Original scientific paper
Journal of Central European Agriculture, 2021, 22(1), p.178-187
DOI: /10.5513/JCEA01/22.1.3113

Harmfulness of two species of weevils (*Sitophilus granarius* L. and *Sitophilus zeamais* Motsch.) on different maize hybrids

Štetnost dviju vrsta žižaka (*Sitophilus granarius* L. i *Sitophilus zeamais* Motsch.) na različitim hibridima kukuruza

Darija LEMIĆ (✉), Katarina ŠIMUNOVIĆ, Ivana PAJAČ ŽIVKOVIĆ

University of Zagreb, Faculty of Agriculture, Department of Agricultural Zoology, Svetošimunska 25, 10000 Zagreb, Croatia

✉ Corresponding author: dlemic@agr.hr

Received: December 1, 2020; accepted: January 20, 2021

ABSTRACT

Storage pests are pests adapted to living indoors, where their entire life cycle occurs on stored agricultural products. Nowadays, insects within storage facilities are the main problem in the storage process. Storage systems such as silos, warehouses, and containers are perfect habitats for insects that feed on stored food because they are protected from weather extremes, have unrestricted access to large food sources, and can live continuously for long periods of time. The objective of this study was to determine the intensity of damage by granary (*Sitophilus granarius* L.) and maize (*Sitophilus zeamais* Motsch.) weevils on field maize and popcorn and their biological potential over 20 weeks of the storage process. During the study, physical properties of maize (weight, hectolitre weight, moisture and sample weight) and changes in population density of weevils were measured. The results showed differential susceptibility of maize hybrids to weevil feeding. No differences were found between weevil species in terms of the damage they caused. Popcorn does not favor weevil feeding, resulting in low grain damage and high mortality rates for both weevil species. In contrast to popcorn, field corn favors both weevil feeding and weevil reproductive potential, ultimately decreasing grain mass and quality and making it unsuitable for human and livestock consumption. More susceptible field maize can be selected for shorter storage time and thus faster delivery to market.

Keywords: corn, granary weevil, hybrids, maize weevil, nutrition, storage pests

SAŽETAK

Skladišni štetnici prilagođeni su životu u zatvorenom prostoru gdje im se cijeli životni ciklus odvija na uskladištenim poljoprivrednim proizvodima. U današnje vrijeme štete od kukaca unutar skladišnih objekata glavni su problem u skladišnom procesu. Skladišni sustavi poput silosa, skladišta i kontejnera savršena su staništa za kukce koji se hrane uskladištenom hranom pošto su zaštićeni od vremenskih ekstrema, imaju neograničen pristup velikim izvorima hrane te dug period žive neometano. Cilj ovoga rada bio je utvrditi intenzitet oštećenja koje pričinjavaju žitni (*Sitophilus granarius* L.) i kukuruzni (*Sitophilus zeamais* Motsch.) žišci na merkantilnom kukuruzu i kukuruzu kokičaru, kao i njihov biološki potencijal kroz 20 tjedana skladištenja. Tijekom istraživanja mjerena su fizikalna svojstva zrna kukuruza (težina, hektolitarska masa, vlaga i masa uzorka) kao i promjene u brojnosti populacija žižaka. Rezultati su pokazali različitu osjetljivost hibrida kukuruza na ishranu žižaka. Nisu utvrđene razlike između vrsti žižaka obzirom na oštećenja koja pričinjavaju. Kukuruz kokičar zbog svoje strukture zrna ne pogoduje ishrani žižaka, što je rezultiralo malim oštećenjima na zrnu te velikom stopom mortaliteta obje vrste žižaka. Za razliku od kokičara, merkantilni kukuruz pogoduje ishrani i razmnožavanju žižaka što naposljetku dovodi do smanjenja njegove mase i kvalitete zrna te postaje neadekvatan za ishranu ljudi i stoke. Merkantilni hibridi zahtijevaju kraće vrijeme skladištenja i bržu isporuku na tržište.

Ključne riječi: kukuruz, žitni žižak, hibridi, kukuruzni žižak, ishrana, skladišni štetnici

INTRODUCTION

Maize (*Zea mays* L.) is a cereal crop grown for food. Field maize is a term for maize grown for livestock silage, ethanol, grain, and processed food products. The major field maize varieties are dent corn, flint corn, meal corn, and waxy corn. Another group includes sweet corn and popcorn, which are commonly used in human food (Boutard, 2012).

The largest producer of maize is the United States, followed by China, Brazil, and the European Union (EU) (Statista, 2020). In the EU, France is the largest producer of maize, accounting for 23.3% of total maize production in the EU, followed by Romania (15.3%), Italy (12.0%) and Hungary (11.3%) (European Commission, 2019). In 2020, maize production in Croatia is expected to reach 2.33 million tons. This year's production is the highest since 2008, when a record of 2.5 million tons was set. One of the reasons for this are Croatia's excellent soil and climate conditions for growing this crop. Croatian maize production is twice as high as the country's demand. According to the data from FAOSTAT, the UN's Food and Agriculture Organization, of 166 countries that are major maize producers, Croatia ranks 48th. Croatia is the ninth largest maize producer in the EU (CroatiaWeek, 2020). After harvest, maize can only be stored well if it has been properly dried. Maize must be dried until a moisture content of less than 13% is reached, then it is suitable for long-term storage. The storage characteristics of the different varieties should be considered at the cultivation planning stage (Bell, 2000).

