ance to corn earworm under natural conditions. Our data show that this resistance was probably due, for the most part, to a very long husk. P.I. 217413 (Zapalote Chico from Mexico) is of considerable interest, since it had low damage ratings when the husk and silk were clipped even with the cob. The data suggest that resistance under normal conditions is due to a tight, tough husk and some form of silk resistance; a resistance factor in the grain was also indicated. Continuing field and laboratory feeding trials with silks and grain should provide additional information as to the nature of resistance in different strains.

REFERENCES CITED

Bennett, S. E., and L. M. Josephson. 1962. Methods of artificial infestation of corn with the earworm, *Heliothis zea*. J. Econ. Entomol. 55 (5) : 797–8.

Luckmann, W. H., A. M. Rhodes, and E. V. Wann. 1964. Silk balling and other factors associated with resistance of corn to corn earworm. J. Econ. Entomol. 57 (5) : 778–9.

Development of the Beet Armyworm and Its Parasite *Chelonus texanus* in Relation to Temperature[1]

GEORGE D. BUTLER, JR.
Department of Entomology, University of Arizona, Tucson

ABSTRACT

Individual beet armyworms, *Spodoptera exigua* (Hübner), were reared on lima bean-agar medium in temperature cabinets. Regression equations are: for the number of days for the egg stage, $\hat{y} = -0.3472 + 0.0083$ X; from the first-instar larva to the prepupal stage, $\hat{y} = -0.0921 + 0.00203$ X; to the pupal stage, $\hat{y} = -0.1032 + 0.00214$ X; and to the adult stage, $\hat{y} = -0.0716 + 0.00147$ X, where $\hat{y}$ is the reciprocal of days and X is the temperature (°F). The rate of development was the same at constant as at fluctuating temperatures. Comparisons indicated a rate of development similar to published life-history records of beet armyworms in Florida asparagus ferneries during 1932–33. *Chelonus texanus* Cresson developed at a similar rate to that of *S. exigua*. The regression equation for the number of days to the death cell from the hatching of the *S. exigua* egg is $\hat{y} = -0.1385 + 0.00283$ X, and to the adult stage is $\hat{y} = -0.0841 + 0.00164$ X.

The beet armyworm, *Spodoptera exigua* (Hübner), is an important insect affecting many of the principal crops in Arizona. This study was undertaken to determine the rate of development of this insect in the laboratory in relation to temperature and to compare the development under similar conditions with that of *Chelonus texanus* Cresson, one of its braconid parasites.

Wilson (1934) found that the duration of the larval stage of the beet armyworm in Florida varied from 12.5 days in the summer to 37.6 days in the winter. The prepupal and pupal stage together averaged 6.7 days. Campbell and Duran (1929) observed a larval stage of 16 days in the summer and 76 days in the winter in California. The prepupal stage lasted 4.7 days, while the pupal stage was 17.2 days in the summer and 90 days in the winter. In Arizona, Frost[2] found that the larval stage was 11 days and the prepupal and pupal stage took 7 days. According to Frost's studies, which were continued in California, the larval stage was 14.2 days for larvae with 5 instars and 16.8 days for those with 6 instars. The prepupal stage was 2 days and the pupal stage 10–12 days. Randolph (1963) found the duration of the larval stage in Texas averaged 14 days and the pupal stage about 7 days. The egg-to-adult development was completed in approximately 3 weeks on alfalfa, but required 27 days on certain varieties of beans and cotton.

C. texanus is one of the commonest braconids in Arizona crop areas and undoubtedly plays an important role in regulating the abundance of lepidopterous pests. Detailed studies of the oviposition of this species in the larval embryo within the host egg were made by Ullyett (1949). The effect of the parasite upon the host larva was described by Pierce and Hollaway (1912), Luginbill (1928), and Bianchi (1944). The time required from the hatching of the host egg to the parasite larva emerging from the host larva following the formation of the "death cell" was found to be 16–20 days by Blanchard and Conger (1932), 11 days in August and 22 days in October by Vickery (1929), 12–14 days by Luginbill (1928), and 12–15 days by Wilson (1933). At Brownsville, Texas, the total length of development varied, according to Luginbill, from 18 to 21 days in July to 27 days in October.

