0.05	25b
0.1	25b
1.0	37.5b
4.5	50a

*mating disruption (%) followed by the same letter are not significantly different at p=0.05 according to contrast option in binary logistic regression.

Tab. 2 Mating disruption of *Ephestia cautella* at different ZETA concentrations (presence of air flow).

Pheromone concentration (mg)	Mating disruption (%)*
0.05	37.5c
0.1	37.5c
1.0	62.5b
4.5	75a

*mating disruption (%) followed by the same letter are not significantly different at p=0.05 according to contrast option in binary logistic regression.

4. Discussion

This study reveals that MD of *E. cautella* increases with the increase in ZETA concentration and the presence of air flow. The higher MD with the presence of air flow compared to that without the air flow may be due to the increase in the dispersion of ZETA through the air.

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Suitability of Poaceae seeds for *Plodia interpunctella* development

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Abstract

One of the most important pests of stored grains is *Plodia interpunctella* (Hübner), whose larvae feed primarily on germinal part of the kernels, causing a reduction of seed germination and seed viability. This is detrimental for seeds of high category. However, seeds of different species within the same taxonomic family have different morphology (thickness of seed-coat, presence or absence of palea, palea loose or firmly attached to the seed etc.), which affects the susceptibility of seeds to *P. interpunctella* attack. The hypothesis was that seed hardness and the absence of palea could also significantly influence the life history of this pest. We assessed the suitability of different seeds from family Poacae (maize, wheat, barley, oats, ray, forage sorghum (variety), forage sorghum (hybrid), Sudan grass and millet) for *P. interpunctella* development and seeds susceptibility to pest attack (expressed in Susceptibility index –SI). The following parameters were monitored: larval mortality, adult emergence, mean developmental duration (from egg to adult) and female fecundity. Observations were carried out weekly, for 49 days. Data were statistically analyzed using Duncan's multiple range Test. The highest larval mortality, the lowest number of emerged moths and the lowest fecundity were recorded on millet, Sudan grass and forage sorghum (variety and hybrid). However, the shortest larval development (27.8 days) and the highest fecundity (109.5-115.6 eggs) were on standard laboratory diet, maize and wheat. Morphometric measures of moths indicate that on unsuitable mediums like millet, Sudan grass, and different sorghum varieties the body lengths were statistically significantly shorter (0.5-0.6 cm) compared to other treatments (0.8-0.9 cm). According to the SI, the most susceptible were maize, wheat, barley, oats and ray, while moderately resistant were Sudan grass and millet. Testing kernel hardness and continuous improving of kernel resistance to storage insect pests could provide lower losses in stored grain quality and quantity.

Key words: *Plodia interpunctella*, Poaceae seeds, development, life history parameters

1. Introduction

Post-harvest losses and reduction of seed quality is one of the main restraints in achieving food security in developing and under developed countries (Rounet, 1992). During storage, the presence of insects is one of the major causes of deterioration of grain quality, reduction of grain weight, nutritional and market value. Indian meal moth, *Plodia interpunctella* (Hübner), is one of the most important polyphagous pests of grains, processed cereals and their products, oilseeds, nuts and manufactured products (Perez-Mendoza, 2003; Rees, 2004; Ozyardimci et al., 2006 Mohandasset al., 2007). It can be found on whole and/or damaged grains in storages, but since larvae feed mostly on germinal part of the seed and a bran layer (Almaši, 1984; Rees, 2004; Silhacek and Murphy, 2005), they lead to the reduction in seed germination and viability, which is detrimental for seed of high category.

Seeds of all cultivated Poaceae species (grains) are vulnerable to insect attack in warehouses because of usually prolonged period of storage. The growing importance of cereal (grain) production, primarily wheat, maize, barley and oats, lies in the fact that grains are the major carbon hydrate source in human and animal nutrition (FAO, 2011). Recently, there is also a growing interest in sorghum production because it has the potential to be used as bioenergy crop (Berti et al., 2013) and it is an attractive forage crop for many tropical and subtropical areas (Naeini et al., 2014). In 2013, sorghum was cultivated on over 300 thousand acres in Europe, while the world production of sorghum took place on the surface of over 42 mill acres (FaoStat, 2014) which also indicates at the growing importance of this crop.