Granary (*S. granarius* L.) and maize weevils (*S. zeamais* Motsch.) are the most common species found in small rural warehouses and large silos (Korunić, 1990; Derera et al., 2014; Rotim and Ostojić, 2014; Vélez et al., 2017). The beetle and larvae attack the grain of cereals (maize, barley, rye, wheat, oats, rice). In addition to grains, weevils also infest flour, bran and pasta. The larvae feed on the contents of the grains. The damage caused by granary and maize weevils not only reduces the quantity and quality of the product but also the germination of the seed as the larva and weevil feed inside the grain (Ritz, 1997; Rees, 2004; Beckett et al., 2007; Ojo and Omoloye, 2012; Tefera, 2012). A pair of beetles has hundreds of thousands of offspring in a year under optimal conditions, so the damage caused by these insects can understandably be very high (Korunić, 1990). Maize losses of 20 to 90% by *S. zeamais* have been reported worldwide (Delima, 1987; Giga et al., 1991; Bergvinson, 2001; Paes et al., 2012). *S. granarius* is a serious pest of storage cereals worldwide, but the amount of damage to maize is still unknown.

The adults of *S. zeamais* are long-lived (several months to a year). Eggs are laid throughout most of adult life, and each female may lay up to 150 eggs. The incubation period of the egg is 6 days at 25 °C (Howe, 1952). Eggs are laid at temperatures between 15 and 35 °C (with an optimum around 25 °C) and at grain humidities above 10% (Birch, 1944). There are four larval stages. At a temperature of 25 °C and 70% relative humidity (RH) pupation occurs after about 25 days, although development times at low temperatures are extremely long (98 days at 18 °C and 70% RH). Pupation occurs inside the grain and the newly developed adult chews its way out, leaving a large hatching hole. Total development time ranges from about 35 days under optimal conditions to over 110 days under unfavourable conditions (Birch, 1944; Howe, 1952). The actual length of the life cycle may vary from 31 to 37 days (CABI, 2021a).

The biology and behaviour of *S. granarius* is similar to that of *S. zeamais*, except that it cannot fly (Longstaff, 1981). Adults live an average of 7 to 8 months. Females usually lay about 150 eggs and may lay up to 300 eggs during their lifetime. The eggs incubate for about 4-14 days, depending on temperature and humidity, before hatching. There are four larval stages. Pupation occurs inside the grain. The newly hatched adult chews its way out of the grain, leaving a characteristic exit hole. Under warm summer conditions, the life cycle can be completed in 28 to 42 days, but in winter it can take up to 17 to 21 weeks. Optimum conditions for development are about 30 °C and 70% RH (Richards, 1947; CABI, 2021b).

While many studies have reported different maize varieties with different levels of resistance to maize weevil (Serratos et al., 1987; Dhliwayo et al., 2005; Lale and Kartay, 2006; Hossain et al., 2007), no resistant varieties to maize weevil have yet been identified in the literature, suggesting that there are still some challenges in developing such varieties (Derera et al., 2014). Knowledge of weevil feeding preferences, extent of damage, and early detection of infestations can help prevent severe damage to stored maize and subsequent economic losses (Wakefield at al., 2005).

This study is based on the hypothesis that different maize hybrids (field maize and popcorn) have different susceptibility to *S. granarius* and *S. zeamais* nutrition. The main objective was to evaluate the degree of damage by *S. granarius* and *S. zeamais* on the most popular field maize and popcorn hybrids in Croatian production. We also aimed to determine the influence of feeding by both weevil species on physical properties of maize (weight, hectolitre mass, moisture, etc.) and to determine the reproductive potential of weevils during feeding on different maize hybrids.

MATERIALS AND METHODS

Experimental design

The experiment was conducted at the Faculty of Agriculture, University of Zagreb, Croatia, from 30 November 2018 to 5 April 2019. A completely randomized experimental design (as recommended in similar studies: Pellegrineschi et al., 2002; Cai et al., 2004; Ozberk et al., 2005; Debona et al., 2014) was used. Two maize hybrids were used in the study: field maize P9911 (produced by Pioneer company) and popcorn hybrid Bc 513 pc (produced by Bc company).

Maize kernels used in the experiments were cleaned of straw, chaff, light grains and other impurities before use in the experiments. Kernels with any form of damage were removed and the samples sterilized (70% ethanol (1 min) followed by 5% sodium hypochlorite (5 min) and rinsed several times with water) to kill any living organisms derived from natural infestation. Samples were then acclimated in woven cotton bags at room temperature (20 ± 2 °C and 25-30% RH). The initial moisture content of the seeds was determined using the oven method (Tabatabeefar, 2003). The two maize hybrids, with eight replicates for each cultivar (total: 16 replicates), were tested over the experimental period of 20 weeks. To each of the eight replicates, 250 g of maize grain was added at the beginning of the experiment. Initial readings for moisture (%), weight (g) and hectolitre mass (kg/l) in a volume of 210 mL were obtained using a grain moisture meter (Draminski S.A., Olsztyn, Poland).

Laboratory insecticide-sensitive strains of *S. zeamais* and *S. granarius* were used. These were cultured on a diet of insecticide-free whole wheat at 25°C and 70% RH. (Photoperiod 14 h light:10 h dark). Weevils were removed from culture prior to bioassays and maintained in clean glass tubes without food for 24 h under the assay conditions. After the initial measurement of maize grains, four replicates (of 250 g) of each hybrid were infested with twenty 10-day-old adult *S. granarius* and twenty 10-day-old adult *S. zeamais* (10 males and 10 females per species), separately by sex, according to the methods of Dinuţă et al. (2009). A total of 16 maize hybrid replicates were infected with a total of 160 adult *S. granarius* and 160 adult *S. zeamais*. In this experiment, treatments were arranged in a Completely Randomized Design (CRD) with four replicates for each maize hybrid. The controlled laboratory temperature was 24 ± 2 °C, and humidity was 50 - 60% throughout the experiment.

