THE INFLUENCE OF CERTAIN TEMPERATURES AND HUMIDITIES UPON THE LARVAL AND PUPAL STAGES OF THE CODLING MOTH (CARPOCAPSA POMONELLA L.)

by

PAUL GRIFFITH LAMERSON

B. S., Kansas State College of Agriculture
and Applied Science, 1927

A THESIS

submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE

KANSAS STATE COLLEGE
OF AGRICULTURE AND APPLIED SCIENCE

1931

TABLE OF CONTENTS

INTRODUCTION

This thesis is based upon a study of the influence of certain temperatures and humidities upon the larval and pupal stages of the codling moth (*Carpocapsa pomonella* L.).

That temperature along with other ecological factors plays an important part in regulating the life histories of insects is acknowledged by practically all workers in the field of entomology.

That either temperature or humidity may be the limiting factor of insect development and that temperature and humidity act together and not as a separate unit is agreed upon by many investigators (Headlee, 1917, 1914, Peairs, 1914; Sanderson, 1908, 1910, 1913; Shelford, 1914; Pierce, 1916).

The purpose of the study was to note the influence of certain humidities and temperatures upon the larval and pupal stages of the codling moth from original investigation. The secondary purpose of the study was to acquaint the student with the influence of the various ecological factors pertaining to the codling moth by review of literature.

REVIEW OF LITERATURE

The influence of temperature and humidity upon the life history of the codling moth is very evident from the review of literature. Seasonal irregularities particularly those dealing with temperature have their influence upon the egg larva, pupa and adult of the codling moth. Various other ecological factors besides temperature and humidity are linked up with the life history. The more important among these are wind and intensity of light.

Temperature plays an important part in influencing oviposition activities of the codling moth. Rate of oviposition, length of oviposition period, length of incubation period and number of eggs laid per moth are all influenced by temperature and humidity. When the temperature drops below 60° F. oviposition ceases entirely (Isley and Ackerman, 1923; Longley, 1921).

Oviposition does not promptly follow emergemce. It may take place over a period of nearly a month. Moths begin to lay from one to three days after emergence if the temperature conditions are right. There is a decline in the number of eggs laid per day with a falling temperature (Isley and Ackerman, 1923).

The average number of eggs laid per moth was higher for the second brood than for the spring brood. Those of the spring brood laid an average of 12 eggs per moth, while those of the second brood laid an average of 46 eggs per moth, due no doubt to more favorable weather conditions. Higher temperatures were responsible for heavier oviposition (Siegler and Plank, 1921).

The duration of the egg stage or the period of incubation depends upon temperature. It may last from four to twelve days depending upon the temperature and other factors (Isley and Ackerman, 1923; Siegler and Plank, 1921).

Hammar (1912) worked out that the average period required for hatching depended upon the temperature. He determined that the eggs required from 15 to 16 days to hatch when the mean daily temperatures were about 60° F. This time gradually became shorter as the temperatures became higher. At a mean temperature of 65° F., 10 days were necessary to hatch the eggs; at 70° F, seven days and at

83.6° F., only four days were necessary. Seventy-nine per cent of the eggs were deposited from 3:00 p.m. to 9:00 p.m. The greatest activity in oviposition was displayed at dusk (Siegler and Plank, 1921).

Headlee (1913) reports that development of the egg proceeds only at temperatures above 50° F. The rate of development increases as the temperature rises above 50° F. until it reaches a temperature of 88° F. at which point development is at a maximum rate.

Jenne (1909) found that the egg stage was greatly lengthened by periods of cool weather such as are apt to occur in early spring. Eggs subjected to very cool weather, including frost, gave an average incubation period of 19.6 days. With the advent of warm weather the egg stage was rapidly shortened. Eggs deposited in May required only 8.5 days to hatch and the lot laid May 10, hatched in 7.5 days. For eggs laid by the second and third brood only a five day incubation period was needed.

