Kragujevac J. Sci. 39 (2017) 201-208. UDC 595.782:591.3/591.53.063(497.11)

SURVIVAL RATE OF *Plodia interpunctella* (LEPIDOPTERA: PYRALIDAE) ON DIFFERENT STATES OF WHEAT AND RYE KERNELS PREVIOUSLY INFESTED BY BEETLE PESTS

Filip N. Vukajlović*, Dragana Z. Predojević, Selena D. Milošević, Dubravka R. Radulović, Snežana B. Pešić

University of Kragujevac, Faculty of Science, Institute of Biology and Ecology, Radoja Domanovića 12, 34000 Kragujevac, Republic of Serbia
*Corresponding author; E-mail: fvukajlovic@kg.ac.rs

(Received April 11, 2016; Accepted June 15, 2016)

ABSTRACT. The present study was undertaken to determine survival rate of *Plodia interpunctella* (Hübner, 1813), reared on different mechanical states of Vizija winter wheat cultivar and Raša winter rye cultivar, previously infested with different beetle pests. Wheat was previously infested with *Rhyzopertha dominica*, *Sitophilus granarius*, *Oryzaephilus surinamensis* and *Cryptolestes ferrugineus*, while rye was infested only with *O. surinamensis.* Kernels were tested in three different mechanical states: (A) whole undamaged kernels; (B) kernels already damaged by pests and (C) original storage kernels (mixture of B and C type). No *P. interpunctella* adult emerged on wheat kernels, while 36 adults developed on rye kernels. The highest abundance reached beetle species who fed with a mixture of kernels damaged by pests and whole undamaged kernels. Development and survival rate of five different storage insect pests depends on type of kernels and there exist significant survivorship correlations among them.

Key words: Indian meal moth, storage pests, Coleoptera, competition, grain.

INTRODUCTION

Grain storage presents a closed man-made ecosystem where stored kernels are primary energy source. This source is fast utilized by pests, mainly insects, fungi and other organisms (SINHA, 1973). Activity of storage pests changes biotic composition of storage ecosystem (ARBOGAST and MULLEN, 1988).

The most important insect pests that cause huge losses to stored grains belong to order Lepidoptera: *Sitotroga cerealella* (Olivier, 1789) and order Coleoptera: *Sitophilus granarius* (Linnaeus, 1758), *S. oryzae* (Linnaeus, 1763), *S. zeamais* (Motschulsky, 1855), *Rhyzopertha dominica* (Fabricius, 1792) etc. (REES, 2004; MASON and MCDONOUGH, 2012). Based on their feeding strategies, storage insect pests that feed on grain and its products are divided into primary and secondary pest species (REES, 2004). Typical primary pests are *R. dominica, S. granarius, S. oryzae, S. zeamays, S. cerealella* etc. Secondary pests, such as *Oryzaephilus* spp., *Tribolium* spp., *Cryptolestes* spp. and *Plodia interpunctella* (Hübner, 1813) occur commonly on grain damaged in process of harvesting, transporting, handling and drying, or by other pre- or postharvest pests (REES, 2004; MASON and MCDONOUGH, 2012).

These insect pests coexist in stored grain facilities and their relations and successions are very complex, because they influence each other's biological, ecological and behavioral characteristics (TREMATERRA *et al*., 2000; ATHANASSIOU *et al*., 2006). A lot of different laboratory studies have been conducted in order to investigate interactions between stored product insect pests (LEFKOVITCH, 1968; WHITE and SINHA, 1980; ARBOGAST and MULLEN, 1988; HAGSTRUM and THRONE, 1989; TREMATERRA *et al*., 2000; ATHANASSIOU *et al*., 2006). LEFKOVITCH (1968) reported that high abundance of *Cryptolestes ferrugineus* (Stephens, 1831) inhibited survival of *Tribolium castaneum* (Herbst, 1797). Moreover, ARBOGAST and MULLEN (1988) showed that if moths (*Cadra cautella* (Walker, 1863), *S. cerealella*, *P. interpunctella*) and beetles (*Oryzaephilus surinamensis* (Linnaeus, 1758), *T. castaneum*, *S. zeamays* and *C. ferrugineus*) coexist in the same storage ecosystem, in the beginning moths dominate, but over the time their presence gradually decreases, while the number of beetles increases, until the complete domination of beetles.

