Studies on The Rush Saw-Fly. III.

Relation of Temperature to The Development of The Rush Saw-Fly.

By

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The following experiments were undertaken with twofold objects, namely, 1) to work out the relation of temperature to the rate of development of the egg and also of the larva of the rush saw-fly, and 2) to investigate the response to temperature of the rush saw-fly found in Okayama Prefecture and that of the one found in Hyôgo Prefecture[1] to see if there is any difference in the behavior between these two. Incidentally, the death rate of larvae at different constant temperatures were observed.

The purpose of the investigation of the relation of temperature to the development of the insect is either to predict the time of appearance or to know the possible extent of the distribution of the insect in question. To carry out an investigation of this kind requires a well equipped laboratory and a long period of painstaking work. The writers are by no means in such a position as to undertake such an elaborate experiment so that the results herein reported are of a preliminary nature. Still the writers believe that the results obtained are sufficient to know the tendency in the behavior of the rush saw-fly larva under different air temperatures. Therefore, the results obtained are reported below in the hope that they might become useful to those who would happen to undertake more elaborate experiments in future.

I. Methods of Experimentation and Calculation of the Average Temperature.

The method of rearing the rush saw-fly larva was similar to that used in the study of the oriental peach moth[2] with slight modifications to make it suitable to the habit of the rush saw-fly larva.

Since the full-grown larva of the rush saw-fly goes into the soil to make a cocoon, the bottom of the Petri-dish was filled to about 6—7 milimeter depth with the soil. This layer of the soil was always kept moderately wet by moistening with a few drops of water when the soil layer got dry.

The calculation of the average temperature was made almost in a similar manner to that used in the case of the oriental peach moth. However, a few modifications were made in this case also.

SHELFORD[8] maintains that the older methods of temperature summing must either be greatly modified or abandoned and he proposed to use degree-hour developmental units instead of effective temperatures. He introduced the idea of "developmental units" on one hand and adopted on the other hand "hour" as the unit of time for calculation of the duration of stages.

In experimenting with the oriental peach moth, the writers[2] adopted "hour" as the unit of time. In the present study, however, the writers used "day" as the unit of time since it was found impossible to determine exactly just when a certain transformation in a stage occurred.

It has been assumed that egg laying and hatching of eggs occur at noon and also that the full-grown larva goes into the soil at noon. This does not always correspond to what really occurs. For instance, some eggs may hatch in the forenoon while others hatch in the afternoon. However, on account of this circumstance it has been considered that the error would be minimized by the calculation carried out under the assumption stated above.

In calculating the average temperature, hourly temperatures were read from the recording sheets, these were added together and devided by the number of hours. When the duration of a certain period is less than 24 hours the duration in hours was devided by 24 and the duration was converted into the decimal fraction of a day. The average temperature multiplied by this fraction of a day was considered the temperature accumulated during that period. For example, suppose that an egg was laid at noon and the average temperature of the whole afternoon was 18° C.

Then, $18 \times 0.5 = 9$.

That is, 9 "degree-days" are the accumulated temperatures in the afternoon.

When an accident occurred during the course of a constant temperature experiment and the temperature was lowered, the duration of this accident and the extent of the fall of the temperature were read from the recording sheet. The method of calculation of the average temperature as described above was used.

The same method of calculation was adopted in the case of variable temperature experiments also.

II. Result of Experiments.

i) The Range of Temperature for the Development of the Egg and the Larva of the Rush Saw-Fly and the Death Rate.

In the experiments here reported, attempt has not been made to determine exactly the range of temperature where the development of the egg and the growth of the larva are possible.

The range of temperature in which the embryonic development is possible seems somewhat larger than that for the growth of the larva. The lowest temperature for the development of the egg of this saw-fly was difficult to determine, because the development of the egg goes on at a very slow rate at temperatures as low as 10° or 11° C and it was almost impossible to keep the potted rush-plants with eggs in a green and healthy condition in an incubator long enough for the completion of the embryonic development. So far as the writers could ascertain, the egg seemed to develop at 10° C. However, the writers were not able to determine the duration of the egg period at this temperature.

Although the egg hatched at 12° C the larva did not grow at this temperature and all died before they were full-grown as the result in Table I shows. This was also the case with the Hyôgo strain of the rush saw-fly. At present, the writers are somewhat uncertain as to whether 12° C is really the actual lowest temperature at which the larval development is possible.

Table I.

Death Rate of Larvae under Various Constant Temperatures.

Temperature C	Okayama Strain				Hyôgo Strain			
	Initial Number of Larvae	Number of Larvae Full-grown	Number of Larvae Dead	Death Rate %	Initial Number of Larvae	Number of Larvae Full-grown	Number of Larvae Dead	Death Rate %
12	40	0	40	100	43	0	43	100
15	57	36	21	37	21	17	4	19
17	41	30	11	26.8	53	43	10	18.8
20	88	81	7	7.9	65	57	8	12.3
25	41	36	5	12.2	61	50	11	18.0
27	64	31	33	51.1	75	14	61	81.3
27.5	24	0	24	100	—	—	—	—
30	—*	—	—	100	—*	—	—	100

* Many larvae were reared under this temperature, but the exact number was not recorded.