The life history of the beet armyworm and of *C. texanus*, as determined by these workers, varied considerably with the seasons, so it seemed desirable to conduct additional life-cycle studies at known temperatures. Parasitized and unparasitized *S. exigua* larvae were reared in individual vials of semi-synthetic diet and the duration of the various stages of the life cycles were determined at different constant and fluctuating temperatures.

METHODS AND MATERIALS.—Nine 11-ft³ household refrigerators were modified by adding thermostats, heating coils, fans, and fluorescent lights. The lights were on for a 15-hr period each day starting at 6 AM. In 1964, 4 cabinets were programmed to maintain temperatures of 55, 65, 75, and 85°F from 6 PM to 6 AM and then each temperature was raised 20°F for the next 12-hr period to simulate a diurnal temperature fluctuation. Three other boxes were held at constant temperatures of 75, 85, and 95°F. In 1965, 3

[1] Arizona Agricultural Experiment Station, Journal Series no. 1114. Accepted for publication June 8, 1966.

[2] M. H. Frost, Jr. 1954. The beet armyworm: its life history and importance to agriculture in Central Arizona. Univ. Arizona, Master's Thesis.

Table 1.—Time in days for the duration of the egg stage of 3 egg masses of beet armyworm at different temperatures.

Temperature °F	Duration (days)
65 (55–75)	5.7
75 (65–85)	3.7
75 constant	3.3
85 (75–95)	2.7
85 constant	2.7
95 (85–105)	2.3
95 constant	2.3
a + bX[a]	− 0.3472 + 0.0083 X
R^2	0.97

[a] Regression equation $\hat{y} = a + bX$, where $\hat{y}$ is the reciprocal of days, X is the temperature.

cabinets had temperatures which fluctuated every 12 hr with lows of 50, 59, and 68°F and highs of 77, 86, and 95°F, respectively. Thermograph records were used to calculate the average daily temperature based on 3-hr readings. Six other boxes were held at constant temperatures at 9° intervals from 50 to 95°F. The thermoswitches regulated the temperatures to within ± 2.5°F.

Beet armyworm adults were collected in a light trap and placed in gallon jars with paper towels on which they laid eggs. The duration of the egg stage was determined in 1964 for 3 egg masses at 7 temperatures by making observations at approximately 4-hr intervals. Paper toweling with egg masses 12–18-hr old were held in petri dishes for 3–4 hr with field-collected *C. texanus* for parasitization. Individual 1st-instar larvae with and without parasites were placed in 6-dr vials with the lima bean-agar medium developed by Shorey (1963). The vials were plugged with cotton, held in cabinets, and observed at 24-hr intervals.

Various mathematical formulae are used by biologists to express the relationship between temperature and speed of development. Davidson (1944) gave details of the use of a formula representing a form of the logistic curve to describe the relationship between temperature and the rate of development of the egg and pupal stages of *Drosophila melanogaster* Meigen at constant temperatures. Browning (1952) determined the mean rate of development of *Gryllulus commodus* Walker eggs and derived a logistic curve from the data. He concluded that 2 or more developmental stages differing in their response to change in temperature may not be considered together when attempting to express trend in the rate of development by a logistic curve. Whether the trend of a stage of development responding uniformly in its rate of development to change in temperature conforms to a logistic curve was questioned. His physiological studies with precisely controlled conditions differed in their objective from the present study in which the rate of development is to be compared with that expected under field conditions with daily fluctuating temperatures. Therefore, linear regression equations were calculated to determine the relationship between temperature and the rate of development (1/Time). Although the true relationship is characteristically sigmoid, the linear functions provided an adequate approximation, as indicated by the large coefficients of determination (R^2). The use of linear regression functions also permitted simple tests of the homogeneity of 2 equations, such as the rate of development of the parasite and of its host under comparable conditions.

RESULTS AND DISCUSSION.—*Development of* Spodoptera exigua.—The duration of the egg stage of the beet armyworm at different temperatures is given in Table 1. The duration varied from 5.7 days at 65° to 2.3 days at 95°F. The number of days required from the hatching of the eggs to the prepupal, pupal, and adult stages at different temperatures is given in

Table 2.—Time in days from the hatching of beet armyworm eggs to the prepupal, pupal, and adult stages at different temperatures. 1964 and 1965.