Data collection and analysis

Ten evaluations were performed every 14 days over a 20-week period. At each evaluation, the physical properties of the kernels including moisture (%), weight (g) and hectolitre weight (kg/hl) were measured using a Draminski apparatus. The total sample weight of each replicate was measured after cleaning of impurities using a precise balance. The number of live and dead S. granarius and S. zeamais was also recorded.

Kernel weight, moisture, hectoliter weight, and the number of live *S. granarius* and *S. zeamais* in each replicate of each cultivar were recorded over the 20-week study period. The collected data were analyzed using repeated-measures ANOVA to determine the difference in resistance of the maize hybrids to *S. granarius* and *S. zeamais* infestation and the differences that occurred in each cultivar between the 14-day study periods. A post-hoc means test was used when significant differences were found (Tukey's HSD). These analyzes were performed using ARM 2019® GDM software (Gylling Data Management, 2020).

RESULTS

During the first two weeks of the experiment, the number of *S. granarius* and *S. zeamais* varied between the maize hybrids, but not significantly. During the next experimental period (4-20 weeks), the populations of *S. granarius* and *S. zeamais* were found to increase in the field maize. In the 12th week of the experiment, the number of *S. granarius* increased more than twofold on field maize and popcorn comparing with initial infestation, while on popcorn both insects significantly decreased their populations. After 20 weeks, field corn remained the more susceptible hybrid to *S. granarius* and *S. zeamais* development and progeny. The popcorn hybrid showed lower susceptibility to *S. granarius* and *S. zeamais* throughout the experimental period. The number of *S. granarius* and *S. zeamais* remained very low throughout the experimental period compared to the initial infestation (Table 1). In the popcorn hybrid, the number of *S. granarius* and *S. zeamais* did not change significantly during the experiment and the numbers remained low. Maximum numbers of *S. granarius* and *S. zeamais* progeny were recorded on field maize during the 18th to 20th week of the experiment, with populations more than five times larger than the initial infestation.

Of the maize hybrids studied, *S. granarius* caused significant weight loss (31%) on field maize during the 10-week period, and the loss was much less (10%) on the popcorn variety. *S. zeamais* caused significant weight reduction on field maize (32 %), and on popcorn the losses were only 7 % (Table 2).

Table 1. The mean number (± SE) of live adult *S. granarius* and *S. zeamais* in field maize and popcorn during the 20-week experimental period

Evaluation Period	*S. granarius*		*S. zeamais*		HSD[1] p = 0.05 **
	Field maize	Popocorn	Field maize	Popocorn	
1	20*	20	20	20	-
2	19.8 ± 0.3 C	18.8 ± 0.8 A	18.8 ± 0.3 D	18.3 ± 1.8 A	3.15
3	19.0 ± 0.4 a C	5.0 ± 2.9 b B	18.8 ± 3.0 a D	2.5 ± 1.3 b B	9.83
4	22.5 ± 0.6 a C	6.5 ± 3.8 b B	25.5 ± 3.6 a D	2.5 ± 1.3 b B	12.01
5	27.3 ± 2.0 a C	4.0 ± 1.4 b B	39.3 ± 7.9 a CD	2.3 ± 1.3 b B	20.47
6	52.3 ± 9.7 a B	2.5 ± 0.5 c B	42.0 ± 11.0 ab BCD	4.8 ± 4.1 bc B	38.4
7	56.0 ± 8.9 ab B	6.0 ± 4.0 b B	79.5 ± 17.9 a ABC	4.8 ± 3.1 b B	52.12
8	81.8 ± 11.7 a AB	5.8 ± 2.8 b B	83.3 ± 17.7 a AB	1.0 ± 1.0 b B	53.55
9	104.8 ± 12.0 a A	5.8 ± 2.5 b B	104.0 ± 22.3 a A	3.3 ± 0.9 b B	54.54
10	111.9 ± 0.1 a A	0.7 ± 0.1 b B	107.4 ± 0.1 a A	1.0 ± 0.2 b B	5.30
HSD[2] p = 0.05***	12.56	50.72	8.50	5.14	

* Initial infestation (20 *S. granarius* & *S. zeamais* per replicates); ** Mean values of the same row followed by the same letter (a, b, ab, bc, c) were not significantly different ($p \geq 0.05$; HSD test); *** HSD was determined by comparing the average *S. granarius* & *S. zeamais* number in field maize and popcorn for each two-week evaluation period; [1]small letters refer to differences among corn hybrids: the data was log (x + 1) transformed; [2]capital letters refer to differences among evaluation periods: the data were arcsin transformed √x

Table 2. Field maize and popcorn (± SE) grain weight (g) across the 20-week experimental period

Evaluation Period	*S. granarius*		*S. zeamais*		HSD[1] p = 0.05 **
	Field maize	Popocorn	Field maize	Popocorn	
1[¥]	167.1 ± 1.2 b*1A2	193.1 ± 0.8 a A	170.4 ± 1.5 b A	189.4 ± 3.5 a A	13.64
2	158.8 ± 3.7 b A	189.1 ± 1.9 a AB	168.5 ± 1.5 b A	189.2 ± 1.9 a AB	12.02
3	158.1 ± 3.1 b AB	188.6 ± 1.4 a AB	158.0 ± 2.9 b AB	187.6 ± 1.5 a AB	8.25
4	155.9 ± 2.6 b AB	185.5 ± 2.2 a AB	154.3 ± 2.5 b B	187.2 ± 1.2 a B	10.49
5	152.3 ± 2.9 b AB	181.1 ± 2.2 a BC	153.9 ± 2.5 b B	186.4 ± 1.2 a B	12.04
6	147.5 ± 3.5 b BC	180.7 ± 1.6 a BC	152.5 ± 3.1 b BC	185.4 ± 1.1 a B	14.19
7	139.2 ± 5.1 b C	180.9 ± 5.1 a BC	138.4 ± 4.3 b CD	180.7 ± 1.9 a B	15.08
8	120.9 ± 2.6 b D	176.5 ± 2.3 a C	129.1 ± 6.4 b DE	180.5 ± 3.7 a C	31.62
9	120.1 ± 2.9 b D	175.5 ± 2.3 a C	122.5 ± 4.9 b E	179.8 ± 1.9 a C	13.65
10	115.7 ± 0.1 b D	173.8 ± 0.0 a C	115.7 ± 0.0 b E	176.9 ± 0.0 a D	24.61
HSD[2] p = 0.05***	10.63	11.82	14.15	12.17	

