Studies on The Rice-Borer, *Chilo simplex* Butler. II.†

Effect of Constant Temperature upon The Development of The Rice-Borer. (i).

By

Chukichi Harukawa, Ryôiti Takato
and Saburō Kumashiro.

[September 9, 1931.]

In order to ascertain the effect of temperature upon the development of the rice-borer, *Chilo simplex* BUTLER, the larvae were reared in the incubator from the egg stage to the adult under various constant temperatures.

The methods of rearing and calculating the average temperature are similar to those employed in the similar experiments conducted with the other insects, which have been reported by the senior writer.

The precaution was taken to keep the humidity in the incubator within the range, approximately 70 to 90 per cent. The rearing at 12 and 15°C. was carried out in an electric refrigerator controlled by a thermostat. The relative humidity in this refrigerator was rather high, being from 80 to 90 per cent. most of the time.

The exact moment at which the oviposition, hatching, pupation and emergence occurred could not always be determined directly by observation. In cases where the direct observation failed, the following assumptions were made, taking into consideration the results of observations reported by various investigators on this insect :

Time of Oviposition	8 : 00 P. M.
Time of Hatching	9 : 00 A. M.
Time of Pupation	Midnight.
Time of Emergence	6 : 00 P. M.

I. Effect of Temperature on The Pupation and Emergence of The Hibernating Rice-Borers.

The hibernating rice-borers were collected before they passed out of the hibernation and began to develop. They were submitted to various constant

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† This is the slightly modified English editions of the writers' paper which was published in " *Nōgaku-Kenkyū*," No. 17, 165—183, 1931.

temperatures and the time of the pupation of the larvae and that of the emergence of the adult insects were recorded. The results obtained are shown in Table I.

Table I.

Results obtained with Hibernating Larvae.

Temperature °C.	Number of Days from the Start of Experiments to Pupation	Pupal Period in Days	Time when Experiments were begun
20	46—63	18.8	I, Jan. 17; II, Feb. 19, 1930.
25	50—65	10.8	II, Feb. 15; III, Feb. 19, 〃
27	42—84	8.3	II, Feb. 15; III, Feb. 25, 〃
30	16—63	6.6	I, Feb. 22; II, Feb. 25, 〃

Besides the experiments described above, two more series of experiments were conducted. In these experiments, however, the time of pupation was not determined, so that only the length of the periods from the beginning of the experiments to the emergence of the moths was found. The results of these experiments are shown in Table II.

Table II.

Periods from The Beginning of The Experiments to Emergence of Moths.

Temperature °C.	Number of Days elapsed before Emergence of Moths	
	In 1928	In 1929
12	—	352.3
15	169	—
20	90	54.1
25	54	49.8
27	47	34.1
30	—	25.2

Examining the results shown in Tables I and II, an interesting fact is noted. The results shown in Table II indicate that when the hibernating larvae were incubated at 12°C., only a few individuals developed and emerged as the moths after the average period of 352.3 days while most of the other individuals died. This result indicates that the rice-borer develops very slowly at 12°C. At 15°C., the period elapsed before the emergence of moth was 169 days. The development at this temperature was also very slow and the percentage of the larvae that transformed to adults was also small.

Under the other temperatures, the periods from the beginning of the experiments to the emergence of adults varied rather conspicuously as is evident from the records in Table II. The causes for such a marked variation can be explained by examining the results of the experiments shown in Table I. The pupal periods which are shown in the third column of Table I indicate that the rise of temperature produces a regular accelerating effect on the development of pupa and that the pupal period is shortened regularly with the rise in temperature. However, the length of the period from the start of the experiments to the pupation as shown in the second column in Table I varied very markedly. It may even be stated that the extreme values of these periods are not necessarily correlated with the temperature under which the experiment was conducted. According to the recent research by SHELFORD, the following three physiologically different periods can be distinguished when hibernating larvae are subjected to experimentation under various temperatures[1), 2)]:

1) Period of time from the beginning of incubation to the moment at which the hibernating larvae pass out of hibernation. (Dormant period of SHELFORD.)
2) Period of time from the breaking-up of hibernation to pupation. (Developmental period.)
3) Period of time from pupation to emergence, i. e., the *pupal period.*

