



PERGAMON

Available online at [www.sciencedirect.com](http://www.sciencedirect.com)

SCIENCE @ DIRECT®

Journal of Stored Products Research 40 (2004) 409–421

Journal of

STORED  
PRODUCTS  
RESEARCH

[www.elsevier.com/locate/jpspr](http://www.elsevier.com/locate/jpspr)

# Development, reproduction, and control of the Indian meal moth, *Plodia interpunctella* (Hübner) (Lepidoptera: Pyralidae), in stored seed garlic in Mexico<sup>☆</sup>

J. Perez-Mendoza\*, M. Aguilera-Peña

*Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias (INIFAP), Campo Experimental Bajío, Celaya, Gto. Mexico*

Accepted 17 March 2003

## Abstract

Developmental time, fecundity, and egg hatch rate were determined for the Indian meal moth, *Plodia interpunctella* (Hübner), reared on fresh garlic seed at room temperature in Mexico. Duration of the egg stage averaged  $4.7 \pm 0.8$  days with an egg hatch rate ranging from 82% to 95%. Five larval instars were determined based on head-capsule width. Total larval developmental time from egg hatch to adult emergence ranged from 42 to 47 days. Adult females began to oviposit within 12–48 h after mating with the maximum oviposition rate occurring during the first 24 h after mating. The mean ( $\pm$ SE) number of eggs laid by females was  $212 \pm 34$  with a range of 117–303. Application of pirimiphos-methyl, malathion, and permethrin to 30 kg lots of garlic seed failed to prevent infestation and bulb damage by the larvae. However, compared with controls, the percentage of damaged bulbs and the number of larvae detected during 12 weeks of storage was smaller on garlic treated with four doses of pirimiphos-methyl. Published by Elsevier Science Ltd.

*Keywords:* *Plodia interpunctella*; Diet; Garlic; Development; Fecundity; Egg hatch; Insecticides

## 1. Introduction

Farmers in Mexico produce about 60 thousand tons of garlic (*Allium sativum* L.) each year (SAGARPA, 2002). Of this amount, about 80% is commercialized (sold) immediately after the

<sup>☆</sup>Mention of trade names or commercial products in this publication is solely for the purpose of providing specific information and does not imply recommendation or endorsement by the US Department of Agriculture or by the Mexican Department of Agriculture.

\*Corresponding author. USDA, Agricultural Research Service, Grain Marketing and Production Research Center, 1515 College Avenue, Manhattan, KS 66502, USA. Tel.: +1-785-537-5570; fax: +1-785-537-5584.

E-mail address: [perez@gmprc.ksu.edu](mailto:perez@gmprc.ksu.edu) (J. Perez-Mendoza).

harvest season and the remainder is stored in warehouses for a period of 4–6 months to be used as seed for the next growing season. Several insect species attack the garlic bulbs inside warehouses. The most important pests are the hairy fungus beetle, *Typhaea stercorea* (L.), the dried fruit beetle, *Carpophilus hemipterus* (L.), and the Indian meal moth, *Plodia interpunctella* (Hübner). However, because of its distribution in stored garlic, population dynamics, and the amount of commodity damage it causes, the Indian meal moth is by far the most important pest of this product in Mexico. In some years, losses from *P. interpunctella* infestations represent more than 30% of the total amount of stored garlic (SAGARPA, 2002). Larval feeding damage not only causes weight loss to the bulb itself, but also the larval tunnels and exit holes make the bulbs much more susceptible to secondary invasion by fungi and bacteria that cause rots and deterioration. In the past, growers normally applied high doses of malathion or fumigated with phosphine to control larval feeding.

The Indian meal moth is a cosmopolitan pest that not only attacks a wide range of stored cereal products (LeCato, 1976; Mbata, 1990; Madrid and Sinha, 1982) but also other food products including dried vegetables (Na and Ryoo, 2000), groundnuts (Mbata, 1987), dried fruits and almonds (Cox and Bell, 1991), pistachios and walnuts (Johnson et al., 1992), raisins and prunes (Johnson et al., 1995), and processed foods (Simmons and Nelson, 1975). In Mexico, the authors have also found this moth attacking several types of dried peppers in storage.

The mean developmental time and adult progeny production of the Indian meal moth are largely influenced by the type of diet on which the moth feeds during the larval stage (LeCato, 1976; Cline and Highland, 1985). Most studies on development of the Indian meal moth have been done on stored cereals, dried fruits, or their products but information on the development of this species in garlic is scanty. Therefore, in the present study, larval developmental time, adult fecundity, and egg hatch rates for moths reared on garlic bulbs were investigated. In addition, the efficacy of three pesticides (including malathion) to protect garlic against infestation by this moth was also tested. Currently, there is no label rate for malathion or any other insecticide for stored garlic that will be used as seed for the next year's crop.

## 2. Material and methods

### 2.1. Insect cultures

A colony of *P. interpunctella* was started from insects collected from the previous season on infested garlic stored in warehouses at Salamanca County in the state of Guanajuato, Mexico. Moths were collected as pupae in strips of corrugated paper placed on the cages containing garlic. The pupae were placed in jars and held for adult emergence. Stock cultures were obtained by placing groups of 50 newly emerged adults in 5 kg of fresh garlic in 30 × 30 × 30 cm cages maintained at room temperature. Spools of corrugated paper were placed in these cages to provide pupation sites and to facilitate transfer of pupae to clean jars for adult emergence and oviposition.

