Factors Influencing the Seasonal Incidence and Breaking of Diapause in *Carposina niponensis* WALSHINGHAM

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INTRODUCTION

The peach fruit moth, *Carposina niponensis*, is virtually bivoltine in the Tsugaru plain, the western part of Aomori Prefecture, as indicated by two distinct peaks of the moth flight in each season normally occurring in the second half of June and in the first half of August, respectively. However, a varying proportion of the first generation larvae have been observed to enter diapause which lasts until the following spring. The senior writer had assumed that this exceptional univoltinism might be due to the heritable trait, and furthermore there might occur two races with different life-cycles. This assumption seems more probable when considerably different features of the seasonal life-cycle of the moth in Nanbu — the north-eastern part of the Tohoku district — have been elucidated. Namely, in the latter locality the univoltine life-cycle of this insect seems to be of common occurrence. Yet, it is also possible that variability in the life-cycle of this fruit moth is attributed to the non-heritable variation in the responsiveness of individuals to environmental conditions.

Before approaching to the problem of genetic heterogeneity or differentiations of local populations of this species, it seems necessary to analyse the environmental relations of its seasonal life-history. Our first effort has naturally been directed to elucidate the diapause behaviour, because the seasonal cycle of the moth may largely be controlled by this regulatory mechanism, as generally known in

many other insects (cf. LEES, 1955). HUKUSIMA (1957) has already dealt with this subject and concluded that both day-length and temperature might be responsible for the incidence of diapause in *Carposina niponensis*, and also that the diapause is terminated at a low temperature during hibernation. His work made our investigation much easier to be undertaken, but despite of his conclusions his data were subjected to great fluctuations so that one would fail to estimate the critical length of day for the induction of diapause, which seems to be the key point of the problem. We have, therefore, tried first to elucidate the seasonal incidence of diapause under conditions almost comparable to those in the field, and then to interpret these results on the basis of our own experiments.

MATERIAL AND METHODS

All the samples used in the present work were collected in the apple orchard of the Experiment Station located at Fujisaki in the vicinity of Hirosaki city, or their progenies reared in the laboratory.

The seasonal incidence of diapause has been determined in the seasons of 1959 and 1960. In both years infested apples were collected at frequent intervals during July, August and September. They were held in a large wooden frame constructed specially to collect mature larvae emerging from infested fruits. The frame was covered with a piece of fine zinc gauze and placed out of doors in the shade; emerging larvae were daily removed from the frame and transferred to large Petri

dishes containing moist saw-dust. The larvae were kept undisturbed in the dishes for several days before examination, in order to allow them completing their cocoons. In the field, the mature larva of *Carposina niponensis* falls onto the ground upon emergence from the fruit, and spins a cocoon at the depth ranging from 0 to 7 cm in the soil, but sterilized saw-dust was found to be a suitable medium for spinning.

Fig. 1. Two types of cocoons spun by mature larvae of *Carposina niponensis*. Upper: winter cocoons; lower: summer cocoons; for further explanation see text.

There are two distinct types of cocoons of this species; one is loosely spun and fusiform in shape, while the other is spherical and compactly woven (see Fig. 1). The latter has been known as the winter cocoon and is formed without exception by the diapausing larva, which abandons this in the spring and once again spins a cocoon of the other type — the so-called summer cocoon. On the other hand, the nondiapausing larva spins only the summer cocoon soon after it has emerged from the fruit. The diapausing and developing larvae were, therefore, readily distinguished by the shape of their cocoons several days after they had fully grown. On this basis the percentage of diapause larvae in the samples daily obtained from the collecting box was determined.

In order to detect the factors responsible for the seasonal incidence of diapause, a series of laboratory tests were carried out. For this purpose, several adults that had been derived from hibernating stocks were kept in glass vessels with a number of young apples, on

which they deposited their eggs. After a day the fruits were examined, and if there were too many eggs on a fruit, the excessive ones were killed or transferred to another fresh apple. Thus each larva was allotted 3 g or more food. This seems to be sufficient to complete the larval growth and also to keep the host apples in a good quality during the feeding period.