Plodia interpunctella (IMM) is one of the most important secondary storage insect pests, especially in processed food, confectionary products and domestic environments (REES, 2004). It can sometimes be found on whole or damaged stored grain, but it feeds mostly on germ and bran layer (REES, 2004). In laboratory conditions, it completes its life cycle on whole kernels of small grains, such as wheat, triticale and rye (F. VUKAJLOVIĆ, unpublished data).

Biology and ecology of IMM is well-studied, but there are very little data on its survival in grain infested by other stored product insect pests and interactions among them. The aim of this study was to investigate the survival of secondary pest moth IMM on different states of wheat and rye kernels, previously infested by wild populations of different storage insect pests and interactions among them.

MATERIALS AND METHODS

Test insects

P. interpunctella culture used in this research originates from population reared for several years in laboratory conditions, at room temperature (22±2 °C), in transparent plastic containers for mass rearing (1.2 L in volume), on the standard laboratory diet for this moth (SILHACEK and MILLER, 1972). This diet is consisted of ground dog meal (10%), rolled oats (4%), white cornmeal (26%), whole wheat flour (23%), wheat germ (2%), brewers' yeast (5%), glycerol (16%) and honey (14%). After eclosion of IMM adults, we isolated 50 pairs of one-day-old adult male and female *in copuli* from containers for mass rearing. Then, we placed IMM adult pairs into 5 L glass jars where females laid eggs. We used one-day-old eggs for the assays.

Other four insect species (*R. dominica*, *S. granarius*, *O. surinamensis* and *C. ferrugineus*) that developed on wheat and rye kernels, originate from wild populations that previously infested wheat and rye kernels in the storage at Center for Small Grains in Kragujevac (CSG).

Commodity

Vizija winter wheat cultivar (*Triticum aestivum* L.) and Raša winter rye cultivar (*Secale cereale* L.), used in this experiment, were obtained from CSG, six months after the harvest (harvested during the season of 2012). After the harvest and prior to setting up the experiment, kernels were kept in mid-sized paper bags in the storage of CSG, where they were infested by different insect pests. Kernels were untreated with pesticides after the harvest.

Before setting up the experiment, kernels did not contain any adult insects, but there were traces of their potential presence, due to characteristic damages on grain caused by them. All kernels were sieved before setting up the experiment, for excluding the potential presence of adult pests.

At the beginning of the experiment, we manually selected three different types of kernels that we used, based on their mechanical state: (A) whole undamaged kernels, (B) already damaged kernels (with obvious cracks, holes or other damages from pests), and (C) original storage kernels (mixture of B and C type, as gained from CSG). Kernels of type C were those originally gained from the storage of CSG, while types A and B were separated by manually selection from kernels of type C.

Experimental procedure

Experiment was set up as randomized 2x3x6 block design. We used two cereal species, wheat (W) and rye (R). Each cereal was tested in three different mechanical states of kernels (A, B, C, as mentioned in previous paragraph). Each grain type and kernel state was repeated six times. We had a total of 36 replications.

In each of 36 glass jars (0.25 L in volume) we put 0.1 L of wheat or rye kernels in different mechanical state and added 50 IMM one-day-old eggs. Jars were sealed with swab of cotton paper coated with cotton cloth, for proper aeration. The jars were kept in laboratory conditions, at room temperature (22 ± 2°C) and relative humidity (60 ± 10%).

The presence of emerged adult insect pests was monitored weekly for 18 weeks. After 18 weeks, the occurrence and the total number of adults for each emerged pest species per replication was recorded.

Data analysis

Data were statistically analyzed using the software package IBM SPSS Statistics 20. The results were presented as mean ± standard error (SE). Differences in number of emerged beetle adults of the same species developed on three mechanical states of wheat and rye kernels were analyzed using one-way ANOVA and Bonferroni test. Pearson’s test was used to establish correlation among the number of emerged adult storage insect pests developed on original storage kernels (WC and RC assays).