## 2.2. Immature development

Duration of the developmental time from egg to adult emergence was determined at room temperature and relative humidity (values of temperature and relative humidity are given in Section 3). Temperature and relative humidity in the laboratory were recorded daily on a hygrothermograph. Eggs of *P. interpunctella* were obtained by placing newly emerged F<sub>2</sub> adults from the stock cultures in clean 900-ml oviposition jars capped with screen lids. Twenty-four hours after adult emergence, jars were inverted over a dish to collect the eggs. Groups of 50 eggs were placed on filter papers inside Petri dishes (100 × 15 mm<sup>2</sup>). The eggs were incubated at room temperature to determine the egg incubation period and the hatch rate (percentage of eggs that produced larvae).

Larval development of *P. interpunctella* was monitored beginning with newly emerged 1st instar larvae. Upon egg hatch, newly emerged 1st instar F<sub>2</sub> larvae were reared individually on garlic cloves. Each larva was placed in an individual 200-ml jar with a lid covered with a fine mesh nylon screen. Each jar contained one garlic clove. Fifty larvae were prepared and kept at room temperature. Four weeks after the larvae were transferred to cloves, infested cloves were observed daily until all wandering larvae bored out of the cloves, pupated, and emerged as adults. The average time in days from egg hatch to adult emergence was calculated as the mean developmental time. We also calculated the average degree-days required for development from egg hatch to adult emergence by using the mean-minus-base method (Pruess, 1983) that uses the difference between the arithmetic mean temperature [(max + min)/2] recorded each day inside the room and the lower developmental threshold temperature (14°C) estimated by Johnson et al. (1995).

Another set of 250 larvae was prepared in the same conditions for measurement of head-capsule size and duration of larval stadia (Dyar, 1890). Five larvae were removed daily from jars and killed with a drop of 70% ethanol. Head-capsule widths of individual larvae were determined by using a binocular microscope equipped with an ocular micrometer.

## 2.3. Adult fecundity

To determine the effect of garlic on adult fecundity, the number of eggs oviposited per female *P. interpunctella* was recorded. Twenty newly emerged (0–24 h old) virgin pairs of males and females were selected from the experiment on larval development. These pairs were placed in 900-ml oviposition jars capped with screen lids (one pair per jar). Every 12 h, jars were inverted over a dish and the number of oviposited eggs per female was recorded until female death. Table Curve 2D software (Jandel Scientific, 1996) was used to generate a regression equation describing the relationship between the number of eggs laid and the period of time after mating.

## 2.4. Efficacy of chemical protectants to prevent moth infestation

Approximately 1170 kg of fresh garlic obtained from a commercial facility was divided in lots of 30 kg. Each lot was stored in a wood box (150 × 150 × 60 cm<sup>3</sup>) and then treated with one of 13 insecticide application rates. Application rates for malathion on the seed garlic were based on estimated rates currently used by some growers. Application rates for pirimiphos-methyl and permethrin were based on current label rates for stored corn. Insecticide solutions (emulsifiable

concentrates) were prepared in water from three different insecticides: malathion (831.3 g active ingredient (AI)/kg) (AgrEvo, SA, Mexico, DF), permethrin (347.3 g AI/l) (AgrEvo, SA, Mexico, DF), and pirimiphos-methyl (432 g AI/l, ICI, Mexico, DF). The garlic was sprayed at a rate of 4 l of formulated spray per 30 kg. Garlic bulbs in each box were spread on the floor (one-bulb-deep), sprayed with the respective formulation, and then returned to the box (dosages applied are given in Section 3). Untreated controls were sprayed only with water. Each treatment was replicated three times (three boxes/treatment).

All application of insecticides was carried out inside a garlic warehouse using an insecticide delivery system equipped with a Teejet nozzle (number 650033). On completion of insecticide applications, treated garlic was transferred to a warehouse that contained garlic that was heavily infested with *P. interpunctella*. The garlic was held under ambient conditions for 3 months from July to September. Samples of 45 garlic bulbs were taken immediately after all boxes were placed in the warehouse (week 0) and subsequently at 2, 4, 6, 8, 10, and 12 weeks of storage. The garlic was sampled by taking three bulbs from each corner of the box and three bulbs from the middle at three depths (upper, middle, and bottom) for a total of 45 bulbs from each replicate box and placing them in plastic bags. On completion of the sampling process, the bags were brought to the laboratory. Each bulb was cut open and the number of insect-damaged bulbs (bulbs with evidence of the presence of insect tunnels, webbing, and skins) and the number of larvae present in each bulb were recorded. Data were analyzed by using a completely randomized design with three replications and 13 treatments. All data were subjected to analysis of variance (ANOVA) (SAS Institute, 1998). A number of different types of regression equations were fitted to the data for each application rate of insecticide versus the percentage of damaged bulbs through period of storage and for each insecticide versus percentage of damaged bulbs at the end of the 12-week period (Table Curve 2D) (Jandel Scientific, 1996). Selection of an equation to describe the data was based on the magnitude and the pattern of residuals, lack-of-fit tests, and  $R^2$  values (Draper and Smith, 1981). We also ensured that the shape of the response surface was reasonable for describing the data.