The fruits, on which eggs were laid, were subjected to various photoperiodic and temperature treatments until mature larvae emerged from them. Rearing jars, each containing several such fruits, were kept in incubators regulated at 21°C, and a 10 Watt 'daylight' fluorescent tube placed at 20 cm above the jars was used as a source of light; and the length of daily illumination was controlled by a time-switch. Full-fed larvae which had crawled out from the fruits were daily removed and put on moist saw-dust in Petri dishes, and the percentage of diapause larvae in each treatment was determined as described above.

Diapausing larvae, which had been obtained in the trials determining the seasonal incidence of diapause, were stored in a field cage until October 6, when they were buried in the soil at 3 cm from the surface. At monthly intervals samples were taken from these field stocks, incubated at 20°C in moist conditions, and their subsequent development into imagines was observed. Other batches of diapausing larvae which had been raised under various experimental conditions were kept at 20°C for about a month, and after thoroughly mixed they were subjected to different low-temperature treatments in order to determine the duration of time and the range of temperature required to complete diapause. They were incubated either at 20 or 25°C after the treatments, and their subsequent development into the adult was observed. Throughout the cold exposure and the following incubation, the cocoons were kept on a piece of moist cotton wool or a layer of damp river sand in Petri dishes.

RESULTS

The Seasonal Incidence of Diapause

From the samples of apples collected in the orchard throughout the season, totals of 2,363 and 4,002 mature larvae were obtained in 1959 and 1960, respectively. Similar trends of seasonal changes in the percentage of diapause larvae were observed among these samples in both seasons (Fig. 2). No larvae which had fed before the third week of July entered diapause, but a few span hibernating cocoons among those larvae which had grown in the last week of the same month. As the larvae grew and matured successively later in the season, the proportion of diapause among them increased progressively; and about one-half of the larvae emerging from fruits at the middle of August entered diapause, while the occurrence of diapause became almost universal by the end of this month. A critical change in the incidence of diapause thus occurred at the middle of August. Since the larvae of the first annual generation continue to become fully grown usually from the middle of July to the middle of August, a considerable number of them may enter diapause and consequently may not produce offspring in the same season, though the proportion of such individuals would not

normally exceed one-half of the total population. On the other hand, the larvae of the next generation begin to mature after the critical date, so that almost all of them may enter diapause. The occurrence of the third generation seems, therefore, to be of little practical importance.

A curve very similar to that presented here was obtained by DICKSON (1949) in illustrating the seasonal trend of the incidence of diapause in *Cydia molesta*. A further example is afforded by GORYSHIN (cited in DANILEVSKY, 1956) with *Chloridea obsoleta*. In these insects, it has been elucidated that the onset of diapause is mainly controlled by day-length. We have thus the plausible hypothesis that the photoperiodic response might be involved also in this regular seasonal inception of diapause in *Carposina niponensis*.

The Effect of Photoperiod on the Induction of Diapause

That the duration of daily light period exerts a profound effect on the evocation of diapause in *Carposina niponensis* is clearly illustrated in Figure 3, in which the results of two series of tests conducted respectively in the two seasons are plotted together. As shown in this figure, all larvae entered diapause when they had been held at 21°C

Fig. 2. Showing the relation between the date of emergence (abscissa) of mature larvae from the host apples and the percentage of diapause (ordinate).

The data in the season of 1959 are indicated by open circles and those in the season of 1960 by closed circles.

in darkness. Similarly, they failed to avert diapause when reared under the illumination lasting less than 14 hours each day. If the duration of daily light period was increased further, the percentage diapause decreased sharply. Thus, in a photoperiod of 15 hours, the majority of larvae formed summer cocoons on maturity, and gave rise to moths without delay. The prevention of diapause was more pronounced in 16 or 18 hours of daily light; under these conditions no larvae entered diapause at all. However, a further increase in the duration of light period again promoted the evocation

of diapause; thus more than two-thirds of the larvae span cocoons of the hibernating type, when they had fed in 20-hour photoperiod. The onset of diapause seemed to be more prevalent in longer photoperiods; thus all the larvae failed to be free of diapause in continuous light. In short, at least at 21°C the larvae *Carposina niponensis* could avert diapause only in the narrow range of photoperiod from 15 to 18 hours.

