

Using a population growth model to simulate response of *Plodia interpunctella* Hübner to temperature and diet

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Abstract Response to temperature and diet are major factors in the potential population growth of *Plodia interpunctella* Hübner, a damaging pest of many stored products. A population growth model was used to simulate population development on an optimal wheat-based diet and a sub-optimal diet of raisins at 20–35°C, using different starting values for initial density and life stage. Predicted population development on the two diets increased with temperature and growth patterns were similar regardless of starting population levels at temperatures over 20°C. The predicted population levels on raisins were much less than those predicted for wheat diet, with the same general patterns of increasing populations with temperature at each starting density level or life stage. Results show that the intrinsic population dynamics for *P. interpunctella* even on a sub-optimal diet and at sub-optimal temperatures are such that density can increase rapidly to levels that would cause extensive economic damage. The ability to predict population growth is a valuable tool to aid pest managers in decision making.

Keywords Temperature · Simulations · Model · Diet

Introduction

Plodia interpunctella Hübner (Lepidoptera: Pyralidae) is a cosmopolitan pest of many different commodities including but not limited to ground and tree nuts, whole grains, dried fruits, chocolate, beans, seeds, flours, and meals (Tzanakakis 1959; Simmons and Nelson 1975; Rees 2004; Mohandass et al. 2007; Jenson et al. 2009). It can cause damage through infestations in raw commodities, and it can also be found throughout the food manufacturing process (Doud and Phillips 2000; Johnson et al. 2003; Mahroof and Subramanyam 2006). While *P. interpunctella* can be found on numerous food products, developmental time varies greatly with diet (Mbata and Osuji 1983; Johnson et al. 1992; Subramanyam and Hagstrum 1993; Sedlacek et al. 1996; Perez-Mendoza and Aguilera-Pena 2004). The number of days required to complete the life cycle is also influenced by a number of other external factors, especially temperature (Howe 1965; Cline 1970) which also can greatly influence the number of eggs laid by females and the rate of growth of larvae (Tzanakakis 1959; Howe 1965; Arbogast 2007a; Mohandass et al. 2007). Short exposures to low temperatures (2.4°C) in the egg stage have been shown to decrease survival (Cline 1970), while high temperatures (35°C) inhibit reproduction (Johnson et al. 1992).

Although diet can influence developmental time and survivorship of *P. interpunctella*, it is difficult to determine long-term influence of changes in these life history parameters on population growth. Throne (1989) used a computer model to investigate influence of changes in developmental time and survivorship on long-term growth of the flat grain beetle, *Cryptolestes pusillus* (Schönherr).

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Even small changes in life history parameters resulted in large changes in long-term population growth. Because of the widespread importance of *P. interpunctella* and the impact of diet on growth and development, the objective of our study was to develop simulation models that would predict population growth of *P. interpunctella* on an optimal and a sub-optimal diet, wheat diet and raisins, respectively, at different temperatures within the developmental range of this species to investigate long-term impact of diet on population growth. This information would be useful in determining the influence of diet on the development of integrated pest management strategies for *P. interpunctella* in warehouses or grocery stores where numerous foods are available that can support *P. interpunctella* development.

Materials and methods

Simulations for this study were conducted using a model originally developed for simulating *P. interpunctella* development on corn (Throne and Arbogast 2010). We modified that model using developmental time (Fig. 1) and survivorship data for development from egg to adult emergence on wheat diet from untreated controls in Jenson et al. (2009). Adult emergence from eggs placed on this diet can be as high as 90%, hence it is an excellent diet to model development of *P. interpunctella* at optimum conditions. We extrapolated the fitted line for developmental time from 10 to 40°C. Survivorship ranged from 86 to 90% at 20–32°C, and we used a constant 88% survivorship rate in the model over this temperature range. Above 32°C, we used linear regression to predict out to no survivorship at 40°C, and survivorship is set to zero below 20°C. Adult

longevity and female fecundity were as described in Throne and Arbogast (2010) except below 15°C, where longevity of young and old females was set to 7 and 20 days, respectively.