Variations in numbers of eggs laid by moths of different broods of the same locality was observed from examining the literature. The total number of eggs laid by individual moths varied. From less than a dozen eggs to 300 eggs per moth were reported by different workers. More eggs per moth were deposited by the individuals from the late summer broods. The oviposition of the moths from the overwintering larvae was more irregular, extended over a greater length of time and fewer eggs per individual moth were recorded. The moths of the late summer broods laid more eggs per moth, the oviposition period was shorter and oviposition was more constant and regular than was that of moths from the overwintering larvae.

The influence of temperature upon the overwintering larvae was evident when the literature was reviewed.

It has been found that temperatures of from 20 to 25°F. will kill from 70 to 80 per cent of all larvae above the ground line (Siegler and Simonton, 1915; Newcomer and Whitcomb, 1924).

The influence of temperature on length of the pupal period has been noted by many workers. The pupal stage becomes progressively shorter as the season advances. Temperature conditions may reduce the time required for the pupal period by one-half. The period of time in the hibernaculum in winter is from six to eight months. The period of time in the cocoon varies from nine to thirty days with the summer broods (Isley and Ackerman, 1923).

That the length of the pupal period varies according to season has been noted by practically all detailed life history studies. The broods that follow the overwintering larvae have a progressively shorter pupal period (Quaintenance and Geyer, 1923; Siegler and Simonton, 1915: Selkregg and Siegler, 1928).

Glenn (1922) claims that the threshold of development for the pupa is approximately 52° F. and that the maximum rate of development for the pupa is 87° F.

Jenne (1909) states the earliest spring pupal stages lasted a month but the later individuals to transform spent only two weeks as pupae so that the time of emergence of the spring moths was shortened by 15 days.

That temperature influences the transformation of the larvae to pupae is easily observed by perusal of literature. Hammar (1910) observed that weather conditions influenced the transformation of the larvae to pupae. He says, "By comparing the daily fluctuations of temperature with the various records showing the behavior of the codling moth, it will be shown that its development has been greatly influenced by temperature. A cold spell was invariably followed by a delay in transformation while a rise in temperature produced a corresponding hastening in development". He cites the instance of the cold wet spring of 1907, saying that the prevailing low temperatures delayed the larvae to such an extent that only three per cent of the first brood transformed.

The length of the pupal period for the overwintering form and the later spring and summer broods varies a lot.

Quaintenance (1917), during his work in the Pecos Valley, found that the pupal period for the overwintering larvae was approximately 22.97 days while that of the summer brood pupal period averaged 12.11 days.

The review of literature seems to indicate that the time of transformation from larvae to pupae is very dependent upon the temperature factor. Time of emergence seems to be dependent upon time of transformation, both being influenced by temperature.

Childs (1918) during his observations of the years 1914-1917 noted that there occurred a variation in the dates of emergence of the first brood of moths due to weather conditions. A warm spring means early emergence. Rainy cold weather will stop emergence. Altitude also made a difference in time of emergence. The higher the altitude the later the time of emergence.

Hammar (1910) in his studies of the codling moth in northwestern Pennsylvania also found that weather conditions influenced time of emergence. Smooth even temperatures mean emergence over a short period of time. Fluctuating temperatures make emergence last over a long period of time.

The height of emergence has its optimum peak. Quaintenance and Geyer (1917) found this to be 67.33° F.

Studies by Brooks and Blakeslee (1915) in their work in the Appalachian region showed a marked difference in the time of appearance of the different broods in the different localities. They drew the following conclusion: For any given locality the variation in time of appearance of spring broods in different years is greater than the corresponding summer and fall broods of the same years.

Investigations in the Yakima Valley by Newcomer and Whitcomb (1924) showed that elevation with its attendant changed weather conditions had a marked effect upon time of emergence.