* Mean values of the same row followed by the same letter (a, b, ab) were not significantly different (p ≥ 0.05; HSD test); ** HSD was determined by comparing the average weight (four replicates) between infected corn hybrids for each two-week evaluation period; 1small letters refer to differences among hybrids infected with different pest: data were log (x + 1) transformed; 2capital letters refer to differences among evaluation periods: data were arcsin transformed √x. ¥ initial readings

Kernel moisture differed significantly between field corn and popcorn, with no changes between pest species. Moisture increased significantly after week 8 in both hybrids. In the final weeks of the experiment, kernel moisture increased by 35% in field corn with *S. granarius* and by 34% in field corn with *S. zeamais*. In popcorn, moisture was 12 % higher in the variant with *S. granarius* and 13 % higher in the variant with *S. zeamais*. Moisture differences between pest species were not significantly different (Table 3).

Significant differences in hectoliter mass after grain feeding by *S. granarius* and *S. zeamais* were observed in both hybrids. The highest significant hectoliter mass was found for the popcorn variant infected with *S. granarius*, with an overall loss of only 4% overall. The popcorn variant infected with *S. zeamais* had an even lower total loss, being only 3%. The lowest hectoliter mass was observed in the field corn hybrid infected with *S. granarius* with a 35% decline. The hectoliter mass of field corn infected with *S. zeamais* decreased by 36% (Table 4). Differences in hectoliter mass among pest species were not significantly different.

At the beginning of the study, a mass of 250 grams was weighed with a precise scale, which represented a repetition in the study. At each evaluation period, each replicate was sieved to remove impurities from the weevil food and reweighed to detect changes in weight. The results obtained are shown in Figure 1, from which it can be seen that the average weight of popcorn decreased by only 10 grams (4%) from the initial 250 grams. At the same time, the average sample weight of field maize decreased by 45 - 47 g (19%).

Table 3. Field maize and popcorn (± SE) kernel moisture across the 20-week experimental period

Evaluation Period	*S. granarius*		*S. zeamais*		HSD[1] *p* = 0.05 **
	Field maize	Popocorn	Field maize	Popocorn	
1[¥]	11.4 ± 0.3 D2	10.3 ± 0.3 C	11.1 ± 0.5 B	10.1 ± 0.4 C	1.43
2	12.3 ± 0.4 D	10.7 ± 0.4 C	11.7 ± 0.2 B	10.3 ± 0.1 C	1.22
3	13.8 ± 0.5 a D	10.9 ± 0.3 b C	12.1 ± 0.7 a B	10.7 ± 0.3 b C	1.93
4	14.4 ± 0.4 a*1CD	11.1 ± 0.3 b B	12.2 ± 0.2 a AB	10.7 ± 0.3 b C	1.34
5	14.4 ± 0.3 a CD	10.9 ± 0.4 b B	12.4 ± 0.1 a AB	10.6 ± 0.2 b C	0.89
6	14.9 ± 0.4 a CD	11.1 ± 0.3 b B	13.1 ± 0.2 a AB	11.1 ± 0.2 b BC	1.17
7	15.4 ± 0.2 a BC	11.0 ± 0.4 b B	14.0 ± 0.5 a AB	11.3 ± 0.4 b BC	1.97
8	16.5 ± 0.6 a AB	11.2 ± 0.2 b AB	14.6 ± 0.3 a AB	11.4 ± 0.2 b B	0.69
9	16.6 ± 0.5 a AB	11.4 ± 0.2 b AB	15.7 ± 0.0 a AB	11.4 ± 0.7 b B	0.62
10	17.4 ± 0.0 a A	11.7 ± 0.0 b A	16.8 ± 0.0 a A	11.6 ± 0.0 b A	2.41
HSD[2] *p* = 0.05***	0.05	1.04	1.67	1.13	

* Mean values of the same row followed by the same letter (a b, ab, c) were not significantly different (p ≥ 0.05; HSD test); ** HSD was calculated by comparing the average kernel moisture (four replicates) between infected corn hybrids for each two-week evaluation period; [1]small letters refer to differences among hybrids: data were log (x + 1) transformed; [2]capital letters refer to differences among evaluation periods: data were arcsin transformed √x. [¥] initial readings

Table 4. Hectoliter mass of field maize and popcorn (± SE) over a 20-week experimental period

