Ecology and Control Thresholds of the Diamondback Moth on Crucifers in Taiwan

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Abstract

Diamondback moth (*Plutella xylostella*) can complete its lifecycle within a temperature range of 10-30°C, with the optimum at 20-25°C. In general, as the temperature rises the development speeds up. The mean generation time at 20, 25 and 30°C is 23, 15.5 and 13 days, respectively. Two to three generations can be completed during a crucifer cropping season. The species can complete 18-21 generations a year in Taiwan, with a considerable generation overlapping. A female moth in her 23, 12 and 7 day lifespan can lay 300±80, 143±85 and 107±47 eggs at 20, 25 and 30°C, respectively. When reared on common kale in a growth chamber, the intrinsic rate of increase at 20, 25 and 30°C was 0.1986, 0.2130 and 0.2389, respectively. Population peaks in the field occur from February to March, June to July and October to December in northern Taiwan, from January to February in central Taiwan, and from January to March in southern Taiwan. Availability of food plants and rainfall are the major factors limiting its population density. Leafy crucifers, such as green petiole pai-tsai, because of their short growing period (about 5 weeks), suffer less damage from the diamondback moth compared to heading types, such as cabbage and cauliflower. The spatial distribution of DBM larvae on cauliflower can be adequately described by a negative binomial distribution. The index of patchiness ranges from 1.36 to 2.90. The relation between variance and mean density is $S^2 = 2.0528\overline{X}^{1.4067}$. Thus, data transformation of field counts and sampling plan are based accordingly. Measurement of feeding on cauliflower as influenced by temperature has been studied. This information serves as a common denominator for the conversion of other caterpillar counts into diamondback moth equivalent units for the development of multispecies control thresholds. The control thresholds of this pest on cauliflower are tentatively determined. Cauliflower seedlings should be protected for three weeks after transplanting to enable seedling establishment. Further control is needed from 31 to 45 days after transplanting to keep insect population density below one larva per plant. Thereafter the threshold is 10 larvae/plant. On cabbage, control action should be taken when its density reaches one per plant before the 10-leaf stage and two larvae per plant thereafter.

Introduction

The diamondback moth (DBM), *Plutella xylostella* L (Lepidoptera: Yponomeutidae), was first recorded as a pest on crucifers in Taiwan by Sonan (1942). It was considered as a potential pest by 1960, although its density was still quite low (Chang 1960, Tao et al 1960). However, in the mid 1960s it ranked as an important pest second only to the pyralids on summer radish (Tao 1966). Extensive field screenings of insecticides for its control were conducted during the late 1960s, indicating that it was already a serious problem (Ho and Liu 1969, Lee 1968, 1969, Tang 1967). So far 36 insecticide formulations have been recommended (PDAF 1984) for DBM control. But poor control by these insecticides has been reported since the late 1960s (Wu 1968). DBM's status as a key pest on crucifers has been scientifically evaluated by Chen and Su (1982). The upsurge of this insect as a serious pest could be due to (1) its rapid development of resistance to insecticides, (2) the lessening of competition for food and habitat with other caterpillars which are more easily controlled by most insecticides, and (3) the elimination of its natural enemies by insecticides.

A survey of literature indicates that from 1940 to 1984 fifty-eight papers—12 on bionomics, 24 on control measures, 15 on pesticide resistance and 7 on sex pheromones—have been published on this pest in Taiwan. Most papers, however, were published from 1971 to 1980 (Table 1). In this paper, we will focus our attention only on DBM bionomics and control thresholds.

Table 1. A survey of publications on DBM in Taiwan[a]

Subject	Number of papers published during				
	1940-60	'61-70	'71-80	'81-84	Total
Bionomics	1	2	5	4	12
Control					
chemical	3	4	2	1	10
biological	0	1	7	0	8
microbial	0	1	2	0	3
integrated	0	1	2	0	3
PesticideE					
resistance	0	0	8	7	15
Sex pheromone	0	0	4	3	7
Total	4	9	30	15	58

[a] Source: Survey of literature in Chiu 1958, Editorial Board on literature on Taiwan's Agriculture, 1956, 1966, 1977, 1983, and Plant Protection Bulletin (Taiwan).