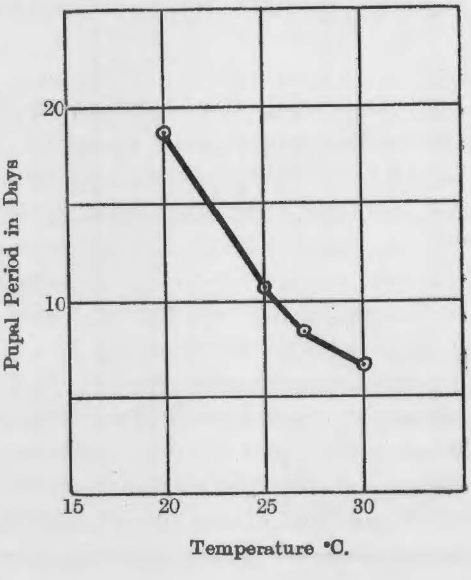
Although these three periods above mentioned may be theoretically distinguished, it is not possible, at the present time, to discriminate the first period from the second by any practical means.

Various factors are considered to be responsible for the breaking-up of hibernation. Some of which are not yet determined so that we are not able to control these unknown factors. In other words, the period from the start of the experiment to the end of the hibernation period, i. e., the dormant period, may vary markedly regardless of the temperature under which the experiment is carried out since it is not possible to eliminate the unknown factors which exert their influence upon the dormant period.

The period from the start of the experiment to the pupation which is shown in the second column in Table I is the sum of the dormant and the developmental periods. Hence, it may show a marked variation even when the hibernating larvae are subjected to the same temperature. The same explanation may also be applicable to the results shown in Table II.

The pupal period of the hibernating rice-borer is shortened regularly with the rise of temperature as it is evident from the records shown in the third column of Table I. The decrease in the length of the pupal period, however, is not directly proportional to the rise of temperature. It is apparent from the shape of the curve in Figure 1 which has been prepared from the data in Table I.

Fig. 1.



II. Effect of Temperature on The Development of Egg, Larva and Pupa.

i. Effect of Temperature upon The Percentage of The Moths that emerge.

The writers have not yet succeeded in obtaining the exact data on the percentages of the moths that emerge in the cases where rearing was started with newly hatched larvae. The results thus far obtained from the experiments are shown in Table III.

Table III.

Temperature and Percentage of The Moths that Emerged.

Temperature °C.	Number of Larvae with which the Rearing was started	Per Cent. of the Moths that emerged	Remarks
15	41	2.4	First and second generations.
20	54	29.6	First generation.
〃	64	25.0	Second generation.
27	128	57.8	First generation.
30	37	13.5 ?	Second generation.
33	47	46.8	Second generation.

A number of the eggs sometimes hatched at 12°C., but it was extremely difficult to rear larvae at this temperature. The hibernating larvae may sometimes develop at this temperature and transform to adult insects, but the percentage that attain the adult stage seems to be very small.

The egg develops at 15°C., but it is difficult to rear the larva to the adult stage at this temperature. Only 2.4 per cent. attained the adult stage in the experiments thus far carried out. At 20°C. the percentage of the larvae that attained the adult stage was approximately from 25 to 30 per cent. The greatest percentage of emergence was obtained at 27°C. according to the experiments thus far conducted. The result obtained at 30°C. seems to be somewhat doubtful. The percentage of emergence at this temperature ought to be much larger than the figure shown in Table III, if we judge from the results obtained under the other temperatures. At 33°C., the percentage of the moths that emerge seems to decrease slightly, but it is still of a considerable number. According to the experiments conducted in 1931, of which the results are not shown in Table III, the eggs did not hatch at 35°C. and the larvae very rarely attained the fullgrowth. When pupae were kept at 35°C., sometimes adult insects were obtained, but these moths were often found to be deformed.