### 3. Results

#### 3.1. Immature development

The temperature in the laboratory facility was not controlled and cycled with the daily outside temperature fluctuation. Average daily maximum temperatures inside the laboratory ranged from 25°C to 27°C from August to December (Table 1). Average daily minimum temperatures ranged from 11°C to 20°C. Relative humidity also fluctuated during the test; average maxima and minima ranged from 74% to 83% and from 40% to 52%, respectively.

Adult female *P. interpunctella* oviposited mainly on walls, cracks and crevices of the garlic boxes, and occasionally directly on the bulbs. The duration of the egg stage (incubation period) averaged  $4.7 \pm 0.8$  days, with a minimum time of 3.5 days and a maximum of 6.3 days. The mean number of degree-days for time of egg hatch was  $28.2 \pm 5.0$ . The eclosion rate varied from 82% to 95% with an average of  $86.0 \pm 5.4\%$ . After egg hatch, larvae crawled to the bulbs and bored into and fed inside the cloves. When the larvae completed feeding in the last larval stage, they bored

Table 1  
Ambient temperature and relative humidity inside the laboratory facility during the study

	Ambient temperature (°C)				r.h. (%)			
	Max	Min	Avg. daily max	Avg. daily min	Max	Min	Avg. daily max	Avg. daily min
Aug.	33	14	26	21	98	41	82	45
Sept.	31	15	26	20	99	45	75	52
Oct.	33	9	27	14	95	38	83	40
Nov.	28	7	25	11	78	38	74	40
Dec.	29	8	25	12	90	42	79	47

Table 2  
Mean ( $\pm$ SE) larval head-capsule widths (mm) and mean growth ratios in various instars of *Plodia interpunctella* reared on fresh garlic

Instars	Head width (mm)	Larval instars compared	Ratio
I	0.16 $\pm$ 0.001	II/I	2.31
II	0.37 $\pm$ 0.001	III/II	1.65
III	0.61 $\pm$ 0.002	IV/III	1.36
IV	0.83 $\pm$ 0.002	V/IV	1.23
V	1.02 $\pm$ 0.003	Mean	1.64

out of the cloves and crawled on the walls of the storage boxes looking for cracks and crevices in which to pupate.

Larval developmental period from egg hatch to adult emergence ranged from 42 to 47 days with an average of  $46.0 \pm 0.8$  days. The mean number of degree-days from egg hatch to adult development was  $364.0 \pm 6.9$ . Five larval instars were determined based on larval head-capsule width measurements. Table 2 shows the mean larval head-capsule widths of the various instars of *P. interpunctella* and the mean growth ratios of the larval head-capsule widths. The highest growth ratios were recorded between the first and second instars.

### 3.2. Adult fecundity

Females started to mate with males during the first 12 h after adult emergence. Fertile females began egg oviposition within 12 h after mating. The maximum oviposition rate (> 60%) occurred during the first 12-h period after mating. Few eggs were laid during the second day following mating. After females had laid all their eggs, they died. The relationship between the number of eggs laid and the period of time after mating was described by the equation ( $\pm$ SE shown in parenthesis):

$$y = -19.5(2.8) + 1025.8(56.1)/x \quad (1)$$

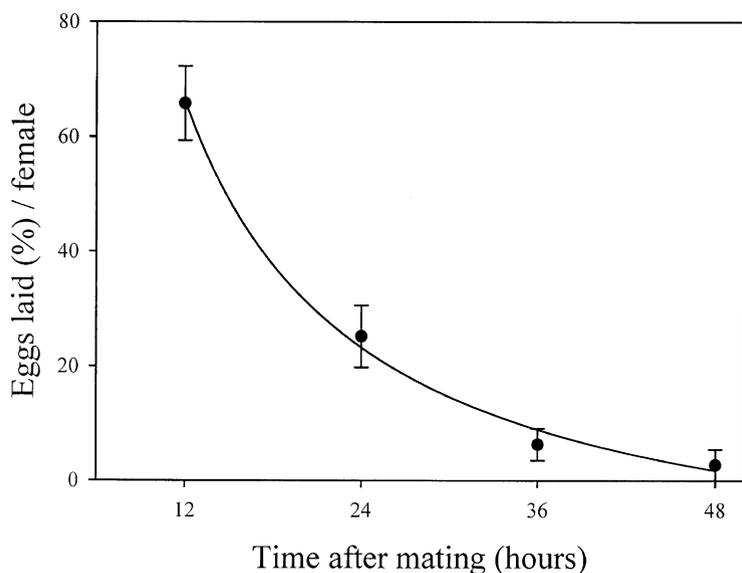


Fig. 1. Relationship between percentage of eggs oviposited (mean  $\pm$  SE of 25 females) and period of time after mating by adult Indian meal moth females reared on garlic. Curve fit line is from Eq. (1).