Ecological factors including temperature and light have a marked effect upon the adult moths. The moths hide away in the day time, seldom becoming active until an hour or two before dusk. Greatest activity is evidenced after sundown. Oviposition seems to be influenced by both light and temperature.

Jenne (1909) found out that the life of the moths was largely dependent upon temperature. During cold weather in spring or fall they remain torpid for long periods of time.

Examination of literature showed that V. E. Shelford (1927) did the most extensive work with the effect of constant temperatures upon the codling moth larvae and pupae. A review of his results from exposing codling moth larvae to different temperatures would be worth while for comparison.

Shelford stated that failure to pupate amounted to 50 per cent in the constant temperature experiments as a whole. Out of 4000 larvae, 2000 pupated and 1100 emerged.

Shelford lists the following ecological factors as affecting the codling moth:

1. Variability of temperature and humidity.
2. Rainfall which soaks the larvae and pupae.
3. Wind or air movement.
4. Quality and intensity of light.
5. Food
6. Mechanical stimuli.
7. Seasonal march of temperature and humidity.

(1) Regarding variability of temperature and humidity the effect of rising or falling mean daily temperature is reflected in the developmental total for the pupal stage and probably for the other stages.

(2) Rainfall and submergence in water.

During the prepupal period in hibernated larvae, submergence in water appeared in some cases to have little or no effect, while in other cases it accelerated development.

(3) Air movement and evaporation.

It appears that higher failure to pupate and higher mortality are accompanied by shorter pupal life under conditions of very rapid evaporation.

(4) Quality and intensity of light.

As compared with diffused daylight, the length of the pupal stage is longest in the dark.

(5) Food.

Larvae develop in picked apples more quickly than in apples on the tree.

(6) Mechanical stimuli and number of spinnings.

In an experiment in 1920 there was no difference in the length of pupal life related to number of spinnings except perhaps to hasten it.

From Shelford's constant temperature experiments the tables show that at 95° F. the percentage of failure to pupate of eight different groups of moths ranged from 25 to 100 per cent. No emergences occurred at this temperature.

At a temperature of 90° F., eight groups of moths showed a percentage of failure to pupate ranging from 0 to 97 per cent.

At a temperature of 85° F., five different groups of moths showed a percentage of failure to pupate ranging from 8 to 100 per cent. The pupal mortality ranged from 20 to 50 per cent.

At a temperature of 80° F., six groups of larvae exposed to that temperature showed a percentage of failure to pupate ranging from 24 to 75 per cent and a pupal mortality ranging from 7 to 29 per cent.

Review of Shelford's work shows that although he worked with larger numbers of groups exposed to the respective temperatures under which his experiment was carried on his mortality rate was very high. His percentage rates were so variable he did not try to draw any definite conclusions.

MATERIAL AND METHODS

This experiment was conducted by exposing groups of codling moth larvae, 50 to a group, to temperatures of approximately 80°, 85°, 90°, and 101° F., respectively. Due to equipment used there was some slight temperature overlap and also some variation in temperature from day to day and at different times of the day.

Each larva was placed in an individual observation cell formed by rasping out ten separate and distinct grooves in a piece of maple wood which was about one and one-half inches wide, one inch thick, and one foot long. Each one of these individual cell pupation sticks had room for ten larvae. A piece of transparent celluloid the same size as the pupation stick was cut, shaped and glued over the cells of the pupation stick. The cells were rasped out of the pupation sticks with a round-surfaced rasp so that the sides of each individual cell were sloping. Each cell was widest at the bottom and narrowest at the top to permit the larvae, which is thigmotropic, to adjust itself in such a manner in the cell that it could be squeezed sufficiently to imitate, insofar as possible, its natural hibernaculum under the scales of bark of the apple trees. The bottoms of the cells were later closed by gluing a narrow strip of transparent celluloid the whole length of the pupation stick. To satisfy the desire of the larvae for darkness, a piece of cardboard was held in place over the celluloid by means of rubber bands. To make provision for oxygen in each cell, two holes were made in each cell with a darning needle. The needs of the larvae for pressure, for darkness, and for air were met in this manner.

