Studies on the Seed-Corn Maggot. IV.

By

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Introduction.

In the first and second reports on the bionomics of the seed-corn maggot, *Hylemyia cilicrura* Rond., the writers reported the results which were obtained up to the middle part of 1931.[1), 2)] In the third paper of this series the writers reported the results of experiments on the control of this insect.[4)] The investigation has been continued since that time and the results obtained are reported here as the fourth report. Some of the data here described are supplementary to the results already reported in the first two papers mentioned above, but the rest, which constitute the main part of the present paper, are new data which have not yet been reported on.

I. Food of the Larva.

There have been many reports regarding the food of the seed-corn maggot and the present writers have also published the results of their own observations. They wish to add here more information to the knowledge of its food by describing the results of their observations which were made after the previous reports had been written.

The seed-corn maggot is remarkably polyphagous in its feeding habit as is well known among economic entomologists. The present writers found that the following substances served as food :

(1) Living plants.

Chrysanthemum coronarium L. "Shungiku".
Daucus carota L. Carrot.
Arctium Lappa L. Great burdock.
Allium cepa L. Onion.
Allium nipponicum Franch. et Sav. "Nobiru".
Rumex acetosa L. A species of sorrel, "suiba".

Rumex japonicus MEISN. "Gishigishi".
Trifolium pratense L. Common red clover.
Taraxacum platycarpum DAHLST. Dandelion.
Equisetum arvense L. Horsetail.
Artemisia vulgaris L. Wormwood.
Nasturtium sublyratum FRANCH. et SAV. "Aze-daikon".
Oenanthe stolonifera DC. "Seri".
Cryptotaenia canadensis DC. "Mitsuba-seri".
Spinacia oleracea L. Spinach.
Zea Mays L. Maize.
Cyperus rotundus L. "Hamasuge".
Zizania aquatica L. Water oats.
Physalis Alkekengi L. Chinese lantern-plant.
Colocasia antiquorum SCHOTT. Taro or elephants ear.
Mentha arvensis L. Japanese mint.
Pirus sinensis LINDL. (Fruit). Japanese pear.
Musa paradisiaca L. (Fruit). Banana.

(2) Dried plant substances.
Soy-bean cake, rape-seed meal, cotton-seed meal, rice bran, wheat flour mixed with water.

(3) Animal substances.
Dried pupae of the silkworm, dried fish, dead insects, eggs of a locust, dead tadpoles.

(4) Other substances.
Horse manure, fowl manure.

According to TANABÉ the larva of the seed-corn maggot grew neither by feeding on barn-yard manure nor by feeding on human excreta if it was diluted. However, it did grow on undiluted human dung and reached the adult stage. It also fed on fish-manure and grew very well.[3)]

The writers have already reported that the seed-corn maggot could not grow by feeding on compost although it grew by feeding on fresh horse dung. In short, these observations show that the seed-corn maggot can develop by feeding on vegetable as well as on animal substances. These substances need not be fresh and living, i. e., they may be dead or dried substances or even such as have begun to rot. However, when putrefaction has progressed much, the maggot can not grow by feeding on them.

TANABÉ is of the opinion that the seed-corn maggot prefers decaying substances to germinating seeds and that it attacks germinating seeds only when it can not find a sufficient amount of decaying substances for its food. In support of this view, he cites the following results of his experiments: "When seed-corn maggots were reared on soy-bean cake, they grew more rapidly, the percentage of pupating maggots was higher and the size of puparia was larger than when they were reared on germinating soy-bean, wheat or barley". Whether his opinion is right may perhaps remain to be tested by further experimentation, but it is a well known fact that decaying or fermenting vegetable matters are highly attractive to the seed-corn maggot. When carrying on experiments on the method of control of this insect, the writers learned that both fermenting cotton seed-meal and pupae of the silkworm were extraordinarily attractive to it.[4)]

II. Longevity of the Adult Insect.

The writers have already published, in the first report, a brief note on the longevity of the adult of this insect. More exhaustive observations were made since that time and the results are described below as a supplement to the previous note. A noteworthy fact was that the longevity of this fly varied rather markedly owing to some causes the nature of which was not fully understood in most cases. On account of this, it was extremely difficult to obtain exact data regarding the longevity of this insect. The results obtained when the adults of the seed-corn maggot were reared by various methods are shown in Table I.

(See Table I on next page.)

According to Table I, (A), the longevity of the adult insect was longest for the adults which emerged in December and became gradually shorter with the rise in air temperature. It was shortest for the adults that emerged in July. Thus, the mean longevity for the male was approximately 26.3 days in January and that for the female about 47 days. The mean longevity in July was about 6 days for the male and about 9 days for the female. In November, the mean longevity for the male was about 46 days and for the female 65 days. It is surprising to find that, under favorable conditions, the adult insects sometimes lived more than 100 days when they emerged in November and December. This fact suggests that the adults of the seed-corn maggot may sometimes overwinter in the adult stage.

In Table I, (B), the results of experiments in which the adult insects were kept in incubators are given. At a constant temperature of 12°C., the male lived about 30 days on the average while the female lived about 45 days. At a constant temperature of 27°C., the average longevity of the male was about 6 days and that of the female about 7 days. From the results of these two series of experiments, it is evident that the most important factor which affects the longevity of this fly is the temperature of the air, though the experience in rearing indicated that atmospheric humidity and soil moisture also affected the longevity to some extent. The longevity of the female was longer than that of the male and the difference became more and more marked with the fall of temperature. Thus, in the hot season the difference was about 1 day while it amounted to 20 days in the winter.

Table I.

The Longevity of Adults of the Seed-Corn Maggot.

(A) Longevity in the Rearing Room.

Month in which Emergence Occurred	♂		♀	
	Ranges of Longevity	Mean Longevity	Ranges of Longevity	Mean Longevity
	Days	Days	Days	Days
January	13 — 53	26.3	20 — 71	46.6
February	22 — 40	—	20 — 40	28.2
May	2 — 28	10.6 (a)	2 — 56	16.1 (a)
June	7 — 30	14.4	7 — 39	20.3
July	4 — 7	6.3	4 — 23	9.3
September	(b)	(b)	(b) — 116	(b)
October	(b)	(b)	(b) — 134	(b)
November	21 — 83	45.6	31 — 121	65.0
December	18 — 90	—	18 — 107	68.2

(B) Longevity under various Constant Temperatures.

Temperature °C.	♂		♀	
	Ranges of Longevity	Mean Longevity	Ranges of Longevity	Mean Longevity
12	12 — 49	29.8	19 — 85	45.3
15 (c)	21 — 45	33.5	24 — 49	37.0
20	18 — 41	23.0	15 — 60	33.0
27	2 — 12	5.6	2 — 14	6.5

Remarks: (a) The mean value is not accurate owing to the limited number of adults available for experiment.

(b) The exact longevity was not determined and the mean longevity could not be obtained owing to the very small number of adults available.

(c) In this experiment, the adults were kept at 15°C. for 38 days, from May 29 to July 5, 1931, and then transferred to 20°C.

III. Preoviposition Period.

The female fly of the seed-corn maggot is not sexually mature when it emerges from the puparium. It needs to feed for some days before it can lay eggs. As the writers pointed out in the second report on this insect, it was very difficult to rear the female up to the time its eggs were mature and laid. After having tested various substances as food for the adult, the writers succeeded in rearing a few females to the mature stage by using an artificial food consisting of water, flour, yeast, cotton-seed meal and a small amount of honey and casein. But nearly all the eggs which were laid by these females were unfertilized. Another great difficulty in the rearing of this fly was that the adult insects did not copulate when they were confined in a breeding cage. When several pairs of adults were reared in a large outdoor breeding cage about one cubic meter in size, only one female laid fertilized eggs. Owing to these circumstances, it was not possible to obtain a sufficiently large amount of data on the preoviposition period of this insect to make an exact statement. The results obtained are shown in Table II.

Table II.

Preoviposition Period.

(A) Adult Insects were kept in the Rearing Room.

Female No.	Data of Emergence	Data of Oviposition	Preoviposition Period in Days	Mean Temperature in °C.
No. 1	May 26, 1931	June 7, 1931	12	20.4
„ 2	„ „ „	„ 9, „	14	20.6
„ 3	„ 27, „	„ 7, „	11	„
„ 4	„ 28, „	„ 14, „	17	21.2
„ 5	„ 29, „	„ 8, „	10	20.8
„ 6	„ „ „	„ 7, „	9	20.6
„ 7	„ 31, „	„ 8, „	8	20.9
„ 8	June 2, „	„ 9, „	7	21.2
„ 9	„ 3, „	„ 10, „	7	21.5
„ 10	„ „ „	„ 9, „	6	21.4
„ 11	„ 24, „	„ 29, „	5	25.2
„ 12	„ 27, „	July 3, „	6	24.8
„ 13	July 1, „	„ 8, „	7	24.9
„ 14	„ „ „	„ „ „	7	„

(B) Adult Insects were first reared in the Outdoor Breeding Cage or in the Rearing Room and then brought into the Laboratory which was heated during the cold Seasons.