The highest temperature under which the embryonic development is possible could not be determined yet from the results of the present experiments. However, it was observed that the eggs of both the Okayama and the Hyôgo strain developed at 30° C. The maximum temperature for the larval growth seems to be a little lower than that for the egg, namely, in the case of the Hyôgo strain about 80 per cent. of the larvae died at 27° C while in the case of the Okayama strain no larva could survive the temperature of 27.5° C. Therefore, it is probable that the maximum temperature for the larval growth lies somewhere about 28° C and the larva is not able to withstand a prolonged exposure to a temperature of 30° C. The results of observations in regard to the death rate which were obtained in the constant temperature experiment are shown in Table I. It shows that the death rate decreases upto 20° C and increases again until it reaches 100% at 27.5° or 30° C. Judging from these results it seems that the optimum temperature lies somewhere between 20° and 25° C. Temperatures higher than 26°—27° C seem to be unfavorable to the larva of the rush saw-fly. This is apparent also from the results obtained in the variable temperature experiments, which are shown in Table II.

Table II.

Death Rate of Larvae When reared under Natural, Variable Temperature.

Strain	Months	Initial Number of Larvae	Number of Larvae Full-grown	Number of Larvae Dead	Death Rate %
Okayama	May to July	61	30	31	50.8
〃	July to August	20	0	20	100
〃	September to November	73	55	18	24.6
Hyôgo	March to July	33	7	26	78.7
〃	July to August	30	0	30	100
〃	September to November	57	50	7	12.2

Table II shows clearly that the death rate is always greater in the spring generation than in the autumn. This seems to be due chiefly to the fact that in the latter part of June to the early part of July the air temperature is not favorable for the metabolic activity of the larva. None of the larvae of the summer generation could attain to full-growth in these rearing experiments. This shows that the warmest part of the summer is the most unfavorable to the rush saw-fly larva.

Figure 1 has been drawn using the data shown in Table I. It shows that the death rate varies markedly with temperature and also that the minimum death rate is situated at about 20° C.

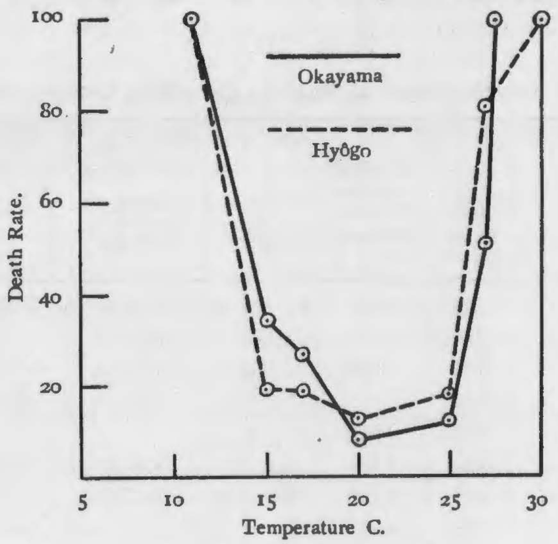
(See Figure 1 on next page.)

Comparison of the Okayama strain with the Hyôgo in regard to the death rate.

In the experiments herein reported, rearing of larvae was carried on primarily to study the velocity of development. The number of larvae which were reared was limited, so that it was not possible to obtain very accurate data in regard to the death rate. Nevertheless, it may possibly be stated, from

Fig. 1

Death Rate under Constant Temperature.



Full line ... ... Okayma strain.
Broken line ... ... Hyôgo strain.

the results of the constant temperature experiments, that at temperatures lower than 25° C the death rate of the Okayama strain and that of the Hyôgo did not show much difference and that at 27° C the death rate of the Hyôgo strain is larger than that of the Okayama strain. The death rate of the Hyôgo strain at 27.5° C was not determined. It has been considered, however, that the death rate of the Hyôgo strain at this temperature would possibly be the same as that of the Okayama strain; namely, it would be 100 per cent.

From the results of rearing in the insectary under natural, variable temperatures the following statement may be made. In both strains, the death rate of the spring and of the summer generation which occur from May to July is always larger than that of the autumn generation.

The death rate of the spring generation of the Hyôgo strain seems to be slightly larger than the corresponding death rate of the Okayama strain. This probably indicates that the weather conditions in June to July in Okayama Prefecture is not favorable for the Hyôgo strain.

ii) Effect of Temperature on The Rate of Embryonic Development.

The egg of the rush saw-fly is laid in the stem and can not be seen from outside, so that it is difficult to know just when a larva hatches out of egg. Therefore, it was inevitable that errors of about half a day have entered into the results of observations on the egg period since the examination of the sample was made only twice or three times a day. In Table III the results of observations on the egg period are given.

Table III.

Embryonic Development at Various Constant Temperatures.