( $F = 334.5$ ;  $df = 1, 79$ ;  $P < 0.01$ ;  $R^2 = 0.95$ ), where  $x$  is the time after mating and  $y$  is the percentage of eggs laid (Fig. 1). The mean number of eggs oviposited by each female of *P. interpunctella* was  $212.0 \pm 34.4$ , with a range of 117–303 eggs.

### 3.3. Efficacy of chemical protectants to prevent moth infestation

The application rates ( $F = 8.2$ ;  $df = 12, 233$ ;  $P < 0.01$ ) and weeks of storage ( $F = 5.6$ ;  $df = 5, 233$ ;  $P < 0.01$ ) were significant, but the interaction of application rates  $\times$  weeks of storage was not significant ( $F = 0.9$ ;  $df = 60, 233$ ;  $P = 0.65$ ) in determining the percentage of damaged bulbs by *P. interpunctella* after 12 weeks of storage. Pirimiphos-methyl was the most effective protectant but with all the three chemicals the percentage of damaged bulbs gradually increased from weeks 0 to 12 for each application rate (Fig. 2).

The slopes of the regression equations that were fitted to the data indicated an increasing percentage of damaged bulbs in all the application rates of the three insecticides tested as time of storage increased (Table 3). The lowest percentage of damaged bulbs occurred in the two highest application rates of pirimiphos-methyl (15.1 and 21.6 ppm) and in the highest of malathion (1666 ppm) compared with the rest of the treatments. The increase in damaged bulbs in the four application rates of permethrin was similar to the increase recorded in the control treatment. The adjusted  $R^2$  values for the equations ranged from 0.66 to 0.98 for the three insecticides (Table 3). The percentage of damaged bulbs decreased as application rate of pirimiphos-methyl and malathion increased at the end of the 12-week storage period. These relationships are described by the following regression equations (Fig. 3):

$$y = a + b \exp(-x/c), \quad (2)$$

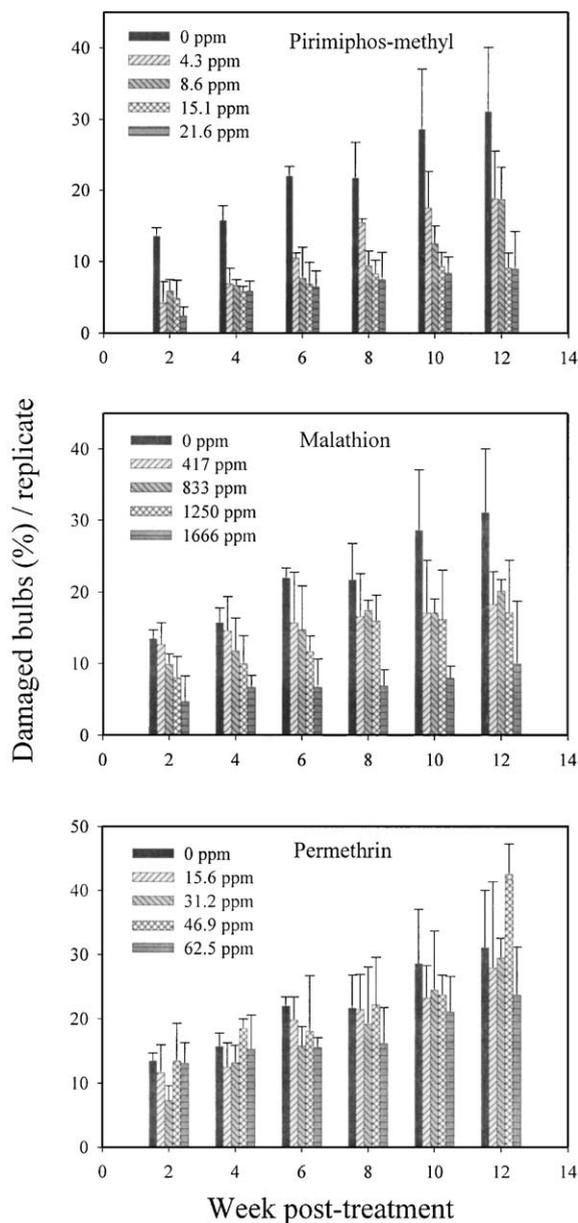


Fig. 2. Percentage of bulbs damaged by Indian meal moth at biweekly intervals on garlic treated with three different insecticides at four application rates. Mean  $\pm$  SE of three replicates per treatment. 45 garlic bulbs per replicate.

where  $x$  is the application rate and  $y$  is the percentage of damaged bulbs at week 12;  $a = 5.9 \pm 0.3$  SE,  $b = 14.4 \pm 0.4$ ,  $c = 6.6 \pm 0.5$ ,  $R^2 = 0.99$  for pirimiphos-methyl and by

$$y = a + bx, \tag{3}$$

Table 3

Linear equations describing the percentage of damaged bulbs by *Plodia interpunctella* larvae feeding in garlic treated with different application rates of three insecticides