The wheat diet model was modified for development on raisins. At 27°C, developmental time on raisins (in control treatments in Jenson et al. 2010a, b) was about twice that on corn (Arbogast 2007a, b), so we doubled mean development times at 20 to 32°C from the Arbogast (2007a, b) study to estimate developmental times on raisins. Standard deviations associated with population growth were calculated using the method of Shaffer (1983). We fit a quadratic equation to the data (Fig. 2), and extrapolated the equation from 10 to 40°C. Survivorship was set to 11% from 20 to 32°C (Jenson et al. 2010a), with no survivorship below 20°C. Above 32°C, we used linear regression to predict out to no survivorship at 40°C. Adult longevity and fecundity were simulated as in the wheat diet model because *P. interpunctella* females will lay their eggs whether or not there is diet present (Mohandass et al. 2007). Adult emergence from eggs placed on the raisin diet is far lower than adult emergence on the wheat diet; hence, the raisin diet model simulates *P. interpunctella* development on a poor diet as opposed to the optimal wheat diet.

We ran simulations for 180 days to compare population development on the two diets at 20, 25, 30, and 35°C, and at 57% RH to represent environmental conditions that may be encountered in warehouse, transportation, or food manufacturing facilities. Simulations on wheat diet were run using starting population levels of one egg, one young female, or one old female. Simulations on raisins were run using starting population levels of 100 eggs, 100 young females, or 100 old females. We used different starting population levels because of the large differences in

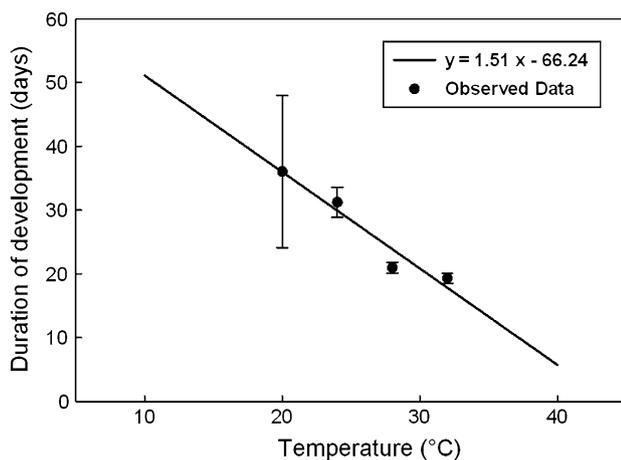


Fig. 1 Simulated duration of development (mean \pm SE days) of *Plodia interpunctella* at different temperatures on wheat diet. Circles are data points (mean \pm SE days) observed from study in Jenson et al. (2009), and the line is the fitted curve

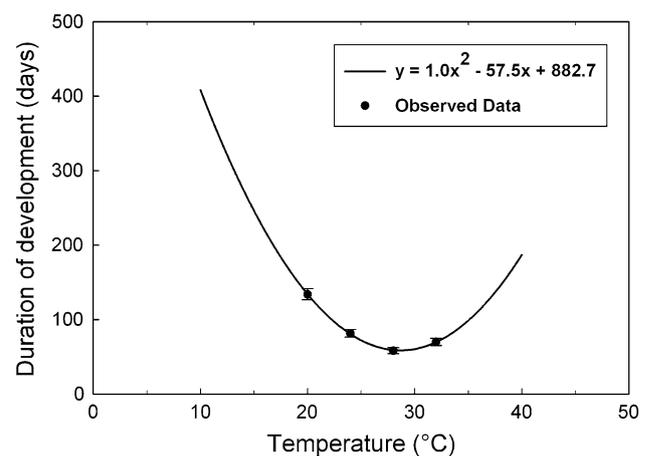


Fig. 2 Duration of development (mean \pm SE days) of *Plodia interpunctella* at different temperatures on raisins. Circles are mean development times observed in Arbogast (2007a, b) multiplied by two, which fit observations in Jenson et al. (2009)

population levels achieved in the simulations on the two diets. The model does not limit population growth based on amount or quality of food source present (carrying capacity).