Okayama Strain				Hyôgo Strain			
Temperature in C	Average Egg Period in Days	Average Velocity of Developt.	Average Accumul. Temperat. above 8° C	Temperature in C	Average Egg Period in Days	Average Velocity of Developt.	Average Accumul. Temperat. above 8° C
12	29.1±3.0	0.0343	120.0	12	30 ±2.5	0.0333	121.0
14.9—15	17.4±1.4	0.0574	121.6	14.8	17 ±0.0	0.0588	115.3
16.7	14 ±0.0	0.0714	121.7	16.7	14 ±0.0	0.0714	121.7
19.8—20	10.8±1.3	0.0925	130.5	19.8—20	10.3±1.6	0.0970	123.7
23	8 ±0.0	0.1250	120.0	—	—	—	—
24.8—25	7.5±1.4	0.1333	126.8	24.8—25	8.0±1.0	0.1250	137.6
27	7 ±0.0	0.1428	133.0	26.8—26.9	7 ±0.0	0.1428	132.1
27.5	7.3±0.0	0.1369	141.5	—	—	—	—

According to Table III it seems that there occurred no error in certain cases. However, it must be borne in mind that an error of about half a day could not be avoided in the writers' experiments as has been stated above.

It was not possible to determine the minimum temperature for the embrynic development. Although it was certain that the egg develops at a temperature as low as 10° C, it was not possible to determine the egg period at this temperature.

With the rising temperature the velocity of development increases at first very rapidly, the rate of increase of the velocity becoming gradually smaller until about 27° C beyond which the velocity does not increase any more. In the case of the Okayama strain, the velocity of the embryonic development seems to attain its highest value at about 27° C while in the Hyôgo strain the temperature of the maximum velocity seems to be slightly higher.

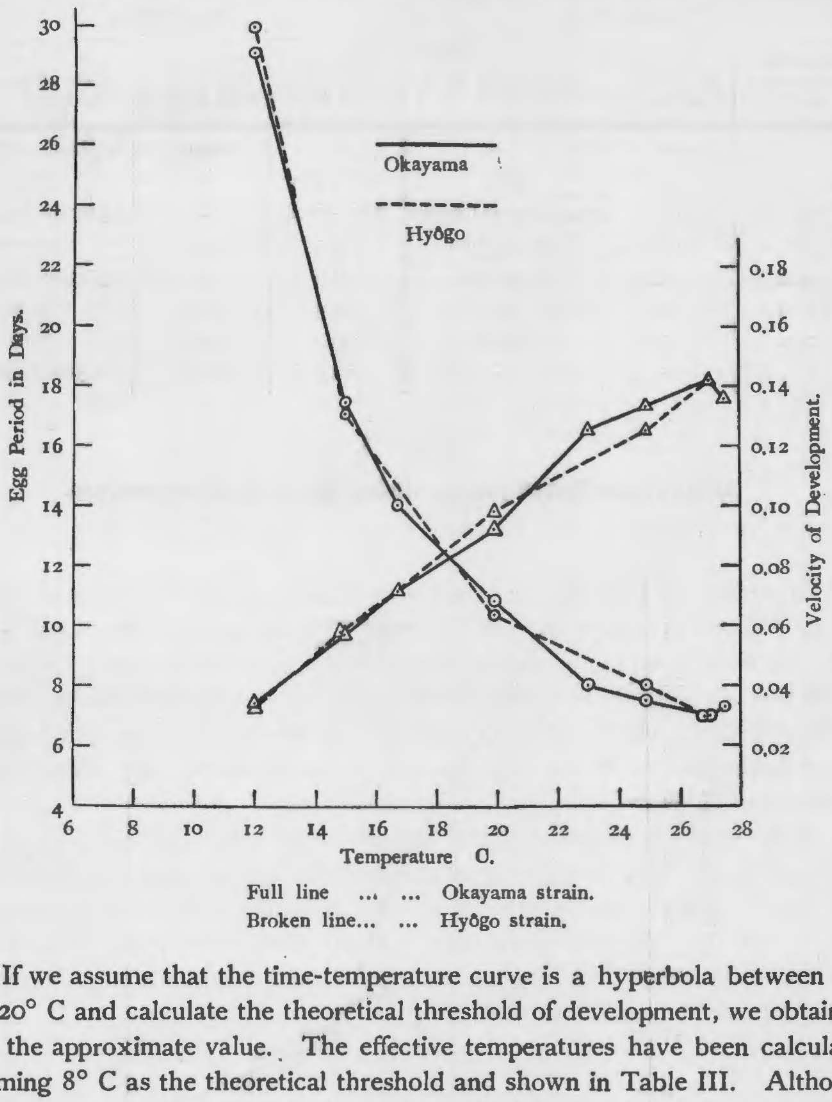
Figure 2 has been drawn using the data shown in Table III.

(See Figure 2 on next page.)

Figure 2 shows clearly that the curve showing the relation between temperature and the duration of the egg stage of the Okayama strain is very nearly the same as that of the Hyôgo strain and also that the time-temperature curve looks like a part of hyperbola. It will be seen that the velocity curve obtained by plotting the reciprocal of the duration of the egg period approaches to a straight line between 12° and 20° C (in the case of the Hyôgo strain) or between 12° and 23° C (in the case of the Okayama strain).

Fig. 2.

Embryonic Development under Constant Temperature.



Full line ... ... Okayama strain.
Broken line... ... Hyôgo strain.