Evaluation Period	*S. granarius*		*S. zeamais*		HSD[1] *p* = 0.05 **
	Field maize	Popocorn	Field maize	Popocorn	
1[¥]	83.5 ± 0.6 b*1 A2	96.6 ± 2.1 a A	85.3 ± 0.7 b A	93.7 ± 2.3 a A	7.77
2	79.1 ± 1.3 b A	95.5 ± 1.8 a A	82.5 ± 1.8 b AB	93.5 ± 2.6 a A	5.72
3	78.23 ± 1.2 b A	94.9 ± 2.9 a AB	79.7 ± 1.1 b ABC	92.8 ± 2.2 a AB	8.98
4	76.4 ± 0.9 b AB	94.7 ± 2.5 a AB	77.1 ± 1.8 b ABC	92.4 ± 1.5 a AB	8.34
5	75.3 ± 0.6 b AB	94.1 ± 2.6 ab AB	75.2 ± 1.6 b BC	92.2 ± 1.2 a B	4.48
6	72.2 ± 1.5 b B	93.9 ± 2.6 a B	74.8 ± 1.3 b BC	92.0 ± 1.8 a B	8.13
7	71.1 ± 1.5 b B	93.8 ± 2.8 a B	73.3 ± 0.6 a C	91.7 ± 1.4 a B	6.56
8	59.4 ± 0.5 b C	94.0 ± 0.7 a B	62.1 ± 2.9 b D	92.1 ± 1.6 a C	6.35
9	56.8 ± 1.4 b C	93.3 ± 1.1 a B	58.8 ± 3.3 b D	92.0 ± 1.6 a C	6.91
10	54.4 ± 0.0 b C	92.9 ± 0.0 a B	55.0 ± 0.0 b D	91.2 ± 0.0 a C	10.1
HSD[2] *p* = 0.05***	5.61	8.72	9.01	9.40	

* Mean values of the same row followed by the same letter (a, b, ab) were not significantly different (*p* ≥ 0.05; HSD test); ** HSD was determined by comparing the average hectoliter mass (four replicates) between corn hybrids for each two-week evaluation period); [1]small letters refer to differences among hybrids: data were log (x + 1) transformed; [2]capital letters refer to differences among evaluation periods: data were arcsin transformed √x. [¥] initial reading prior to experiment

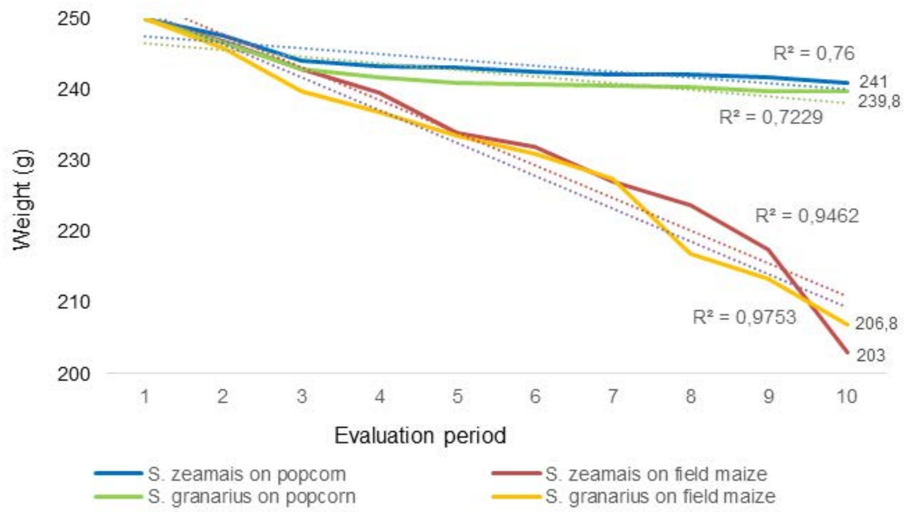

Figure 1. Changes in average weight of a maize hybrids during the total evaluation period

DISCUSSION

The study was conducted with the main objective of determining the harmfulness of two weevil species (*S. granarius* and *S. zeamais*) on two different maize hybrids (field maize and popcorn). The additional objective was to determine the reproductive potential of these weevil species during feeding on different maize hybrids.

Based on the results we conclude that different maize hybrids have different susceptibility to *Sitophilus* species. According to Horber (1988), the index of susceptibility assumes that the more F1 progeny and the shorter the development period, the more susceptible the seeds would be. In this study, field maize was highly susceptible to both weevil species and affected their biological potential, i.e. reproduction and population growth, while popcorn showed some resistance to both *Sitophilus* species. The results corroborate the studies of Rajkumar et al. (2015) who found that popcorn hybrids showed some resistance to weevils due to their nuclear structure which does not affect insect feeding. It is believed that this is due to the kernel hardiness of this variety. In their studies, high mortality rate of rice weevil (*S. oryzae* L.) was observed while feeding on popcorn. In our study, higher mortality rate of *S. granarius* and *S. zeamais* was observed in the popcorn variant as compared to the field maize variant. A similar result was reported by Suleiman et al. (2015) and Keba and Sori (2013) who concluded that small grains like popcorn, which are hard and compact, lead to a resistance to infestation by *S. zeamais*. For *S. oryzae*, grain hardness was reported as the main resistance parameter (Bamaiyi et al., 2007). Previous research groups are studying *S. zeamais* and *S. oryzae*, while we observed the same pattern in *S. granarius*.

No differences in final abundance were found when comparing Sitophilus species. Ritz (1997) found that *S. zeamais* requires 26-30 days at 25°C for a complete development cycle, while *S. granarius* requires 35-45 days in Croatian conditions. That is, *S. zeamais* has a 10 to 15 days shorter development cycle compared to *S. granarius*. It was observed that *S. zeamais* had a slightly shorter developmental cycle than *S. granarius* under the same conditions. This was not the case in our study where no significant differences were observed between *Sitophilus* species throughout the experimental period. Also, Goftishu and Belete (2014) found that *S. zeamais* required less development time in soft grain varieties (31 days) while the resistant varieties required longer development time (42 days). Dobie (1974) found that the mortality rate of *S. zeamais* on different field maize cultivars was low. Abraham (1991) also suggested that mortality rate is not a good indicator of susceptibility because adult weevils can survive more than ten days without food. However, in this study, it is possible to conclude that the popcorn cultivar may be resistant because both *Sitophilus* species reduced their populations without developing an F1 generation.