The susceptibility of different grains (Poaceae seeds) to *P. interpunctella* attack and suitability for pest development depend on different characteristics of grains. In the first place it depends on the type of grain (hulless seeds like wheat, maize and rye, or seeds with palea like oats, barley, millet, Sudan grass), the type of palea (firmly attached to the seed – millet and Sudan grass, or loose palea -oats and barley) and the grain hardness (depends on grain density, structure of the grain, and the level of moisture). As a rule, grains without palea have higher density (Anonymous, 2017). Also, there can be a difference in seed characteristics between hybrids and varieties of the same species. For example, a variety of forage sorghum has palea firmly attached to the seed, while a hybrid of forage sorghum (crossing of male line of Sudan grass and female line of grain sorghum) does not have palea, since the female line is the grain sorghum.

This work aimed to assess susceptibility of different Poaceae seeds (wheat, maize, barley, oats, ray, millet, three genotypes of sorghum) for *P. interpunctella* attack and suitability for insect development.

2. Material and methods

2.1. Seed commodities

The experiment was carried out with seeds of nine different cultivated species from family Poaceae. Maize (*Zea mays* L.), wheat (*Triticum vulgare* L.), barley (*Hordeum vulgare* L.), oats (*Avena sativa* L.), ray (*Secale cereale* L.) and millet (*Pennisetum glaucum* L.) were used as nutrient medium for *P. interpunctella* development. Three varieties of sorghum (*Sorghum bicolor* Moench) were also used: a hybrid of forage sorghum, a variety of forage sorghum and Sudan grass. According to the agronomic classification based on different methods of sorghum cultivation and use, *S. bicolor* species is divided into agronomic forms: grain sorghum, forage (sweet) sorghum, broomcorn and Sudan grass (Sikora and Berenji, 2011). Forage sorghum hybrids are obtained by crossing grain sorghum as the female parent and Sudan grass as the male parent (Pataki et al., 2010). This process of breeding provides seeds of sorghum without palea, which is the reason why it is more susceptible to insect attack. All seeds were obtained from the Institute of Field and Vegetable Crops, Novi Sad, Republic of Serbia, vegetation season 2016.

The grains were not treated with insecticides and prior to the experiment and were exposed to deep freezing (-80 °C) in order to eliminate the presence of other pests and/or superficial harmful organisms.

2.2. Experimental design

P. intepunctella parental population originates from a laboratory population reared in plastic containers, at 28 ±1 °C, R.H. 60 ± 10% and 14:10 (L:D) photoperiod, on a standard laboratory diet (SLD) for *P. intepunctella* (Silhacek and Miller, 1972). 50 one-day-old eggs were placed on 100 g of grains into 0.25 L glass jars. Jars were sealed with a cotton swab for proper aeration. The experiment was set in 4 replicates and carried out at the same conditions as the rearing of parental population.

The following life history parameters of *P. intepunctella* were monitored: larval mortality, mean developmental duration (from egg to adult), adult emergence, adult lifespan and female fecundity. The observations were carried out weekly, until the last larva pupated. Once the emergence of adults began, assays were checked each 24 h and the number of the emerged moths was recorded. Newly emerged unmated moths from the same treatment were paired and each pair was isolated in a separate test tube until the oviposition. The fecundity was defined as the total number of eggs laid after the mating.

