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# Exposure of *Tribolium castaneum* (Herbst) (Coleoptera: Tenebrionidae) Females to Spinosad: Effect on the Fitness of Their Progeny †

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**Abstract:** The red flour beetle, *Tribolium castaneum* (Herbst) (Coleoptera: Tenebrionidae) is a widespread pest of stored products. While the direct effects of several pesticides have been evaluated on this notorious species, little is known on their indirect effects in terms of progeny fitness. In this study, we investigated the cost of different exposure intervals of *T. castaneum* females to spinosad by calculating the life table parameters of its progeny. For this purpose, females of *T. castaneum* were exposed for 5, 10 and 20 min to spinosad and birth or death rates of progeny were estimated. Water was used as a control treatment. The mean values of the net reproductive rate, the intrinsic rate of increase, the finite rate of increase, the mean generation time and the doubling time of the control treatment were 6.3 females/female, 0.029 females/female/day, 1.029, 63.6 days and 24.1 days, respectively, which are indicative of the potential population increase of *T. castaneum*. When female parental time exposure to spinosad was 5, 10 and 20 min, the corresponding values were 0.073, 0.135 and 0.097 females/female; -0.045, -0.031 and -0.048 females/female/day; 0.956, 0.970 and 0.953; 60.6, 67.7; and 50.3 days; -15.9, -23.3 and -14.8 days, respectively, which indicate a population decrease. However, based on the 95% confidence intervals criterion, the different exposure intervals of *T. castaneum* females to spinosad did not affect the fitness of their progeny. These results may have bearing on the management of *T. castaneum* in storage facilities.

**Keywords:** red flour beetle; demography; pest management; intrinsic rate of increase; spinosad

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## 1. Introduction

The red flour beetle, *Tribolium castaneum* (Herdst) (Coleoptera: Tenebrionidae) is a notorious stored-product species with global distribution [1]. It infests several commodities such as cereal grains, nuts, spices, chocolate, cacao, dried fruits and animal products [2]. A common method to reduce *T. castaneum* infestations in stored-products is the application of insecticides [3,4,5]. However, due to the economic importance of this species, as well as its tolerance to several insecticides [4], a precise evaluation of the management strategies seems imperative and important for its control.

Demography is an efficient tool in order to elucidate insect fitness components. Tabulating birth and death rates, several parameters can be calculated that are indicative of the potential population increase of species. This method is appropriate in for the estimation of time-varying processes such as insect survival and reproduction through time [4] and has been widely used in order to evaluate the potential population increase of insects [6,7,8,9]. However, it is rarely applied to evaluate the efficacy of insecticides [4,5,10].

Therefore, aim of this study is to explore possible indirect effects of spinosad on *T. castaneum*. For this purpose, we investigated the cost of different exposure times of parental *T. castaneum* females to spinosad on the fitness of the progeny, based on the resulting demographic parameters. We adopted a recently proposed demographic approach that is suitable to explore the indirect effects of insecticides [10].

## 2. Materials and Methods

Females of *T. castaneum* were exposed for 5, 10 and 20 min to spinosad, while water was used as a control treatment. Groups of eggs laid by these females (150 eggs per exposure time to spinosad and 80 for the control treatment) were placed separately in Petri dishes, without food, and then transferred into an incubator set at 30 °C, 65% relative humidity and continuous darkness. Dishes were inspected daily to assess larval emergence. The newly emerged larvae were separately transferred to new dishes with soft wheat flour. The lids of dishes had a central circular opening (covered by muslin cloth) to allow the aeration of the content. Mortality of immatures was inspected daily. Pairs of newly emerged adults were separately transferred to new dishes that contained soft wheat flour. The adult mortality and female fecundity were recorded every 24 h until all individuals became dead.

Using the above data, the following demographic parameters were calculated [11]: the net reproductive rate: $R_0 = \sum(l_x \times m_x)$, where $lx$ denotes the age-specific survival and $m_x$ the age-specific fecundity, i.e., the per capita rate of progeny production in an interval equal to cohort study interval; the intrinsic rate of increase ($r_m$): $\sum\left(e^{r_m \times x} \times l_x \times m_x\right) = 1$, i.e., the rate of natural increase in a closed population (subjected to constant age-specific schedules of fertility and mortality for a long period); the finite rate of increase: $\lambda = e^{r_m}$, i.e., the rate at which the population will increase in each time step; the mean generation time: $T = \frac{\ln R_0}{r_m}$, i.e., the time required for the population to increase by a factor equal to the net reproductive rate; the doubling time: $DT = \frac{\ln 2}{r_m}$, i.e., the time required for the population to double. In addition, the 95% confidence intervals of all the calculated parameters were obtained by bootstrapping in R [12].