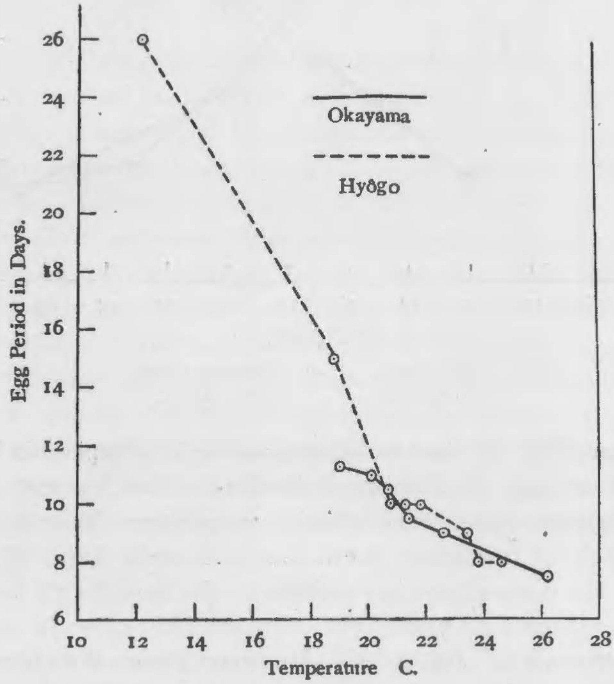
If we assume that the time-temperature curve is a hyperbola between 12° and 20° C and calculate the theoretical threshold of development, we obtain 8° C as the approximate value. The effective temperatures have been calculated assuming 8° C as the theoretical threshold and shown in Table III. Although these accumulated temperatures are not strictly the same for all temperatures at which the experiments are carried out, they are fairly close to each other for temperatures between 12° and 20° C. However, these values become markedly larger beyond 25° C and this shows that the time-temperature curve does not conform to a hyperbola above this temperature.

In the case of the rearing experiments at constant temperatures fairly uniform results have been obtained as has been shown above. At variable temperatures, however, the results obtained were not very regular as will be apparent from Table IV and Figure 3.

Table IV.
Egg Period under Variable Temperatures.

Okayama Strain			Hyôgo Strain		
Average Temperature in C	Average Egg Period in Days	Time of the Year	Average Temperature in C	Average Egg Period in Days	Time of the Year
—	—	—	12.1	26	March to April
18.5—18.6	11.3	May	18.8—18.9	15	May
20.1	11.0	September to October	20.7—20.8	10	September to October
20.7	10.5	May to June	21.3	10	September
21.4	9.5	September	21.8	10	September to October
22.6	9.0	June	23.4	9	July
26.2	7.5	August	23.8	8	June
—	—	—	24.6	8	June to July

Fig. 3.
Embryonic Development under Variable Temperature.



Full line ... ... Okayama strain.
Broken line... ... Hyôgo strain.

Various factors would have been responsible for this irregularity of the results. The writers consider that the most important one of these factors must have been the daily fluctuation of the air temperature. When the air temperature does not much exceed the range of the temperatures which is suitable to the development of the egg, the fluctuation would not give much ill effect on the embryonic development. Similarly it would not produce much ill effect on the development when the duration of the time during which the air temperature is outside the range of the suitable temperature is very short. On the contrary, when the air temperature markedly exceeds the temperature which is suitable to the embryonic development, the dairy fluctuation must have ill effect on the egg and the egg period would not get shorter in proportion to the rise of the mean daily temperature.

It has already been shown by SHELFORD[9] that the variable temperature may have an accelerating effect on the development of the insect. However, it must be pointed out that an accelerating effect on the development of an egg can be expected only when the fluctuation of temperature is within a certain range of temperature. Thus, we see that the magnitude of the mean air temperature alone is not a good index of the velocity of development. Examples of this kind are found among the data shown in Table IV where the same durations of the egg period are seen in certain cases even when the mean temperatures are different.

Comparison between the Okayama and the Hyôgo strain. By examining the data in Table III as well as the curves in Figure 2, we see that there is almost no difference between the Okayama and the Hyôgo strain in regard to the velocity of the embryonic development. The theoretical threshold is approximately the same in the two strains and the accumulated temperatures above the theoretical threshold are also nearly the same in the two cases. Therefore, we may conclude that the two strains show similar response to temperature at least in the egg stage when the egg is incubated at constant temperatures.

When the egg periods of the two strains observed at variable temperatures are compared, no marked difierence in the velocity of development can be found in most cases. In the spring generation, however, the velocity of development of the Okayama strain seems to be larger than that of the Hyôgo strain. For instance, at an average temperature of 18.5°—18.6° C the egg period of the Okayama strain was 11.3 days while that of the Hyôgo strain at 18.8°—18.9° C was 15 days.

iii) Effect of Temperature on the Growth of Larva.

Larvae were reared at various constant temperatures and the duration of the growing period was observed. The results obtained are given in Table V. Using the data shown in Table V curves have been drawn to show the relation between temperature and the growth of larva. These curves are shown in Figure 4.