The results of moisture measurements during the study showed that the moisture increased in the variant with field maize (with the increased number of weevils). Weevils cause mechanical damage and increas moisture content (Bhusal and Khanal, 2019). Although this study confirmed that higher percentage of moisture favors insect reproduction (Maceljski, 2002), we can also conclude that high reproduction of weevils and their biological activity is strongly related to increased moisture in the field maize variant. In the popcorn variant, moisture increased only by 1.4 - 1.5% during the 20 weeks of the study, and such a low percentage of moisture may be a limiting factor for further weevil reproduction and the cause of their low numbers throughout the experiment (Ritz, 1997).

Results of hectoliter mass measurements of the hybrids showed a significant decrease in field maize during the 20 weeks of the study. The hectoliter mass of field maize decreased by 35-36% during the study, while the hectoliter mass of popcorn decreased by only 3-4% during the same period. The results confirm the fact that the decrease in hectolitre mass is caused by soft flours, hollow and unfilled kernels (Dobričević et al., 1995). The results showed no difference between the diet of *S. granarius* and *S. zeamais*, both species caused almost identical decrease in hectolitre mass of both maize hybrids.

Each sample in the study had an initial weight of 250 grams. Weight changes during the 20 weeks of the study are evidence of the harmfulness of weevils to maize grain. Weight loss was highly correlated with maize varieties. The highest weight loss was found in field maize variety with high progeny emergence compared to popcorn with low progeny emergence or high mortality. Popcorn weight decreased by an average of only 4% throughout the study period, which was expected given the very small number of individuals that survived in these samples. At the same time, the weight of field maize decreased by an average of 19%. Our study agrees with the findings of Okoroafor et al. (2017) who investigated the harmfulness of weevils to popcorn and local field hybrids. It was confirmed that popcorn contains phytochemicals and minerals that determine the resistance of the cultivar to weevil feeding and consequently lead to a reduction in the number of weevils, i.e. mortality. In the mentioned studies, weevils caused great damage to grain maize, which not only resulted in the loss of mass of stored maize, but this maize became inappropriate for human and livestock consumption. As was stated in Caneppele et al. (2003) the higher the insect infestation was, the greater were the changes in commercial standards. This study showed that both weevil species (*S. zeamais* and *S. granarius*) caused equal damage to the field maize variety. The weevils' diet on field maize also favors their reproduction. Infestation with *S. granarius* and *S. zeamais* significantly reduces the physiological quality of field maize seed and affects commercial grain grading.

CONCLUSION

Different maize hybrids show different susceptibility to weevils. Both weevil species have the same influence on the physical properties of the grain. No differences in changes in weight, hectoliter mass and moisture were found between maize infested with different weevil species, but differences in all measured properties were significant between maize hybrids. Because of its grain structure, popcorn does not favor feeding by weevils, i.e., it has some resistance to weevils. Field maize has characteristics that favor feeding and reproductive potential of weevils, resulting in a reduction in its weight and quality and making it unsuitable for human and livestock consumption. Maize weevil (*S. zeamais*) and granary weevil (*S. granarius*) equally cause damage to field corn. Popcorn varieties with low susceptibility indices can be stored for a longer period.

REFERENCES

Abraham, T. (1991) The biology, significance and control of the maize weevil, *Sitophilus zeamais* Motsch. (Coleoptera: Curculionidae) on stored maize. An M.Sc. Thesis, University of Agriculture, Ethiopia. p. 250.

Bamaiyi, L.J., Dike, M.C., Onu, I. (2007) Relative susceptibility of some sorghum varieties to the rice weevil *Sitophilus oryzae* L. (Coleoptera: Curculionidae). Journal of Entomology, 4 (5), 387-392. DOI: https://doi.org/10.3923/je.2007.387.392

Beckett, S.J., Fields, P.G., Subramanyam, Bh. (2007) Disinfestation of stored products and associated structures using heat. In: Tang, J., Mitcham, E., Wang, S., Lurie, S., eds. Heat Treatments for Postharvest Pest Control, CAB International, UK, pp. 182-237.

Bell, A. (2000) Protecting stored maize cobs against pests by the use of non chemical products: a strategy of integrated post-harvest protection. CABI 6 pp.

Bergvinson, D.J. (2001) Storage pest resistance in maize. In: Maize Program Maize Research Highlights, 1999 e 2000. CIMMYT, Mexico D.F, pp. 32-39.

Bhusal, K., Khanal, D. (2019) Role of Maize Weevil, *Sitophilus zeamais* Motsch. on Spread of *Aspergillus* section flavi in Different Nepalese Maize Varieties. Advances in Agriculture, Article ID 7584056. DOI: https://doi.org/10.1155/2019/7584056

Birch, L.C. (1944) Two strains of *Calandra oryzae* L. (Coleoptera). Australian Journal of Experimental Biology and Medical Science, 22 (4), 271-275. DOI: https://doi.org/10.1038/icb.1944.39

Boutard, A. (2012) Beautiful Corn: America's Original Grain from Seed to Plate. New Society Publishers, Gabriola Island, Canada.

CABI (2021a) Invasive Species Compendium: *Sitophilus zeamais* (greater grain weevil). [Online] Available at: https://www.cabi.org/isc/datasheet/10926#D340A884-698C-4A90-9676-0F7A683A1700 [Accessed 10 January 2021]

CABI (2021b) Invasive Species Compendium: *Sitophilus granarius* (grain weevil). [Online] Available at: https://www.cabi.org/isc/datasheet/10850. Accessed: 10.1.2021.