RESULTS

This experiment started with 1800 IMM eggs, divided on three different mechanical states of wheat and rye kernels. No IMM adult emerged on wheat kernels, while 36 developed on rye kernels (Tab. 1). In assays with wheat, four beetle (*R. dominica*, *O. surinamensis*, *C. ferrugineus*, *S. granarius*) species were registered, while in assays with rye, only *O. surinamensis* was recorded.

Survival rate of Plodia interpunctella in competition with beetles on wheat kernels

Eighteen weeks since the beginning of the experiment, no IMM adult emerged in assays with wheat kernels (Tab. 1). However, four species of beetle insect pests (*R. dominica, O. surinamensis, C. ferrugineus, S. granarius*) completed their development and emerged as adults.

In WA assays, four beetle adult species emerged, all in small number per replication. The mean number of *S. granarius* was the highest, followed by *O. surinamensis, R. dominica* and *C. ferrugineus* (Tab. 1).

Sitophilus granarius was the most numerous in WB assay, followed by *R. dominica* and *O. surinamensis*. In this assay, adults of *C. ferrugineus* did not emerge (Tab. 1).

In WC assay, adults of *R. dominica* were the most numerous, where 412.00 adults per replication emerged, followed by *O. surinamensis* (191.00). *Cryptolestes ferrugineus* (50.33) and *S. granarius* (4.67) were present in smaller number (Tab. 1).

Table 1. The mean number±SE of emerged adult insect pests developed on three different mechanical states (A, B, C) of wheat (W) and rye (R) kernels.

Assay	*S. granarius*	*R. dominica*	*C. ferrugineus*	*O. surinamensis*	*P. interpunctella*
WA	2.50±0.85ab	1.17±0.48a	0.17±0.16a	1.33±0.95a	0.00±0.00a
WB	0.83±0.31a	0.50±0.22a	0.00±0.00a	0.17±0.16a	0.00±0.00a
WC	4.67±1.02b	412.00±50.47b	50.33±17.31b	191.00±52.89b	0.00±0.00a
RA	/	/	/	0.00±0.00a	1.33±0.42a
RB	/	/	/	0.00±0.00a	3.17±1.54a
RC	/	/	/	4.17±1.01b	1.50±0.43a

Vertical values, having different letter (a, b) in superscript, are significantly different (p < 0.05).

One-way ANOVA and Bonferroni tests showed that differences in number of emerged beetle adults of the same species that developed on three mechanical states of kernels were statistically significant (Tab. 2).

Table 2. Statistical differences (p) in the number of emerged adult insect pests that developed on different mechanical states (A, B, C) of wheat (W) and rye (R) kernels.

Compared assays	*S. granarius*	*R. dominica*	*C. ferrugineus*	*O. surinamensis*	*P. interpunctella*
WA vs WB	0.464	1.000	1.000	1.000	/
WA vs WC	0.211	<0.0005*	0.009*	0.002*	/
WB vs WC	0.011*	<0.0005*	0.009*	0.001*	/
RA vs RB	/	/	/	1.000	0.581
RA vs RC	/	/	/	<0.0005*	1.000
RB vs RC	/	/	/	<0.0005*	0.705

* - The mean difference is significant at the 0.05 level.
/ - Adult did not develop.

These results showed that mechanical state of wheat kernels had huge impact on the total number of emerged adults (Tab. 1, 2). All pests (except *S. granarius*) were significantly more numerous in original storage kernels (WC assay), where *R. dominica* was the most abundant. In WA and WB assays, there were no significant differences in the number of emerged adults of the same species. Only the number of *S. granarius* between WA and WC was not statistically significant (Tab. 1).

Strong significant positive correlation between *R. dominica* and *O. surinamensis* (p = 0.002; r = 0.961) was observed. When the number of *R. dominica* adults increases, the number of *O. surinamensis* adults also increases and vice versa. The increased number of *R. dominica* and *O. surinamensis* adults strongly negatively affected the number of *C. ferrugineus* adults (p = 0.022; r = -0.876; p = 0.005; r = -0.941, respectively).

Survival rate of P. interpunctella in competition with O. surinamensis on rye kernels

Plodia interpunctella adults emerged in all assays with rye kernels, but their number varied depending on the state of kernels (Tab. 1). The highest number of IMM adults was recorded in RB assay (3.17), followed by RC (1.5) and RA (1.33). There was no statistical significance among the number of emerged IMM adults that developed on three different mechanical types of rye kernels ($p = 0.348$; $F = 1.133$) (Tab. 1, 2).