Chemical	Application Rate (ppm)	Equation parameters $\pm$ SE			F	P > F
		a	b	R <sup>2</sup>		
Pirimiphos-methyl	4.3	0.67 $\pm$ 0.32	1.63 $\pm$ 0.10	0.98	258.4	0.01
	8.6	0.99 $\pm$ 1.30	1.29 $\pm$ 0.18	0.91	50.5	0.01
	15.1	2.19 $\pm$ 0.95	0.69 $\pm$ 0.13	0.84	26.9	0.01
	21.6	1.32 $\pm$ 0.78	0.72 $\pm$ 0.11	0.90	44.6	0.01
Malathion	417	6.53 $\pm$ 2.73	1.17 $\pm$ 0.38	0.66	9.6	0.03
	833	4.38 $\pm$ 1.91	1.44 $\pm$ 0.26	0.86	29.6	0.01
	1250	3.37 $\pm$ 1.54	1.32 $\pm$ 0.21	0.88	38.0	0.01
	1666	2.20 $\pm$ 1.00	0.66 $\pm$ 0.14	0.82	22.1	0.01
Permethrin	15.6	4.23 $\pm$ 2.00	2.07 $\pm$ 0.28	0.92	55.6	0.01
	31.2	1.83 $\pm$ 0.96	2.30 $\pm$ 0.13	0.98	296.2	0.01
	46.9	3.51 $\pm$ 2.81	2.72 $\pm$ 0.53	0.84	26.8	0.01
	62.5	5.57 $\pm$ 2.49	1.57 $\pm$ 0.35	0.81	20.7	0.01
Control	0	5.1 $\pm$ 2.3	2.3 $\pm$ 0.32	0.91	51.6	0.01

Relationship is  $y = a + bx$ , where  $y$  is the percentage of damaged bulbs,  $x$  the weeks of storage, and  $R^2$  is the percentage variation in  $y$  accounted for by using a linear model.

where  $x$  is the application rate and  $y$  is the percentage of damaged bulbs at week 12;  $a = 20.1 \pm 1.0$  SE,  $b = -0.0072 \pm 0.001$ ,  $R^2 = 0.94$  for malathion.

The application rates ( $F = 7.0$ ;  $df = 12, 233$ ;  $P < 0.01$ ) and weeks of storage ( $F = 15.1$ ;  $df = 5, 233$ ;  $P < 0.01$ ) were significant, but the interaction of application rates  $\times$  weeks of storage was not significant ( $F = 1.5$ ;  $df = 60, 233$ ;  $P = 0.25$ ) for the average number of larvae detected in each treatment after 3 months of storage. Although there is no clear tendency, the number of larvae gradually increased from week 0 to 12 in garlic treated with the three insecticides (Fig. 4). However, the number of larvae detected in garlic protected with pirimiphos-methyl was smaller compared with those detected in the other two insecticide treatments during the 12-week period. The number of larvae decreased as the application rate increased with both pirimiphos-methyl and malathion at the end of the 12-week storage period. These relationships were described by the equation (Fig. 5):

$$y = ab/(b + x), \quad (4)$$

where  $x$  is the application rate and  $y$  is the number of larvae;  $a = 21.3 \pm 1.1$  SE,  $b = 1.8 \pm 0.4$ ,  $R^2 = 0.98$  for pirimiphos-methyl and, for malathion,  $x$  is the application rate and  $y$  is the number of larvae;  $a = 21.1 \pm 1.0$  SE,  $b = 397.9 \pm 57.1$ ,  $R^2 = 0.98$ .

There was no clear relationship between the number of larvae and the application rates of permethrin. The number of larvae was lower in the four application rates of pirimiphos-methyl compared with the number of larvae detected in the other two insecticide treatments.

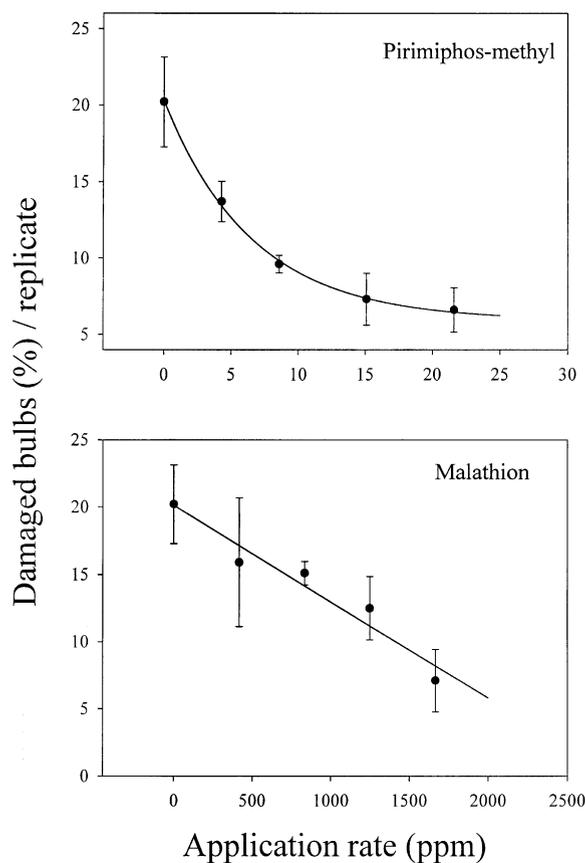


Fig. 3. Relationship between percentage of damaged bulbs (mean  $\pm$  SE) at the end of week 12 of storage and application rates of pirimiphos-methyl and malathion. Curve fit lines are from Eqs. (2) and (3).