The orchards of the Arkansas River Valley furnished codling moth larvae for this experiment. Early in September

Dr. R. L. Parker and the writer made a trip to the Arkansas River Valley near Wichita and placed forty bands on apple trees in an orchard where there was quite an infestation of codling moth. These bands were left on the trees until the last of October, the worms collected and counted, and notes taken on the abundance of the larvae and their distribution in the orchard.

It was found upon collecting and counting the larvae that the catches were poorer near the edges of the orchard than in the interior of the orchard. Review of literature later showed that this was due to the fact that the adult codling moth does not like the wind so consequently it shuns the edges of the orchard.

Catches were poorer under the bands that were made out of exceedingly porous burlap. The reason probably was that these bands let in too much light, thus failing to satisfy the desire of the larvae for darkness.

Catches were better under the bands that reached all the way around the tree due perhaps to the fact that no pathways of escape to the ground were left when the trees were banded all the way around. Perhaps some of the larvae from the trees whose bands did not extend all the way around the tree, established themselves under scales of bark near the ground line.

Catches of larvae were better under the snug bands than under those that were loose on the tree, showing that the larvae are positively thigmotropic.

A total of 499 larvae were collected from under the 40 banded trees, an average of twelve larvae per tree.

These larvae were allowed to spin up in corrugated cardboard, the sort that has small openings in it. They were held inside the house for three days to allow them to spin up well then transferred to a shed, one side of which was open to the outdoors.

There was no way of knowing how many larvae were in each of these cardboard squares when the experiment began and it would have been of no use to have counted them beforehand for review of literature later showed that the larvae are cannibalistic.

Lack of an adequate scheme to keep track of the numbers of larvae in the cardboard squares, and with no method to make observations except to tear the cardboard, thus disturbing the larvae and pupae, destroying their hibernaculae and failing to secure necessary subsequent data on the same larvae and pupae observed, led the writer to further review of literature and the use of the pupation stick previously referred to and solved the observation difficulties.

The fact that the constant temperature machine in the insectary greenhouse had a daily temperature fluctuation of some ten degrees, led Dr. R. L. Parker and the writer to seek adequate facilities which were found in the Poultry Department for carrying on the experiment.

Finally all the larvae collected in the fall were used up so another collecting trip was made to the Arkansas Valley on March 9, 1931. The writer was fortunate enough to find an orchard of 20 acres that had been banded the summer previously and the bands had never been inspected or the worms killed. Collections from the bands of four rows of trees of this orchard yielded some 250 larvae which were sufficient. Inspection of apple packing boxes yielded about ten to fourteen worms per packing box. The bands of trees adjacent to the packing shed collected many more larvae than those farther out in the orchard, giving one the suggestion that the codling moth does not like to migrate far and that those moths emerging from the packing sheds fly to the nearest trees available, making infestation of the trees near the packing shed especially severe. The owner of the orchard said that the number of worms per apple was materially reduced in his orchard by using bands and killing the larvae collected under them.

Before proceeding with the results of this experiment, it might be of life history interest to record some observations regarding the prepupal and pupal stages of the codling moth as well as the method of emergence from the cocoon.

The larvae of the codling moth before transforming into the pupal stage assumes a straight position in place of the curved one it assumed in the larval stage. Often the larvae crawled out of the hibernaculum before going into the rather rigid straight form it assumed while undergoing transformation from the larval to the pupal stage. The transformation was rapid, only two or three days being necessary to make the change. The observer would see a straight dormant larvae and the next night a pale colored pupae would be observed. The pupae assumed a brown color in a few days time, the coloration occurring gradually.