Life History Traits and Population Parameters

Life history statistics have been collected under various rearing conditions. In general, the lifecycle can be completed at temperatures ranging from 10 to 30°C. As temperature increases the period for each stage shortens. The longer the larval period the greater is the foliage consumption. DBM takes 18, 11, and 9 days and consumes 7, 5, and 4 cm^2 cauliflower leaf to complete its larval period at 15, 20 and 25°C, respectively (Chen and Su 1978). The optimum for growth and development is somewhere around 20—25°C. In the growth chamber at 20—25°C DBM takes 17-20 days to complete a lifecycle. While in a screenhouse with fluctuating temperature, DBM takes 18-39 and 28-48 days, respectively in southern and northern Taiwan (Table 2).

A high variation exists in reported fecundity, ranging from zero to several hundreds eggs/female. This could be a result either of inclusion of data taken from unmated females, or because the number of eggs laid is directly related to the longevity of a female which is also quite variable. A female in her 23, 12 and 7 days lifespan can respectively lay 300+80, 143+85 and 107+47 eggs at 20, 25 and 30°C (Liu et al 1985).

Population parameters have been obtained by rearing the insect on common kale in a growth chamber. The intrinsic rate of increase, r, at 20, 25 and 30°C is 0.1986, 0.2130 and 0.2389 and the mean generation time (T) 23, 15.5 and 13 days, respectively (Table 3) (Liu et al 1985). Variation, however, exists in local populations. Thus, the r values for Banchau (northwestern), Hsihu (centralwestern) and Taitung (southeastern) populations are 0.1514, 0.2281 and 0.1884, respectively (Liu 1983). The r value is

Table 2. Life history statistics of DBM in Taiwan[a]

Duration (days)	Screen house (natural conditions)	Growth chamber (20-25°C)
Egg	3- 4	3- 5.5
Larval	7-10	8-11.5
Pupal	4- 6	5- 7
Adult	5- 8	12-23
Oviposition	3- 5	5- 9
Generation	18-39(S)[b] 28-49(N)[b]	17-20
Eggs/female	47-120	145-300

[a] Data compiled from Chen and Su (1978), Hsu and Wang (1971), Hwang (1970), Leu and Lee (1984), Liu et al. (1985) and Wu (1968). [b] S = southern and N = northern part of Taiwan.

Table 3. Population parameters of DBM reared on common kale in the growth chamber[a]

Temperature	$\bar{T}$	Ro	$\underline{r}$	λ	$\bar{x}$ eggs/ female
20°C	23	90.66	0.1986	1.2197	300 ± 80
25°C	15.5	27.00	0.2130	1.2374	143 ± 85
30°C	13	21.60	0.2389	1.2698	107 ± 47

[a] Source: Liu et al 1985.

predominantly determined by the reproductive schedule; the earlier oviposition begins and the sooner egg-laying reaches its peak the greater is the r value (Table 4 and Fig. 1) (Liu et al 1985).

Table 4. Population parameters of DBM collected from different locations in Taiwan[a]

Deme source	$\bar{T}$	$\bar{X}$ eggs/ female	Oviposition Time 1st	Oviposition Time peak	Ro	$\underline{r}$	λ (day^{-1})
Banchau (Northern)	23	139 ± 48	19	22	31.9	0.151	1.1635
Hsihu (Central)	14	128 ± 56	11	13	26.1	0.228	1.2562
Taitung (Eastern)	16	86 ± 57	13	15	20.0	0.188	1.2073

[a] Source: Liu 1983. Rearing conditions: Common kale, 25 ± 1°C, 60 ± 5% RH, 12D:12L.