	To prepupal stage		To pupal stage		To adult stage	
Temperature °F	No. individ.	Mean no. days	No. individ.	Mean no. days	No. individ.	Mean no. days
50 constant	20	86.1	No development		No development	
59 constant			9	45.6	6	66.8
59 constant	37	38.3	31	42.8	21	65.3
65 (55–75)	58	27.9	57	30.4	50	46.4
68 constant	55	22.6	51	25.6	41	40.0
68 constant			44	25.2	44	37.1
75 constant	44	17.0	41	18.6	38	27.3
75 (65–85)	55	16.9	52	19.0	45	28.2
76 (59–86)			11	15.5	8	24.0
77 constant	66	14.6	61	15.8	52	22.9
77 constant			42	12.7	47	19.7
83 (68–95)			44	13.0	30	19.1
85 (75–95)	42	11.9	33	13.6	25	19.0
85 constant	62	13.2	60	14.3	55	20.4
86 constant	67	10.7	60	11.6	87	17.1
86 constant			113	11.4	52	16.5
95 (85–105)	82	11.0	54	11.6	37	16.3
95 constant	21	11.0	43	10.3	37	15.4
95 constant	39	8.8	36	9.7	28	14.3
95 constant			24	9.4	27	14.5
a + bX[a]	−0.0921 + 0.00203 X		−0.1032 + 0.00214 X		−0.0716 + 0.00147 X	
R^2	0.95		0.93		0.95	

[a] Regression equation $\hat{y} = a + bx$, where $\hat{y}$ is the reciprocal of days, X is the temperature.

Table 2. In the rearing of hosts and their parasites, it is more convenient to calculate time from the hatching of the eggs or the appearance of the 1st-instar larva through the following stages than to sum the times for the various stages such as larval, prepupal, and pupal.

One of the objectives of this study was to determine whether the rate of development was similar at constant and fluctuating temperatures. Regression equations showed that there were no significant differences between the rate of development under constant and fluctuating temperature programs during the larval, pupal, egg-to-pupal, or egg-to-adult periods. Therefore the regression equations in Tables 1 and 2 are common regressions for constant and fluctuating temperatures.

Wilson (1934) presented information on the duration of the stages of the beet armyworm in asparagus ferneries in Florida during 1932 and 1933 and included monthly temperature records. Values were calculated by Wilson's mean monthly temperatures in the regression equations obtained in our Arizona laboratory studies. These calculated durations of the egg stage were compared with Wilson's observed values and were found to be similar ($\chi^2 = 2.60$, with 10 df, $P = 0.995$). The calculated duration of the larval stage did not agree with the observed values ($\chi^2 = 17.94$. 9 df, $P = 0.05$). However, it was noted that 82% of the deviation came from the observation of November 1933. Wilson recorded a low temperature during this month of 37°F. Development of larvae probably does not take place at this low temperature. If we exclude this month from our calculation, Wilson's observed and our calculated values for the duration of the larval stage are similar ($\chi^2 = 3.19$, 8 df, $P = 0.90$). The calculated and observed values for the duration of the pupal stage are also similar (constant temperature: $\chi^2 = 0.76$, 9 df, $P = > 0.995$; fluctuating temperature: $\chi^2 = 1.29$, 9 df, $P = > 0.995$). These comparisons indicate that rate of development of the beet armyworm on semisynthetic medium in constant and fluctuating temperatures in the laboratory is similar to the development in Florida ferneries during 1932 and 1933.

Development of Chelonus texanus.—Table 3 shows the time in days from the hatching of beet armyworm eggs to the formation of the death cell of the larva and to the appearance of the adult *C. texanus* in 1965. Regression equations are given in Table 4 for the time from hatching of beet armyworm eggs to the formation of the death cell, to the emergence of the *Chelonus* larva, to the formation of the *Chelonus* pupa, and to the appearance of the adult *Chelonus*. There was no difference in the rate of development between the fluctuating and constant temperatures and the regression equations in Table 4 are therefore common regressions for constant and fluctuating temperatures.

Table 3.—The time in days from the hatching of beet armyworm eggs to the appearance of the death cell and of the adult *Chelonus texanus* at different temperatures. 1965.