The susceptibility of different Poaceae seeds was assessed based on Susceptibility index (SI) described by Dobie (1974):

$$SI = \frac{\left(\ln\left(F_1\right)\right)}{D} \quad 100$$

ln – The natural logarithm of the mathematical constant *e*

F1 – average number of emerged moths per treatment

D –average developmental duration (egg to adult) in days

Seeds were rated as resistant (R), moderately resistant (MR), moderately susceptible (MS) and susceptible (S) according to Mensah (1986) as follows:

$0 \leq SI \leq 2.5(R)$

$2.6 \leq SI \leq 5\ (MR)$

$5.1\ SI \leq 7.5\ (MS)$

$7.6 \leq SI \leq 10\ (S)$

2.2. Statistical analysis

Data were statistically processed using Duncan's multiple range Test to analyse the differences between life history parameters on different grains, in software package SPSS 21 (P>0.05).

3. Results and discussion

3.1. Larval mortality

The highest mortality of *P. intepunctella* larvae was recorded on millet (34.9%) and Sudan grass (21.5%) and was significantly higher compared to other grains (0.9-15.3%). The lowest larval mortality was on SLD (0.7%), during the entire experiment (Tab. 1). The difference between treatments was statistically highly significant (F=300.66**, P<0.01). According to Subramanyam

(1995), the mortality of *P. intepunctella* larvae can reach 28% on yellow maize, while in this work it was significantly lower on maize (12.8%).

3.2. Mean development duration

The results on *P. intepunctella* developmental duration on nine different Poaceae seeds and SLD are presented in Tab. 1. The fastest development was on SLD (27.8 days), while the slowest was on millet (49.8 days) followed by forage sorghum hybrid, forage sorghum variety and Sudan grass (41.8, 42.0 and 42.0 days, respectively). The differences between developmental duration were statistically highly significant (F=96.14**, P<0.01). As reported by Williams (1964), duration of *P. intepunctella* development could range from 36 to 327 days. Developmental rate depends on maize variety (Abdel-Rahman et al., 1968) and also kernel damage. Mbata (1990) reported that the shortest development from egg to adult on the whole maize kernels was 31.2 days (tested on 13 varieties) and the slowest was 37.0 days, which was similar to the results of this work. Also, developmental dynamics of *P. intepunctella* depends on nutritive quality and mechanical state of food (Locatelli and Limonta, 1998; Vukajlović and Pešić, 2012; Kočović, 2014). Many researchers reported that life-cycle of *P. interpunctella* ranges from 27 to 52 days depending on factors such as temperature, food odor, presence of oil in diet, type of food, size and physiological state of females, availability of drinking water, food source and temperature (Allotey and Goswami 1990; Johnson et al., 1992; Nansen and Phillips, 2003; Mohandass, 2006). However, diet is the most important factor for determining the developmental period of the insects (Mbata 1985; Johnson *et al.,* 1992; Nansen and Phillips, 2003; Silhacek, et al., 2003; Silhacek and Murphy, 2005) and according to Vukajlović et al. (2017), when reared on whole wheat and rye kernels, this moth successfully completes life-cycle.

3.3. Adult emergence

The highest number of emerged adults was recorded on SLD (36.0), wheat (30.0) and maize (28.0), with statistically significant difference between treatments (F=172.12, p<0.01). The lowest number of emerged adults was on millet and Sudan grass (6.2, and 7.5, respectively). Other seeds were also less suitable for larval development, based on the number of emerged moths (10.5-18.5 moths). Essien (2006) reported that emergence of adult insect can be enhanced by the diet chemical composition, which was proven in this work, based on other life history parameters.