Fig. 3. The relation between the daily light hours during the larval feeding stage (abscissa) and the percentage diapause (ordinate). Mean number of mature larvae obtained in each treatment is 46.

In this respect, this moth is conspicuously different in its photoperiodic response from many other multivoltine insects which avert diapause in any photoperiod longer than the critical length. There have been known only a few instances of the photoperiodic response similar to that found in the present work. GAYSPITS (cited in DANILEVSKY, *l. c.*) demonstrated that the larvae of certain univoltine lymantriid moths such as *Leucoma salicis*, *Euproctis chrysorrhoea* and *E. similis* develop continuously only in the day-length ranging from 18 to 20 hours. BULL & ADKISSON (1960) showed that, when reared on an oil-rich diet, the larvae of *Pectinophora gossypiella* are free of diapause in 14-hour photoperiod while a substantial proportion of them enter diapause either in a longer photoperiod of 19 hours or in a shorter one of 10 hours. It should be

noted that in the latitude of Aomori Prefecture the day-length around the summer solstice does not exceed 17 hours even if the twilight hours are included. Therefore, the diapause-inducing action of the extremely long day-length has probably no ecological significance. It would merely be a manifestation of the physiological mechanism triggering the photoperiodic response.

The Stage of Development Sensitive to Photoperiod

As shown in Table 1, the eggs of *Carposina niponensis* received no appreciable action of photoperiod concerning the future onset of diapause. The fate of the larvae, i. e. whether they undergo diapause or not, is largely destined during the feeding period irrespective of the light conditions experienced in the egg stage. In order to know if there was a particular stage especially important for the determination of diapause, several batches of larvae were subjected to different photoperiodic treatments at different times of their development. The results are not positive for suggesting the existence of such a critical stage, as represented in Table 2. It might be inferred that photoperiod was more or less operative during the most part of the larval life.

Table 1. The effect of photoperiod during the egg and larval stages on the induction of diapause at 21°C in *Carposina niponensis*

Light hours per day during		Number of mature larvae	Number of diapause larvae	Percentage diapause
Egg stage	Larval stage			
16	16	47	0	0
12	16	53	0	0
16	12	33	33	100
12	12	44	44	100

Table 2. The effect of photoperiod during various stages of larval development on the induction of diapause at 21°C in *Carposina niponensis*

Light hours per day during the larval life of			Number of mature larvae	Number of diapause larvae	Percentage diapause
First 4 days	Next 4 days	Last 5-11 days			
12	16	16	73	7	9.6
12	12	16	86	66	77.1
16	12	12	229	222	97.0
16	16	12	70	36	51.0
12	12	12	50	50	100
16	16	16	100	0	0

The Effect of Temperature on the Induction of Diapause

The evocation of diapause in *Carposina niponensis* is affected also by the temperature, as indicated by the results summarized in Table 3. Most of the larvae entered diapause when Table 3. The effect of the temperature during the larval feeding stage on the induction of diapause in darkness in *Carposina niponensis*

Temperature (°C)	Number of mature larvae	Number of diapause larvae	Percentage diapause
18	81	80	98.8
19	110	110	100
21	38	38	100
25	157	144	92.2
30	86	26	30.2
33	73	29	39.7

they had been reared at the temperatures below 25°C in darkness. Substantial proportions of them were free of diapause only at the temperatures higher than 30°C. These high temperatures might perhaps exert the action preventing the onset of diapause, because the tests were carried out in darkness that was comparable in its effect on diapause to a short day-length. Such high temperatures would not normally prevail during the whole period of the larval development at any time of the season; the mean temperature in the hottest month does not scarcely reach 25°C. However, if the heat spell unusually hits the area, the occurrence of an abnormal behaviour of diapause among the larvae might not be ruled out. Then it seems necessary to test Table 4. The effect of temperature during various stages of larval life on the induction of diapause in *Carposina niponensis*.

The test was carried out in darkness and the insects had been kept at 20°C in the egg stage.