#### 4. Discussion

The Indian meal moth is the most destructive pest of stored seed garlic in Mexico and farmers are very concerned about economic losses resulting from infestations of this pest. The results of this study show that garlic is a suitable diet for this moth because the larval development period, egg hatch, and adult fecundity of Indian meal moth reared on garlic were similar to those parameters when the moth was reared on known, favorable diets. For example, the egg incubation period in the present study (3.5–6.3 days) fell close to the range of 4–8 days incubation period at room temperature reported by Tzanakakis (1959). This period is also similar to those reported in several temperature-controlled studies. For example, the incubation period of *P. interpunctella* reared on a wheat diet at 25°C and 70% r.h. varied from 4 to 6 days and from 3 to 5 days in field and laboratory strains, respectively (Bell, 1975). Similarly, the incubation period of this species reared on groundnuts varied from 4 to 7 days depending on temperature and relative humidity (Mbata and Osuji, 1983). The percentage of egg hatch on garlic is also comparable with those observed by other authors. Johnson et al. (1992) showed that egg hatch of *P. interpunctella* varied from 88% to 96% in pistachios and almonds, respectively. Allotey and Goswami (1990) reported

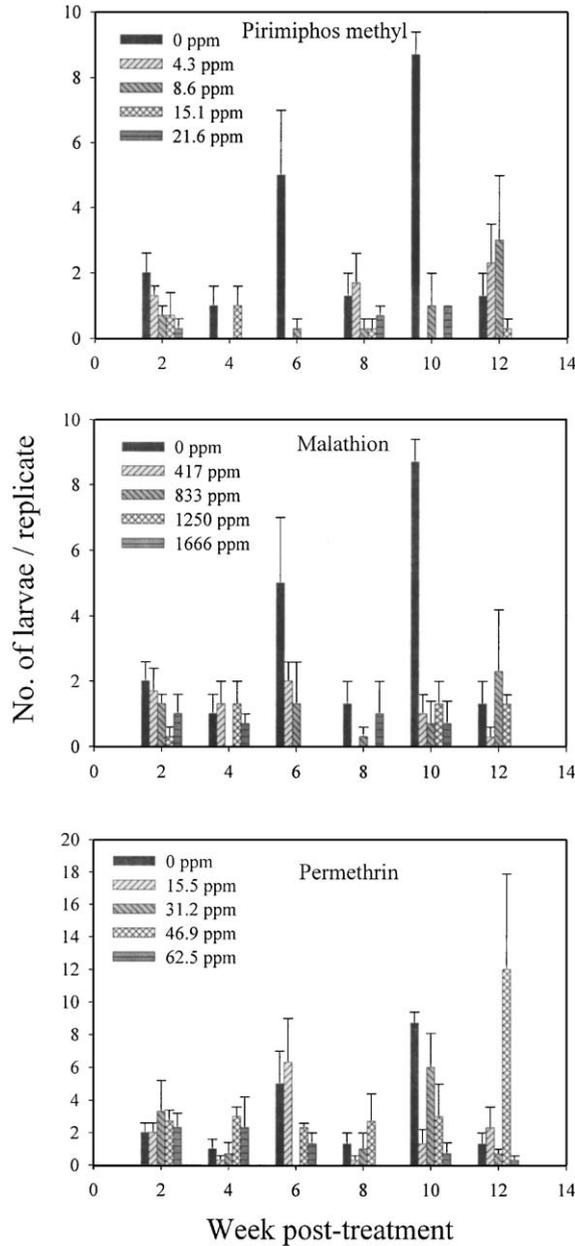


Fig. 4. Number of Indian meal moth larvae detected at biweekly intervals on stored garlic treated with three different insecticides at four application rates. Mean  $\pm$  SE of three replicates per treatment. 45 garlic bulbs per replicate.

that 98.6% of the eggs oviposited by adult females in a wheat diet hatched in a period between 4 and 5 days.

Development times from egg hatch to adult emergence for *P. interpunctella* on garlic ranged from 42 to 47 days, with an average of  $46.0 \pm 0.8$  days. Although this is the first report on