Eighteen weeks since the beginning of the experiment, *O. surinamensis* adults emerged (4.17) in RC assay, besides IMM (Tab. 1). There was no statistically significant correlation between the number of emerged adults of these two species ($p = 0.607$; $r = 0.269$), which shows that *O. surinamensis* did not statistically influenced development of IMM and vice versa.

DISCUSSION

Plodia interpunctella is a secondary pest of stored grain and it feeds mainly on the germ and bran layer (REES, 2004). When reared alone on whole wheat and rye kernels, this moth successfully completes life cycle (F. Vukajlović, unpublished data). Wheat kernels are much preferable food for IMM than rye (F. Vukajlović, unpublished data), primarily because rye kernels are much harder than wheat kernels (WEIPERT, 1996). Also, population size and developmental dynamics of IMM depends on nutritive quality and mechanical state of available food (LOCATELLI and LIMONTA, 1998; VUKAJLOVIĆ and PEŠIĆ, 2012; KOČOVIĆ, 2014). IMM is susceptible to low content of polyunsaturated fatty acids, vitamins and steroids in the diet. Although, the larvae mandibles are strong, they do not easily break the pericarp of wheat and especially of rye kernels, so whole kernels are not the most suitable food for this moth (LOCATELLI and LIMONTA, 1998; KOČOVIĆ, 2014). Studies report that IMM larvae are easily developed on crushed grain, rather than on whole ones (LECATO, 1976; KOČOVIĆ, 2014).

Eighteen weeks since the beginning of the experiment, only 36 IMM adults developed, all in assays with rye kernels. In assays with wheat kernels, no IMM adult emerged, but four other beetle pest species emerged (*R. dominica*, *O. surinamensis, C. ferrugineus* and *S. granarius*), especially in assay with original storage kernels (WC). In assays with rye kernels, only *O. surinamensis* emerged, besides IMM. The presence of two or more species in the same area causes an alteration in their behavior, biology and ecology (TREMATERRA *et al*., 2000; ATHANASSIOU *et al*., 2006). ATHANASSIOU *et al*. (2006) showed that grains previously infested by different insects may affect the behavior of other species that visits these grains later, in comparison with noncontaminated grains. Semiochemicals, produced by some pests, can alter the behavior of the same or other species in stored grain. ATHANASSIOU *et al*. (2006) studied behavior of a beetle *T. confusum* on commodity previously infested by a moth *Ephestia kuehniella* Zeller, 1879 and concluded that noticeable interactions between their semiochemicals and behavioral changes are primarily affected by the contamination interval. Also, PHILLIPS *et al.* (1993) reported that some grain volatiles were repulsive to *T. castaneum,* while attracted *S. oryzae. Rhyzopertha dominica* locates potential grains to infest, primary using olfactory-guided mechanisms (EDDE, 2012).

In present study, the most diverse pest population occurs in assays with original storage kernels (WC). These kernels are consisted in large portion of undamaged kernels and in smaller number of those already damaged, either by insect pests or in process of harvest, transport, drying etc. *Rhyzopertha dominica*, as primary pest of stored grain, needs high proportion of whole grains for its satisfactory development, because it feeds on endosperm of the kernel, completely destroying inside structure of the kernels (COOMBS and WOODROFFE, 1963; REES, 2004; MASON and MCDONOUGH, 2012). It completes life cycle faster in whole undamaged kernels, than in cracked or broken kernels (VUKASOVIĆ *et al*., 1972). This is the reason why *R. dominica* was so abundant in original storage kernels, comparing to its number in assays with other mechanical states of kernels.

Preserving the grain quality is a great problem (GRAS *et al*., 2000; JONES *et al*., 2012). Damages into kernels are not always visible. Therefore, in our study, some stored grain insect pests developed in assays with whole kernels that seemed undamaged (WA and RA). Certain pests, such as *O. surinamensis*, detect if the kernels were damaged mechanically or by other insect pests, because they could sense certain grain volatiles (IRSHAD and TALPUR, 1993; TREMATERRA *et al*., 2000; ATHANASSIOU *et al*., 2006). Also, TREMATERRA *et al*. (2000) reported that kernels damaged by primary pests are much more attractive to secondary pests, than whole kernels or those damaged mechanically. *Oryzaephilus surinamensis*, *C. ferrugineus* and IMM as secondary pests, feed primarily on damaged kernels, i.e. broken kernels, germ or grain dust (STOREY, 1987). That is why the number of emerged *O. surinamensis* was in positive correlation with the number of emerged *R. dominica*.