Observation of the emergence of one moth from the pupal case took place in this manner: In emerging from the pupal case the pupa gives a convulsive contraction of the thorax and abdomen, the pupa case rips open on the dorsal side in the region of the thorax, the moth extrudes its head and climbs out of the slit. Its wings begin to quiver at once when it emerges and it is some time before they assume their normal size and shape. The moth soon after emerging deposits a mass of white excrement. The whole process, from time of emergence to the time the wings assumed their full size and shape, occupied less than one hour.

The larvae collected during this trip were placed in the individual observation cell pupation sticks referred to before and were allowed to spin up afterwards for some 48 hours.

The larvae, 50 in each group, were introduced to their respective temperature compartments on March 12. From then on until the close of the experiment temperatures were taken at eight, twelve and seven o'clock. Beginning March 21, daily inspection of all larvae under observation occurred. Note of deaths, pupation and emergence were recorded as to the date upon which they occurred.

The inspection of March 14 showed that the larvae that were being exposed to the temperature of 101° were injured severely. Twelve of them were dead and the rest were refusing to spin up very well and all of them showed signs of slowed down activities in regard to response to touch and light. Examination on March 26 showed that all the larvae in this group were dead. The duration of life for this group of larvae was twelve days. None in this group pupated and none of them spun adequate hibernaculae as compared with those exposed to the lower temperatures.

Of the 90° group, 20 larvae went into the pupal stage. Of these, three emerged. Thirty died without pupating. The average length of the pupal stage of the moths that emerged was eight and one-third days.

Fifteen of the larvae in the 85° group pupated. Seven of these pupae emerged. Thirty five of the larvae of this

Table I. Life History Chart of 80° Group

Larval					March									Day of Month									April							
number	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	1	2	3	4	5	6	7
1																	F*													
2																	F													
3																P'												F		
4													P										F							
5															F															
6															F															
7																								F						
8																			F											
9															F															
10															P													F		
11															F															
12													P													F				
13																										F				
14															F															
15																						F								
16																										F				
17															F															
18															F															
19																		F												
20																							F							
21													P																	F
22																			F											
23													F																	
24																				F										
25																										F				
26														F																
27																		F												
28															F															
29																	F													
30													F																	
31																						F								
32																F														
33																			P											
34																	P													
35																	P													
36													P																	
37																F														
38																F														
39																								F						
40																F														
41													F																	
42													F																	
43															F															
44																														
45																										F				
46																									F					
47													F																	
48																														
49															F															
50													F																	

*Fatality

'Pupated

Table II. Life History Chart of 85° Group

Larval					March								Days of Month													April				
Number	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	1	2	3	4	5	6	7
1															P*											F'				
2													P					E''												
3																												F		
4															P					E										
5																F														
6																		F												
7																F														
8																							F							
9																							F							
10																		P										F		
11													F																	
12																							F							
13													P							E										
14																			F											
15																										F				
16													F																	
17													P																	
18															F															
19																		P												F
20															F															
21													P																	
22													F																	
23						F																								
24																				F										
25																	F													
26															P															
27													F																	
28																				F										
29																P														
30															F															
31																	F													
32																					F									
33															F															
34																	P													
35																		F												
36																								F						
37													P																	
38																						F								
39																												F		
40															F															
41																												F		
42																														
43																									F					
44															F															
45																												F		
46																												F		
47															P					E										
48																									F					
49																			F											
50																			F											

*Pupated

'Fatality

''Emerged

Table III. Life History Chart of 90° Group

Larval					March									Days of Month											April					
Number	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	1	2	3	4	5	6	7
1																						F*								
2													F																	
3																				P'										
4													P						E''											
5																F														
6															P															
7															P							E								
8															P													F		
9															P									E						
10															P												E			
11																F														
12																										F				
13																		F												
14																					F									
15																							F							
16															P											F				
17																									F					
18																											F			
19															P															
20																									P			E		
21																												F		
22															P													F		
23																										F				
24																											F			
25													F																	
26																		P										F		
27													F																	
28																	P													
29																		F												
30													F																	
31																									F					
32																			F											
33																		P										F		
34																							F							
35																P										F				
36															F															
37																											F			
38																											F			
39																F														
40																						F								
41																						P								
42													F																	
43																P														F
44																P										F				
45																														F
46																														
47																														
48																				P						F				
49																	F													