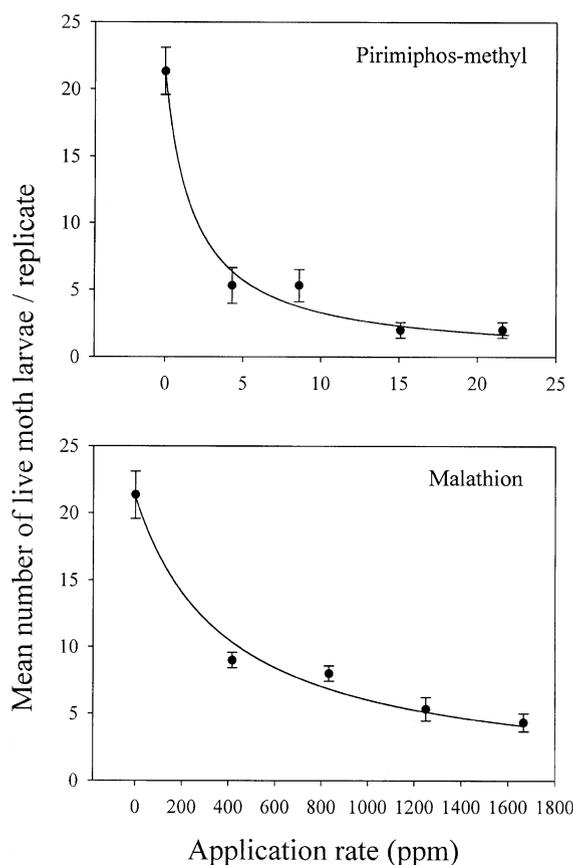


Fig. 5. Relationship between the number of live Indian meal moth larvae (mean  $\pm$  SE) at the end of week 12 of storage and the application rate of pirimiphos-methyl and malathion. Curve fit lines are from Eq. (4).

development of this species on garlic, this development time is very similar to those reported for this species when reared on different diets. Bell (1975) showed that the development period for moths reared on whole wheat at 20°C and 25°C and 70% r.h. varied from 34 to 60 and from 34 to 57 days, respectively, in laboratory and field strains. Similarly, Johnson et al. (1995) and Mbata and Osuji (1983) found that development of *P. interpunctella* was 47.2 and 44.3 days from egg hatch to adult emergence at 25°C and 60–70% r.h. on walnuts and groundnuts, respectively. Na and Ryoo (2000) studied the development of this species on several dried vegetables at different temperatures. They found that when the moth was reared on onions, the average development time was  $54.1 \pm 6.0$  and  $43.7 \pm 4.8$  days at 25°C and 28°C, respectively and at 70–80% r.h.

The mean fecundity of *P. interpunctella* in the present study ranged from 117 to 303 eggs per female. Simmons and Nelson (1975) found that the average number of eggs per female on dried fruit was 170. The average number of adult progeny produced by female *P. interpunctella* reared on walnuts, almonds, and wheat bran diet were 258, 274, and 280, respectively (Johnson et al., 1992).

The humidity and moisture contents of the diet affect both the development and survival of *P. interpunctella*. Johnson et al. (1992) reported that developmental rate was significantly

correlated with moisture content of diet when reared at 25°C, 28.3°C, and 31.7°C. [Abdel-Rahman et al. \(1968\)](#) showed that more adult moths, with more eggs in their ovaries, were produced on corn varieties with high moisture content. The developmental time was also shorter on high-moisture corn. Similarly, [Mbata and Osuji \(1983\)](#) found that the development of this species was better on peanuts at 70–80% r.h. The softness of the diet also has been found to affect the development rate of this species. [Na and Ryoo \(2000\)](#) reported that *P. interpunctella* developed faster on green onions compared with drier diets. Garlic tissue is soft and the bulbs contain about 65% water, 28% carbohydrates, 2.3% organosulfur compounds, 2% protein (mainly alliinase), 1.2% free amino acids, 1.5% fiber, and 0.15% lipids ([Block, 1985](#)). Thus, emerging larvae can easily penetrate the bulb and develop inside it until the last larval instar is ready to pupate.

The feeding behavior of *P. interpunctella* in garlic is different from the normal behavior of moth larvae feeding on cereals and dried fruits, in which the larva is an external feeder ([Pedersen, 1992](#)). This change in feeding behavior makes it very difficult to protect the bulbs from attack because the larvae develop entirely inside the bulbs and therefore are not exposed to insecticides. According to several farmers, even fumigation with phosphine fails to completely eliminate all these larvae. Therefore, the only chance to avoid moth infestation is by protecting the bulbs with residual insecticides at storage time before adult moths lay eggs. Our results with chemical protectants indicate that the percentage of damaged bulbs and the number of larvae present in the bulbs was directly related to the application rates of pirimiphos-methyl and malathion, but not to permethrin. The percentage of damaged bulbs and number of larvae decreased with an increasing application rate of those two insecticides. Lowest percentages of damaged bulbs and insect populations were observed after 15.1 and 21.6 ppm pirimiphos-methyl and 1666 ppm malathion treatments.

Our results indicate that permethrin was not effective in preventing *P. interpunctella* infestation on garlic at any application rate tested. Similar results with *P. interpunctella* 4th instar larvae were found for cyfluthrin ([Arthur, 1995](#)) and deltamethrin ([Arthur, 1997](#)). This suggests that synthetic pyrethroids may not be effective against this pest. Pirimiphos-methyl and malathion provided reasonable protection from insect infestation for the 3 months of storage. However, neither pirimiphos-methyl nor malathion was able to completely prevent the development and adult emergence of *P. interpunctella*. Nevertheless, based on our studies, most growers in Mexico are now using pirimiphos-methyl for protection of stored seed garlic from attack by *P. interpunctella*.

## Acknowledgements

We thank the Asociacion Nacional de Productores de Ajo (Mexico) for their economic support to this project. We also thank James E. Baker and Frank H. Arthur (USDA, ARS, Grain Marketing Production & Research Center), George N. Mbata (Department of Biology, Fort Valley State University), and Kun Yan Zhu (Department of Entomology, Kansas State University) for their critical comments and suggestions on an earlier version of the manuscript.

