Since *S. paniceum* sex pheromone attracts only males and loses its attractive capacity after two weeks at room temperature (Kodama et al., 1987), it is desirable to exploit alternative attractants for monitoring this pest. In anobiid beetles that feed on stored products, the use of food volatiles that, acting as kairomones, synergize the pheromone lures have been successful tested on *L. serricorne* (i.e. VOCs from *Capsicum* spp.) (Mahroof and Phillips, 2007). Similarly, the results of our study showed that the headspace elution, containing the VOCs from *S. paniceum* colony, is an attractant for both sexes of this pest species. In this context, our study gave the basis for the development of a new alternative and sustainable attractant for trapping the drugstore beetle. Further investigations are in progress aimed to identify which are the behavioral-active VOCs of the entire chemical composition involved in the attraction of *S. paniceum* adults.

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Field trials on attractiveness of the synthetic sex pheromone of the four-spotted bean weevil, *Callosobruchus maculatus* Fabricius (Coleoptera: Bruchidae).

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Abstract

Quarantine pests of legumes pose a threat to many countries of the world including Russia. Pests that can enter the country as a result of the transportation of regulated articles (by sea, air, road, rail, etc.) pose a particular danger (Shutova, 1970; Dankvert *et al*., 2009). Monitoring and identification of legume pests is complicated by the fact that small beetles have a hidden mode of life. One of the most dangerous quarantine pest is the four-spotted bean weevil *Callosobruchus maculatus* Fabricius (Coleoptera: Bruchidae), which is widespread throughout the world and can cause serious economic losses in agriculture of Russia. Research work on the identification, synthesis and laboratory evaluation of the synthetic sex pheromone of *Callosobruchus maculatus* was carried out at the All-Russia Plant Quarantine Center (Bykovo, Moscow region). Tests have shown that synthesized sex pheromone of *C. maculatus* has a high attractiveness for males. An effective dose of pheromone that attracts males of the four-spotted bean weevil has been found at the laboratory and is equal to 0.5 µg per dispenser. Thereafter tests have shown that the concentration of pheromone above 2 µg does not cause behavioral response in beetles and doesn't result in contact with the stimulus. Dispensers with doses of pheromone from 4 to 8 mg have been used with a Delta trap in storage. The use of pheromone traps can help in pest identification, decreasing or complete avoidance of repeated treatments with chemicals at low pest population. The results of this study will be presented and discussed on the basis of laboratory and literature data.

Keywords: *Callosobruchus maculatus*, synthetic sex pheromone, pheromone trap, monitoring, plant quarantine.

Introduction

Polyphagous bruchids of genus *Callosobruchus* Pic (Coleoptera: Bruchidae) are the most dangerous pests of legumes. The most severely damaged crops are mung bean (*Phaseolus aureus*), chickpea (*Cicer*), pigeon pea (*Cajanus*), green pea (*Pisum sativum*), field bean (*Vicia faba*), cow pea (*Vigna*), soybean (*Glycine max*), lentil (*Lens*) and bean (*Phaseolus*) – in these crops seed damage can reach up to 100%. Beetles not only reduce the yield in fields, but also are imported to storages with harvested seeds and continue developing as storage pests without diapause. Therefore, pests drastically reduce the food value and crop quality in many legumes. Totally the genus *Callosobruchus* includes 15 species. In practice, 4 species of this genus are most often imported to Russia, namely: *Callosobruchus phaseoli* Gyll. – cosmopolitan seed beetle, *C. analis* L. – Graham bean weevil, *C. chinensis* L. – Chinese bean weevil and *C. maculatus* F. – four-spotted bean weevil (Sadomov and Mordkovich, 2004). All these species are similar in biology, harmfulness and habitats. Morphologically they clearly differ in adult form, but larvae are indistinguishable. Species of genus *Callosobruchus* are designated in the unified list of quarantine objects of the Eurasian Economic Union (approved by the Council Decision of the Eurasian Economic Commission dated November 30, 2016 № 158, entered into force from 1st of July 2017).

Fig. 1 Male imago of the four-spotted bean weevil *Callosobruchus maculatus* F.

Fig. 2 Male imago of the four-spotted bean weevil *Callosobruchus maculatus* F. feeds on a pea seed.