Some storage insect pests can reduce the population size by feeding on IMM eggs, such as *O. surinamensis* (BARNES and SIMONS, 1952; LECATO, 1975). *Tribolium castaneum* also affects the population size of IMM by feeding on its eggs and died individuals (LECATO and FLAHERTY, 1973).

Based on our results, IMM survival and development is highly influenced by the presence of other stored grain insect pests. In the presence of two primary and two secondary beetle pests, IMM did not complete life cycle. On the other hand, in competition with another secondary insect pest (*O. surinamensis*), IMM was not being suppressed. Still, much remains to be learned about IMM survival and development, when competing with other stored grain insect pests. Further, detailed studies in dual, triple and multiple interactions among IMM and other insect pests would be needed to confirm species-specific responses, ecology and behavior of this moth.

CONCLUSION

The findings of this study reflect the correlations and competition between storage pest insects, a moth and four beetle species, on different mechanical state of stored wheat and rye kernels. The results have shown that *P. interpunctella*, in competition with four beetle species (*R. dominica*, *S. granarius*, *O. surinamensis* and *C. ferrugineus*), have no chance to finish life cycle on wheat kernels, due to effect of other storage pests on its population size and its lower affinity to wheat as food source. Our results show statistically important positive correlation between abundance of *R. dominica* and *O. surinamensis,* but negative between *R. dominica* and C. *ferrugineus*, as well as *O. surinamensis* and *C. ferrugineus*. Also, our results are in accordance with previous findings that storage pests develop faster on damaged grains, then on undamaged ones. The highest abundance was reached with individuals that fed ona mixture of kernels damaged by pests and whole undamaged kernels.

References:

[1] ARBOGAST, R.T., MULLEN, M.A. (1988): Insect succession in a stored corn ecosystem in Southeast Georgia. *Annals of the Entomological Society of America* **81**: 899-912.

[2] ATHANASSIOU, C.G., KAVALLIERATOS, N.G., XYRAFIDIS, S.N., TREMATERRA, P. (2006): Behavioural responses of *Tribolium confusum* Jacquelin du Val (Coleoptera: Tenebrionidae) to flour previously infested or contaminated by *Ephestia kuehniella* Zeller (Lepidoptera: Pyralidae) semiochemicals. *9th International Working Conference on Stored Product Protection,* October 15-18, Cāmpinos, Sao Paulo, Brazil, 441-445.

[3] BARNES, D.F., SIMMONS, P. (1952): Competition between saw-toothed grain beetle and Indian-meal moth. *Journal of Economic Entomology* **45**: 750-75l.

[4] COOMBS, C.W., WOODROFFE, G.E. (1963): An experimental demonstration of ecological succession in an insect population breeding in stored wheat. *Journal of Animal Ecology* **32** (2): 271-279.

[5] EDDE, P.A. (2012): A review of the biology and control of *Rhyzopertha dominica* (F.) the lesser grain borer. *Journal of Stored Product Research* **48**: 1-18.

[6] GRAS, P.W., KAUR, S., LEWIS, D.A., O'RIORDAN, B., SUTER, D.A.I., THOMSON, W.K.T. (2000): How and why to keep grain quality constant. In: M. WOOTTON *et al.* (eds): *Cereals 2000, Proceedings 11th Cereal and Bread Congress and of the 50th Australian Cereal Chemistry*, Gold Coast, 11-14 September. 526-530.

[7] HAGSTRUM, D.W., THRONE, J.E. (1989): Predictability of stored-wheat insect population trends from life history traits. *Environmental Entomology* **18**: 660-664.

[8] IRSHAD, M., TALPUR, S. (1993): Interaction among three coexisting species of stored grain insect pests. *Pakistan Journal of Zoology* **25** (2): 131-133.