*Fatality

'Pupated

''Emerged

Table IV. Life History Chart of 101° Group

Larval Number	Days of Month: March 14	21	23	24	25	26
1	F*					
2		F				
3		F				
4		F				
5		F				
6		F				
7		F				
8	F					
9		F				
10		F				
11		F				
12	F					
13		F				
14		F				
15		F				
16		F				
17	F					
18		F				
19		F				
20		F				
21		F				
22		F				
23	F					
24		F				
25		F				
26		F				
27		F				
28		F				
29	F					
30		F				
31	F					
32			F			
33						F
34		F				
35		F				
36		F				
37		F				
38		F				
39		F				
40	F					
41		F				
42			F			
43		F				
44	F					
45		F				
46		F				
[illegible]		[illegible]				
48	F					
49	F					
50		F				

*Fatality

Table V. Daily Temperature Range

Date				
March 12	80.33	84.33	87.00	101.00
13	80.66	84.00	90.00	101.00
14	81.33	84.33	88.00	101.00
15	81.66	84.00	85.66	100.00
16	82.00	84.66	86.33	98.00
17	81.33	84.00	88.00	100.33
18	82.00	84.33	89.00	100.00
19	82.33	84.66	89.00	101.33
20	82.33	84.66	88.00	102.10
21	82.33	84.33	87.33	101.66
22	83.33	82.50	84.00	101.33
23	82.33	84.66	88.00	101.00
24	82.66	85.33	85.33	101.00
25	82.66	83.33	85.00	
26	82.66	84.00	86.66	
27	81.66	84.00	85.80	
28	82.33	83.33	87.66	
29	82.33	82.33	87.33	
30	83.00	83.33	86.33	
31	82.66	82.00	87.66	
April 1	83.00	82.33	87.33	
2	83.33	82.66	87.66	
3	83.00	82.00	86.50	
4	83.66	82.00	87.33	
5	82.00	83.00	86.66	
6	83.33	82.66	85.66	
Average	82.31	83.5	87.04	100.7

group died before pupating.

Eight of the larvae of the group that were exposed in the 80° compartment transformed to pupa. None of these pupae emerged. Forty-two of these larva died without pupating.*

It is possible that the relative humidities of the compartments in which the insects were placed had much to do with the mortality rate of the insects under observation. A table of the percentages of humidity in the respective compartments used in this experiment is presented here. It represents records taken by the hygrothermograph over a period of one week's readings for each compartment used in the experiment.**

---

* See Tables I to V.

** See Tables VI and VII.

Table VI. Percentages of Humidity

Temperature	Average Humidity	Low Extreme	High extreme
80	60	55	70
85	55	40	60
90	58	56	70
101	63	52	68

Table VII
Life History Data at Various Temperatures

Group	Per cent to pupate	Per cent of emergences	Died without pupating	Percent pupated and died	Average duration of pupal stage
80	16	0	84	16	0
85	30	14	70	16	7.8
90	40	6	60	34	8.33
101	0	0	100	0	0

SUMMARY

1. One hundred one degrees Fahrenheit seemed to be lethal to the larvae. None of this group transformed and the average duration of life under these conditions was twelve days.

2. The highest percentage of pupation occurred from the 90° group.

3. The highest percentage of emergence occurred from the 85° group.

4. The 80° group showed the lowest percentage of pupation, next to the 101° group.

5. This experiment seems to indicate that higher percentages of emergence and pupation occur between 85° to 90° F. than occurs at temperatures of 101° and 80° F.

6. The results hint that perhaps temperatures of 80°F. and below are not as favorable to the development of the larvae as those that are higher.