Results

Starting the simulations with young females resulted in the highest population levels compared with the other scenarios on both diets (Figs. 3, 4; Table 1). As temperature increased from 25 to 30°C, population growth rates on wheat diet also increased, while at 20 and 35°C population growth rates were the lowest regardless of diet. Many more progeny were produced on wheat diet than on raisins, despite the fact that the initial populations were 100 times greater on raisins than on wheat (Table 1). The impact of detrimental high temperature (35°C) was much more apparent on the poor diet, raisins, than on the optimal wheat diet. At 20°C, the populations died out on wheat diet during the first month, but the populations did not die out

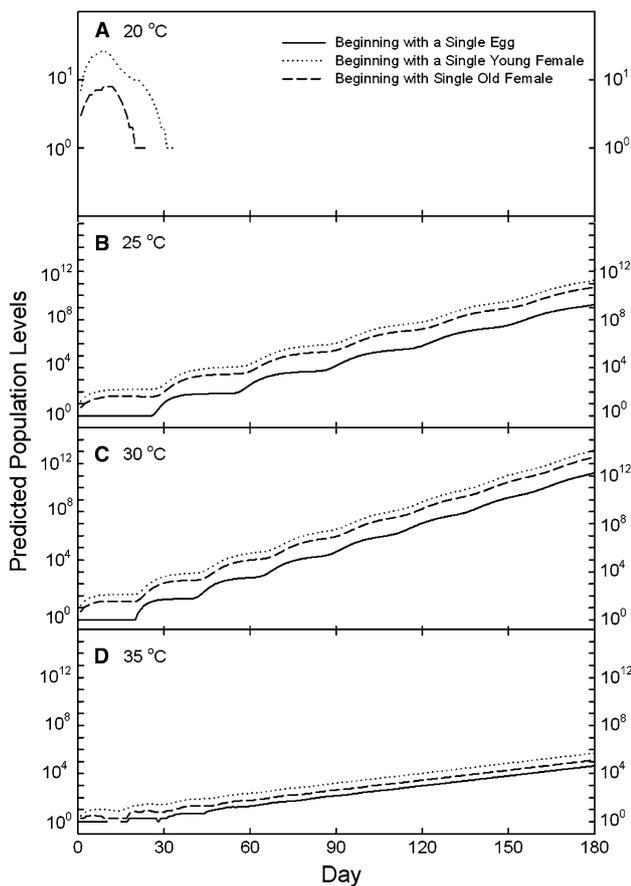


Fig. 3 Simulated population growth of *Plodia interpunctella* on an optimal wheat diet at 20°C (a), 25°C (b), 30°C (c), and 35°C (d), when simulations were started with one egg, one young female, or one old female