Larvae were kept at		Number of mature larvae	Number of diapause larvae	Percentage diapause
33°C during	18°C during			
first 4 days.	last 11-21 days	68	61	89.8
" 7	" 8-18	66	64	97.0
last 9-17	first 7	39	34	87.2
" 5-9	" 13	116	96	82.8
whole stage	—	73	29	39.7
—	whole stage	81	80	98.8

the action of high temperature lasting for a brief period during the larval feeding stage. As indicated by the results of this test (Table 4), however, even the temperature as high as 33°C, exerted only a partial, if any, effect upon the prevention of diapause, when it was applied either in the first or in the second half of the larval stage.

The Effect of Temperature on the Completion of Diapause

Under the natural conditions, the diapausing larvae of *Carposina niponensis* occurring in late summer or autumn remain in their winter cocoons until the beginning of the following May, when they make their way out and again spin cocoons of the other type for pupation. The larvae thus enclose themselves in the overwintering case for as long as 7 to 9 months. The sequence of behaviours beginning from the opening of the winter cocoon and culminating in pupation and adult emergence could be evoked by artificial heating only after larvae had spent a considerable length of time in their natural hibernating quarters. As shown in Table 5, most of the larvae overwintering under the field conditions failed to respond to incubation in October, and only one larva gave rise to the adult at a constant temperature of 20°C, taking as long as 83 days to do so. On the other hand, when the larvae were incubated at the end of November or later, a number of adults appeared after one to two months at 20°C. The relation between the number of emerging adults and the time of incubation during hibernation could not, however, precisely be detected because of high mortalities caused by fungous diseases in certain batches. By the same reason a comparison of the two series of samples collected in August and September, respectively, provides no information about the difference in the intensity of diapause between them.

Exposure to 5°C for longer than two months brought about the same effect as hibernation under the natural conditions (Table 6). It is apparent that the sequence

Table 5. The effect of incubation at 20°C at various times during the hibernation on the adult emergence from winter cocoons of *Carposina niponensis*

Time of incubation		Cocoons formed in August			Cocoons formed in September		
		Total no. of cocoons	Number emerging as adult	Days required at 20°C	Total no. of cocoons	Number emerging as adults	Days required at 20°C
October	26	59	1	83	57	0	—
November	25	60	27	37-58	57	28	35-67
December	25	60	51	33-56	60	33	38-64
January	24	30	23	30-45			
February	23	57	23	31-47			

Table 6. The effect of cold exposure (5°C) on the termination of diapause in *Carposina niponensis*

Length of exposure in days	Total number	Number emerging at 20°C	Days required for emergence at 20°C
0	53	5	174-178
30	53	2	54-60
60	53	36*	40-63
90	53	36*	34-47
120	53	40*	36-51

*Including dead pupae.

Table 7. The effect of different temperatures on the termination of diapause in *Carposina niponensis*

Temperature of exposure (°C)	Duration of exposure in days	Total number of cocoons	Number emerging as adults	Days required for emergence at 25°C
0	72	30	0	—
	102	30	0	—
5	77	25	9	30-46
	72	40	1	34
	80	25	18	27-42
	102	30	16	25-35
	114	25	17	22-40
10	47	25	14	32-14
	72	30	27	31-44
	80	25	20	20-38
	102	30	25	13-34
15	47	25	2	32-35
	80	25	17	27-44
	114	50	31	12-39
25	constant	25	1	103

of behaviours preceding metamorphosis is set in motion by the rupture of diapause, and the results stated above show that a low temperature is necessary for the termination of diapause. This is the agreement with the results obtained by HUKUSIMA (1957).

The range of temperature required for the completion of diapause might be roughly

estimated as being 5-15°C from the results summarized in Table 7. The table suggests further that the rate of the completion of diapause seems to be the highest at about 10°C. In these tests also, certain batches suffered from fungous diseases, and due to the resulting mortality and also to the small numbers of samples involved a clear-cut tendency could not be observed. It may be seen, however, that a prolonged exposure to a temperature near the freezing point was inadequate for the resumption of activity. Although the effect of a very brief exposure to sub-zero temperatures was not tested (cf. HOGAN, 1961), it seems likely that a temperature of this order might have little ecological significance in the case of *Carposina niponensis*, because the hibernating cocoons are usually protected from severe cold by deep snow cover, at least in the western part of Aomori Prefecture.