To summarize the results, the minimum temperature for the development of the rice-borer seems to be approximately 10—11°C. and the maximum temperature is probably a little higher than 35°C. It is noteworthy, in this connection, that it is difficult to let the newly hatched larvae bore into the rice-culm although the eggs hatch at 33°C. This was often the cause of failure in rearing the larvae at this temperature.

ii. Effect of Temperature upon The Rate of Development and Growth.

An interesting phenomenon which was observed in the experiments with the rice-borer is that a certain number of the larvae which were treated quite similarly sometimes stopped to develop for a certain period of time. This state of the arrested development mostly occurred at the end of the larval stage. We considered that such larvae entered into a state of dormancy, although it is open to question whether the larvae in the quiscent state were really in a dormant state or not. Some of the larvae that entered into this quiscent state overwintered and pupated only in the next spring while the others remained in this state for a varying length of time and pupated in that season after the lapse of a certain period. This quiscent state occurred both in the first and the second generations. It was neither confined to the individuals which were reared at low temperatures nor to those reared at high temperatures. Thus, it was not possible for the writers to understand the true nature of this state of the arrested development.

A) *Egg Period and Temperature.*

The results of the incubation of eggs under various constant temperatures are shown in the following Table.

Table IV.

Incubation Period.

Temperature °C.	Average Egg Period in Days	Relative Velocity of Development	Remarks
32.3	5.5	0.1852	A part of the second generation in 1927.
31.6	4.5	0.2222	A part of the first generation in 1927.
31.5	3.5	0.2857	Second generation in 1927.
29.5	6.5	0.1538	First generation in 1927.
28.9	3.5	0.2857	A part of the second generation in 1927.
26.8—26.9	5.9	0.1695	First generation in 1929.
26.6	5.5	0.1818	A part of the first generation in 1928.
26.4—26.5	6.1	0.1639	First generation in 1927.
25.0	6.1	0.1639	First generation in 1929.
24.9—25.0	5.9	0.1695	Second generation in 1928.
20.2	11.5	0.0869	First generation in 1928.
〃	11.5	0.0869	Second generation in 1927.
19.9	12.5	0.0800	First generation in 1928.
19.4—19.5	11.5	0.0869	First generation in 1927.
15.3—15.4	18.0	0.0556	Second generation in 1928.
15.1	21.5	0.0465	First generation in 1928.
14.8	21.5	0.0465	First generation in 1929.

A small number of the eggs hatched at 12°C., but the majority died. It seems, therefore, that the minimum temperature for the development of the egg lies somewhere about 11 or 11.5°C. According to the experiments in 1931, the eggs do not hatch at 35°C. Therefore, the maximum temperature seems to be approximately at 34 or 35°C. The optimum temperature where the velocity of development is the greatest seems to be situated between 30 and 31°C.

An interesting phenomenon that can be seen in the results shown in Table IV is that the egg period of the first generation and the egg period of the second generation reared at about 29°C. or higher temperatures differed markedly. Thus, the egg period of the first generation was 4.5 days at 31.6°C. while it was 3.5 days in the second generation at 31.5°C. Similarly, the egg period of the first generation was 6.5 days at 29.5°C. while it was only 3.5 days at approximately 29° (28.9°C.) in the second generation. It will be noticed that the egg period of the second generation is considerably shorter than that of the first generation. This tendency was not observed at 25°C. or lower. The cause of this peculiar result seems to lie in the difference of the environment in which the eggs matured.