No. 1	November 16, 1932	January 16, 1933	61	7.0
„ 2	„ „ „	„ 18, „	63	7.1
„ 3	January 15, 1933	February 12, „	28	8.3
„ 6	„ 26, „	„ 18, „	23	8.4
„ 8	November 9, 1932	November 25, 1932	16	10.5
„ 9	„ 6, „	December 23, „	47	8.7

(C) Adult Insects were kept in Incubators at various Constant Temperatures.

Female No.	Temperature in °C.	Date of Emergence	Date of Oviposition	Preoviposition Periods in Days
No. 1 — No. 4	12	May 29 — June 17, 1931	—	—
No. 5	15	May 29, 1931	June 21, 1931	23
„ 6	„	June 3, „	„ 20, „	17
„ 8	20	May 29, „	„ 6, „	8
„ 9	„	June 3, „	„ 18, „	15
„ 10	„	„ 4, „	„ 12, „	8
„ 11	„	„ 17, „	„ 28, „	11
„ 12	27	„ 1, „	„ 8, „	7
„ 13	„	„ 4, „	„ 10, „	6

According to Table II, the adults which emerged near the end of May began to oviposit in 10 to 14 days when the mean temperature of the air was approximately 20°C., and in about a week when the mean air temperature was about 21°C. Near the end of June, when the mean air temperature was about 25°C., the adult began to oviposit about 5 days after emergence.

In the experiments the results of which were shown in Table II, (B), the flies were first reared in the outdoor breeding cage or in the rearing room for a certain period of time and were then brought into the laboratory which was heated for about 8 hours during the daytime after the beginning of December. In spite of the rather low mean temperature in the laboratory, a few females reached maturity and oviposited. The preoviposition period was about 60 days at a mean temperature of 7°C., and about 23 days at a mean temperature of 8.4°C. *Fly No. 1* in Table II, (B), lived for 114 days and its preoviposition period was 61 days.

Under a constant temperature of 12°C., the writers were not able to rear the flies to maturity, but one female lived for a little more than 30 days at this temperature. On dissecting this fly after death, the writers were able to find many mature eggs in the ovaries. Therefore, it may be stated that the preoviposition period is probably a little longer than 30 days. At a constant temperature of 15°C., the first female to oviposit began to lay eggs 17 days after emergence. The preoviposition period was 8 days at 20°C. while it was about 6 days at 27°C.

The data in Table II indicate that the length of the preoviposition period changes inversely with the air temperature. Namely, it is shorter under high temperature and longer under low temperature. The writers were not able to determine the preoviposition period in October, but it may be stated from the results of observations that it would be approximately 14 days since the mean temperature in October in Kurashiki is slightly over 16°C.

In regard to the oviposition period of the seed-corn maggot, the writers were able to observe only 2 instances. *Fly No. 1* in Table II, (B), laid 133 eggs during the oviposition period of 52 days. The mean temperature during this period was 7°C. *Fly No. 6* lived more than 30 days and its oviposition period was 10 days, the mean temperature during this period being about 8.4°C. Thus, it is evident that the adult of the seed-corn maggot may live and oviposit for a very long period when the temperature of the air is low.

IV. Relation of Temperature to the Development of the Seed-Corn Maggot.

The relation between temperature and longevity and between temperature and the preoviposition period has been considered in the preceding paragraph. In the present paragraph, the relation between temperature and development will be considered under two headings: (1) temperature and death rate, (2) temperature and development and growth.

Methods of experimentation.

Rearing was carried out in incubators which were kept at various constant temperatures. The relative humidity in the incubator was not accurately controlled, but it was kept roughly from about 70 to 80 per cent by placing one or two large, shallow glass dishes filled with water in the incubator. To rear the seed-corn maggot a small amount of moderately wet soil was placed in Petri dishes. For the food of the maggot one or two soy-beans which were soaked in water were used. If the beans began to rot, they were not taken away because the maggot rather seemed to prefer such beans to fresh ones. A small quantity of water was added whenever it seemed necessary.

Since the rearing was carried out as described above, the writers can not claim that the relative humidity of the air and the moisture of the soil in the dishes were kept accurately constant for all experiments. However, it is believed that these two factors did not vary enough to seriously affect the results of the experiments. Therefore, the writers consider that the results obtained are sufficient to show the approximately correct relationship between temperature and the development of the seed-corn maggot.

1. Percentage of Eggs, Larvae and Pupae which successfully pass the respective Stages.

Egg.

When eggs were kept under natural conditions, it was observed that approximately 4 per cent remained unhatched. Some of these eggs must have been unfertilized while the cause for the death of the other eggs was unknown. Therefore, the normal rate of hatching may be considered as approximately 96 per cent.

The eggs of the seed-corn maggot can develop at a very low temperature. According to the results of experiments, only 7 per cent died even at a temperature as low as 10°C. Therefore, it may be stated that nearly all hatched at this temperature. At a constant temperature of 35°C., usually about 70 per cent of the eggs died. Between 12° and 33°C., nearly all of the fertilized eggs hatched.

Although the writers were not able to determine accurately the minimum and maximum temperatures for the development of the egg, it can be stated that the minimum temperature is lower than 10°C. and that the maximum temperature is slightly higher than 35°C.

Larva and Pupa.

Larvae and pupae of the seed-corn maggot were reared in incubators of various constant temperatures. The percentage of larvae that successfully pupated and that of larvae that produced adult insects were determined. The results obtained are shown in Table III.

Table III.

Percentage of Individuals that pupated and of those that emerged as Adults.

Temperature °C.	Per Cent Pupated	Per Cent* Emerged
12	92.5	86.1
15	85.7	80.9
20	96.3	91.2
25	92.8	85.7
27	94.5	90.5
30	98.7	91.1
33	81.2	41.6
35	0	0

* These figures show the percentage of adult insects that emerged from the total number of larvae used in the experiment. The experiment was started with from 70 to a little more than 100 newly hatched larvae.

According to Table III, approximately 90 per cent of the larvae that hatched from the eggs developed successfully and pupated under various constant temperatures of from 12° to 33°C. At a constant temperature of 33°C., the percentage of pupating larvae decreased to approximately 80 per cent and none pupated at a constant temperature of 35°C. Although the results obtained at a constant temperature of 10°C. are not shown in Table III, it was observed that a considerable percentage completed the growth at this temperature and emerged as adults. From these results we may conclude that the minimum temperature for the growth of the larva would probably lie somewhere near 8° or 9°C. The maximum temperature seems to be slightly lower than 35°C. and would lie somewhere about 34°C.

The number of individuals that died during the pupal period was very small. Therefore, it seemed that practically all of the larvae that pupated emerged as adult insects. According to Table III, at least 80 per cent of the larvae completed development and emerged as adult insects in all cases where the temperature was lower than 33°C., but when the temperature was 33°C. the percentage of emergence decreased markedly and only approximately 41 per cent emerged. No adults appeared at a constant temperature of 35°C. Therefore, the maximum temperature for the pupal development must be lower than 35°C. Since approximately 86 per cent of the larvae emerged as adults at a constant temperature of 12°C., the minimum temperature for the pupal development would be considerably lower than 12°C. It is worth while to note that, although a considerable number of pupae transformed to adult insects at a constant temperature of 33°C., the adult insects were not able to break through the puparia and died. This fact indicates that the development of the pupa goes on at a constant temperature of 33°C., but that this temperature is not suitable for the normal activity of the adult insect.

Another interesting fact was that, under such low temperatures as 12° or 15°C., some pupae ceased to develop for a period of varying duration. This phenomenon will be considered in a later paragraph.

From what has been stated above, it is apparent that the maximum temperature for the development of the egg is the highest of the maximum temperatures for the three stages, the egg, the larva and the pupa, and also that the maximum temperature for larval development is next highest.

2. *Effect of Constant Temperature upon the Duration of the Egg, Larval and Pupal Stages.*

The egg, larva and pupa were reared in incubators of various constant temperatures in order to study the relation of temperature to the duration of each of the three stages. While carrying on similar experiments on the rice-borer, *Chilo simplex* BUTLER, the writers observed that, under certain constant temperatures, a portion of the larvae ceased to develop near the end of the larval stage and they considered that these larvae had probably entered a dormant state.[5] The fact that a certain percentage of larvae sometimes enter a temporary dormant state at the end of the larval stage or even overwinter has also been confirmed in the cases of some other insects.[6, 7] A similar phenomenon was observed when the seed-corn maggot was reared in the rearing room under variable temperature and also in the present experiments when pupae were incubated under certain constant temperatures. Therefore, care should be taken in considering the relation of temperature to the pupal development. Another noteworthy fact which was observed in the rearing experiments with the rice-borer under constant temperature was that there was a slight difference in the velocity of development between the first and the second generations. Since a similar phenomenon was expected to occur also in the case of the seed-corn maggot, the data of the spring generation and those of the autumn generation were treated separately in calculating the mean duration of a stage so far as it was practicable to do so. The facts which have been mentioned above must be taken into consideration when examining the results of the experiments which are described below.

Development of the egg and temperature relationship.

The incubation periods required at various constant temperatures are given in Table IV.

Table IV.

Temperature and the Egg Period.