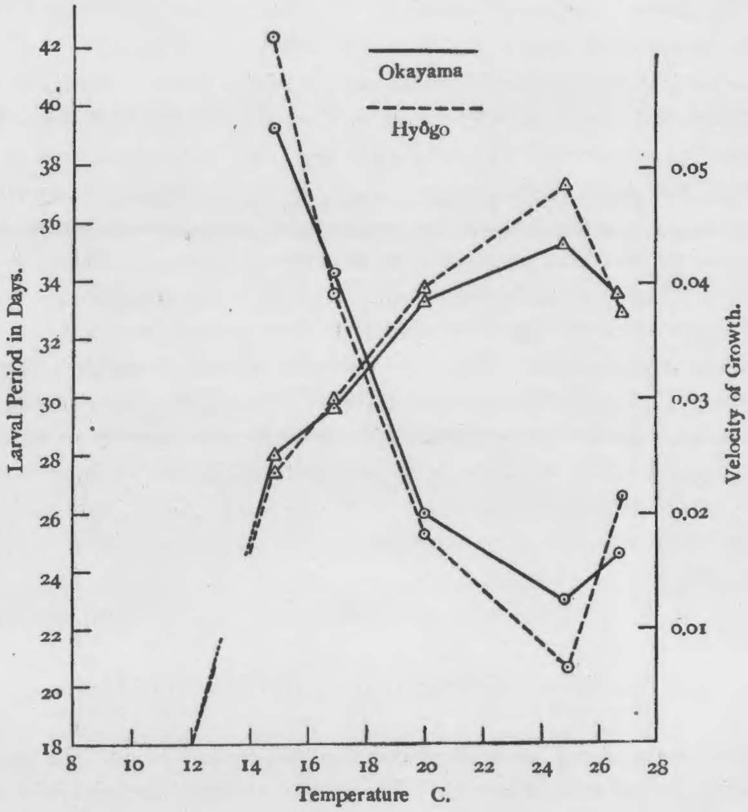
Table V.

Growth of Larva at Constant Temperatures.

Okayama Strain			Hyôgo Strain		
Temperature in C	Average Growing Period in Days	Average Velocity of Developt.	Temperature in C	Average Growing Period in Days	Average Velocity of Developt.
14.8—14.9	39.3±3.7	0.0255	14.8—14.9	42.5±4.5	0.0235
16.8—17.0	34.3±3.4	0.0291	16.8—17.0	33.6±4.2	0.0297
19.9—20.1	26.0±4.2	0.0384	19.8—20.1	25.8±2.0	0.0395
24.7—24.9	23.0±3.1	0.0434	24.8—25.0	20.6±3.1	0.0485
26.6—26.8	25.6±2.9	0.0390	26.8—26.9	26.6±2.7	0.0375

Fig. 4.

Growth of Larva under Constant Temperature.



Full line ... ... Okayama strain.
Broken line... ... Hyôgo strain.

As has been stated already, none of the larvae which were reared at 12° C attained to maturity. The actual threshold of growth, therefore, seems to be situated somewhere about 12° C, although the writers are inclined to consider that 12° C is somewhat too high to be the threshold of the growth of the larva of the rush saw-fly.

The velocity of growth increases rapidly from this point with the rise of temperature and the maximum of the velocity is attained at about 25° C. Beyond this temperature the velocity seems to decrease again. As will be apparent from Figure 4, the velocity curve is of a peculiar shape and it does not look like a straight line in any range of temperatures. Therefore, the time-temperature curve does not seem to be a hyperbola in this case.

The larva of the rush saw-fly seems to be variable in a high degree. Moreover, it seems to be very sensitive to the change in the environmental conditions. Presumably owing to these circumstances the duration of the growing period showed a fairly large variation even among individuals hatched from one batch of the eggs laid by the same female at a time. The standard deviations shown in Table V will give the idea of the magnitude of this variation.

It has been considered useless to calculate the accumulated temperature since the time-temperature curve does not look like a hyperbola.

Growth of larva at variable temperatures. The results of rearing at variable

Table VI.

Growth of Larva at Variable Temperatures.

A. Okayama Strain.

First Generation				*Second Generation*			
Average Temperature in C	Average Growing Period in Days	Average Velocity of Growth	Date	Average Temperature in C	Average Growing Period in Days	Average Velocity of Growth	Date
21.3—21.5	29.0	0.0344	May 30—June 29	16.5	49	0.0204	Oct. 1—Nov. 19
21.7—21.9	32.8	0.0304	May 30—July 3	16.7—16.8	46	0.0217	Oct. 1—Nov. 16
22.5—22.6	30.5	0.0327	June 9—July 9	17.0—17.1	38.7	0.0258	Oct. 1—Nov. 10
22.8	35.5	0.0281	June 9—July 14	17.3—17.4	36.0	0.0277	Oct. 1—Nov. 7
23.0—23.2	34.8	0.0287	June 13—July 15	18.4	34.1	0.0293	Sept. 24—Oct. 28
—	—	—	—	18.5—18.6	32.2	0.0310	Sept. 24—Oct. 26

B. Hyôgo Strain

First Generation				*Second Generation*			
16.5—16.6	40.7	0.0245	April 21—June 1	15.3—15.5	44	0.0227	Oct. 8—Nov. 22
20.8—21.0	31.6	0.0316	May 16—June 20	15.7—15.8	37.5	0.0266	Oct. 8—Nov. 17
—	—	—	—	17.1—17.3	35.7	0.0280	Oct. 12—Nov. 18
—	—	—	—	17.5—17.7	31.5	0.0317	Oct. 12—Nov. 15
—	—	—	—	18.5—18.7	29.8	0.0335	Sept. 24—Oct. 25