The high mortality rate of the larvae and pupae used in this experiment is largely unexplainable. In such temperature and humidity experiments as have been carried on by previous workers, this high mortality rate persists and is not explained. This is shown especially by the work of Shelford, which shows an extreme variability of results with different groups of larvae under the same temperature conditions. A suggestion that 95° F. was perhaps too hot for rearing codling moths was shown by a pupal mortality rate of 100 per cent. Examination of another set of trials at 95° F. showed emergence of a few moths but the pupal mortality rate was relatively quite high. In general, the response of the larvae or different groups of larvae to the same temperature under constant temperature conditions was exceedingly erratic and inconsistent.

No very definite conclusions can be drawn regarding the results from Shelford's work concerning the influence of temperature and humidity upon codling moth larvae and pupae. Results from the various groups of moths under the same temperature conditions were too variable. The most outstanding fact concerning Shelford's work and the work carried on here was the high mortality rate of larvae and pupae at all temperatures. Perhaps this might be explained by the fact that under natural conditions under scales of bark on the apple trees the larvae and pupae obtain a steady and readily constant supply of moisture from the green bark of the tree upon which one side of their tightly spun hibernaculae is attached. Whether the larvae gets much moisture from rainfall under the scales of bark is open to some question for the scales of bark hang downward, making an efficient shed for the larvae underneath.

The summer of 1930 was one of extreme high temperatures at times. Drougth conditions prevailed in the Arkansas Valley at this time. Perhaps the unfavorable weather conditions experienced during the summer before hibernation for winter had some unfavorable effect upon the vitality of the larvae used in this experiment and would to some extent explain why there was such a high mortality under experimental conditions.

ACKNOWLEDGMENTS

Thanks of the writer are due to Dr. R. L. Parker of the Department of Entomology for suggestions and encouragement while the experiment was in progress, and to the Poultry Department of K. S. C. for furnishing facilities for carrying on the experiment.

LITERATURE CITED

Simpson, C. B. 1903
The codling moth.
U. S. Bur. Ent. Bul. 41:1-105.

Jenne, E. L. 1909
The codling moth in the Ozarks
U. S. Dept. Agr. Bur. Ent. Bul. 80:1-32.

Hammar, A. G. 1910
Life history of the codling moth in Northeastern Pennsylvania.
U. S. D. A. Bur. Ent. Bul. 80:1-101.

Peairs, L. M. 1911.
A third brood of codling moth in Kansas.
Jour. of Econ. Ent., 5:243-246.

Hammar, A. G. 1912
Life history studies on codling moth in Michigan.
U. S. D. A. Bur. Ent. Bul. 115:1-86.

Headlee, Thomas J. 1913
A brood study of codling moth.
Jour. Econ. Ent., 6:389-396.

Jones, R. R. and Davidson, W. M. 1913
Life history of the codling moth in the Santa Clara Valley of California.
U. S. D. A. Bur. Ent. Bul. 115:113-181.

Wilson, H. F. and Childs, L. 1913
Entomological investigations.
Oreg. St. Bien. Rpt. Hood River Sta. 1913-14:40-50.

Brooks, F. E. and Blakeslee, E. B. 1915
Studies of the codling moth in the Central Appalachian region.
U. S. Dept. Agr. Bul. 189:1-49,

Siegler, E. H. and Simonton, F. L. 1915
Life history of codling moth work in Maine.
U. S. Dept. Agr. Bul. 252:1-50.

Felt, E. P. 1916
Climate and variations in the habits of the codling moth.
Jour. Econ. Ent., 9:107-110.

Glenn, P. A. 1915-17
Codling moth investigations of the state entomolgists office.
Ill. Nat. Hist. Survey Bul. 14:219-288.

Quaintenance, A. L. and Geyer, E. W. 1917
Life history of the codling moth in the Pecos Valley.
U. S. D. A. Bul. 429:1-100.