Temperature °C.	Mean Egg Period in Days	Mean Velocity of Development	Remarks
10.0	7.8	0.1282	Oct. 25, 1931 — Nov. 2, 1931.
11.0	5.5	0.1818	„ 23, 1932 — Oct. 28, 1932.
11.3	5.7	0.1754	Feb. 20, 1930 — Feb. 25, 1930, A.
11.9	4.3	0.2325	Apr. 8, 1930 — Apr. 12, 1930, B. June 18, „ — June 22, „ , D.
15.0	3.4	0.2941	Nov. 1, 1929 — Dec. 4, 1929, D, E.
„	4.4	0.2272	Mar. 30, „ — May 21, „ , A, B, C.
18.6	2.5	0.4000	Oct. 23, 1932 — Oct. 25, 1932, B.
20.0	1.9	0.5263	Nov. 4, 1929 — Nov. 6, 1929, C.
19.9—20.0	2.0	0.5000	Mar. 30, 1929 — May 16, „ , A, B. May 21, 1932 — „ 26, 1932, A, A'.
24.3	1.6	0.6250	Oct. 25, 1932 — Oct. 26, 1932, A.
25.0	1.4	0.7142	May 14, 1929 — May 15, 1929, B. „ 23, 1932 — „ 24, 1932, A.
25.4	1.6	0.6250	May 30, 1929 — June 1, 1929, C.
27.0	1.7	0.5882	Nov. 1, 1929 — Dec. 1, 1929, C.
30.0	1.6	0.6250	June 4, 1930 — June 6, 1930.
„	1.0	1.0000	Oct. 25, 1932 — Oct. 26, 1932.
33.0	1.6	0.6250	Oct. 10, 1929 — Dec. 1, 1929.
35.0	2.5	0.4000	Nov. 5, 1929 — Nov. 7, 1929. Mar. 6, 1930 — June 22, 1930.

In many cases the exact time of oviposition and hatching could not be determined by direct observation. Considering the habit of the adult insect, it has been assumed that oviposition occurred at noon and that the eggs hatched at night. An error of about half a day might have occurred by making this assumption, but it could not be avoided since it was not desirable to examine the eggs, larvae and pupae in incubators more than twice a day.

According to the data in Table IV, the average egg period of the autumn generation was 7.8 days at a constant temperature of 10°C., about 2 days at 20°C. and about 1 day at 30°C. The velocity of development of the egg was the greatest at 30°C. and the duration of the egg period became gradually longer beyond this temperature. Thus, at 33°C. the egg period was 1.6 days and at 35°C. it was 2.5 days.

Comparison of the spring and summer generations in regard to the duration of the egg period reveals the following relations: The eggs of the spring generation in 1929 required 4.4 days on the average under a constant temperature of 15°C., while the eggs of the autumn generation required 3.4 days at the same temperature. The egg period of the spring generation in 1930 was 1.6 days at 30°C. while it was 1 day for the autumn generation in 1930. It may be suspected from these two instances that the egg period of the spring generation is longer than that of the autumn generation. However, in the other instances the differences between the spring and the summer generations was not apparent. For instance, at a constant temperature of 20°C. the egg period was 2 days both for the eggs which were laid in March, 1929, and for those which were laid in May, 1932, while the egg period of those which were laid in November, 1929, was 1.9 days at the same temperature. Again, for 2 batches of eggs, the one laid in May, 1929, and the other laid in May, 1932, the egg period was 1.4 days at 25°C., while, for the eggs laid in October, 1932, the egg period was 1.6 days at 24.3°C. In these instances, practically no difference in the duration of the egg period exists between the spring and the summer generations.

To show the relation of temperature to the duration of the egg period and to the velocity of development, the curves shown in Figure 1 were constructed using the data in Table IV. In cases where differences in the egg periods under the same temperature existed between the spring and the autumn generations, the smaller values, i. e., the egg periods of the autumn generation were adopted for constructing the curves. This procedure was considered to be reasonable, because there must have been some factors other than temperature which affected the spring generation and prolonged the egg period.

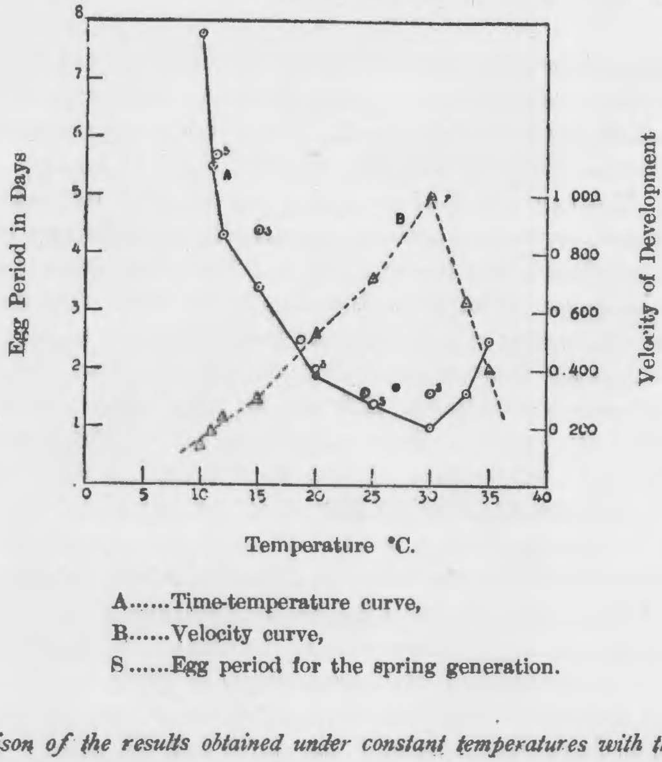
(See Fig. 1 on next page.)

In Figure 1, curve A shows the relation of temperature to the duration of the egg period and curve B shows the relation of temperature to the velocity of development. In the present rearing experiments, the writers could not accurately determine either the maximum or the minimum temperature for the development of the egg. However, it is possible to determine these temperatures approximately from the shape of the velocity curve in Figure 1. Thus, the maximum temperature lies a little beyond 35°C. and the minimum temperature seems to be well below 10°C. The optimum temperature is approximately 30°C.

These values for the maximum, minimum and optimum temperatures are approximately the same as those which the writers found from the study of the mortality of eggs.

Fig. 1.

Relation of Temperature to the Development of the Egg.



A......Time-temperature curve,
B......Velocity curve,
S......Egg period for the spring generation.

Comparison of the results obtained under constant temperatures with those obtained under variable temperatures.

In the second report of this series, the writers reported the results of the rearings carried out in the rearing room under natural, variable temperatures. These results are compared below with those which have been described above.

The egg period of the spring generation was about 6 days at a constant temperature of 11°C. and in the variable temperature experiment the egg period was also 6 days at a mean temperature of about 11°C. At a constant temperature of 15°C. the egg period of the autumn generation was 3 days, and under variable temperature the mean of which was approximately the same the egg period was also 3 days. Again, at a constant temperature of 20°C. the egg period was 2 days for the autumn generation and in the variable temperature experiment the same egg period was obtained at a mean temperature of approximately 20°C. According to these results, it is evident that the development of the egg under a constant temperature is of the same velocity as under a variable temperature, the mean value of which is equal to the constant temperature which is used.

Temperature and Development of the Larva.

Larvae were reared under various constant temperatures and the larval period was determined. When the time of pupation was not accurately determined, it was assumed that pupation took place at midnight. Strictly speaking, a certain duration of time must intervene between the completion of the puparium and actual pupation of the maggot. However, it was not practicable to examine the inside of the puparium without causing any harm to it. Therefore, the writers assumed that the larval stage came to an end when the puparium was formed. The results of rearings are shown in Table V.

Table V.

Temperature and the Larval Period.

Temperature °C.	Mean Larval Period in Days	Mean Velocity of Development	Remarks
10.0	31.2	0.0320	Oct. 29, 1932 — Dec. 4, 1932, A, A′.
11.7—11.8	31.0	0.0322	Apr. 13, 1930 — May 16, 1930, B.
11.9—12.0	25.8	0.0387	Feb. 26, 1930 — Mar. 27, 1930, A. Apr. 13, 1930 — May 11, 1930, B.
14.1	18.5	0.0540	May 22, 1929 — June 11, 1929, C.
15.0	15.9	0.0628	Nov. 5, 1929 — Nov. 23, 1929, D. Dec. 4, 1929 — Dec. 18, 1929, E.
19.8—19.9	8.6	0.1162	Oct. 26, 1932 — Nov. 8, 1932, B.
20.0	10.2	0.0980	May 16, 1929 — May 26, 1929, B. May 23, 1932 — June 7, 1932, A, A′.
20.0	9.5	0.1052	Nov. 6, 1929 — Nov. 19, 1929, C. Oct. 28, 1932 — Nov. 4, 1932, B′.
25.0	8.0	0.1250	May 25, 1932 — June 3, 1932, A.
„	6.0	0.1666	Oct. 25, 1932 — Nov. 1, 1932, B.
26.9—27.0	6.1	0.1612	May 26, 1929 — June 3, 1929, B. June 8, 1930 — June 15, 1930, A.
30.0	5.8	0.1960	June 6, 1930 — June 13, 1930.
„	4.7	0.2127	Oct. 26, 1932 — Oct. 31, 1932, A, A′.
33.0	5.8	0.1724	Oct. 12, 1929 — Dec. 7, 1929.
35.0	—	0.0000	——