## 3. Results

The estimated demographic parameters are presented in Table 1. The values of the net reproductive rate, the intrinsic rate of increase, the finite rate of increase, the mean generation time and the doubling time of the control treatment were 6.3 females/female, 0.029 females/female/day, 1.029, 63.6 days and 24.1 days, respectively. When parental females were exposed for 5 min to spinosad, the values of the net reproductive rate, the intrinsic rate of increase, the finite rate of increase and the doubling time were significantly lower, i.e., 0.073 females/female, -0.045 females/female/day, 0.956 and -15.9 days, respectively, while the estimated mean generation time did not differ significantly (60.6 days). An increase to the parental exposure time did not further affect *T. castaneum* demographic parameters. Thus, the estimated net reproductive rate was 0.135 and 0.097 females/female, the intrinsic rate of increase -0.031 and -0.048 females/female/day, the finite rate of increase 0.970 and 0.953, the mean generation time 67.7 and 50.3 days and the doubling time -23.3 and -14.8 days when parental females were exposed for 10 and 20 min to spinosad, respectively.

**Table 1.** Values of net reproductive rate ($R_0$), intrinsic rate of increase ($r_m$), finite rate of increase ($\lambda$), mean generation time ($T$) and doubling time ($DT$) of *T. castaneum* (mean, 95% confidence intervals) at several exposure times of parental female to spinosad.

| Exposure (min) | $R_0$ (females/female) | $r_m$ (females/female/day) | $\lambda$ | $T$ (days) | $DT$ (days) |
|---|---|---|---|---|---|
| 0 | 6.3 a (4.8–8.1) | 0.029 a (0.024–0.033) | 1.029 a (1.024–1.034) | 63.6 a (61.7–66.0) | 24.1 a (20.9–28.8) |
| 5 | 0.073 b (0.027–0.127) | -0.045 b (-0.063–0.033) | 0.956 b (0.939–0.968) | 60.6 ab (53.2–67.5) | -15.9 b (-21.0–-11.1) |
| 10 | 0.135 b (0.043–0.241) | -0.031 b (-0.046–0.021) | 0.970 b (0.955–0.979) | 67.7 ab (55.8–77.7) | -23.3 b (-32.4–-15.1) |
| 20 | 0.097 b (0.028–0.197) | -0.048 b (-0.068–0.034) | 0.953 b (0.935–0.966) | 50.3 b (45.0–55.8) | -14.8 b (-20.2–-10.2) |

Means in the same column followed by different letters are significantly different.

## 4. Discussion

Our study clearly shows that *T. costaneum* female exposure to spinosad is associated with differences in the performance of their progeny. All the tested exposure intervals of *T. castaneum* females to spinosad had detrimental effects to the fitness of their progeny. This is due to the negative values of the intrinsic rate of increase and the doubling time, as well as the lower to 1 estimates of the net reproductive rate and the finite rate of increase, which indicate a continuous population decrease in all cases. This further means that in all treatments, spinosad is highly efficient against *T. castaneum* in terms of offspring survival and reproduction. Although this insecticide did not have a direct effect on the parental *T. castaneum* population, as a consequence of direct toxicity or through delayed mortality, we showed that its offspring production will suffer serious effects that could lead to the extinction of their colonies. This is particularly important for the management of this species and should be taken into account as it could reduce the insecticide applications. Similar results have been reported by Skourti et al. [4], as they stated that the fitness of the progeny of *T. costaneum* is seriously affected when parental females were exposed to pirimiphos-methyl.

The demographic approach we followed in this study allowed us to investigate the indirect effects of spinosad on the progeny of *T. castaneum* females, by tabulating their birth and death rates. This methodology is particularly useful for highlighting the effectiveness of the insecticides, accounting for time-varying effects. We expect future studies to shed light into the indirect effects of insecticides on stored-product insect pests taking advantage of this method, in order to gather together more information on their efficacy.

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