Temperature °F	To death cell		To adult *Chelonus*	
	No. individ.	Mean no. days	No. individ.	Mean no. days
59 constant	134	36.9	16	79.1
67 (50–79)	76	18.1	68	38.7
68 constant	106	22.1	82	41.7
76 (59–86)	132	12.4	115	24.5
77 constant	225	11.6	224	21.7
83 (68–95)	59	10.2	36	18.8
86 constant	147	10.1	158	16.3
95 constant	243	7.7	237	14.8

Table 4.—Regression equations[a] for the development of *Chelonus texanus* from the hatching of the beet armyworm larva. 1965.

Developmental period	Regression equation	R^2
to the death cell	$-0.1385 + 0.00283\ X$	0.97
to the larval emergence	$-\ .1221 + \ .00249\ X$	.97
to the pupa	$-\ .0970 + \ .00198\ X$	.97
to the adult	$-\ .0841 + \ .00164\ X$	.98

[a] Regression equation $\hat{y} = a + bX$, where $\hat{y}$ is the reciprocal of days, X is the temperature.

Comparison of the Rate of Development of S. exigua *and* C. texanus.—The rate of development of *C. texanus* to the adult stage was similar to that of the beet armyworm as determined by a test of homogeneity of the 2 regression coefficients. The actual time required to reach the adult stages was also similar, as determined by comparing the observed time required for *C. texanus* to develop in 1964 and 1965 with values calculated by the regression coefficient for the time for the beet armyworm to become adult. ($\chi^2 = 4.1$, df 13, $F = 0.990$). Tests of the homogeneity of the regression coefficients indicated that the rate of development of *C. texanus* to the pupal stage is no different than that of the beet armyworm to the prepupal stage.

REFERENCES CITED

Bianchi, F. A. 1944. The recent introduction of armyworm parasites from Texas. Hawaiian Planters' Rec. 68: 203–12.

Blanchard, R. A., and C. B. Conger. 1932. Notes on *Prodenia praefica* Grote. J. Econ. Entomol. 25: 1059–70.

Browning, T. O. 1952. The influence of temperature on the rate of development of insects, with special reference to the eggs of *Gryllulus commodus* Walker. Australian J. Sci. Res. Bull. 5: 96–111.

Campbell, R. E., and V. Duran. 1929. Notes on the sugar-beet armyworm in California. California Dep. Agr. Mon. Bull. 18: 267–75.

Davidson, J. 1944. On the relationship between temperature and rate of development of insects at constant temperature. J. Anim. Ecol. 13: 26–38.

Luginbill, P. 1928. The fall armyworm. USDA Tech. Bull. 34. 92 p.

Pierce, W. D., and T. E. Holloway. 1912. Notes on the biology of *Chelonus texanus* Cress. J. Econ. Entomol. 5: 425–8.

Randolph, N. M. 1963. Life cycle, habits and control of the beet armyworm. Texas Agr. Exp. Sta. Progr. Rep. 2287.

Shorey, H. H. 1963. A simple artificial rearing medium for the cabbage looper. J. Econ. Entomol. 56: 536–7.

Ullyett, G. C. 1949. Distribution of progeny by *Chelo-*

nus texanus Cress. (Hymenoptera: Braconidae). Can. Entomol. 81: 25–44.

Vickery, R. A. 1929. Studies on the fall armyworm in the Gulf Coast District of Texas. USDA Tech. Bull. 138. 64 p.

Wilson, J. W. 1933. The biology of parasites and predators of *Laphygma exigua* Huebner reared during the season of 1932. Florida Entomol. 17: 1–15.

1934. The asparagus caterpillar: its life history and control. Florida Agr. Exp. Sta. Bull. 271. 25 p.

Effects of the Fall Environment on the Boll Weevil in Northeast Mississippi[1, 2, 3]

F. A. HARRIS,[4] E. P. LLOYD,[5] and D. N. BAKER[6]

ABSTRACT

Limited studies of the preoviposition and developmental periods of the boll weevil, *Anthonomus grandis* Boheman, were made in the field in the fall of 1964. More extensive studies were made with simulated fall temperatures and day lengths in the laboratory during the winter 1964–65. Both field and laboratory data indicated that with the cooler temperatures of the fall, the preoviposition period of emerging boll weevils was generally longer than that of weevils emerging earlier in the season, though some individual females had a preoviposition period shorter than 1 week until night temperatures dropped to 50°F or lower. Each developmental stage of the boll weevil was considerably longer, with cooler temperatures and shorter photoperiods. The total developmental period from egg to adult was as short as 24 days when eggs were laid in squares early in September and as long as 60 days when eggs were laid in bolls in mid-September. The time to emergence of adult boll weevils from eggs deposited on a given date in the fall showed a wide range. The data indicated that an egg laid on or after October 1 would not contribute to the overwintered population of weevils.