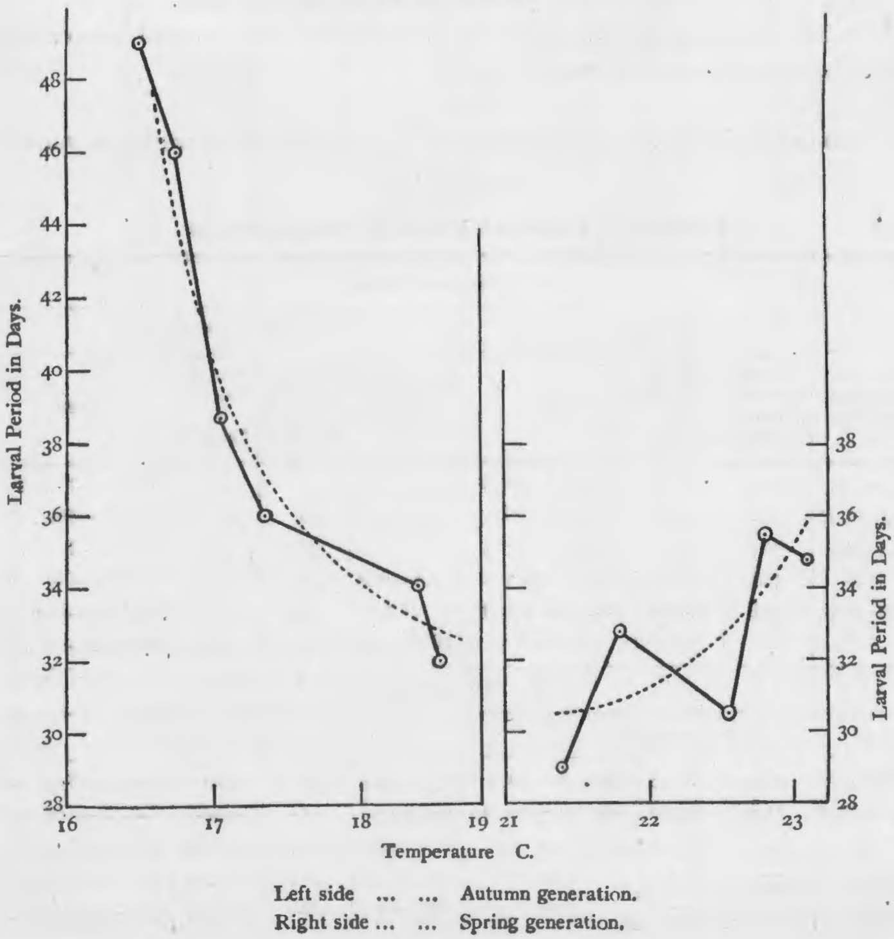
temperatures are given in Table VI. Figures 5 and 6 were drawn plotting the data shown in Table VI.

In the rearing experiments at constant temperatures fairly uniform results were obtained. At variable temperatures, on the contrary, the results obtained were rather irregular as will be apparent from the data in Table VI as well as from Figures 5 and 6. There were a few individuals which required an extraordinarily long period for growth among the larvae which hatched from the eggs laid by the same female at a time. This abnormally slow growth seemed in certain instances to be due to a sudden rise either of the maximum or of the minimum temperature to such an extent as to be unfavorable for the growth while in the other instances the cause of this unusually slow growth of larva was utterly unknown.

Since the number of such larvae was scarce, they were excluded in calculat-

Fig. 5.

Growth of Larva under Variable Temperature.
Okayama Strain.



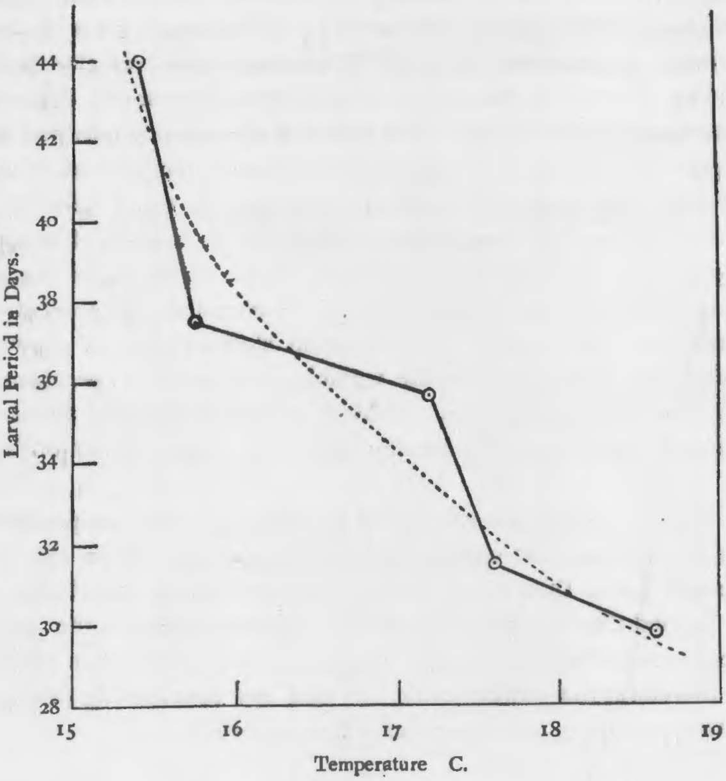
Left side ... ... Autumn generation.
Right side ... ... Spring generation.

ing the average larval period. The results of the experiments, the average temperature of which differed only 0.1° to 0.2° C, were averaged together to eliminate irregularities in the results. The results given in Table VI were obtained in this way.