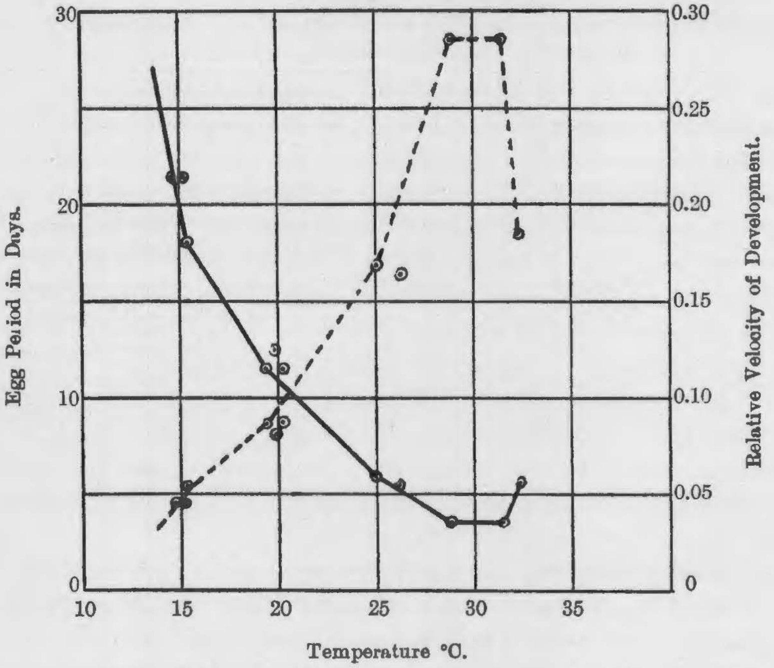
Shelford states that the rate of the development of the insect decreases slightly when the mean air temperature gradually rises and that the rate increases slightly when the mean temperature gradually descends.1), 2) The peculiar phenomenon which we have just mentioned may be comparable to Shelford's observation. In the spring and early summer when the hibernating larvae transform to adult insects, the air temperature is rather low. Thus, the eggs of the first generation mature when the air temperature is much lower than 27 or 28°C. Therefore, the development of the egg seems to be impaired when it is suddenly transferred to a constant temperature of 28°C. or higher. The eggs of the second generation develop and mature when the air temperature is fairly high. The maximum temperature of this season is higher than 28 or 29°C. in most cases so that the eggs are acclimatized to a rather high temperature. Consequently, the development of the egg of the second generation is not impaired even if they are transferred to a constant temperature of 28°C. or higher.

The egg periods of the first and the second generations were almost the same when they were incubated at 24°C. or lower, as it is evident from the result shown in Table IV. This is probably due to the circumstance that the temperature in the incubator was not higher than the air temperature of the outside so that the temperature of the incubator did not give ill effect on the development of the egg.

The fact that the velocity of the development of the egg in the first generation decreased at higher temperature seems to be partly explained in the manner just described above. However, the difference between the first and the second generations is fairly conspicuous and it may be questioned whether the explanation given above is valid in every case or not.

The relation of temperature to the development of the egg of the second generation is graphically shown in Figure 2. Where there are more than one result of the experiments which were conducted under approximately the same temperatures, the shorter egg period was adopted for preparing the time-temperature curve in Figure 2.

Fig. 2.



The egg periods of the first and the second generations did not show almost any difference at 24—25°C. or lower. Therefore, both the egg period of the first generation and that of the second were used for making Figure 2.

As it is evident from Figure 2, the velocity of the development was greatest at about 30—31°C. and beyond this temperature the velocity decreased rapidly. The velocity curve (shown in dotted line) is of a peculiar shape and there seems to be no straight-line-part in it. This fact indicates that the time-temperature curve does probably not conform to a hyperbola.

B) *Temperature and Growth of the Larva.*

The results of the rearing of the rice-borers under various constant temperatures are shown in Table V.

(Consult Table V on page 216.)

It has been stated previously that a certain part of the larvae ceased to develop further when they reached to the end of the larval stage and that they transformed to pupae after a certain period of time elapsed. The writers assumed that such larvae entered into a state of dormancy. The larvae of the second generation in 1928 which were reared at 27.0°C., those of the same generation which were reared at 25°C. and also those of the same generation which were reared at 19.9°C. entered into a dormant state and overwintered.

Table V.

Larval Period.

Temperature °C.	Average Larval Period in Days	Relative Velocity of Development	Remarks
33	22.8	0.0439	Second generation in 1929.
32.8	57.6 *	0.0174	First generation in 1927.
32.6—32.7	26.7	0.0375	Second generation in 1927.
30.0	48.6 *	0.0206	First generation in 1927.
〃	29.8	0.0336	Second generation in 1927.
27.2—27.3	34.7	0.0288	A part of the first generation in 1929.
27.0	65.6 *	0.0152	A part of the first generation in 1929.
〃	162.3	—	A part of the second generation in 1928.
25.0	187.6	—	A part of the second generation in 1928.
20.0—20.1	79.6	0.0130	A part of the first generation in 1928.
19.9	201.5	—	A part of the second generation in 1928.
15.0	199.1	0.0050	Second generation in 1928.