DISCUSSION

As elucidated by the present work, the onset of diapause in the field in the larvae of *Carposina niponensis* seems to be correlated primarily with the calendar dates of their growing stage irrespective of the brood to which they belong. Thus, even in the first annual brood, a considerable proportion of those larvae which have been fully-fed in the first half of August enter diapause, whereas those which have emerged from infested fruits before the end of July transform into pupae directly. A sharp rise in the percentage of diapause among the larvae occurs at the middle of August, the hottest time in the year. In view of the results of laboratory tests, however, such a high tem-

perature that will suppress the onset of diapause does not usually prevail in this part of the main island of Japan. Furthermore, despite that the mean air temperature during the larval stage was about 1 to 3°C higher in the season of 1959 than that of 1960, there was no conspicuous difference in the seasonal prevalence of diapausing larvae between the two seasons. For these reasons, it might be assumed that the induction of diapause is scarcely affected by the temperature in the field; and hence the length of day deserves special considerations so far as our investigation concerns.

Fig. 4. The relation between the number of hours from sunrise to sunset (abscissa) during the larval feeding stage and the percentage of diapause (ordinate).

Dotted lines: open circle, *Carposina niponensis*; closed circle, *Cydia molesta*. Full lines indicate the results of laboratory tests using artificial light; open square, *Carposina niponensis*; closed square, *Cydia molesta*. The curves for *Cydia molesta* are based on the data presented by DICKSON (1949).

TSUGAWA & YAMADA (1960) inferred that the larva of this fruit moth requires about two weeks from hatching to maturity in the field, based on the measurements of the head width of larvae taken at regular intervals from an apple orchard. Our own experience has also given the same estimation. Therefore, the onset of diapause might probably be controlled by the day-length during the two weeks preceding the emergence of the larvae from the host fruit. Based on this supposition, the average day-length (i. e.

hours from sunrise to sunset) during the larval feeding stage was estimated for different groups of larvae having matured on different dates, and the percentage of diapause in each group was plotted against it. The resulting curve is illustrated in Figure 3. From this curve the day-length evoking diapause in one-half of the individuals may be estimated about 14 hours and 10 minutes. This is about 30 minutes shorter than the value obtained by a rough interpolation of the results of the laboratory tests. Twilight hours are probably responsible for this difference. A similar treatment of the data presented by DICKSON (1949) with *Cydia molesta* in California yields the curve also drawn in the same figure. In the latter case, the addition of about 20 minutes to the hours from sunrise to sunset is necessary to coincide the field data with the curve of photoperiodic response secured by experiments. Now, DICKSON elucidated that the threshold intensity of light exerting photoperiodic action was around 3 f.c. Considering the longer twilight hours in the earlier season when *Carposina niponensis* enters diapause in this relatively northern locality, figure 3 may well indicate that these two species of fruit moths might be photoperiodically sensitive to the light intensity of similar magnitudes.

The conspicuous difference in the length of critical photoperiod between the Californian population of *Cydia molesta* and the Tsugaru population of *Carposina niponensis* may well account for their different timings of entrance into diapause. Thus the critical date for the inception of diapause occurs at the middle of August in the latter, while it lies at the end of the first week of September in the former. This difference most clearly depicts the importance of the photoperiodic response for the survival of these insects. In Tsugaru, the shorter growing season enables *Carposina niponensis* to produce only two broods in each season, and the entrance into diapause in the second, partially in the first, annual generation is indispensable for permanent habitation. This is undoubtedly achieved by its longer critical photoperiod. On the other hand, the larval

feeding stage might be extended, if food is available, to later dates for *Cydia molesta* in California, where mild weathers prevail much later in autumn.

Moreover, it may be inferred that, even if the two forms occur in the same locality (as they really do in certain districts of Japan) *Cydia molesta* could utilize a longer period of time for growth and breeding in each year than does *Carposina niponensis*, for the former is able to thrive on more variable kinds of food. It seems probable that the Californian population of *Cydia molesta* is able to exploit the richer environmental possibilities in its habitat by its shorter critical day-length. The photoperiodic response is thus an efficient physiological mean of adaptation in these insects as in many other species.