Cai, Q.N., Zhang, Q.W., Cheo, M. (2004) Contribution of indole alkaloids to *Sitobion avenae* (F.) resistance in wheat. Journal of Applied Entomology, 128 (8), 517 – 521. DOI: https://doi.org/10.1111/j.1439-0418.2004.00770.x

Caneppele, M.A.B., Caneppele, C., Lázzari, F.A., Lázzari, S.M.N. (2003) Correlation between the infestation level of *Sitophilus zeamais* Motschulsky, 1855 (Coleoptera, Curculionidae) and the quality factors of stored corn, *Zea mays* L. (Poaceae). Revista Brasileira de Entomologia, 47(4), 625-630. DOI: https://doi.org/10.1590/S0085-56262003000400015

CroatiaWeek (2020) Croatia's 2020 maize crop highest in the past 10 years. CroatiaWeek, October 15, 2020. [Online] Available at: https://www.croatiaweek.com/croatias-2020-maize-crop-highest-in-past-10-years/ [Accessed 20 November 2020]

Debona, D., Rodrigues, F.A., Rios, J.A., Nascimento, K.J.T., Silva, L.C. (2014) The effect of silicon on antioxidant metabolism of wheat leaves infected by Pyricularia oryzae. Plant Pathology, 63 (3), 581–589. DOI: https://doi.org/10.1111/ppa.12119

Delima, C.P.F. (1987) Insect pests and postharvest problems in the tropics. International Journal of Tropical Insect Science, 8, 673-676. DOI: https://doi.org/10.1017/S1742758400022773

Derera, J., Pixley, K.V., Giga, D.P., Makanda, I. (2014) Resistance of maize to the maize weevil: III. Grain weight loss assessment and implications for breeding. Journal of Stored Products Research, 59, 24-35. DOI: https://doi.org/10.1016/j.jspr.2014.04.004

Dhliwayo, T., Pixley, K.V., Kazembe, V. (2005) Combining ability for resistance to maize weevil among 14 Southern African maize inbred lines. Crop Science, 45 (2), 662-667. DOI: https://doi.org/10.2135/cropsci2005.0662

Dinuţă, A., Bunescu, H., Bodis, I. (2009) Contributions to the Knowledge of Morphology of the Granary Weevil (*Sitophilus granarius* L.), Major Pest of the Stored Cereals. Bulletin of University of Agricultural Sciences and Veterinary Medicine Cluj-Napoka. Agriculture, 66, 59–66. DOI: https://doi.org/10.15835/BUASVMCN-AGR:3731

Dobie, P. (1974) The laboratory assessment of the inherent susceptibility of maize varieties to post harvest infestation by *Sitophilus zeamais* Motsch. (Coleoptera: Curculionidea). Journal of Stored Products Research, 10 (3-4), 183-197. DOI: https://doi.org/10.1016/0022-474X(74)90006-X

Dobričević, N., Pliestić, S., Marijić, M. (1995) Promjene hektolitarske mase kukuruza u procesu sušenja. XI Međunarodno savjetovanje tehnologa sušenja i skladištenja, Zbornik radova, Stubičke Toplice.

European Commission (2020) Main Annual Crop Statistics. European Commission, Eurostat. [Online] Available at: https://ec.europa.eu/eurostat/statistics-explained/pdfscache/28946.pdf [Accessed 25 November 2020].

Giga, D.P., Mazarura, U.M. (1991) Levels of Resistance to the Maize Weevil, *Sitophilus Zeamais* (Motsch.) in Exotic, Local Open-Pollinated and Hybrid Maize Germplasm. International Journal of Tropical Insect Science, 12 (1-2-3), 159-169. DOI: https://doi.org/10.1017/S1742758400020646

Goftishu, M., Belete, K. (2014) Susceptibility of sorghum varieties to the maize weevil *Sitophilus zeamais* Motschulsky (Coleoptera: Curculionidae). African Journal of Agricultural Research, 9 (31), 2419-2426. DOI: https://doi.org/10.5897/AJAR2014.8634

Gylling Data Management Inc. ARM 2019® GDM Software, Revision 2019.4, August 5, 2019 (B = 25105); Brookings, South Dakota, USA, 2019.

Horber, E. (1988) Methods to detect and evaluate resistance in maize to seed insects in the field and in storage. In. Towards insect resistance maize for the third world: Proceedings of international symposium on methodologies for developing host plant resistance to maize insects. pp. 140-150. CYMMYT, El Batan, Mexico D.F. CYMMYT.

Hossain, F., Bodduplli, P.M., Sharma, R.K., Kumar, P., Singh, B.B. (2007) Evaluation of quality protein maize genotype for resistance to stored grain weevil *Sitophilus oryzae* (Coleoptera: Curculionidae). International Journal of Tropical Insect Science, 27, 114-121. DOI: https://doi.org/10.1017/S1742758407814676

Howe, R.W. (1952) The biology of the rice weevil, *Calandra oryzae* (L.). Annales of Applied Biology, 39 (2), 68-180. DOI: https://doi.org/10.1111/j.1744-7348.1952.tb00895.x

Keba, T., Sori, W. (2013) Differential resistance of maize varieties to maize weevil (*Sitophilus zeamais* Motschulsky) (Coleoptera: Curculionidae) under laboratory conditions. Journal of Entomology, 10 (1), 1-12. DOI: https://doi.org/10.3923/je.2013.1.12

Korunić, Z. (1990) Štetnici uskladištenih poljoprivrednih proizvoda. Gospodarski list, Zagreb.