Those individuals, the relative velocities of which are not shown, entered into dormancy and overwintered.

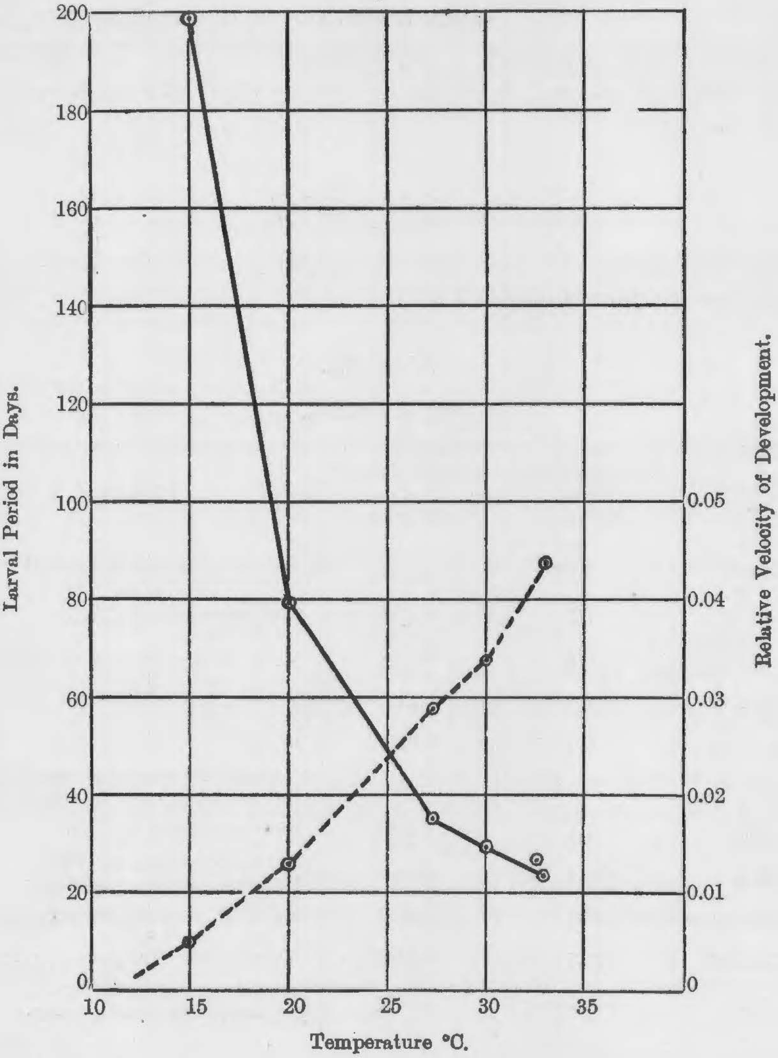
A remarkable feature in the results recorded in Table V is that the larval period of the first generation was much longer than the larval period of the second generation which was reared under the similar conditions. (See the figures in Table V marked with an asterisk.) For instance, the larval period of the second generation in 1929 which was reared at 33°C. was approximately 23 days while a part of the first generation in 1927 which was reared at approximately the same temperature (32.8°C.) required 57.6 days to attain the pupal stage. Another example is the result of the rearing at 30.0°C. in 1927.

It may be assumed, to explain these results, that the development of the larvae of the first generation was impaired because they were brought under the high constant temperature, just as we have assumed to explain the similar phenomenon which was observed in the case of the egg. However, this explanation does not seem to be sufficient in this case. In the first place, the difference between the two larval periods is too large. In the second place, when the larvae of the first generation in 1929 were reared under approximately the same temperature (27.0—27.3°C.), two kinds of larvae appeared: one with short larval period (34.7 days) and the other with much longer larval period (65.6 days).

