Henneberry, R. C. Weddle, E. T. Natwick, J. R. Carson, C. Valenzuela, S. L. Birdsall, and R. T. Staten. 1996. Reduction of pink bollworm (Lepidoptera: Belechiidae) populations in the Imperial Valley, California, following mandatory short-season cotton management system. J. Econ. Entomol. 89: 175-182.

Flint, H. M., S. Kuhn, B. Horn, and H. A. Sallem. 1974. Early season trapping of pink bollworm with gossyplure. J. Econ. Entomol. 67: 238-240.

Fye, R. E., and H. K. Poole. 1971. Effect of high temperatures on fecundity and fertility of six Lepidopterous pests of cotton in Arizona. USDA, Agric. Res. Serv., Prod. Res. Rep. No. 131, 8 pp.

Gaston, L. K., R. S. Kaae, H. H. Shorey, and D. Sellers. 1977. Controlling the pink bollworm by disrupting sex pheromone communication between adult moths. Science. 70: 904-905.

Graham, H. S., and O. T. Robertson. 1970. Host plants of *Heliothis virescens* and *H. zea* in the lower Rio Grande Valley. Environ. Entomol. 5: 666-668.

Hartstack, A. W., J. A. Witz, and D. R. Buck. 1979. Moth traps for the tobacco bud worm. J. Econ. Entomol. 72: 519-522.

Henneberry, T. J., and A. N. Kishaba. 1966. Pupal size and mortality, longevity, and reproduction of cabbage loopers reared at several densities. J. Econ. Entomol. 59: 1490-1493.

Lingren, P. D., J. Burton, W. Shelton, and J. R. Raulston. 1980. Night vision goggles: for design, evaluation and comparative efficiency determination of pheromone trap for capturing live adult male pink bollworms. J. Econ. Entomol. 73: 622-630.

Natwick, E. T. 1983. Beneficial insect monitoring as part of a pest abatement district requiring application of gossyplure to cotton in the Imperial Valley, pp. 193-194. *In* Proc. Beltwide Cotton Prod. Res. Conf., San Antonio, TX. National Cotton Council, Memphis, TN.

Pearson, A. C., V. Sevacherian, G. R. Ballmer, P. V. Vail, and T. J. Henneberry. 1988. Spring annual hosts of five noctuid pests in the Imperial Valley of California (Lepidoptera: Noctuidae). Environmental Entomol. 18: 970-979.

Noble, L. W. 1969. Fifty years of research on the pink bollworm in the United States. USDA, ARS, Agric. Handbook 357.

Watson, T. F. 1980. Methods for reducing winter survival of the pink bollworm, pp. 29-34. *In* H. Graham (ed.) Pink bollworm control in the western United States. U.S. Dept. Agric. Sci. Edu. Admin., ARM-W-16.

Wright, R. J. 1977. Cold tolerance of laboratory - reared diapausing pink bollworms, *Pectinophora gossypiella* (Saunders). Master of Science thesis, University of Arizona, Tucson, AZ