Seasonal Changes and Effects of Temperature on Flight Ability of the Diamondback Moth, *Plutella xylostella* (L.) (Lepidoptera: Yponomeutidae)

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Seasonal changes in the forewing length and flight ability of *Plutella xylostella* were examined for female and male adult moths collected from a cabbage field in Mie Prefecture in 1988. Flight ability was measured by a flight mill. Flight duration and flight distance were longer in winter and spring than in summer. Flight velocity and proportion of moths with long-time consecutive flight did not show a distinct seasonal change. Flight duration and flight distance showed a significant correlation with forewing length; the larger moths in winter and spring had a higher capacity for long distance flight than the smaller moths in summer. In the same months, the flight ability of female moths was almost equal to that of males. The optimum temperature suitable for flight activity of male moths was estimated at ca. 23°C, with a range from 18 to 28°C.

Key words: diamondback moth, flight ability, forewing length, seasonal change, *Plutella xylostella*

INTRODUCTION

The diamondback moth, *Plutella xylostella* (L.) is one of the most serious pests of cruciferous crops. Their control is difficult, not only in Japan but also in many countries of Southeast Asia, because of high insecticide resistance. *P. xylostella* has already developed resistance to the synthetic pyrethroids which were applied from the early 1980s (CHENG, 1986; HAMA, 1987; KOSHIHARA, 1988 a). One of practical ways to prevent the development of resistance in this moth might be to rotate several insecticides with different mechanisms of insecticidal action (HAMA, 1986; KOSHIHARA, 1988 a). Regrettably, this approach has not yet been validated by research in the field. In order to make rotational application an effective control measure, it is necessary to determine the area of vegetable crop fields to which the measure should be applied. It is therefore important to investigate flight ability and population parameters of the moth in the fields, especially for immigration and emigration. *P. xylostella* has been reported to show a long-distance migration in Europe and Japan (FRENCH and WHITE, 1960; SHAW and HURST, 1969; LOKKI et al., 1978; MIYAHARA, 1987). However, there are few studies on its potential flight ability, except for the flight velocity estimated

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from body size (DANTHANARAYANA, 1986).

In this study, the seasonal change in flight ability of *P. xylostella* was investigated in Mie Prefecture, central Honshu, where the moth can survive winter at all life stages from egg to adult. The effects of temperature on flight activity of male moths were also examined in both the winter and summer seasons.

MATERIALS AND METHODS

Seasonal change in forewing length. Pupae were collected from a cabbage field at the National Research Institute of Vegetables, Ornamental Plants and Tea (NIVOT) in the middle ten days of every month from January to December 1988. Following emergence in the laboratory, 30 to 40 adult moths of both sexes were selected randomly for forewing length measurement.

Seasonal change in flight ability. Moths were collected in the same way as in the forewing length measurement. Flight ability was measured using a flight mill device with an automatic data recorder linked to a personal computer. The male adults used were collected from January to November, with the exception of September. Female adults were examined in February, May and November. Both sexes used were one day after emergence, unmated and unfed. The flight mill was almost the same as that used by KAWAMOTO et al. (1987) for measuring flight ability of the cabbage webworm, *Hellula undalis* (FABRICIUS). The device for *P. xylostella* had a lighter rotor made of balsa wood (0.44 g), with a shorter diameter of rotor (18.0 cm), and adopted a stainless insect pin (No. 1, Shiga) instead of a vinyl-coated wire to connect the pronotum of the cabbage webworm with the rotor of the flight mill. After anesthetization with carbon dioxide for five to ten sec, the moth was attached to the end of the insect pin with a small amount of adhesive agent (Bond G17®, Konishi). Flight ability was measured for 48 hr under constant conditions of 23°C, ca. 60% RH, 0.1 m/s wind velocity, and in darkness. Illumination was applied twice a day at 12 hr intervals to check for mortality and dislocation from the flight mill. Four parameters representing flight ability (duration, velocity and distance of flight, and duration of consecutive flight) were computed. Long-time consecutive flight was defined as flight continuing for more than 120 min. The moths which died or fell down within 24 hr after the start of the test were not included in the data.

Effects of temperature on flight activity. The effects of temperature on flight activity were examined for male adult moths collected in the winter (late February to early March) and summer (late June to early July). Pupae were collected from a cabbage field at NIVOT, and unmated moths were examined one day after emergence. Flight mill tests were conducted at five different temperatures (13, 18, 23, 28, and 33°C) and flight ability was measured under the same conditions as for the test on seasonal change except for temperature conditions.