Fig. 6.

Growth of Larva under Variable Temperature.
Hyôgo Strain.

Autumn Generation.



In starting each experiment a group of larvae which had hatched on the same day from the same batch of eggs were used. In spite of this precaution all of them did not attain to maturity on the same day, but full-grown larvae appeared scatteringly over a number of days. Therefore, when the average temperature for each larva was calculated, it was found that the number of larvae which had encountered quite the same temperature was generally rather scarce. This circumstance was certainly one of the causes which made the averages of the results of the experiments rather irregular.

Since the results obtained at variable temperatures were not very accurate, it is not possible to draw any definite conclusion from these results. However, we are able to see some important tendencies in them. If we may venture to smooth up the curves showing the relation of temperature to the duration of the growing period, the smoothed curves would be something like the ones shown in the dotted line in Figures 5 and 6.

Comparison of the results of experiments at constant temperatures with those at variable temperatures.

In comparing the results of experiments at variable temperatures with those at constant temperatures, a striking feature is that the temperature of the maximum velocity of growth in the variable temperature experiments is situated much lower than in the constant temperature experiments. Thus, in the constant temperature experiments the point of the maximum velocity lies somewhere about 25° C while in the variable temperature experiments it seems to be situated somewhere about 21° C. This apparent discrepancy between the two kinds of experiments is due to the fact that the average temperature of the variable temperature experiment was used in comparing its result with the result of the constant temperature experiment. The daily fluctuation of temperature may be so great that the daily maximum is above the optimum for the growth of the larva, even though the mean of daily air temperature is apparently close to the optimum for the growth. The apparent slow velocity of growth at a comparatively high temperature in the variable temperature experiments must have been due to this circumstance. Thus, it is evident that the fluctuation of temperature does not always give accelerating effect on the growth of the larva of the rush saw-fly.

In the Okayama strain the velocity of growth at variable temperatures was somewhat smaller than that under constant temperatures when the average temperature was lower than about 18° C. In the case of the Hyôgo strain, however, it seemed that there was no distinct difference between the two kinds of experiments even when the average temperature was lower than 18° C. In either case, therefore, the writers could not find any accelerating effect of the fluctuating temperature in the experiments here reported.

Comparison between the Okayama strain and the Hyôgo strain.

Figure 4 shows that, in the constant temperature experiments, the time-temperature curve of the Hyôgo strain follows fairly closely that of the Okayama strain. At first sight the velocity of the Hyôgo strain at about 25° C seems to be slightly larger than that of the Okayama strain while at about 15° C the velocity of the Okayama strain seems to be slightly larger than the Hyôgo strain. However, the difference is hardly larger than the standard deviation so that it would be better to consider that the response as manifested in the velocity of growth to temperature is almost the same in the two strains of the rush saw-fly.

When the results obtained at variable temperatures are compared it is found that the velocity of the growth of the Hyôgo strain is always slightly larger than that of the Okayama strain so far as the mean daily temperature is below

19° C. Thus, according to Figures 5 and 6, the growing periods of the two strains at various temperatures are approximately as follows : —

Average Temperature C	Okayama Strain.	Hyôgo Strain.	Difference.
15.5	More than 50 Days	About 42 Days	More than 8 Days
16.5	About 49	〃 36.5	12.5
17.5	〃 36	〃 32.5	3.5
18.5	〃 33	〃 30	3.0

The difference is not always very large, but the velocity of the Hyôgo strain is always somewhat larger than that of the Okayama strain. At a temperature of 16.5° C or lower the difference in the velocity is quite distinct. Therefore, we may probably conclude that the two strains of the rush saw-fly are somewhat different in regard to the response to the variable temperature.

III. Discussion.

In the experiments herein reported the pupal stage was not included. As has been reported already, the full-grown larva of the rush saw-fly has hibernation and estivation in its seasonal life-cycle. It is not yet clearly understood just what conditions cause the rush saw-fly larva to enter into hibernation or estivation, although the fall and rise of the air temperature have probably something to do with the initiation of hibernation and estivation, respectively. Just as the cause of the initiation of hibernation or estivation is not clearly known, it is extremely difficult to determine the exact time when an insect awakes from hibernation or estivation. Unless we are able to determine this time it is not possible to determine the exact duration of the cocoon period. Experience in rearing the rush saw-fly larva has shown that some of the larvae may continue development while others may enter into dormancy after constructing a cocoon. For these reasons it has been considered necessary to exclude, for the present, the cocoon period in discussing the relation between temperature and the growth of the rush saw-fly larva.