Such considerations may give a further basis to the assumption that the length of day would be a principal factor responsible for the determination of diapause of *Carposina niponensis* in the field. It should be pointed out, however, that the temperature may cause annual fluctuations in the incidence of diapause of the first annual brood. In cooler years the spring emergence of adults is retarded and the growth of their progeny is delayed, so that a larger proportion of the larvae would feed and mature after the critical date than in warmer years. The result is obvious; a higher percentage of the larvae will enter diapause. This may imply that the size of the population effective for producing a second brood in the same season would be influenced, at least partly, by the conditions of temperature during the first half of the season. In extremely cool years, it would occur that most of the first-generation larvae mature after the critical date, and consequently enter diapause. In such a case, only a small population would be built up in the autumn. In Tsugaru, where it is usually hot in summer, a situation like this may scarcely occur, but in the cooler climate of Hokkaido the record shows that it has really been encountered. In the season of 1953, unusually cool weathers prevailed in Sapporo, and the first flight period of the moth occurred about two weeks later

than usual. This resulted in the onset of diapause in most of the offspring larvae, probably because they had to feed after the critical date under the short days. Subsequently, a second flight of the moth was not found in this season (MIYASHITA, *et al.* 1955). The existence of a correlation between the population density in the second generation and the mean temperature during June and July might also be explicable by this hypothesis (cf. MIYASHITA, *et al.*, 1956). Thus temperature seems to be one of the important factors to be considered in predicting the seasonal prevalence of this orchard pest, even though it is not primarily responsible for the onset of diapause in the field.

It should be noticed, however, that the prediction of outbreaks of this moth may not be accomplished by the same method in different localities, because there may be differentiations in the diapause behaviour between local populations. There is some circumstantial evidence supporting this presumption. According to a survey made by MIYASHITA and others (1955, 1956) at Sapporo, the percentage of winter cocoons formed by the larvae in the first half of August is usually not lower, or rather higher, than that at Fujisaki, in spite of the longer day-length in summer at the northern location of the former locality. It might be supposed that the critical length of day for the induction of diapause in the Sapporo strain is a little longer than in the Fujisaki strain, if the phenotypical modification of the photoperiodic response under the influence of different local conditions of temperature, as suggested in *Chloridea obsoleta* by GORYSHIN (cited by DANILEVSKY, *l.c.*), is not operative. In other respects, the Sapporo strain is physiologically similar to the Fujisaki strain, inasmuch as there are normally two conspicuous periods of moth flight in both localities, and also there is no remarkable delay in the spring appearance of adults from the hibernating generation. On the other hand, in the eastern part of northern Honsyu, the local inhabitants seem to be distinctively differentiated in their physiological traits from those found on the Japan

Sea coast in the same district. One of the most remarkable differences between them can be seen in the time of the adult emergence after hibernation. In the Tsugaru plain, moths from hibernated population begin to appear from the second week of June and virtually disappear before the end of July, whereas at Gonohe, east of the Hakkōda mountains, the moths first appear after the middle of June and continue to emerge from the hibernated brood until the middle of August (Anonymous 1, 1961). As a result of this scattered and protracted emergence from hibernation, a much higher proportion of the first annual brood at Gonohe would enter diapause without producing their progeny in the same season. It is, in fact, believed in Nanbu that the fruit moth is virtually univoltine. A similar, but less conspicuous, tendency of the delayed emergence of the moth was observed at Morioka (Anonymous 3, 1961). Here the overwintering population of the 1959 brood gave rise to adults from June 9 to August 4.

These phenological differences between the local populations might be attributed to the heritable variation in the physiological traits, because when winter cocoons of the Tsugaru and the Nanbu stocks had been interchanged and kept in field cages side by side with the native stocks, they persisted their distinct modes of emergence from hibernation (Anonymous 2, 1961). It might be presumed that diapause in the larvae of the Nanbu strain persists for a longer time than in those of the Tsugaru one. Moreover, at least some populations found in Nanbu seem to have a stronger tendency to enter diapause than their counterparts in Tsugaru; according to observations made by the Iwate Agricultural Experiment Station at Morioka, the mean percentage of diapause among the larvae having matured during consecutive five-day periods from the end of July to the middle of August was as high as 73 per cent (Anonymous 3, 1961), while it was only 24 per cent at Fujisaki during the corresponding dates of the same year. This conspicuous difference could not be attributed to any climatic factor

and it seems highly probable that the local strains are physiologically differentiated — particularly in their diapause behaviours. A careful study should be carried out in order to draw a more perfect picture of this story. At present, the Nanbu strain seems to be distinguished by its strong genetic tendency towards univoltinism from the Tsugaru strain.