Statistical significance was tested by *t*-test ($p=0.05$) for the forewing length, flight duration, flight velocity and flight distance, and by χ^2 -test ($p=0.05$) for the rate of moths with long-time consecutive flight and survival rate at the end of the flight mill test.

RESULTS

Seasonal change in forewing length

The forewing lengths of both sexes were significantly longer in winter and spring than in summer and autumn. The average length of forewings of females were always longer than those of males through the year, but the differences were not significant (Fig. 1).

Seasonal change in flight ability

Figure 2 shows the seasonal changes in flight ability of both sexes. For males, the flight duration was longer in winter to spring than in summer to autumn, with a significant difference between durations in March (maximum) and August (minimum). Flight velocity was almost constant throughout the seasons. Flight distance showed similar patterns to those of flight duration; there was a significant difference between the maximal distance in March and minimal distances in August and October. The rate of moths with long-time consecutive flight was very low only in October (less than 10%), differing significantly with rates in the other nine months. In February, May and November, the flight duration, velocity, distance and the rate of moths with long-time consecutive flight showed no difference between females and males.

Effects of temperature on flight activity

In winter (Fig. 3), flight duration reached a maximum at 23°C, being significantly different from the minimum at 33°C. Flight velocity increased in proportion to temperature, and the minimum at 13°C was significantly different from velocities at 28°C and 33°C. Flight distance had similar patterns to flight duration, reaching a maximum at 23°C. There were significant differences between the minimum distance at 13°C and those from 18°C to 28°C. In terms of the rate of moths with long-time consecutive flight, there was a significant difference between the maximum at 23°C and the minimum at 13°C. The survival rate at the end of the flight mill test was 0.0% at 33°C.

Fig. 1. Seasonal changes in the forewing length of female (open circles) and male adult moths (solid circles) of *Plutella xylostella* at Ano, Mie Prefecture in 1988. Vertical bars show 95% confidence limit.

Fig. 2. Seasonal changes in the flight ability of female (open circles) and male adult moths (solid circles) of *P. xylostella* at Ano, Mie Prefecture in 1988. The rate of moths with long-time consecutive flights (%) = Number of moths flying consecutively for more than 120 min / total number of tested moths. Vertical bars show 95% confidence limits. The numbers of male moths measured by the flight mill were 35 (Jan.), 32 (Feb.), 29 (Mar.), 33 (Apr.), 34 (May), 30 (Jun.), 25 (Jul.), 27 (Aug.), 22 (Oct.), and 32 (Nov.). The numbers of measured female moths were 33 (Feb.), 35 (May), and 17 (Nov.).

Fig. 3. The effects of temperature on the flight ability and the survival of male adult moths in the winter season. Vertical bars show 95% confidence limit. The numbers of moths measured by the flight mill were 32 (13°C), 31 (18°C), 33 (23°C), 32 (28°C), and 17 (33°C).

only, significantly different from the rates at 13°C to 28°C. On the other hand, summer flight duration did not show significant differences among the five sets of temperatures (Fig. 4). Flight velocity increased in proportion to temperature, and there were significant differences between the maximum at 33°C and the velocities at 13°C and 18°C. The minimum flight distance was observed at 13°C, being significantly different from distances at 18°C to 33°C. The rate of moths with long-time consecutive flight did not differ among the five sets of temperatures. Survival rate at the end of the flight mill test was highest at 18°C, being significantly different from the rates at 28°C and 33°C, respectively.

Fig. 4. The effects of temperature on the flight ability and the survival of male adult moths in the summer season. Vertical bars show 95% confidence limit. The numbers of moths measured by the flight mill were 22 (13°C), 21 (18°C), 29 (23°C), 22 (28°C), and 20 (33°C).