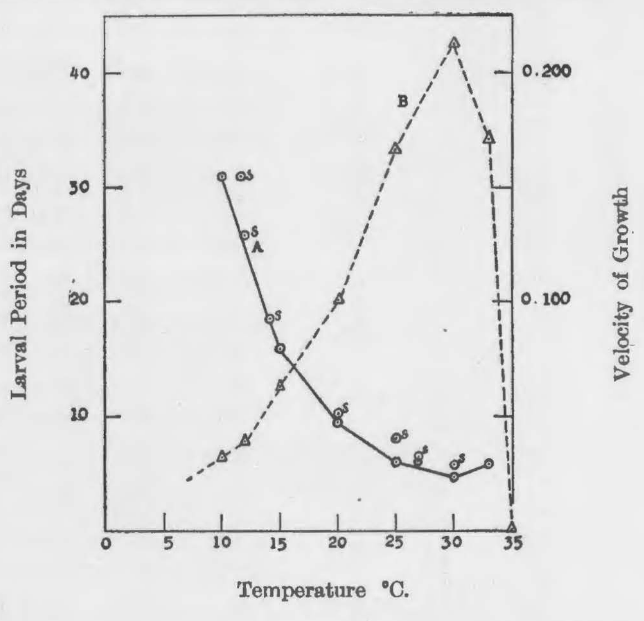
The results shown in Table V can be summarized as follows: The duration of the larval stage of the autumn generation was approximately 31 days at 10°C. At 15°C., it was about 16 days for the autumn generation. At 20°C., the larval period was 9 days for the autumn generation and about 10 days for the spring generation. At 25°C., it was 6 days for the autumn generation and 8 days for the spring generation. At 30°C., the larval period of the autumn generation was about 5 days and that of the spring generation about 6 days; at 33°C. the larval period of the autumn generation was about 6 days. At 35°C., all the larvae died before reaching the pupal stage.

According to these results, the larval period of the spring generation was slightly longer than that of the autumn generation under constant temperatures of from 20° to 30°C. Although the difference in the larval periods between the two seasons, spring and autumn, was not large, this finding is in agreement with the result which the writers obtained in rearing the seed-corn maggot in the rearing room under natural variable temperatures and it indicates that the velocity of development may differ according to the season in which the insect appears.

Using the data in Table V, the curves shown in Figure 2 were constructed.

Fig. 2.

Temperature and the Larval Development.



Curve A represents the relation of temperature to the larval period and curve B that of temperature to the velocity of development. For constructing curve A the larval periods of the autumn generation were chiefly made use of. The reason for this has already been stated in the preceding paragraph.

An examination of these curves shows that the duration of the larval stage decreases very regularly as temperature rises. Judging from the shape of the curves, the larva of the seed-corn maggot is able to develop at a temperature considerably lower than 10°C. The optimum temperature of the growth is approximately 30°C. Beyond 33°C. the velocity of growth rapidly decreased and at 35°C. the velocity became zero. From the results thus far obtained from rearing, the exact course of the curves between 33° and 35°C. can not yet be determined. However, it can be stated that the maximum temperature for the growth is somewhere near 34°C. It has been stated that the percentage of larvae which successfully pupated did not differ much between 12° and 30°C. and also that, even at a temperature as low as 12°C., more than 90 per cent pupated successfully. This fact indicates that the minimum temperature for the growth must be very low. The course of the velocity curve in Figure 2 is in good agreement with the conclusion just made.

Comparison of the results of rearing carried out under constant temperature with those obtained under variable temperature.

When the results in Table V are compared with the results of rearing which were carried out under variable temperatures and published in the second report, the following facts are noticed: In the constant temperature experiment the larval period of the autumn generation was about 30 days at 10°C. When larvae were reared under variable temperatures, the mean of which was 9.8°C., the larval period was 31 days. The larval period of the spring generation was about 10 days at a constant temperature of 20°C. while under variable temperature, the mean of which was 20.5°C., the larval period was about 8 days. Similarly, at a constant temperature of 25°C. the larvae of the spring generation were full-grown in 8 days while the larval period under fluctuating temperature, the mean of which was 24.5°C., was about 7 days. These instances indicate that the velocities of growth under two different temperature conditions did not differ markedly, but beyond 20°C. the velocity of growth under variable temperature seems to have been slightly greater than under constant temperature.

Temperature and development of the pupa.

Newly formed puparia were kept in incubators of various constant temperatures and the period from the formation of puparium to the emergence of adult was determined. As has been stated already, the duration of time from completion of puparium to the emergence of adult was looked upon as the pupal period.

The majority of the adults of the seed-corn maggot appear in the morning. The time of appearance was not always a definite hour of the day, but most of the adults seemed to appear about 8 o'clock in the morning. Therefore, when the exact time of emergence was not known, it was assumed that emergence took place at 8 o'clock a.m. The results of experiments are shown in Table VI.

(See Table VI on next page.)

The curves which are shown in Figure 3 were constructed to show the relation of temperature to the duration of the pupal period and also that of temperature to the velocity of development of the pupa. When two different durations of pupal period were observed under the same temperature, the smaller values were adopted for constructing the curves shown in Figure 3.

Table VI.

Temperature and the Pupal Period.

Temperature °C.	Mean Pupal Period in Days	Mean Velocity of Development	Remarks
10.0	83.3—97.3 *	—	Nov. 28, 1932 — Mar. 5, 1933.
"	50.1	0.0199	Nov. 28, 1932 — Jan. 20, 1933.
11.0—11.1	42.1	0.0238	Mar. 24, 1930 — May 4, 1930, A. May 11, 1930 — June 30, 1930, B.
11.0	76.3 *	—	May 11, 1930 — July 26, 1930, B.
12.3—12.5	34.4	0.0290	Mar. 22, 1930 — Apr. 30, 1930, A.
13.6—13.7	24.3	0.0411	June 6, 1929 — July 5, 1929, C.
14.6	23.4	0.0427	Dec. 18, 1929 — Jan. 11, 1930, E.
15.0	22.8	0.0438	Nov. 21, 1929 — Dec. 16, 1929, D.
20.0	13.6	0.0735	Nov. 2, 1932 — Nov. 19, 1932, B.
20.0—20.2	14.1	0.0709	May 28, 1929 — June 12, 1929, B. May 31, 1932 — June 16, 1932, A.
20.3—20.4	14.2	0.0704	June 2, 1932 — June 23, 1932, A, A'.
24.7—24.8	9.9	0.1010	Oct. 30, 1932 — Nov. 12, 1932, B, B'.
24.8—24.9	9.9	0.1010	June 9, 1929 — June 22, 1929, C. June 1, 1932 — June 13, 1932, A.
26.9—27.0	8.0	0.1250	Nov. 9, 1929 — Dec. 18, 1929, C.
26.8—26.9	8.7	0.1149	June 13, 1930 — June 25, 1930, A. May 31, 1929 — June 12, 1929, B.
29.1—29.2	9.4	0.1063	Oct. 31, 1932 — Nov. 10, 1932, A, A'.
29.9	8.0	0.1250	June 11, 1930 — June 23, 1930.
32.8—33.0	7.0	0.1428	Oct. 16, 1929 — Dec. 16, 1929.
35.0	—	0.0000	——

(See Fig. 3 on next page.)

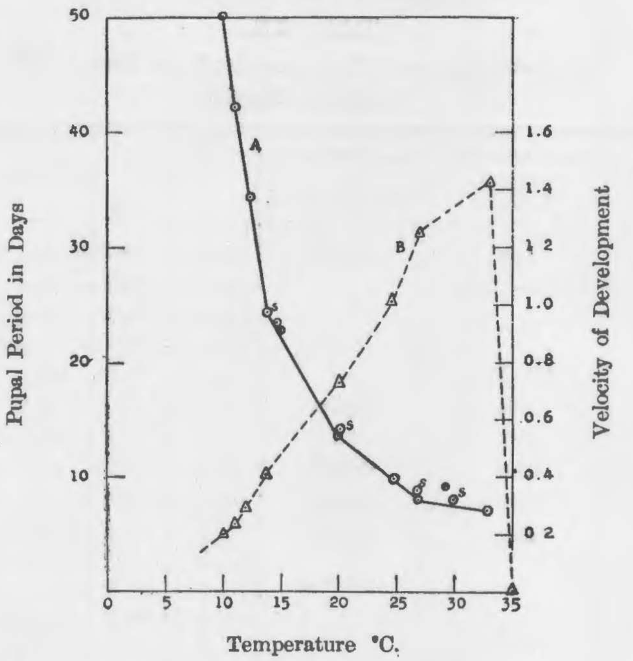
Examination of the data in Table VI shows that the change in the duration of the pupal period was in good harmony with the rise or fall of the temperature under which the pupae were incubated except in a few cases which are marked with asterisks in the table. The individuals which showed exceptionally long pupal periods are considered to have entered a temporary dormant condition of varying duration.

The results given in Table VI can be summarized as follows: The pupal period was about 50 days at 10°C., about 23 days at 14.6°C., about 14 days at 20°C., about 10 days at 24.8°C., 8 days at 30°C. and 7 days at 33°C. At a constant temperature of 35°C., none emerged as adult insects.