It would seem probable that the larvae with the longer larval period temporarily entered into a short quiscent stage. If this assumption is tenable in the explanation of the results obtained at 27°C., there seems to be no reason why the same assumption is not applicable to the cases where larvae were reared at 30 or 33°C. The writers, however, are not able to draw a definite conclusion regarding this point at the present time.

Figure 3 was prepared to show the relation of temperature to the growth of the larva graphically.

Fig. 3.



The shorter larval periods (i. e., the larval periods of the second generation) were used for the higher temperatures in drawing the time-temperature curve shown in Figure 3 while for 27°C. and the lower temperatures the larval periods of the first generation were used since the larvae of the second generation entered into hibernation.

According to Figure 3, the velocity of the growth of the larva is quite great even at a temperature as high as 33°C. and the velocity does not show the tendency to decrease.

The minimum temperature for the growth of the larva has not been accurately determined. However, the results of the experiments showed that the majority of the larvae do not develop at 12°C. Therefore, the threshold of growth seems to be approximately 11 or 12°C.

The velocity of growth seems to be proportional to the rise of temperature between 20 and 30°C. The growth becomes extremely slow at 15°C. and the larval period at this temperature is approximately 200 days. This fact indicates that the rice-borer can not thrive in the locality where the air temperature is 15°C. or lower.

C) *Pupal Period and Temperature.*

The results of the observations on the pupal period under various constant temperatures are shown in Table VI.

Table VI.

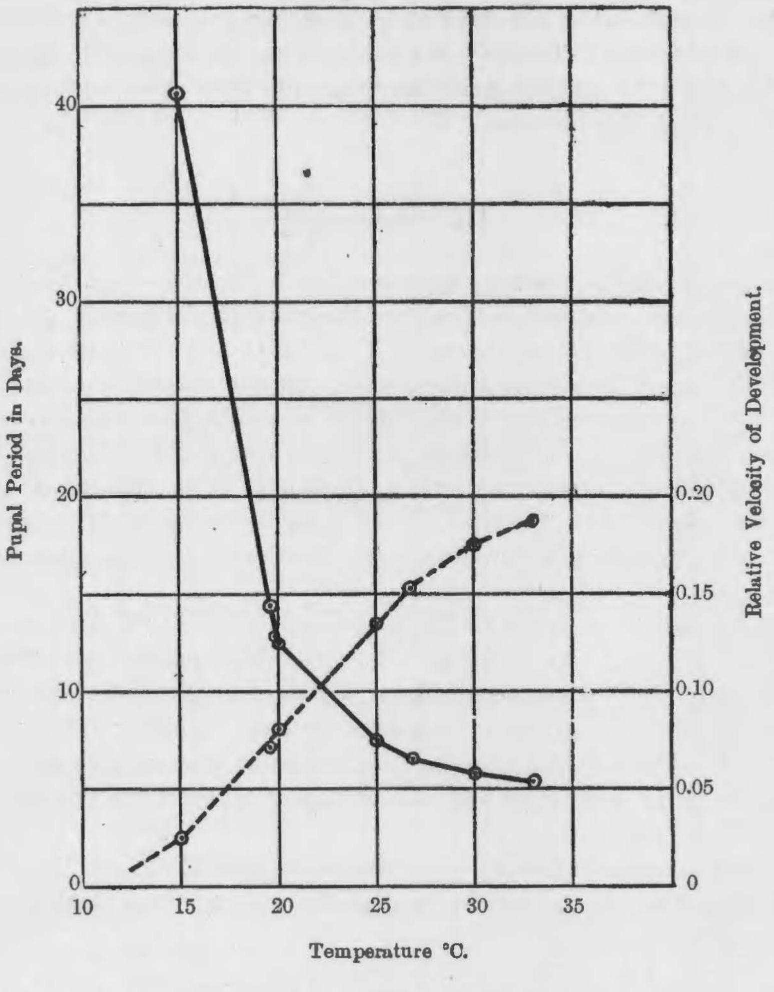
Pupal Period.