## References

- Abdel-Rahman, H.A., Hodson, A.C., Christensen, C.M., 1968. Development of *Plodia interpunctella* (Hb.) (Lepidoptera: Phycitidae) on different varieties of corn at two levels of moisture. *Journal of Stored Products Research* 4, 127–133.
- Allotey, J., Goswami, L., 1990. Comparative biology of two phycitid moths, *Plodia interpunctella* (Hubn.) and *Ephestia cautella* (Wlk.) on some selected food media. *Insect Science and its Application* 11, 209–215.
- Arthur, F.H., 1995. Susceptibility of fifth-instar Indianmeal moth and almond moth (Lepidoptera: Pyralidae) to cyfluthrin residues on peanuts. *Journal of Entomological Science* 30, 318–323.
- Arthur, F.H., 1997. Residual susceptibility of *Plodia interpunctella* to deltamethrin dust: effects of concentration and time of exposure. *Journal of Stored Products Research* 33, 313–319.
- Bell, C.H., 1975. Effects of temperature and humidity on development of four pyralid moth pests of stored products. *Journal of Stored Products Research* 11, 167–175.
- Block, E., 1985. The chemistry of garlic and onions. *Scientific American* 252, 114–119.
- Cline, L.D., Highland, H.A., 1985. Survival, reproduction, and development of seven species of stored-product insects on the various food components of lightweight, high-density, prototype military rations. *Journal of Economic Entomology* 78, 779–782.
- Cox, P.D., Bell, C.H., 1991. Biology and ecology of moth pests of stored food. In: Gorham, J.R. (Ed.), *Ecology and Management of Food-Industry Pests*. FDA Technical Bulletin 4, Association of Official Analytical Chemistry, Arlington, VA, pp. 181–193.
- Draper, N.R., Smith, H., 1981. *Applied Regression Analysis*, 2nd Edition.. Wiley, New York.
- Dyar, H.G., 1890. The number of molts of lepidopterous larvae. *Psyche* 5, 420–422.
- Jandel Scientific, 1996. *Table Curve 2D*, version 4 for Windows 95. Jandel Scientific, San Rafael, CA.
- Johnson, J.A., Wofford, P.L., Whitehand, L.C., 1992. Effect of diet and temperature on development rates, survival, and reproduction of the Indian meal moth (Lepidoptera: Pyralidae). *Journal of Economic Entomology* 85, 561–566.
- Johnson, J.A., Wofford, P.L., Gill, R.F., 1995. Developmental thresholds and degree-day accumulations of Indian meal moth (Lepidoptera: Pyralidae) on dried fruits and nuts. *Journal of Economic Entomology* 88, 734–742.
- LeCato, G.L., 1976. Yield, development, and weight of *Cadra cautella* (Walker) and *Plodia interpunctella* (Hübner) on twenty-one diets derived from natural products. *Journal of Stored Products Research* 12, 43–47.
- Madrid, F.J., Sinha, R.N., 1982. Feeding damage of three stored-product moths (Lepidoptera: Pyralidae) on wheat. *Journal of Economic Entomology* 75, 1017–1020.
- Mbata, G.N., 1987. Studies on the susceptibility of groundnut varieties to infestation by *Plodia interpunctella* (Hubner) (Lepidoptera: Pyralidae). *Journal of Stored Products Research* 23, 57–63.
- Mbata, G.N., 1990. Suitability of maize varieties for the oviposition and development of *Plodia interpunctella* (Hubner) (Lepidoptera: Pyralidae). *Tropical Pest Management* 36, 122–127.
- Mbata, G.N., Osuji, F.N.C., 1983. Some aspects of the biology of *Plodia interpunctella* (Hübner) (Lepidoptera: Pyralidae), a pest of stored groundnuts in Nigeria. *Journal of Stored Products Research* 19, 141–151.
- Na, J.H., Ryoo, M.I., 2000. The influence of temperature on development of *Plodia interpunctella* (Lepidoptera: Pyralidae) on dried vegetable commodities. *Journal of Stored Products Research* 36, 125–129.
- Pedersen, J.R., 1992. Insects: identification, damage, and detection. In: Sauer, D.B. (Ed.), *Storage of Cereal Grains and their Products*. American Association of Cereal Chemists, Inc., St. Paul, MN, pp. 435–489.
- Pruess, K.P., 1983. Day-degree methods for pest management. *Environmental Entomology* 12, 613–619.
- SAGARPA, 2002. *Estadísticas básicas de producción Agrícola en México: series históricas*. Centro de Estadística Agropecuaria. Secretaría de Agricultura, Ganadería, Desarrollo Rural, Pesca y Alimentación.
- SAS Institute, 1998. *The SAS System version 7 for Windows*. SAS Institute, Cary, NC.
- Simmons, P., Nelson, H.D., 1975. *Insects on dried fruits*. USDA, Agricultural Handbook 464, Washington, DC.
- Tzanakakis, M.E., 1959. An ecological study of the Indian meal moth *Plodia interpunctella* (Hübner) with emphasis on diapause. *Hilgardia* 29, 205–246.