When the data in Table VI as well as the curves in Figure 3 are carefully studied, the following conclusions may be drawn : The minimum temperature for the development of the pupa is considerably lower than 10°C. The temperature under which the velocity of development is greatest is approximately 33°C. and the maximum temperature for the development of the pupa lies somewhere about 34°C. It has been stated in a previous paragraph that the percentage of emergence was about 90 per cent at 30°C. and that it dropped to about 40 per cent at 33°C. If this fact is taken into consideration, it can not be said that the optimum temperature for the development of the pupa is 33°C. Though some of the pupae developed at 33°C. and reached the adult stage, a considerable percentage of them were not able to break through the puparia and died. This fact

Fig. 3.

Temperature and Pupal Development.



indicates that a constant temperature of 33°C. affects the vitality of the adult insect greatly. The difference in the velocity of development between the spring and the autumn generations which has been noticed for the egg and larva was not apparent for the pupa.

The pupal period under constant temperature compared with that under variable temperature.

The pupal period of the spring generation at a constant temperature of 13.6°C. was approximately 24 days, while it was about 29 days under variable temperature the mean of which was 13.5°C. At a constant temperature of 20°C., the pupal period of the spring generation was about 14 days, while under variable temperature, the mean of which was approximately 20°C., it was 15 days. Again, at a constant temperature of 26.8°C. the pupal period of the spring generation was about 9 days, while under variable temperature, the mean of which was 26.6°C., it was about 9 days. These results seem to indicate that there is almost no difference between the effect of constant temperature and that of variable temperature.

Relation of temperature to the time required from oviposition to emergence of the adult.

The results of observations on the period of time required from the deposition of eggs to the appearance of adults under various constant temperatures are presented in Table VII.

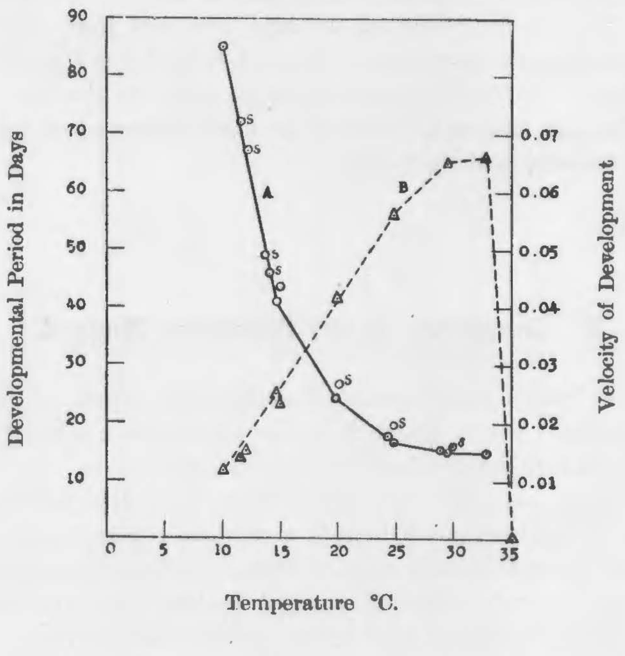
Table VII.
Temperature and Time required for Reaching the Adult Stage.

Temperature °C.	Mean Duration required. In Days	Mean Velocity of Development	Remarks
10.0	84.8	0.0117	Oct. 23, 1932 — Jan. 20, 1933, A.
"	* 117.8—135.8	—	Oct. 23, 1932 — Mar. 8, 1933, A.
11.4—11.5	71.9	0.0139	{ June 18, 1930 — Aug. 29, 1930, D. { Apr. 8, 1930 — June 30, 1930, B.
11.6	* 145.7—163.7	—	No. 74—77, 88, 1930, D.
12.1—12.2	66.6	0.0150	Feb. 20, 1930 — May 4, 1930, A.
13.6	48.7	0.0205	Apr. 9, 1929 — May 30, 1929, B.
14.0	45.6	0.0219	May 18, 1929 — July 6, 1929, C.
14.7	40.7	0.0245	Nov. 30, 1929 — Jan. 9, 1930, E.
15.0	43.4	0.0230	Nov. 1, 1929 — Dec. 16, 1929, D.
19.7—19.9	24.1	0.0414	{ Oct. 23, 1932 — Nov. 19, 1932, B. { Oct. 25, 1932 — Nov. 18, 1932, B'.
20.0—20.1	26.8	0.0373	{ May 14, 1929 — June 12, 1929, B. { May 21, 1932 — June 23, 1932, A, A'.
24.3—24.4	17.7	0.0564	Oct. 23, 1932 — Nov. 12, 1932, B.
24.8	16.8	0.0561	Oct. 25, 1932 — Nov. 12, 1932, B'.
24.9	19.4	0.0515	{ May 30, 1929 — June 17, 1929, C. { May 23, 1932 — June 13, 1932, A.
25.2	19.5	0.0512	May 30, 1929 — June 22, 1929, C.
26.9	17.3	0.0578	{ May 24, 1929 — June 12, 1929, B. { June 5, 1930 — June 25, 1930, A.
26.9—27.0	17.4	0.0574	Nov. 1, 1929 — Dec. 21, 1929, C.
28.9	15.7	0.0636	Oct. 25, 1932 — Nov. 10, 1932, A.
29.5	15.3	0.0653	Oct. 25, 1932 — Nov. 10, 1932, A'.
29.9	16.0	0.0625	June 4, 1930 — July 5, 1930.
32.7—32.8	15.1	0.0662	Oct. 10, 1929 — Dec. 16, 1929.

The data shown in Table VII can be summarized as follows: The time required from oviposition to the appearance of the adult insect was about 85 days at a constant temperature of 10°C., about 42 days at 15°C., about 24 days at 20°C., about 17 days at 25°C. and about 15 days at 29.5°C. Beyond 30°C. the time required did not decrease even if the temperature was raised to about 33°C., and at 35°C. no individuals completed the development from egg to adult. Curves, which were constructed from the data in Table VII to show the relation of temperature to the duration of the period required from oviposition to emergence of adults and also the velocity of development, are presented in Figure 4.

Fig. 4.

Temperature and Period of Time from Oviposition to Emergence of Adult.



Comparison of the egg, larva and pupa in regard to their response to temperature. Examination of the time-temperature curves and the velocity curves shows that each stage has a curve which is peculiar to that stage, but the curves for the egg and the larval stages are more or less alike. When the time-temperature curves for the egg and larval stages are examined in their entirety, it is evident that they are not hyperbolae. That they are not hyperbolae is evident from the fact that the velocity curves each have a maximum point and that there is no straight line present in them. The time-temperature curves look like an asymmetrical catenary, as Janisch maintains. As is evident from the velocity curves, the development of the egg is most rapid at 30°C. and that of the larva is most rapid at approximately 33°C., and beyond these temperatures the velocity decreases gradually. The larva grows with a considerable velocity even at 33°C., but the velocity of the development of the egg decreases greatly at this temperature. The egg still develops at 35°C. though the velocity decreases greatly. The velocity of larval development decreases rapidly beyond 33°C. and at 35°C. all larvae die before reaching the pupal stage. The velocity curve for the pupal development approximates a straight line between 10° and 25°C. so that the time-temperature curve in this range of temperature nearly conforms to a hyperbola. However, it is evident from the shape of the velocity curve that the time-temperature curve is no longer a hyperbola beyond 25°C. The velocity of the development of the pupa increases up to 33°C., but it decreases very sharply beyond this temperature and at 35°C. no adult successfully emerged. It is apparent from these results that the temperature at which the greatest velocity of development occurs is highest in the case of the pupa and also that the rate of the decrease of velocity beyond this temperature is likewise greatest in the case of the pupa. The velocity curves of the egg, larva and pupa indicate that the minimum temperature for development is considerably lower than 10°C. in either of the three stages. Of the three minima, the minimum for the larva seems to be the lowest. The fact that each stage has a characteristic curve for its development is very interesting and significant.

V. Dormancy in the Seed-Corn Maggot.

Under the climatic conditions at Kurashiki the pupae of the seed-corn maggot can develop even in winter if the air temperature is not very low, but they sometimes cease to develop due to some unknown causes. Such pupae that cease to develop may pass out of the dormant state some days later and begin to develop again. It has been pointed out in a previous report that the time when such pupae pass out of dormancy seems to differ in different individuals for some unknown reasons. Further observations and experiments have been made in regard to this point and the results obtained are described below.

Puparia of known age were divided into a few lots, each consisting of some 30 to 40 individuals. The first lot was kept in the rearing room under natural and variable temperature conditions and the second lot was placed in an incubator which was kept at a constant temperature of 12°C., while the third lot was kept in an incubator of 15°C. The emergence of adult insects from these puparia was recorded. The records on the emergence of representative individuals are shown in Table VIII.

Table VIII.

Dormancy in the Pupal Stage under various Conditions of Rearing.

(A) Reared in the Rearing Room.

Exper. No.	Period from the Beginning of Experiment to the Appearance of Adults.	Pupal Period in Days	Sex	Number of Adults Emerged	Mean Temp. for the Pupal Period. °C.
I	Jan. 1, 1931 — Mar. 5, 1931	63.3	♀ ♂	1 1	6.3
	„ — Mar. 10, 1931	68.3	♂	1	6.5
	„ — Mar. 17, 1931	75.3	♀	2	6.8
	„ — Mar. 28, 1931	86.3	♂	2	7.3
	„ — Apr. 6, 1931	95.3	♀	1	7.6
	„ — Apr. 17, 1931	106.3	♂	1	8.0
	„ — Apr. 28, 1931	117.3	♂	1	8.7

[Remark] The puparia used for *Experiment I* were formed at the end of December, 1930.