DISCUSSION

The population density of *P. xylostella* in Mie Prefecture increases in spring and autumn, but decreases in mid-summer (KOSHIHARA, 1988 b). This study revealed the seasonal changes in forewing length and flight ability of this moth; males in winter to spring had a larger body size and longer flight duration than in summer. The seasonal change in flight distance depended on the change in flight duration, because flight velocity was almost constant throughout the seasons. Therefore, moths in winter to spring have a higher capacity to fly a longer distance than in summer. According to the flight mill experiment, the potential flight distance for two days averaged 13.3 km

Table 1. Correlations between the forewing length of male adult moths (X ; mm) and four flight ability parameters (Y) of *P. xylostella*

Y	Correlation coefficients ^a with forewing length	Regression equation
Flight duration (min)	$r=0.7968^{**}$	$Y=-930.3+237.0X$
Flight velocity (m/min)	$r=0.6295^{ns}$	
Flight distance (km)	$r=0.7851^{**}$	$Y=-15.6+3.8X$
Rate of long-time consecutive flights (%)	$r=0.5022^{ns}$	

^a $N=10$, ** significance ($p<0.01$), ns : no significance.

in March, but less than 4.8 km in August. The females appeared to have the same seasonal changes as males.

Table 1 shows the relationships between four flight ability parameters and the forewing length of the male adult. Flight duration and flight distance showed a significant correlation with forewing length, but flight velocity and rate of moths with long-time consecutive flight did not. This correlation analysis suggests that larger adult moths would be able to fly further than smaller ones. It is not known why larger moths can fly further; however, the size of the adult moth may influence the amount of storage energy such as carbohydrates and lipids which are used as a fuels for flight. It seems unlikely that a larger adult moth has more active flight with a faster velocity, or is more suited to long-time consecutive flight than a smaller moth.

YAMADA and UMEYA (1972) originally reported the seasonal change in the forewing length of *P. xylostella* for the Hiratsuka population in Kanagawa Prefecture, and their results agree well with this study. They mentioned that the forewing length was determined only by temperature conditions during the larval stage irrespective of other factors such as rearing density, diet conditions and rearing photoperiod. Thus the larvae reared under a lower temperature developed into larger adult moths due to longer developmental periods. These relationships between larval size and temperature conditions were also observed in the Wakayama (MORISHITA and AZUMA, 1990) and Sapporo populations (SARU, unpublished). When reared at a lower temperature, food consumption by larva was higher (MORISHITA and AZUMA, 1990), resulting in a heavier pupal weight and subsequently a larger adult moth. It is obvious that flight ability is related to size of adult moths such as forewing length, because the larger adults are generated under a lower temperature in the field.

The effects of temperature on flight ability did not differ between the moths in winter and summer. Flight velocities in both seasons increased in proportion to temperature, but the highest temperature (33°C) was apparently unfavourable for survival, especially in winter, because of the very low survival rate. On the other hand, the lowest temperature (13°C) markedly reduced flight activity in both seasons. Based on the flight ability parameters and the survival rate, it was concluded that the temperature suitable for flight activity has an optimum at *ca.* 23°C, with a range from 18 to 28°C.

From the results of the flight mill test, the potential flight distances for two days were estimated to be 7.3 to 13.3 km in winter to spring, and 4.8 to 6.2 km in summer. In view of the temperature range suitable for flight, a moth in spring is likely to have

higher flight capacity and activity than one in winter. According to temperature data obtained in the field (Chronological Scientific Tables, 1990), it is estimated that flight of *P. xylostella* may be most active between May and June in Mie Prefecture, corresponding with the season for spring-sown cabbage. It may be the most active between July and August in the mountainous area of Nagano or Gunma prefectures with altitudes above 1,000 m, corresponding with the season of summer cabbage. In these active seasons, the moths of both sexes have a potential capacity to fly more than 10 km.

If we take into account these flight ranges of *P. xylostella*, effective rotational application of insecticides should be applied on a wide extent of the crop fields in order to prevent the development of resistance. Up to now, no field research on *P. xylostella* has indicated its long-distance movement among cruciferous crops. For example, KOSHIHARA (1988 b) mentioned that the damage to spring-sown cabbage in Mie Prefecture was caused mostly by infestation of populations derived from various cruciferous plants including weeds around the cabbage fields after the seedlings had been planted out. RHAN (1988) also reported that *P. xylostella* in western France showed short-distance movement from old cruciferous crops to new sowings or young plants during spring. These results, however, were not obtained by research methods involving population dynamics. SIVAPRAGASAM et al. (1988) conducted a mark-recapture experiment on adult moths in a small cabbage field (20 × 20 m) in Aichi Prefecture, but did not refer to flight distance. A mark-recapture experiment on a larger scale with a wide survey area should be carried out in order to evaluate how far *P. xylostella* can fly within or beyond a vegetable crop field.

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