Temperature °C.	Average Pupal Period in Days	Relative Velocity of Development	Remarks
33	5.3 *	0.1887	A part of the second generation in 1927 and in 1929.
30	7.2	0.1389	First generation in 1927.
〃	5.7	0.1754	A part of the second generation in 1927.
26.9—27.0	6.6	0.1515	A part of the first generation in 1928 and in 1929.
26.7—26.8	6.6	0.1515	Ditto.
27.0	10.2 *	0.0980	A part of the second generation in 1928. Pupated after overwintering.
25.0	7.4	0.1351	First generation in 1929.
20.0	12.4	0.0806	Second generation in 1927. Pupated after overwintering.
19.9—20.0	12.8	0.0781	A part of the first generation in 1928.
19.5—19.6	14.3	0.0704	A part of the first generation in 1928.
15.0	40.7	0.0246	Second generation in 1928. Pupated after overwintering.

According to the records in Table VI, the pupal period of the first generation in 1927 which was reared at 30°C. was slightly longer than the corresponding pupal period of the second generation. This is the same tendency as that which was observed in the egg and the larval stages. The pupae of the second generation in 1928 required a considerably longer period than the pupae of the first generation which were reared under approximately the same temperature (26.9—27.0°C.). This is just the reverse of the tendency which was described above. The cause of such a peculiar result is not known at the present time. At 20°C. there was no difference between the pupal period of the first generation and that of the second generation.

Figure 4 represents the relation of temperature to the pupal period of the rice-borer.

Fig. 4.



To draw the time-temperature curve in Figure 4, the pupal period of the second generation was used for 30 and 33°C. For 20°C. or lower temperatures, the pupal periods of both the first and the second generations were used since there was no difference in the length of the pupal periods of these two generations. For 27°C. the shorter pupal period, i. e., the pupal period of the first generation was used. The curve thus obtained is a fairly smooth and regular one.

According to Figure 4 the velocity of the development of the pupa seems to be proportional to temperature between 15 and 25°C. Beyond 26 or 27°C. the rate of the increase in the velocity of development gradually decreases so that the velocity is no longer proportional to temperature.

At 35°C. some of the pupae developed and transformed to adult insects according to the experiments conducted in 1931. However, the adults that emerged were often deformed, and many of the pupae died. This fact indicates that 35°C. is no longer suitable to the development of the pupa. It seems, therefore, the maximum temperature is slightly higher than 35°C. The pupa develops at 12°C., but the velocity of development is extremely slow as it is apparent from the records in Table II. Therefore, the minimum temperature for the development of pupa seems to be situated somewhere near 10—11°C. The velocity curve in Figure 4 also indicates the same.

III. Summary.

The results of the rearing experiments with the rice-borer, *Chilo simplex*, under the constant temperature have been described in the present paper. The number of the experiments conducted at 35°C., 15°C. and 12°C. are limited and beyond the limit of these temperatures, the experiments are still wanting. Therefore, it is not yet possible to draw a definite conclusion from the results which have been described above. However, we may summarize the results as follows:

A small portion of the eggs sometimes develop at 12°C. The pupa develops also at this temperature. The larva, however, hardly grows at this temperature. Thus, it is apparent that the threshold of the development of the larva seems to be the highest.

The optimum temperature for the development of the egg seems to be somewhere near 30—31°C. At 33°C. the velocity of development falls off rapidly. The velocity of development of the larva and pupa does not decrease at 33°C. The velocity of the growth of the larva seems to show a tendency to increase even beyond 33°C. This fact indicates that the rice-borer is more resistant to high temperature in the larval stage and can develop at higher temperatures than in the egg and the pupal stages.

Further investigation under more accurately controlled conditions will be carried out in future so that the results then obtained may throw further light on the subject.

Literature.

1) SHELFORD, V. E., Laboratory and Field Ecology. 1929.

2) ——————, An Experimental Investigation of the Relations of The Codling Moths to Weather and Climate. Bulletin, Illinois Nat. Hist. Surv., XVI, Art. 5, 1927.

Acknowledgments.

In carrying out these experiments the writers were greatly assisted by Mr. K. MORINAGA. Dr. A. ITANO of this Institute kindly assisted the writers in the preparation of the English text. The writers wish to express their heartiest thanks to them at this time.