Exper. No.	Period from the Beginning of Experiment to the Appearance of Adults.	Pupal Period in Days	Sex	Number of Adults Emerged	Mean Temp. for the Pupal Period. °C.
II	Jan. 16, 1931 — Mar. 28, 1931	71.3	♂	1	7.5
	„ — Apr. 4, 1931	78.3	♀	1	7.9
	„ — Apr. 7, 1931	81.3	♂	1	8.0
	„ — Apr. 12, 1931	86.3	♂	1	8.1
	„ — Apr. 17, 1931	91.3	♂	2	8.4
	„ — May 1, 1931	105.3	♀	1	9.3

[Remark] The puparia used for *Experiment II* were formed about the middle of January, 1931.

Exper. No.	Period from the Beginning of Experiment to the Appearance of Adults.	Pupal Period in Days	Sex	Number of Adults Emerged	Mean Temp. for the Pupal Period. °C.
III, (i)	Nov. 18, 1931 — Jan. 6, 1932	49.3	♀	1	9.3
	„ — Jan. 10, 1932	53.3	♀	1	9.1
	„ — Jan. 11, 1932	54.3	♂	1	9.0
	„ — Jan. 14, 1932	57.3	♀ ♂	3 2	8.8
	„ — Jan. 17, 1932	60.3	♀ ♂	1 1	8.7

Exper. No.	Period from the Beginning of Experiment to the Appearance of Adults.	Pupal Period in Days	Sex	Number of Adults Emerged	Mean Temp. for the Pupal Period. °C.
III, (ii)	Nov. 22, 1931 — Jan. 18, 1932	57.8	♂	1	8.4
	„ — Jan. 22, 1932	61.8	♂	1	„
	„ — Jan. 24, 1932	63.8	♀	1	„
	„ — Jan. 27, 1932	66.8	♀	1	„
	„ — Jan. 29, 1932	68.8	♀	1	8.3
	„ — Jan. 31, 1932	70.8	♂	1	„
III, (iii)	Nov. 27, 1931 — Feb. 3, 1932	68.3	♀	2	7.9
	„ — Feb. 7, 1932	72.3	♀	1	7.7
	„ — Feb. 12, 1932	77.3	♀ ♂	1 1	7.6
	„ — Feb. 15, 1932	80.5	♀ ♂	1 1	7.6
III, (iv)	Dec. 9, 1931 — Feb. 29, 1932	82.3	♂	1	6.4
	„ — Mar. 7, 1932	89.3	♀	1	6.7
	„ — Mar. 14, 1932	96.3	♀ ♂	1 4	„
	„ — Mar. 21, 1932	103.3	♀ ♂	1 1	6.6
	„ — Apr. 4, 1932	117.3	♀	1	6.9
	„ — Apr. 13, 1932	126.3	♀ ♂	2 1	7.1
	„ — Apr. 15, 1932	128.3	♂	4	„
	„ — Apr. 24, 1932	137.3	♂	1	7.5

(B) Reared in Incubators of Constant Temperature.

Exper. No.	Period	Pupal Period in Days	Sex	Number of Adults Emerged	Temperature °C.
(i)	Jan. 10, 1931 — Jan. 29, 1931	19.3	♂	2	12.0
	„ — Jan. 30, 1931	20.3	♀ ♂	2 1	„
	„ — Feb. 1, 1931	22.3	♀ ♂	1 1	„
	„ — Feb. 5, 1931	26.3	♀ ♂	1 2	„
	„ — Feb. 9, 1931	30.3	♀ ♂	1 2	„
	„ — Feb. 16, 1931	37.3	♂	1	„
	„ — Feb. 24, 1931	45.3	♂	1	„
	„ — Feb. 28, 1931	49.3	♀	1	„
	„ — Mar. 12, 1931	61.3	♀	1	„
	„ — Mar. 20, 1931	69.3	♀	1	„
	„ — Mar. 24, 1931	73.3	♂	1	„

[Remark] The puparia used for *Experiment* (*i*) were formed at the end of December, 1930, and were placed in an incubator at 12°C. on January 10, 1931. For *Experiment* (*ii*) and those following, the puparia were placed in incubators on the same day they were formed.

(ii)	Nov. 19, 1931 — Dec. 19, 1931	30.3	♀ ♂	4 4	12.0
	„ — Dec. 20, 1931	31.3	♀ ♂	4 3	„
	„ — Dec. 21, 1931	32.3	♀ ♂	4 4	„
	„ — Dec. 24, 1931	35.3	♂	1	„
	* „ — Jan. 20, 1932	62.3	♂	1	„
	* „ — Feb. 4, 1932	77.3	♂	1	„
(iii)	Nov. 20, 1931 — Dec. 20, 1931	30.3	♀ ♂	1 3	12.0
	„ — Dec. 21, 1931	31.3	♀ ♂	1 3	„
	„ — Dec. 22, 1931	32.3	♀ ♂	1 1	„
	* „ — Jan. 23, 1932	64.3	♂	1	„

Exper. No.	Period	Pupal Period in Days	Sex	Number of Adults Emerged	Temperature °C.
(iv)	Nov. 28, 1931 — Dec. 24, 1931	26.3	♂	1	12.0
	„ — Dec. 25, 1931	27.3	♀ ♂	3 1	„
	„ — Dec. 26, 1931	28.3	♀ ♂	2 2	„
	„ — Dec. 27, 1931	29.3	♀ ♂	2 3	„
(v)	Dec. 8, 1931 — Jan. 5, 1932	28.3	♀ ♂	6 5	12.0
	„ — Jan. 6, 1932	29.3	♀ ♂	1 2	„
	„ — Jan. 7, 1932	30.3	♀ ♂	1 2	„
	„ — Jan. 8, 1932	31.3	♀	1	„
(vi)	Dec. 2, 1931 — Dec. 24, 1931	22.3	♀ ♂	3 1	15.0
	„ — Dec. 25, 1931	23.3	♀ ♂	2 8	„
	„ — Dec. 26, 1931	24.3	♀ ♂	1 1	„
	„ — Dec. 27, 1931	25.3	♀ ♂	3 1	„
	„ — Dec. 28, 1931	26.3	♂	1	„
	* „ — Feb. 6, 1932	66.3	♂	1	„
(vii)	Dec. 8, 1931 — Dec. 30, 1931	22.3	♂	1	15.0
	„ — Dec. 31, 1931	23.3	♀ ♂	8 5	„
	„ — Jan. 1, 1932	24.3	♀ ♂	2 1	„
	„ — Jan. 2, 1932	25.3	♂	1	„
	* „ — Jan. 19, 1932	42.3	♀	1	„

As is evident from the records in Table VIII, the emergence of adult insects did not occur within a short period of a few days, but the emergence period extended over a very long period of time, sometimes for more than 40 or 50 days, one or two adults appearing on every other day or at an interval of several days. Therefore, several adult insects that appeared at intervals of from 5 or 6 to 15 or 16 days were selected as being representative and the dates of their emergence were recorded in Table VIII. The mean temperature for the pupal periods of those individuals that were selected as representatives was calculated and recorded in the table.

According to the data obtained in the rearing room (Table VIII, A), the shortest pupal period was 49 days at a mean temperature of 9.3°C. for the group which pupated on the 18th of November, 1931 and used for *Experiment III, (i)*, while the pupal period of the last individual to emerge as adult in *Experiment II* was about 105 days at approximately the same mean temperature. The fact that the pupal period of the first adult to appear in *Experiment II* was only 71 days at a lower mean temperature than that for the last adult was surprising. According to Table VI, the pupal period at a constant temperature of 10°C. was about 50 days for the individuals which seemed to have developed without going into dormancy. When this result is compared with that of *Experiment III, (i)* in Table VIII, it is found that the first adult to emerge in the latter instance had nearly the same pupal period even though the mean temperature in the rearing room was slightly lower than 10°C. Therefore, it may be concluded that the puparia used for *Experiment III, (i)* developed without entering a dormant state and also that the last individual to emerge in *Experiment II* fell into a dormant period of some 50 days after the lapse of which it resumed development and emerged.

In all experiments which were carried out under variable temperatures, the pupal periods varied within a wide range. Especially in *Experiments I, II* and *III, (i)* the differences between the shortest and the longest pupal periods were conspicuously large. In *Experiment I* the shortest pupal period was about 63 days at a mean temperature of 6.3°C., while in *Experiment III, (iv)* the shortest pupal period was about 82 days under nearly the same mean temperature as in *Experiment I.* Judging from this result, the first individual to emerge in *Experiment III, (iv)* must have passed a dormant period of a certain number of days before it appeared as an adult insect.

The following result is more striking : The pupal period of the first individual to emerge in *Experiment III, (iv)* was about 82 days and the pupal period of those which followed became increasingly longer despite the fact that the mean air temperature gradually became higher as the season advanced. The longest pupal period in this experiment was approximately 137 days at a mean temperature of 7.5°C. and between these two extreme individuals there were many the pupal periods of which were of various intermediate durations. Since there was no factor other than temperature which affected the pupa, it must be concluded that the pupae used in this experiment must have passed dormant periods of various durations. A similar conclusion also applies to the pupae which were used for the other experiments.