Field Population Ecology

DBM can be found on crucifers year round, provided that the host crop is planted continuously (Chang 1960, Wang 1984, Leu and Lee 1984, Talekar and Lee 1985). In Taiwan DBM has 18 to 21 generations per year. The population is more abundant during the winter crop season (December to March). Thus, population peaks occur from February to March in central and northern Taiwan and January to March in southern Taiwan (Table 5). In summer (June-September) DBM is almost absent from the fields under conventional culture conditions. High temperature (Chin 1973, Hwang 1970, Lee and Lee 1984, Wang 1984), food availability (Wang 1984), and heavy rain (Leu and Lee 1984, Talekar and Lee 1985, Wang 1984) are important factors affecting DBM's abundance. We feel that high temperature limits the food availability in space and time, which in turn puts constraints on the pest's abundance. But we agree with Talekar and Lee (1985) that heavy rainfall is the major decimating factor accounting for the minimum

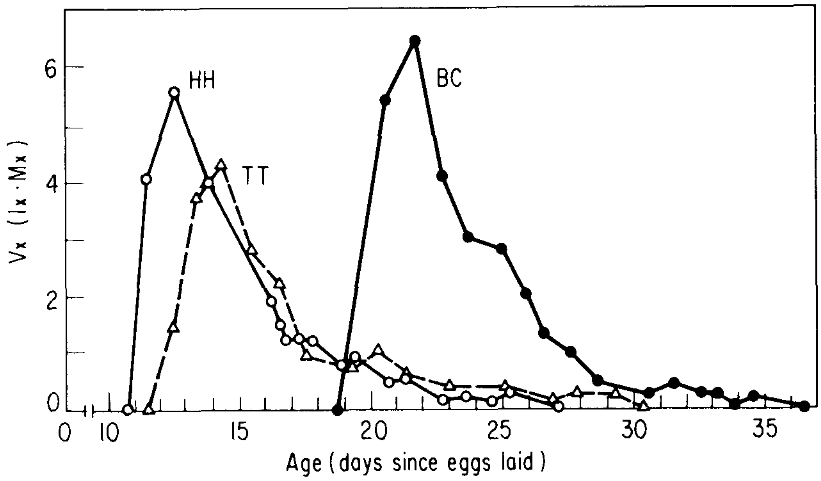

Figure 1. Reproductive schedule of DBM collected from Banchau (BC), Hsihu (HH), and Taitung (TT) and reared at 25°C

Table 5. Number of generations and population peaks of DBM at different regions in Taiwan

Region	Host plant	Generations per year	Population peaks	References
North	Cabbage	18-19	Feb - Mar	Chin 1973
	Common kale		Feb - Mar Jun - Jul Oct - Dec	Wang 1984
	Pak-choi		May & Aug	Chang 1960
Central	Cabbage & cauliflower	19-20	Feb - Mar	Su and Chen 1984
South	Common cabbage Chinese cabbage	20-21	Jan - Mar	Talekar and Lee 1985

population level in summer. Heavy rainfall not only washes off young larvae from the plant, but also hinders flight and egg-laying activity of the adults. Nevertheless, an intensive study of DBM's population dynamics in Taiwan is still lacking.

The pest is more serious on crops which require longer growing periods (Wang 1984). For instance, the pest seldom has the chance to build up its population so as to cause heavy damage to pak-choi (*Brassica campestris* ssp *chinensis*), which takes only 1 to 1.5 months per crop season. By contrast, cabbage (*B. oleracea* var *capitata*), which requires 2.5 to 3 months per crop season (long enough for the pest to complete two to three generations), is often severely attacked.

DBM larvae tend to aggregate on the plants. Their spatial distribution on cauliflower can be adequately described by a negative binomial distribution. Index of patchiness ($\mathring{m}/m$) ranges from 1.36 to 2.90 and the relation between mean ($\bar{x}$) and variance (s^2) is $s^2 = 2.0528\bar{x}^{1.4067}$ (Chen and Su, unpublished). Accordingly, data from field counts can be transformed by $Z = x^{0.3}$ (Taylor 1961) for further statistical analysis. And optimal sample size (n) can be obtained (Table 6) according to $n = (t/D)^2 a m^{b-2}$ (Chen

Table 6. Optimal sample size for DBM sampling[a]

Mean density (larvae/plant)	Sample size	
	D = 0.1	D = 0.2
0.1	3754	939
0.5	1445	361
1.0	958	239
5.0	368	92
10.0	244	61
20.0	162	40

[a] Source: Chen and Su (unpublished data).

1984), where t is the Student's t value at $p = 0.05$, D = precision level, m = mean density, a and b are parameters in Taylor's power law shown above.