SHELFORD[6] has shown that the duration of a stage under variable temperature is approximately 7 per cent. shorter than under constant temperature when temperature varies slowly within a certain range of temperatures. According to the results of our experiments with the rush saw-fly, the velocity of the growth of the larva under constant temperature is slightly larger than that under variable temperature, especially when the mean of variable temperature is fairly high. This apparent disagreement of our result with that obtained by SHELFORD seems to be accounted for, at least partly, by the fact that the optimum temperature for the rush saw-fly is rather low so that during the warmer hours of a day the air temperature may exceed the optimum temperature for this insect. If the range of the daily fluctuation exceeds the temperature which is favorable to the growth of the rush saw-fly larva, the velocity of growth would become smaller in spite of the mean daily temperature being equal to or even slightly lower than the optimum.

Therefore, it is evident that the mean daily temperature alone is not a sufficient index of the growth of the rush saw-fly larva. We have to take the range of daily variation of temperature into consideration when we desire to know the velocity of growth at a certain mean temperature.

The death rate of the larvae which were observed during the rearing experiments under constant temperature showed that the largest percentage of larvae reached to maturity at a constant temperature of 20° C. It may be stated that the optimum temperature for the larva of the rush saw-fly is 20° C. In the case of the egg the maximum velocity of the embryonic development has been observed at 27° C while in the larval stage the maximum rate of growth occurred between 25° and 26° C. It may be stated, therefore, that the optimum temperature for the embryonic development is 27° C and that for the larval growth lies between 25° and 26° C. Therefore, we see that the so-called optimum temperature differs according to the point of view from which we judge the most suitable temperature. What is then the best criterion by which to judge the most suitable temperature to the success of an insect? Death rate, the rate of development and the rate of multiplication by reproduction, all have an important bearing on the success of an insect.

In the experiments herein reported the writers could ascertain neither the most suitable temperature for the reproduction of this saw-fly nor the limits of the range of temperatures where reproduction is possible. The writers are able to take only two factors into consideration, namely, the death rate and the velocity of development. Since the success of the rush saw-fly in a certain locality is more closely related to the death rate than to the velocity of growth, and since the temperature where the death rate is the smallest is lower than the temperature of the maximum velocity of growth, the temperature where the death rate is minimum may be considered to be nearer to the optimum temperature for this species than the temperature of the maximum velocity of growth.

When the Okayama strain and the Hyôgo are compared in regard to their response to the air temperature it is found that they are fairly similar to each other. However, their response is not exactly the same. When the Hyôgo strain was brought to Kurashiki and reared under natural variable temperatures, the death rate of the spring brood which appear from March to the beginning of June was slightly larger than that of the corresponding generation of the Okayama strain. The same tendency was observed also in the constant temperature experiment when the temperature reached 27° C. The velocity of the growth of the larva of the Hyôgo strain when brought to Kurashiki and reared under natural variable temperature seemed to be slightly larger than that of the Okayama strain so far as the mean temperature did not exceed 18.5° C. However, the results of the constant temperature experiments did not show that there is a distinct difference between the two strains in regard to the rate of growth.

In a previous paper[4)] one of the writers (HARUKAWA) has shown that the Hyôgo strain showed certain peculiarities when it was brought to Kurashiki and reared under natural, variable temperatures. Namely, the adult appeared slightly earlier in the spring than the Okayama strain and a certain part, at least, of the Hyôgo strain was three-brooded.

All these facts seem to indicate that the response of the Hyôgo strain to the weather condition in Okayama Prefecture is somewhat different from that of the Okayama strain and that it is probably physiologically differentiated from the Okayama strain, although the two strains are undoubtedly closely allied to each other.

A few more remarks should be made before closing this discussion regarding the curves which show the relation of temperature to the development and the growth of this saw-fly larva. As will be apparent from Figure 2, the time-temperature curve of the egg period closely resembles an equilateral hyperbola. It shows, however, that the rate of development begins to decrease again when temperature reaches 27° C. The time-temperature curve of the growth of the larva is of a peculiar shape. At first, the duration of the larval period decreases rapidly untill about 24°—25° C. and it increases very rapidly when temperature exceeds 25°—26° C. As a result of this rapid increase of the larval period beyond 25° C the time-temperature curve does not look like a hyperbola, but it resembles an assymmetrical catenary. To decide whether the time-temperature curve in the case of the larva is really an assymmetrical catenary needs further experimentation under conditions perfectly controlled in regard to temperature and humidity.

IV. Summary.

The results of the experiments which were conducted to investigate the relation of temperature to the development of the egg and also to the growth of the larva of the rush saw-fly have been described.

Although the actual threshold for the development of the egg has not been definitely determined yet, it seems to be somewhat lower than 10° C.

The maximum temperature for the embryonic development seems to be slightly higher than 30° C and the optimum temperature is about 27° C.

The minimum temperature for the growth of the larva has been found to be about 12° C and the maximum temperature seems to be situated between 27° and 28° C. The temperature of the maximum velocity of growth lies somewhere about 25° C. However, this can hardly be called the optimum tempera-

ture for this saw-fly when we take the death rate of larva into consideration.

The two strains or races of the rush saw-fly, the one found in Okayama Prefecture and the other in Hyôgo have been compared in regard to their response to temperature. It has been found that they are somewhat different in their physiological characters and for that reason they may be distinguished as two different physiological races, although the two races are not separable by their morphological characters.

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