The results of the constant temperature experiments will be now examined. According to the results of *Experiments* (*ii*) to (*vii*) in Table VIII, B, the majority of the pupae transformed to adult insects following pupal periods of nearly equal duration when placed in incubators of 12° or 15°C. immediately after the completion of the puparia which took place from the middle of November to about the 10th of December. But a few of these individuals entered very long pupal periods regardless of the temperature under which they were incubated. Such puparia are indicated with an asterisk in Table VIII, and it has been considered that these individuals entered a dormant state temporarily from some unknown causes.

Of seven experiments which were carried out under constant temperatures, *Experiment* (*i*) gave the most striking result. The puparia which were used for this experiment had been formed near the end of December, 1930 and they were placed in incubators of 12°C. on January 10th, 1931. The emergence of adults from these puparia began about 19 days after the puparia had been placed in incubators and the longest pupal period was about 73 days. Between these two extreme individuals there were many which had different pupal periods of various intermediate durations. The puparia which were used in *Experiment* (*i*) had been kept in the rearing room for about 10 days before they were placed in incubators. If this period of 10 days is taken into account the shortest pupal period observed in *Experiment* (*i*) is of nearly the same duration as those observed in *Experiment* (*ii*) to (*v*). The striking difference is, however, that, in *Experiment* (*i*), the duration of the pupal period varied greatly, ranging from about 19 to 73 days. The explanation for the occurrence of such a wide variation in the duration of the pupal period seems to be that the majority of puparia entered a state of dormancy and that the duration of the dormant state varied greatly in different individuals due to some innate physiological causes. In *Experiment* (*ii*) to (*vii*) the majority of puparia did not enter a dormant state so that the pupal periods were of nearly the same duration for the majority of individuals.

The following question may be raised: Why did the majority of individuals enter a dormant state only in *Experiment* (*i*) and not in the other experiments? The reasons for this difference are not clearly understood, but one reason, if not the sole one, for this seems to be that the air temperature at the time of pupation was much lower in *Experiment* (*i*) than in the other experiments and also that the puparia used in *Experiment* (*i*) had been exposed to this low temperature for about 10 days before they were placed in the incubator. Why the time of passing from the dormant state varied so greatly in different individuals can not be explained at the present time. At any rate, these experiments indicate that a considerable percentage of puparia of the seed-corn maggot which appear late in the autumn may enter a dormant state and hibernate and that they emerge as adults in March and April of the following year.

VI. Effect of Soil Moisture on the Development of the Seed-Corn Maggot.

Since the seed-corn maggot passes the egg, larval and pupal stages in the soil, it may reasonably be expected that the moisture of the soil may affect its development and growth. HAWLEY stated that an abundant precipitation and moderately low temperature in the spring appear to be favorable to the seed-corn maggot and that dry, warm weather in the summer is detrimental to its development.[8] The writers conducted some experiments in order to study the effect of soil moisture on the seed-corn maggot. The results of these experiments are described below.

The amount of water which is sufficient to saturate the soil was reckoned as 100 per cent and the amount contained in soil which was thoroughly dried by airing* as 0 per cent. The amount of moisture intermediate between these two extremes was expressed as per cent saturation. The experiments were carried out in the rearing room using glass-jars or porcelain pots as containers for the soil. These jars and pots were filled with a definite amount of air-dry soil and a definite amount of water just sufficient to produce a required moisture percentage was added. In most of the experiments, the container of the soil was covered with a glass lid. The containers were weighed at times and the amount of water lost by evaporation was supplemented. The results of experiments are shown in Table IX.

(See Table IX on pages 246—249)

Effect of soil moisture on the percentage of eggs, larvae and pupae that successfully develop.

As is evident from Table IX, A, I, approximately 30 per cent of the eggs hatched in air-dry soil under the experimental conditions in the rearing room. One may be tempted to think from these results that the egg of the seed-corn maggot is very resistant to desiccation. However, it must be borne in mind that a great difference exists between the conditions of experiments and those in the field. Under the conditions in the experiments in the rearing room the eggs were neither exposed to direct rays of the sun nor to a strong desiccating action of wind. Therefore, it may easily be expected that, under natural conditions in the field, a decidedly lower percentage of eggs would be able to hatch in a very dry soil than in the experiments here described. When the moisture content was 35 per cent, the percentage of eggs that hatched was from 85 to 93 per cent. Beyond a moisture content of 35 per cent the percentage of eggs hatched did not increase. On the whole, the eggs of the seed-corn maggot are fairly resistant to desiccation in spite of their fragile nature. This is perhaps accounted for, at least partly, by the fact that the development of the egg is very rapid.

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* For the sake of convenience this soil was termed "air-dry soil".

Table IX.

Effect of Soil Moisture on the Development of the Seed-Corn Maggot.

(A) Effect of Moisture on the Percentage of Eggs, Larvae and Pupae that successfully develop.

I. Effect on the Development of the Egg.

(a) With cover on the glass-jar.

Moisture of Soil	0%		10%	20%		35%		65%		100%	Remarks
Experim. No.	Number of Eggs			Number of Eggs		Number of Eggs		Number of Eggs			
	Used	Hatched		Used	Hatched	Used	Hatched	Used	Hatched		
(i)	45	16		—	—	45	45	45	40		May, 1930.
(ii)	18	6		20	18	20	16	20	14		„ 1932.
Total	63	22				65	61	65	54		
Per cent hatched		34.5%			(90%)		93.8%		83.0%		

(b) Without cover on the glass-jar.

(i)	60	13		—	—	40	34	—	—		May, 1930.
(ii)	15	10		15	11	15	13	15	14		„ 1932.

Total	75	23					55	47	—	—			May, 1930.
Per cent hatched		30.6%				(73.3%)		85.4%		(93.3%)			„ 1932.

II. Effect on the Development of the Larva.

Experim. No.	Number of Larvae		Number of Larvae		Number of Larvae		Number of Larvae		Number of Larvae		Number of Larvae		Remarks
	Used	Pupated	Used	Pupated	Used	Pupated	Used	Pupated	Used	Pupated	Used	Pupated	
(i)	—	—	—	—	—	—	75	63	70	52	—	—	May, 1930.
(ii)	—	—	—	—	—	—	23	23	23	23	24	24	November, 1931.
(iii)	40	0	40	16	40	38	40	39	40	33	—	—	June, 1932.
(iv)	30	0	—	—	30	20	30	27	30	24	—	—	May, 1932.
(v)	—	—	—	—	—	—	25	23	25	21	25	25	„ 1933.
(vi)	—	—	—	—	25	7	25	23	25	21	—	—	June, 1933.
(vii)	—	—	—	—	30	28	21	17	25	25	—	—	April, 1933.
(viii)	—	—	—	—	20	18	20	19	20	19	—	—	May, 1933.
Total	70	0			145	111	259	234	258	218			
Per cent pupated		0%		(40%)		76.5%		90.3%		84.4%		(100%)	

III. Effect on the Development of the Pupa.

Moisture of Soil	0%		10%		20%		35%		65%		100%		Remarks
Experim. No.	Number of Pupae		Number of Pupae		Number of Pupae		Number of Pupae		Number of Pupae		Number of Pupae		
	Used	Emerged	Used	Emerged	Used	Emerged	Used	Emerged	Used	Emerged	Used	Emerged	
(i)	—	—	—	—	—	—	63	58	52	52	—	—	May, 1930.
(ii)	20	14	20	20	—	—	20	19	20	18	(20)	(20)	November, 1931.
(iii)	—	—	23	22	—	—	23	20	23	23	(23)	(23)	" "
(iv)	—	—	16	15	38	38	39	38	33	26	21	6	June, 1932.
(v)	—	—	—	—	20	19	27	27	24	23	—	—	" "
(vi)	—	—	—	—	—	—	17	17	23	23	20	0	May, 1933.
(vii)	—	—	—	—	46	45	38	37	33	32	33	0	" "
(viii)	—	—	—	—	33	32	21	19	33	32	33	0	May, 1933. Constant at 25°C.
(ix)	—	—	—	—	24	23	25	23	25	24	25	0	May, 1933. Conatant at 25°C.
Total			59	57	161	157	273	258	266	253	132	6	
Per cent emerged				96.6%		97.4%		94.4%		95.1%			

(B) Effect of Soil Moisture on the Velocity of Development.