Lale, N.E.S., Kartay, M.O. (2006) Role of physical characteristics of the seed in the resistance of local cultivars of maize to *Sitophilus zeamais* infestation in storage. Tropical Science, 46 (1), 1-3. DOI: https://doi.org/10.1002/ts.5

Longstaff, B.C. (1981) Biology of the grain pest species of the genus *Sitophilus* (Coleoptera: Curculionidae): a critical review. Protection Ecology, 3 (2), 83-130.

Maceljski, M. (2002) Poljoprivredna entomologija II. dopunjeno izdanje. Čakovec: Zrinski d.d.

Ojo, J.A., Omoloye, A.A. (2012) Rearing of maize weevil, *Sitophilus zeamais* on an artificial maize-cassava diet. Journal of Insect Science, 12 (1), 69. DOI: https://doi.org/10.1673/031.012.6901

Okoroafor, E., Job, M.O. (2017) Post-Harvest Loss And Nutritional Quality Of Popcorn And Local Maize Varieties Infested And Damaged By Maize Weevil, *Sitophilus zeamais* Motsch (Coleoptera: Curculionidae). IOSR Journal of Biotechnology and Biochemistry, 3 (4), 63-67. DOI: https://doi.org/10.9790/264X-03046367

Ozberk, I., Atlıb, A., Pfeifferc, W., Ozberkd, F., Coskune, Y. (2005) The effect of sunn pest (*Eurigaster integriceps*) damage on durum wheat: Impact in the marketplace. Crop Protection, 24 (3), 267–274. DOI: https://doi.org/10.1016/j.cropro.2004.07.013

Paes, J.L., Faroni, L.R.D., Dhingra, O.D., Cecon, P.R., Silva, T.A. (2012) Insecticidal fumigation action of mustard essential oil against *Sitophilus zeamais* in maize grains. Journal of Crop Protection, 34, 56–58. DOI: https://doi.org/10.1016/j.cropro.2011.11.021

Pellegrineschi, A., Brito, R.M., Velazquez, L., Noguera, L.M., Pfeiffer, W., McLean, S., Hoisington, D. (2002) The effect of pretreatment with mild heat and drought stresses on the explant and biolistic transformation frequency of three durum wheat cultivars. Plant Cell Reports, 20, 955–960. DOI: https://doi.org/10.1007/s00299-002-0438-z

Rajkumar, Z., Firoz, H., Vignesh, M., Mukesh, C., Pradyumn, K., Javaji C.S., Satish K. G., Narendra, K.S., Napolean, T., Hari, S.G. (2015) Popping quality attributes of popcorn hybrids in relation to weevil (*Sitophilus oryzae*) infestation. Indian Journal of Genetics and Plant Breeding, 75 (4), 510-513. DOI: https://doi.org/10.5958/0975-6906.2015.00081.4

Rees, D.P. (2004) Insects of Stored Products. CSIRO Publishing, Victoria, Australia; Manson Publishing, London, UK, 181 pp. Manson Publishing, Ltd., UK.

Richards, O.W. (1947) Observations on grain weevils, Calandra (Col., Curculionidae). I. General biology and oviposition. Proceedings of the Zoological Society in London, 117 (1), 1-43. DOI: https://doi.org/10.1111/j.1096-3642.1947.tb00492.x

Ritz, J. (1997) Uskladištavanje ratarskih proizvoda. Knjiga 1. Zagreb: Pbi d.o.o., 28 pp.

Rotim, N., Ostojić, I. (2014) Najvažniji štetnici uskladištenih poljoprivrednih proizvoda na području Bosne i Hercegovine. Glasnik zaštite bilja, 37 (6), 40¬–45.

Serratos, A., Arnason, J.T., Nozzolillo, C., Lambert, J.D.H., Philogène, B.J.R., Fulcher, G., Davidson, K., Peacock, L., Atkinson, J., Morand, P. (1987) Factors contributing to resistance of exotic maize populations to maize weevil, *Sitophilus zeamais*. Journal of Chemical Ecology, 13, 751–762. DOI: https://doi.org/10.1007/BF01020157

Statista (2020) Global corn production in 2019/2020, by country. Statista. [Online] Available at: https://www.statista.com/statistics/254292/global-corn-production-by-country/#statisticContainer [Accessed 25 November 2020].

Suleiman, R., Rosentrater, K., Bern, C. (2015) Evaluation of maize weevils *Sitophilus zeamais* Motschulsky infestation on seven varieties of maize. Journal of Stored Products Research, 64 Part B., 97-102. DOI: https://doi.org/10.1016/j.jspr.2015.09.005.

Tabatabeefar, A. (2003) Moisture-dependent physical properties of wheat. International Agrophysics, 17 (4), 207–211.

Tefera, T. (2012) Post harvest losses in African maize in the face of increasing food shortage. Food Security, 4, 267–277. DOI: https://doi.org/10.1007/s12571-012-0182-3

Vélez, M., Barbosa, W.F., Quintero, J., Chediak, M., Guedes, R.N.C. (2017) Deltamethrin- and spinosad-mediated survival, activity and avoidance of the grain weevils *Sitophilus granarius* and *S. zeamais*. Journal of Stored Products Research, 74, 56-65. DOI: https://doi.org/10.1016/j.jspr.2017.10.002

Wakefield, M.E., Bryning, G.P., Chambers, J. (2005) Progress towards a lure to attract three stored product weevils, *Sitophilus zeamais* Motschulsky, *S. oryzae* (L.) and *S. granarius* (L.) (Coleoptera: Curculionidae). Journal of Stored Products Research, 41 (2), 145-161. DOI: https://doi.org/10.1016/j.jspr.2004.01.001