Childs, L. 1918
Seasonal irregularities of the codling moth.
Jour. Econ. Ent., 11:224-231.

Dean. G. A. and Martin, W. R. 1918-19
The control of the codling moth in the Arkansas Valley Fruit Belt.
Kans. State Hort. Soc. Bien. Rppt. 35:89-102.

Treherne, R. C. 1919
The history of the codling moth in British Colombia.
Agr. Gaz. Canada 1:19-24.

Newcomer, E. J. 1920
Winter Kill of codling Moth.
Jour. Econ. Ent., 13:441-443.

Isley, D. and Ackerman, A. J. 1920
Some features of the codling moth problem in the Ozarks.
Jour. Econ. Ent., 13:159-166.

Longley, L. E. 1921
The codling moth in the Payette Valley.
Idaho St. Bul. 124:1-27.

Siegler, E. H. and Plank, H. K. 1921
Life history of the codling moth in the Grand Valley of Colorado.
U. S. D. A. Bul. 932:1-119.

Fite, A. B. 1921
Six years of life history studies on the codling moth.
N. M. Sta. Bul. 127:1-183.

Glenn, P. A. 1922
Relation of temperature to the development of the codling moth.
Jour. of Econ. Ent., 15:193-198.

Isley, D. and Ackerman, A. J. 1923
Life history of the codling moth in Arkansas with special reference to factors limiting abundance.
Ark. Exp. Sta. Bul. 189:1-57.

Gossard, H. A. 1923
Codling worm life history and correlated spraying program.
Ohio Sta. Bul. 8:73-78.

Newcomer, E. J. and Whitcomb, W. D. 1924
Life history of the codling moth in the Yakima Valley of Washington.
U. S. D. A. Bul. 1235:1-76.

Townsend, M. T. 1926
Breaking up of hibernation in the codling moth.
Ann. Ent. Soc. Am., 19:429-439.

List, G. M. and Yetter, W. R. 1927
Codling moth in the Grand Valley of Colorado.
Col. Sta. Bul. 322:1-46.

Shelford, V. E. 1927
Experimental investigation of the relations of the codling moth to weather and climate.
Ill. Nat. Hist. Survey Bul. 16:311-340.

Selkregg, E. R. and Siegler, E. H. 1928
Life history of the codling moth in Delaware.
U. S. D. A. Tech. Bul. 42:1-60.

Farr, M. D. and Flint, W. P. 1930
How to raise codling moth larvae throughout the year.
Jour. of Econ. Ent., 23:41-44.

Loeb, Jacques and Northrup, J. H. 1906
On the influence of food and temperature upon the duration of life.
Jour. Biol. Chem., 32:103-106.

Sanderson, E. D. 1908
The influence of temperature in regard to hibernation of insects.
Jour. Econ. Ent., 1:56-65.

Sanderson, E. D. 1910
Relation of temperature to the growth of insects.
Jour. Econ. Ent., 3:113-140.

Shelford, V. E. 1914
The importance of measurement of evaporation in economic studies of insects.
Jour. Econ. Ent., 7: 229-233.

Headlee, T. J. 1914
The effects of temperature and moisture on the rate of insect metabolism.
Jour. Econ. Ent., 7:413-417.

Peairs, L. M. 1914
The relation of temperature to insect development.
Jour. Econ. Ent., 7:174-179.

Pierce, W. D. 1916
A new interpretation of the relationships of temperature and humidity to insect development.
Jour. Agr. Res., 5:1183-1191.

Headlee, T. J. 1917
Some facts relative to the influence of atmospheric humidity on insect metabolism.
Jour. Econ. Ent., 10:31-38.

Loeb, Jacques and Northrup, J. H. 1917
On the influence of food and temperature upon the duration of life.
Jour. Biol. Chem., 32:103-121.

Morgulio, S. 1924
Effects of environmental temperature on metabolism.
Am. Jour. Physiol., 71:49-59.