I. Effect on the Development of the Larva.

Moisture of Soil / Duration of the Stage / Experim. No.	10% Number of Days Min.	Max.	Aver.	20% Number of Days Min.	Max.	Aver.	35% Number of Days Min.	Max.	Aver.	65% Number of Days Min.	Max.	Aver.	100% Number of Days Min.	Max.	Aver.	Mean Temperature of Air for the Period covered °C.	Remarks
(i)	—	—	—	21	25	22.6	18	21	19.2	17	20	18.6	22	—	—	13.9	April 11 — May 5, 1933.
(ii)	—	—	—	16	18	16.3	16	19	17.1	15	18	15.9	(All died)			14.4	April 16 — May 5, „
(iii)	—	—	—	—	—	—	7	8	7.8	7	8	7.4	(All died)			21.6	May 28 — June 5, „

II. Effect on the Development of the Pupa.

Experim. No.	10% Min.	Max.	Aver.	20% Min.	Max.	Aver.	35% Min.	Max.	Aver.	65% Min.	Max.	Aver.	100% Min.	Max.	Aver.	°C.	Remarks
(i)	66	88	78.2	—	—	—	66	89	80.4	71	92	82.0	66	89	81.3	6.9	November 30, 1931 — February 29, 1932.
(ii)	—	—	—	17	19	18	18	20	18.7	15	18	17.4	—	—	—	17.5	April 28 — May 18, 1933.
(iii)				16	18	17	16	18	17.1	16	18	17.1				18.6	May 1 — May 20, 1933.
(iv)				10	12	10.8	10	12	10.8	10	12	10.9				25.0	Constant temperature. May 2 — May 15, 1933.
(v)				10	12	10.3	10	11	10.0	9	11	10.1				„	Constant temperature. May 4 — May 16, 1933.

III. Effect on the Duration of the Period from Oviposition to Emergence of Adult Insects.*

Experim. No.	10% Min.	Max.	Aver.	20% Min.	Max.	Aver.	35% Min.	Max.	Aver.	65% Min.	Max.	Aver.	100% Min.	Max.	Aver.	°C.	Remarks
(i)	26	29	27.8	26	30	27.9	25	28	26.5	26	31	27.9	29	31	30.3	18.7	May 12 — June 12, 1932.
(fi)	—	—	—	25	34	28.6	24	27	25.6	25	28	26.3	—	—	—	19.0	May 18 — June 21, „

* In this series of experiments all eggs were kept, for the greater part of their egg periods, in soil the moisture content of which was some 60 to 65 per cent and prior to their hatching they were distributed to soils of different moisture contents. Therefore, the influence of different moisture content is to be expected only on the combined duration of the larval and pupal periods. But the figures in the table represent the number of days from oviposition to appearance of the adult insects.

Larva. The larvae did not grow in the air-dry soil and all died before they were full-grown. Generally only a very small percentage of larvae completed the larval stage when the moisture content was 10 per cent. However, when larvae were reared with moist food in a cool or cold season, sometimes a fairly large percentage reached the pupal stage. At a moisture content of 20 per cent, about 76 per cent of the larvae were full-grown. Even in soil with a moisture content of 20 per cent, only a small percentage of larvae grew when they were fed with dry food such as dry soy-bean cake. At a moisture content of 35 per cent the percentage of larvae that reached the pupal stage increased and about 90 per cent of the larvae successfully reached the pupal stage. Beyond a moisture content of 35 per cent the percentage of larvae that successfully developed did not seem to increase. Larvae grew successfully in the soil saturated with water when the food for the larvae was placed on the soil surface and the larvae and the soil were left untouched. When the soil was stirred often to examine for pupating larvae, most of the larvae which were buried in the soil died and a small percentage seemed to escape from the container.

Pupa. Usually the pupa could not develop successfully in the air-dry soil, but a small percentage developed and emerged as adults when the experiment was carried out in the autumn and winter. When pupae were placed on the surface of soil which was saturated with water they developed successfully, but they could not develop and all died when they were buried in soil saturated with water. When the moisture content was 10 per cent, about 96 per cent of the pupae emerged as adults. Increase of moisture content from 10 per cent to 65 per cent seemed to have little influence upon the percentage of pupae that developed and in all moisture contents tested the percentage of emergence was always more than 94 per cent. These results seem to indicate that the moisture content of the soil does not have a decided effect on the development of the pupa under the conditions existing in these experiments, but it can not be expected that the percentage of emergence under natural conditions in the field would be the same as obtained in these experiments. For, in these experiments, the soil containers were provided with covers, and the soil and the pupae within were protected from direct rays of the sun as well as from wind. These conditions prevented evaporation of water from the soil in the container and must have been of great advantage to the successful development of pupae even in soil with a little moisture content.

Effect of soil moisture on the velocity of development.

Three stages of the seed-corn maggot were reared in soils with different moisture contents in order to investigate whether different moisture contents have any influence on the velocity of development. The method of experimentation was the same as described in the previous experiments. The containers for the soil were covered with glass lids so that evaporation of water from the soil practically did not occur. Therefore, it may be said that the larvae and pupae were exposed only to the desiccating action of the soil when the soil was very dry and that the evaporation of water from their body surface was very slight. From 30 to 50 individuals were used in each experiment, but many died during the course of an experiment, especially in very dry (10 to 20 per cent moisture) or very damp (100 per cent moisture) soils. Consequently the number of individuals that reached the pupal or the adult stage was not very large, being in most cases from 20 to 40. In a very few instances, the ultimate number was only 9 or 10. The results of these experiments are shown in Table IX, B.

When the soil was saturated with water and stirred many times in order to examine for larvae, the majority of the larvae either died or escaped from the container, and in the soil of a moisture content of 10 per cent only a small percentage of larvae reached the pupal stage. Because of these circumstances, it was not possible to obtain sufficient data for these two moisture contents. According to Table IX, B, I, the average larval period was 22.6 days for 20 per cent soil moisture and 18.6 days for 65 per cent moisture in *Experiment* (*i*) while, in *Experiment* (*ii*), the average larval period was 16.3 days for 20 per cent moisture and 15.9 days for 65 per cent moisture. These results seem to indicate that different moisture contents of the soil had very little effect upon the velocity of development under the conditions of these experiments.

According to the data in Table IX, B, II, the average pupal periods hardly differed for different moisture contents when the moisture content was between 20 and 65 per cent. The results of *Experiment* (*i*) seem to indicate that even the saturated soil had no ill effect on the velocity of development if the pupae were placed on the soil surface.

In Table IX, B, III, the results of experiments which were carried out to determine the effect of moisture on the combined duration of the larval and pupal periods are given. The results were essentially the same as those in the two previous series of experiments, the only difference being that the results of *Experiment* (*i*) of this series showed that 100 per cent moisture had a slight retarding effect upon the velocity of development.

In short, these experiments indicate that different moisture contents of the soil had only a slight effect on the velocity of development when the moisture content was more than 20 per cent. However, this may be true only under the conditions in the writers' experiments. Under natural conditions in the field the effect of soil moisture may be somewhat different from what has been observed by the writers in the rearing room, since the soil in the field is exposed to various factors such as direct rays of the sun, wind, etc. which tend to accelerate evaporation of water from the soil.

VII. Summary and Conclusion.

Further observations and experiments were made on the food of the seed-corn maggot and a list of the substances which served as food is given.

The longevity of the adult of the seed-corn maggot varies greatly according to the season as well as from some unknown causes. In summer, longevity varies from 2 or 3 days to 30 or 40 days. In winter, it is at least 12 days and it may reach as much as 120 days. Generally speaking, it is short during warm weather and long when the weather is cool.

The preoviposition period of the seed-corn maggot varies according to the season, being long during the cool months of spring and autumn and short during the warm months of summer. In December and January it occupies from 20 to 60 days and in May and June from 5 or 6 to 16 or 17 days.

The egg of the seed-corn maggot can develop under a very low temperature. At a constant temperature of 10°C., 90 per cent hatched while under a constant temperature of from 12° to 33°C. nearly all hatched. At a constant temperature of 35°C., only 30 per cent hatched. About 90 per cent of the larvae and pupae developed successfully at a constant temperature of 12°C., and at 33°C. about 80 per cent of the larvae pupated. When larvae were reared at a constant temperature of 35°C. all died. At a constant temperature of 33°C. only about 40 per cent of the pupae developed successfully and at 35°C. all pupae died.

The duration of the egg, larval and pupal stages was studied by rearing under various constant temperatures. The egg period was about 8 days at 10°C. and at 30°C. it was only one day for the autumn generation. The development of the egg was most rapid at 30°C. The maximum temperature for egg development is slightly above 35°C. The larval period was about 30 days at a constant temperature of 10°C. and about 5 days at 30°C. The development of the larva was most rapid at about 30°C. The maximum temperature for the larval development was found to be situated between 33° and 35°C. The pupal period was about 50 days at 10°C. and about 7 days at 33°C. The development of the pupa was most rapid at about 33°C. The maximum temperature for pupal development lies between 33° and 35°C.

Pupae sometimes entered a temporary dormant state when they were reared at a temperature as low as 10° or 12°C. and the time that such pupae passed out of the dormant state varied greatly in different individuals due to some unknown causes.

The duration of time from oviposition to emergence of the adult insect was about 85 days at 10°C., 24 or 25 days at 20°C., and 16 or 17 days at 25°C. Adding the preoviposition period to these figures, the duration of the life-cycle of the seed-corn maggot becomes about 100 days during winter and 21 or 22 days during the early summer. Under outdoor conditions the air temperature gradually rises or falls according to the season and this change of the mean temperature affects the velocity of development to some extent. Therefore, the period of time required for one life-cycle may differ slightly from the figures given above.

The effect of the moisture content of the soil on development was studied in the rearing room. According to the results of this experiment, the larva and pupa could not develop in a very dry soil. When the moisture content of the soil was 20 per cent or more of the amount of water required for saturation, mortality as well as the velocity of development was affected only slightly.

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