The demonstration that the boll weevil, *Anthonomus grandis* Boheman overwinters in diapause (Brazzel and Newsom 1959) has led to extensive research on the kill of diapausing boll weevils with insecticides in the fall as a means of population control, suppression, or eradication. Studies in 1959 in the Big Bend area of Texas (Brazzel et al. 1961) indicated that overwintering populations of boll weevils could be greatly reduced when methyl parathion was applied at ½ lb/acre 4 times at about 2-week intervals between September 30 and November 8.

These results encouraged workers in Mississippi to make similar studies in the field in the rain belt of the mid-South. A boll weevil diapause-control experiment conducted in 1960 in the hills of Carroll County, (Lloyd et al. 1964) reduced the overwintering population with 7 applications of methyl parathion spray applied at ½ lb/acre at weekly intervals beginning September 14, but they did not eliminate it; major problems affecting control were heavy emergence of weevils from squares infested before the 1st treatment and reduction in the kill of weevils with methyl parathion in October. Other workers (Meeks et al. 1966) also encountered similar problems. In a recent study Lloyd et al. (1966) used 6 applications of methyl parathion at ½ lb/acre at 4- or 5-day intervals in September to kill off the last reproducing generation before the plants were defoliated in late September to reduce fruiting forms for weevil food and Bidrin® (3-hydroxy-*N*,*N*-dimethyl-*cis*-crotonamide dimethyl phosphate) was applied at 1 lb/acre on October 15 to kill diapausing boll weevils; reduction of the population of overwintering boll weevils was satisfactory with this reproduction-diapause control program, but the need for more efficient use of the insecticide against reproducing weevils was indicated.

Because of variations in effectiveness of diapause-control programs in areas of the cotton belt that have different environmental conditions in the fall, Knipling[7] pointed out the need for detailed information on the preoviposition and developmental periods of boll weevils during that period in each area. The work reported here is a study of the preoviposition and developmental periods of the boll weevil in the fall in northeast Mississippi. Our aim was to determine the most effective interval between applications of the insecticide in fall boll weevil control programs for prevention of egg deposition, the period during which reproducing boll weevils should be controlled, and the latest date that eggs are laid that will develop into adult boll weevils capable of overwintering successfully.

METHODS.—*Field Experiments.* — A 10-acre cotton field situated about 6 miles northeast of State College, Miss., was used for the field experiment.

Studies of the development of immature stages of the boll weevil were begun in the field in early October. A 42×6×7-ft plastic screen cage placed over cotton planted in midsummer excluded field boll weevils. Single eggs oviposited on October 6 by a field strain of weevils held in the laboratory were implanted in 300 squares on the caged cotton plants on October 8 as follows: a hole 1 mm in diam was drilled in each square with a glass capillary tube. Then an egg was placed into the hole in each square with a small artist's brush, and the hole was sealed with paraffin. Also 300 bolls of cotton grown in the greenhouse were so infested and held in small screen cages within the large field cage.

The experiment was designed to permit us to observe the developmental stages of 10 weevils from squares and 10 from bolls each day for 30 days. Larval instars were determined by measuring the diameter of the head capsule at 15× with an ocular micrometer mounted in a binocular microscope, and

[1] Coleoptera: Curculionidae.
[2] In cooperation with the Mississippi Agricultural Experiment Station, State College. Accepted for publication June 13, 1966.
[3] The use of trade or proprietary names does not necessarily imply endorsement of these products by the USDA.
[4] Graduate student, Mississippi State University, State College.
[5] Entomology Research Division, Agr. Res. Serv., USDA, Boll Weevil Research Laboratory, State College, Miss.
[6] Soil and Water Conservation Research Division, Agr. Res. Serv., USDA, Boll Weevil Research Laboratory, State College, Miss.

[7] E. F. Knipling. 1963. An appraisal of the relative merits of insecticidal control directed against reproducing versus diapausing boll weevils in efforts to develop eradication procedures. (Mimeo.) 22 p.