Optimal Control Thresholds

Because the demand of vegetables in terms of quantity and quality is ever-increasing, farmers in Taiwan tend to take an 'insurance approach' to reduce risk of crop loss due to pests. Thus, insecticides are still the major weapon for the control of DBM and other pests on vegetable crops. At least weekly applications of chemicals are common. As a result, the rapid development of DBM resistance to pesticides is the bane of scientists, and farmers are faced with the escalation of pesticide use and thus of input cost. The general public regards pesticide residues in vegetables as one of its major health concerns nowadays. At any rate, to find a way to cut down on pesticide usage is an urgent problem.

One way to reduce the frequency of chemical application is to work out the optimal control thresholds for DBM. In this regard, we conducted a series of both laboratory and field experiments during 1976 to 1981.

By means of artificial defoliation we found that the cauliflower plant is more sensitive to defoliation within 65 days after transplanting (DAT); the earlier injury occurred the heavier was the damage. Persistent leaf loss of up to 25% of total leaf area after 75 DAT will not affect the normal growth of the curd (Su and Chen 1984); field experiments support the findings. In order to ensure seedling establishment, protection of the seedlings from attack by the pest is definitely needed. Further, the control is warranted only when the pest level reaches one larva per plant during 31 to 45 DAT. Thereafter, the control threshold can be set at 10 larvae per plant. According to these thresholds, only four to five applications of insecticide (in this case methamidophos 50EC) are needed to keep the DBM level under the control thresholds, while conventionally at least nine weekly sprays are practiced. If *Bacillus thuringiensis* mixed with carbaryl or methomyl is used, six to seven applications are optimal according to the cost-benefit analysis, provided that the unit price of the produce is NT$7 (US$0.18) per kg (Su and Chen 1984).

Since two to three species of caterpillar can be found attacking crucifers at the same time, we have established a conversion system to convert the caterpillar counts into DBM-equivalent units as shown in Table 7 (Chen and Su 1982). Hence, control thresholds for the caterpillar guild can be expressed in DBM equivalent units. Based upon this, we concluded that for the best results of caterpillar management on cauliflower the following control strategy is recommended. (1) Keep DBM units at a minimum during the first three weeks after transplanting (WAT). This will ensure a high percentage of plants harvested. (2) Spray only when DBM units reach one per plant during 4-7 WAT.

Table 7. Conversion of caterpillar counts into DBM-equivalent units[a]

Instar	Mean daily leaf consumption (cm²/larva)			DBM-units[b]		
	SCW[c]	CL	TAW	SCW	CL	TAW
2	0.27	0.26	0.77	0.7	0.7	2.0
3	2.20	1.00	3.13	5.5	2.5	8.0
4	6.23	3.40	5.03	15.6	8.5	12.6
5	6.93	13.00	10.77	22.3	32.5	27.0
6	—	—	19.23	—	—	48.0

[a] Source: Chen and Su 1982. [b] 1 DBM-unit = 0.4 cm^2/larva/day. [c] SCW = Small cabbage white butterfly (*Artogeia rapae crucivora*), CL = Cabbage looper (*Trichoplusia ni*), TAW = Tobacco armyworm (*Spodoptera litura*).

This will prevent the loss of average curd weight. (3) Spray again only when the level reaches 10 units per plant after 7 WAT. This will protect the curd from contamination by larval feces or pupae and increase marketability. In central Taiwan five or six sprays of fenvalerate, quinalphos, carbofuran or *B. thuringiensis* will be needed to keep the caterpillar guild under control thresholds (Chen and Su unpublished).

The same approach has been taken for tests on winter cabbage. We reached the following conclusions. Control action should be taken whenever DBM units reaches one per plant before the 10-leaf stage, and two per plant thereafter. Cost-benefit analysis showed that in a 1980 crop, three sprays of either fenvalerate, permethrin or cartap were needed. The net profit per NT$1 input was 8.7, 6.7 and 3.0 NT$, respectively. In a 1981 crop five sprays of either deltamethrin, permethrin or prothiophos were warranted. The rate of return on investment was NT$4 per NT$1 invested. (Chen and Hsiao unpublished).

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