3.4. Female fecundity

The highest female fecundity (115.6 eggs) was recorded for females reared on SLD (Tab. 1). Between different grains, females reared on maize and wheat laid significantly higher number of eggs (110.2, and 109.5 eggs, respectively) which was at the same level of significance with the number on SLD. Females reared on millet laid the lowest number of eggs (16.2 eggs). The difference in fecundity among females reared on different grains and SLD was statistically highly significant (F= 432.43**, P<0.01). The food source is an important factor for determining fecundity of moths which can be influenced by different diets (Mohandass et al., 2007; Fathipour and Naseri, 2011; Madboni and Pour Abad, 2012), thus the low fecundity indicates at relatively poor nutrient medium (Arbogast, 2007). Values of *P. interpunctella* fecundity reported in the literature vary widely. Allotey and Goswami (1990) reported fecundity of 96.8 eggs per female on wheat and 174.2 eggs for moths reared on split maize kernels. According to Onaolapo (2017), the fecundity on formulated diet can reach 161 eggs, while Almaši (1984) reports only 26 laid eggs on whole wheat grains. In the research of Mbata (1990), among 13 tested Nigerian maize hybrids, some were more some less attractive for oviposition, regardless on the type of maize. This indicated at the presence of certain ques, i.e. ovipositional attractants that were not related to the type of maize. Babić et al. (2013) emphasized that dent type of maize kernels are the softest kernel type since it contains higher percentage of floury endosperm. Thus, we can speculate that the consumption of dent kernels is easier and the lower energy is needed for breaking the kernel pericarp, which might lead to higher mean fecundity.

3.5. Moth lifespan

The lifespan of moths differed depending on the grains, i.e. Poaceae species. The longest lifespan was recorded for moths reared on forage sorghum hybrid (9.5), millet (9.0), forage sorghum variety (8.5), barley (8.5) and Sudan grass (8.0), which was significantly longer compared to SLD and wheat - 6.0 days (F=6.11*, P>0.01). Subramanyam (1995) reported that the longevity of adult stage depends primarily on the environmental factors (temperature and humidity), occurrence of mating, opportunity for oviposition and the presence or absence of water for consumption.

3.6. Moth body lengths

Moths reared on SLD had the longest body sizes, 0.9 cm on average (Tab. 1). The smallest average body lengths were measured for moths reared on millet, Sudan grass, forage sorghum variety and hybrid (0.5-0.6 cm). The difference between body lengths of moths reared on different Poaceae seeds were statistically highly significant (F=66.32**, P<0.01). Akinneye (2009) reports that adult moths reared on the formulated diet produce the highest body lengths, which is in accordance with the results of this work since the longest body sizes were on SLD.

Tab. 1 *Plodia intepunctella* life history parameters on different Poaceae seeds and SLD

Commodity	Mortality of larvae (%)	MDD (days)	Adult emergence	Fecundity	Moth lifespan	Body lengths
Maize	12.8 ±1.25cd	28.3 ±0.58 c	28.0 ±2.08 b	110.2 ±2.64 a	6.5 ±0.56 c	0.8 ±0.08 ab
Wheat	2.9 ±0.85 e	32.0 ±0.50 c	30.0 ±1.82 b	109.5 ±0.96 a	6.0 ±0.81 c	0.8 ±0.02 ab
Barley	10.3 ±0.96 d	34.7 ±0.81 c	18.5 ±1.29 c	58.2 ±3.55 b	8.5 ±1.29 ab	0.7 ±0.09 ab
Oats	11.3 ±1.71 d	32.8 ±0.52 c	16.3 ±0.50 c	44.2 ±1.71 d	7.5 ±0.58 b	0.6 ±0.05 b
Ray	0.9 ±0.30 f	32.0 ±1.71 c	10.5 ±1.29 d	51.8 ±2.62 c	7.0 ±0.96 bc	0.6 ±0.05 b
Forage sorghum (hybrid)	13.0 ±1.29 c	41.8 ±1.25 b	14.0 ±1.71 cd	22.8 ±1.63 e	9.5 ±0.58 a	0.6 ±0.05 c
Forage sorghum (variety)	15.3 ±1.50 c	42.0 ±0.81 b	11.8 ±0.95 d	24.5 ±1.71 e	8.0 ±0.00 b	0.5 ±0.13 c
Sudan grass	21.5 ±1.29 b	42.0 ±1.00 b	7.5 ±0.96 e	27.5 ±1.71 e	8.0 ±0.81 b	0.5 ±0.09 c
Millet	34.9 ±1.03 a	49.8 ±1.29 a	6.2 ±1.26 e	16.2 ±1.55 f	9.0 ±0.00 a	0.5 ±0.21 c
SLD	0.7 ±0.37 f	27.8 ±1.29 d	36.0 ±1.00 a	115.6 ±3.40 a	6.0 ±0.58 c	0.9 ±0.08 a
F value	**300.66****	**96.14****	**172.12****	**432.43****	**6.11****	**66.32****