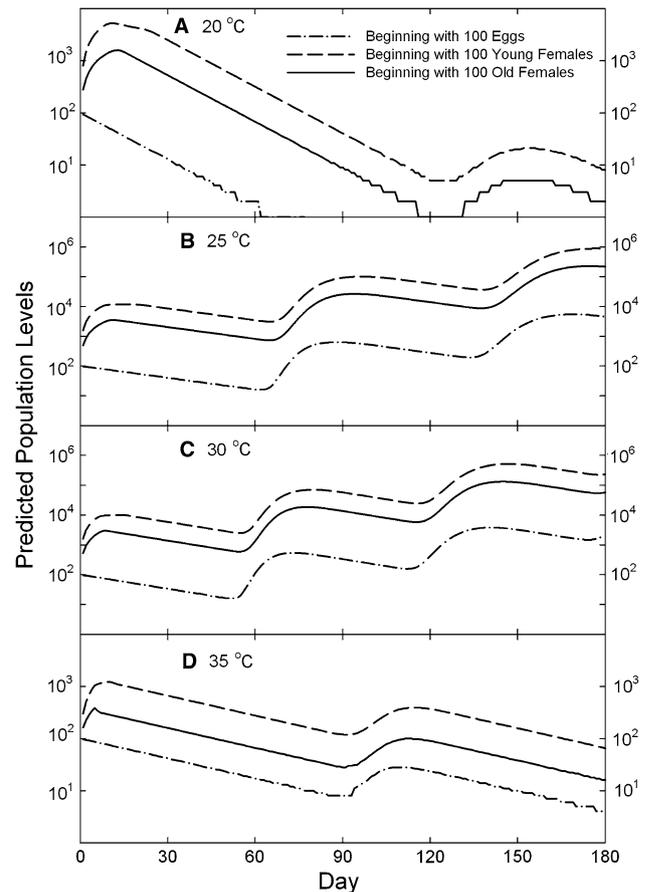


Fig. 4 Simulated population growth of *Plodia interpunctella* on a raisin diet at 20°C (a), 25°C (b), 30°C (c), and 35°C (d), when simulations were started with 100 eggs, 100 young females, or 100 old females

completely on the raisin diet when the simulations were started with females.

Discussion

Population growth of *P. interpunctella* on raisin and wheat diets was very different, as would be expected with such large differences in mean survivorship for each diet. On wheat diet, 600–800 million times more *P. interpunctella* were produced at 30°C than on raisins. This dropped to 200,000–400,000 and 7,000–10,000 times more *P. interpunctella* produced on wheat diet at 25 and 35°C, respectively, than on raisins. The wheat diet is an example of a “worst-case scenario” from a pest management perspective because it is a product that can support rapid population growth. The model assumes that food is accessible and present in sufficient quantity to support the extremely high population numbers predicted in our simulations. Management of *P. interpunctella* in any area containing products that contained an optimal diet like wheat diet would be

Table 1 Simulated population levels of *P. interpunctella* on wheat and raisin diets after 180 days at four temperatures and with varying initial population levels

	Temperature (°C)	Beginning number of individuals		
		One egg	One young female	One old female
Wheat diet	20	0	0	0
	25	1.82E+09	1.85E+11	5.02E+10
	30	1.67E+12	1.28E+14	3.56E+13
	35	4.49E+04	4.98E+05	1.33E+05
	Temperature (°C)	Beginning number of individuals		
		100 eggs	100 young females	100 old females
Raisins	20	0	8	2
	25	4,573	862,492	216,880
	30	2,129	233,995	57,503
	35	4	65	16

crucial to avoid generating huge numbers of *P. interpunctella* moths and product loss.

Raisins were chosen for this study as a contrast to wheat diet because dried fruit products can be infested by *P. interpunctella* and significant damage can occur (Johnson and Vail 1989; Johnson et al. 2002). With their high reproductive capacity, populations on raisins were also able to reach high levels in less than 6 months. This is remarkable given that *P. interpunctella* typically has a low survival and long development time on this commodity (Johnson et al. 1995).

Population levels were greatest when the simulations were started with young females, although differences in population levels after 6 months did not differ much with the type of initial population. Young females are the most likely stage to migrate and infest a new food source. Population levels increased the most at the optimal temperatures of 30 and 25°C, with populations dying out or almost dying out at 20°C and much lower population levels developing at 35°C.

Temperatures inside a food warehouse or manufacturing facility may have minimal daily fluctuation but can follow broad seasonal patterns. Temperatures during the cooler months are unlikely to eliminate populations of *P. interpunctella* (Kaliyan et al. 2007a, b; Johnson 2007), especially in climate-controlled facilities that allow population levels to remain high throughout the year. Although the model does not account for movement of individuals in or out of populations, sampling and monitoring can be used to estimate seasonal population fluctuations and pinpoint sources of infestation in food processing and manufacturing situations (Doud and Phillips 2000; Arbogast et al. 2005). The rapid growth of *P. interpunctella* populations on both optimal and sub-optimal diets indicates the need for regular sampling to

quickly treat problem areas to avoid rapid population growth. The model described above illustrates the reproductive capacity of *P. interpunctella* on an optimal and sub-optimal diet, and shows the potentially rapid population development even on the sub-optimal diet. This rapid population growth on a broad range of diets accounts in part for the widespread dispersal and abundance of *P. interpunctella*, and the ability to exist on a variety of foods.

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