[9] JONES, C., CASADA, M., LOEWER, O. (2012): Drying, handling, and storage of raw commodities. In: D.W. HAGSTRUM *et al*. (eds): *Stored product protection*. Kansas State University, 101-120.

[10] KOČOVIĆ, D. (2014): Development of Indian meal moth (*Plodia interpunctella* Hbn.) depending on state of corn kernels. *M.Sc. Thesis*. Faculty of Science, University of Kragujevac, Kragujevac. [in Serbian]

[11] LECATO, G.L. (1975): Interactions among four species of stored-products insects in corn: a multifactorial study. *Annals of the Entomological Society of America* **68** (3): 677-679.

[12] 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.

[13] LECATO, G.L., FLAHERTY, B.R. (1973): *Tribolium castaneum* progeny production and development on diets supplemented with eggs or adults of *Plodia interpunctella*. *Journal of Stored Products Research* **12**: 43-47.

[14] LEFKOVITCH, L.P. (1968): Interactions between four species of beetles in wheat and wheat feed. *Journal of Stored Product Research* **4**: 1-8.

[15] LOCATELLI, D.P., LIMONTA, L. (1998): Development of *Ephestia kuehniella* (Zeller), *Plodia interpunctella* (Hübner) and *Corcyra cephalonica* (Stainton) (Lepidoptera: Pyralidae) on kernels and whole meal flours of *Fagopyrum esculentum* (Moench) and *Triticum aestivum* L. *Journal of Stored Products Research* **34** (4): 269-276.

[16] MASON, L.J., MCDONOUGH, M. (2012): Biology, behavior, and ecology of stored grain and legume insects. In: D.W. HAGSTRUM *et al*. (eds): *Stored product protection*. Kansas State University, 7-20.

[17] PHILLIPS, T.W., JIANG, X.L., BURKHOLDER, W.E., PHILLIPS, J.K. and TRAN, H.Q. (1993): Behavioural responses to food volatiles by two species of stored-product Coleoptera, *Sitophilus oryzae* (Curculionidae) and *Tribolium castaneum* (Tenebrionidae). *Journal of Chemical Ecology* **19**: 723-734.

[18] REES, D. (2004): *Insects of stored products*. CSIRO Publishing, Collingwood, Australia, p. 181.

[19] SINHA, R.N. (1973): Ecology of storage. *Annales de Technologie Agricole* 22: 361-369.

[20] SILHACEK, D.L. and MILLER, G.L. (1972): Growth and development of the Indianmeal moth, *Plodia interpunctella* (Lepidoptera: Phycitidae) under laboratory mass-rearing conditions. *Annals of the Entomological Society of America* **65**: 1084-1087.

[21] STOREY, C.L. (1987): Effect and control of insects affecting corn quality. In: S.A. WATSON and P.E. RAMSTAD (eds): *Corn Chemistry and Technology*. American Association of Cereal Chemistry, St Paul, pp. 185–199.

[22] TREMATERRA, P., SCIARRETTA, A. and TAMASI, E. (2000): Behavioral responses of *Oryzaephilus surinamensis*, *Tribolium castaneum* and *Tribolium confusum* to naturally and artificially damaged durum wheat kernels. *Entomologia Experimentalis et Applicata* **94** (2): 195-200.

[23] VUKAJLOVIĆ, F.N. and PEŠIĆ, S.B. (2012): Contribution to the studies of the Indian meal moth *Plodia interpunctella* Hbn. (Lepidoptera: Pyralidae). *Kragujevac Journal of Science* **34**: 107-115.

[24] VUKASOVIĆ, P., STOJANOVIĆ, T. and ŠENBORN, A. (1972): *Storage pests. Biology and management with basics in storage of agricultural commodities*. Institute for plant protection, Faculty of Agriculture, Novi Sad. p. 540. [in Serbian]

[25] WEIPERT, D. (1996): Rye and triticale. In: R.J. HENRY and P.S. KETTLEWELL (eds): *Cereal grain quality*. Chapman & Hall, London, UK, pp. 205-224.

[26] WHITE, N.D.G. and SINHA, R.N. (1980): Changes in stored-wheat ecosystems infested with two combinations of insect species. *Canadian Journal of Zoology* **58**: 1524-1534.