Mean values ±SD, Values with the same letter in the column are on the same level of significance, ** - P<0.01, * - P<0.05, ns - P>0.05

3.7. Susceptibility of Poaceae seeds to *P. intepunctella* development

The calculated SI (Tab. 2) indicates that maize and wheat kernels (SI=11.90, and 10.62, respectively) were the most susceptible to *P. intepunctella* attack (S), while the least suitable were millet and Sudan grass (SI=3.65, and 4.95, respectively), that were rated as moderately resistant (MR).

Grain resistance to environmental factors is influenced by the characteristics of the seed coat that covers its entire surface. The seed coat consists of extinct woody cells with thickening walls, made of cellulose, hemicellulose, lignin and other materials that provide high strength, and also additional resistance towards insect pests (Anonymous, 2017).

According to Weipert (1996) wheat kernels are much preferable to insect pests than rye, primarily because rye kernels are much harder and this is in accordance with the result of this work, where rye was less susceptible to *P. interpunctella* attack. Although, *P. intepunctella* larvae have strong mandibles, 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), which is why *P. intepunctella* larvae are easily developed on crushed grain, rather than on whole ones (Lecato, 1976; Kočović, 2014). Barley seeds differ from the wheat and rye because palea is firmly attached to the seed coat and its share in the grain is 7-15% (Anonymous, 2017). This part of seed may provide additional protection insect attack, so we can speculate that it is a reason for higher mortally of larvae. The outer layer of maize seed coat is more developed than in other cereals, but without palea. The total thickness of the maize seed coat (6 - 10% of the total grain weight) can be 0.5 mm, thus is easier to be damaged by insects, while for sorghum seeds, the seed coat thickness and the presence of palea depends on agronomic form.

Tab. 2 Susceptibility of different Poaceae seeds and SLD for development of IMM

Commodity	Susceptibility Index	Rating
Maize	11.90	S
Wheat	10.62	S
Barley	9.03	S
Oats	8.66	S
Ray	7.19	S
Forage sorghum (hybrid)	5.71	MS
Forage sorghum (variety)	6.28	MS
Sudan grass	4.95	MR
Millet	3.65	MR
SLD	12.80	S

R- resistant; MR – moderately resistant; MS – moderately susceptible, S - susceptible

Considering the above mentioned, it is obvious that aside from standard measures for control of storage insects, especially *P. interpunctella*, host plant resistance is one of the promising practices and more sustainable in integrated pest management, but also cheaper and ecologically safer (Abebe et al., 2009; Tefera et al., 2011).

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Population growth and development of *Liposcelis obscurus* Broadhead (Psocodea: Liposcelididae) at constant temperatures and relative humidities

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Abstract

The effects of nine temperatures (22.5, 25, 27.5, 30, 32.5, 35, 37.5, 40, and 42.5°C) and four RHs (43, 55, 63, and 75%) on the population growth and development of the parthenogenetic *Liposcelis obscurus* Broadhead (Psocodea: Liposcelididae) were investigated in laboratory studies. Results showed that *L. obscurus* did not survive at 43% RH at all temperatures tested. At 55% RH, *L. obscurus* survived at 22.5, 25, and 27.5°C; none survived at 42.5°C and ≤63% RH. *Liposcelis obscurus* survived and the population increased 56–fold from an initial population of five adult females at 42.5°C and ≤75% RH. Population growth was highest at 40°C and 75% RH, where population increase was 215-fold. *Liposcelis obscurus* has three-to-five nymphal instars, and the percentages of third, fourth, and fifth instars were 52, 41, and 7%, respectively. Temperature-dependent developmental equations were developed for *L. obscurus* eggs, individual nymphal, combined nymphal, and combined immature stages. *Liposcelis obscurus* populations grew much faster at 30–42.5ºC and 75% RH. These