From these facts and considerations, it should again be emphasized that the prediction of the seasonal prevalence of this fruit moth could not be undertaken on the same basis in different areas. The local differentiation in the diapause behaviour seems to be widespread in insects (cf. MASAKI, 1961), and it is important to elucidate the essential features of this adaptational variation from economic as well as scientific point of view.

SUMMARY

Diapause in *Carposina niponensis* occurs at the end of the larval stage, and the diapause larva spins the characteristic winter cocoon. In the field, few larvae enter diapause in July, but a number of diapausing larvae begin to appear from the beginning of August, and thereafter the percentage diapause increases regularly towards the end of that month, when almost all larvae enter diapause on maturity. The transition in the growth pattern of the larvae from non-diapause to diapause thus occurs at about the middle of August.

In the laboratory, the onset of diapause was readily controlled by light hours per day artificially applied during the larval feeding stage. Namely, at 21°C the larvae averted diapause only within a narrow range of photoperiod lasting from 15 to 18 hours per day, and the incidence of diapause was increased by either a longer or a shorter photoperiod. In darkness the occurrence of diapause was suppressed to a certain extent by a temperature as high as 30 or 33°C, while diapause was prevalent at a temperature of 25°C, or lower. The larvae were sensitive to both day-length and temperature during the entire feeding stage, and there could be recognized no particular instar critical for the induction

of diapause.

When diapausing larvae were constantly kept at a temperature of 20°C, or higher, most of them could not emerge from their winter cocoons and failed to pupate for a long period. Previous exposure to a low temperature between 5 and 15°C promoted the emergence from winter cocoons and the subsequent metamorphosis. The diapausing larvae required about two months at these temperatures to terminate diapause, but a temperature close to the freezing point was found to be detrimental for the larvae.

From these results of field and laboratory tests, it is concluded that the length of day might be the principal factor governing the onset of diapause in the field.

Possible occurrence of local differentiations in the diapause behaviour of *Carpocapsa niponensis* is discussed to a certain extent in view of the available information on the phenology of this orchard pest in various localities.

摘 要

モモシクイガの休眠と環境条件

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1959年および1960年の7月から9月にわたってリンゴ畑からモモシクイガの被害果を採集し、自然に近い条件下において成長を終わって脱出してくる幼虫の休眠率の季節的変化のありさまを調べた。その結果休眠幼虫は7月末から現われ始め、そののち次第に数を増して8月半ばには成熟幼虫の半数に達し、同月末にはほとんど全部の幼虫が冬繭を作って休眠した。その後不休眠幼虫は現われなかった。

このような休眠誘起の季節的消長を支配している要因を知るために室内で幼虫発育期の日長時間の影響を調べたところ、これまでにあまり知られていない光週期反応の型が観察された。すなわち21°Cにおいては藤崎産のモモシクイガの幼虫は15~18時間の日長によってのみ休眠しないでさなぎになることができる。この限られた範囲外では長短いずれの日長下においても幼虫は全部休

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眠する。

休眠決定の条件としての日長効果を感じるのは幼虫期に限られているが、幼虫期の中では特に敏感な令期を認めることはできなかった。温度も休眠誘起に影響するが、休眠阻止の作用は30°C以上の高温でないと現われないので自然界においては日長が主要な作用要因であると考えられる。

休眠を終わるためには5~15°Cの温度に2~3ヵ月接触することが必要である。20°C以上の高温や0°Cに近い低温はいずれも休眠完了に不適な条件であると思われる。

以上の結果に基づいてモモシクイガの1世代目の幼虫の休眠率の年次変動について考察し、またこの害虫が休眠性に関して地域的に分化している可能性があることを既存の知見に基づいて指摘した。