In practice, the Russia's federal service for veterinary and phytosanitary surveillance uses a complex visual method to identify the four-spotted bean weevil. But one may significantly reduce labor costs and improve efficiency of quarantine monitoring of beetles by using pheromone traps in the field and storages for monitoring and identification (Smetnik *et al*., 1986; Burov and Sazonov, 1987; Phillips *et al*., 1996). Synthetic pheromone was synthesized at the Department of Synthesis and Application of Pheromones in All-Russia Plant Quarantine Center in 2012. In laboratory tests with olfactometer synthesized pheromone has attracted males of *C. maculatus* effectively at dose of 0.5 µg. The experiments as well have shown that the concentration of pheromone above 2 µg does not cause behavioral responses by beetles and doesn't result in their contact with the stimulus (dispenser).

Field trials on attractiveness of synthetic sex pheromone of the four-spotted bean weevil were conducted on the basis of the "Nikola Pushkarov" Institute of Soil Science and Agroecology in Bulgaria as part of bilateral R&D work. Trials were carried out in order to determine the biological activity of pheromone of the four-spotted bean weevil *C. maculatus* F. for early detection in the area of its distribution.

Materials and Methods

Field trials

Field trials were conducted in 2014 from 15th of August till 14th of September. The experimental field is located in the village of Skryt (*41°23'53"N, 23°12'27"E*), which is suburb of Petrich, Blagoevgrad region, close to the border with Macedonia. The trial has been set at the field of *Vigna sinensis* L. in the time of the ripening of beans when the beetles cause the highest danger.

Delta traps with sticky inserts were used for trials, at the center of which the dispensers with correspondent doses of pheromone of *C. maculatus* were placed. Insect monitoring was carried out within a month from the date of installation, in total 6 records were carried out. Pheromone doses applied to the dispenser are the following: variant I (control)– 0 mg, II – 1 mg, variants III and IV – 2 and 3 mg, respectively. A rubber cork has been chosen as a material for the dispenser, which has the property of prolonged and gradual release of the chemicals for a long period of time. The number of replications over all variants was 3.

Storage trials

In 2015 and 2017, trials on the biological activity of the pheromone during storage of legumes were conducted in the storage at the Institute of Soil Science and Agroecology in Kostinbrod (Bulgaria). Trials were carried out in a facility with a total area of 25 m^2. In a storage, damaged leguminous crops infested by *C. maculatus* in the field were stored. *Vigna radiata* L. and *Vigna sinensis* (L.) Walpers were stored crops in 2015 and 2017 respectively, that had been grown in the southwest of Bulgaria in the territory of ecological agriculture and were not treated by pesticides during periods of cultivation and storage. In the course of trial, there were no other insect pests and diseases on beans. The average temperature in the storage ranged from 23°C to 25°C, and relative air humidity was 65-70%. The experimental traps were placed in a randomized way throughout the area of the storage at a height of 1.5 m at available places (Lebedev *et al.*, 1984; Dospekhov, 1985). The distance between traps was not less than 2 meters.

In 2015, the doses of pheromone applied to the dispenser were the following: variant I – 2 mg, II – 10 mg, variants III and IV – 6 and 20 mg, respectively. Rubber cork was used as dispenser for variants I and III, and spongy material wicks for variants II and IV. A Delta trap with sticky glue insert was used for catching imago of *C. maculatus*. The research was carried out on *Vigna radiata* L. over 26 days (from 8th of August to early September). There were 5 replications and 6 surveys were done during the season. In 2017, an identical trial was set up during the storage period of beans of *Vigna sinensis* L. Walpers. The following doses of pheromone (by variants) were used: I – 2 mg, II – 4 mg, III – 8 mg and IV – 16 mg. There were 6 replications and 5 surveys were done during the season. Two types of traps were used: Delta and "Book" (storage trap type); dispenser with the appropriate dose of synthetic sex pheromone of the four-spotted bean weevil was placed to the center of the traps. Insect monitoring was carried out for 41 days (from 2nd of August to 11th of September). The recording and sampling of insects from traps was made every 10 days from the period of adult emergence and the beginning of insect flight.

Obtained data was processing by statistical methods and differences determined with least significant difference test (LSD).

Results

Field trials

Results of 2014 trial showed that the dynamics of imago flight to traps was extremely low, that was probably due to the low number of beetles in the field. Statistical differences (*LSD test,* F_{05}, t_{05}) between the tested variants were not revealed (Table 1). However, traps with the dispenser of variant II (1 mg of synthetic pheromone per dispenser) showed the highest attractiveness, and can be recommended for quarantine monitoring. Traps with dispensers III and IV (2 mg and 3 mg pheromone on the dispenser, respectively), and control traps (variant I without pheromone application) showed similar results (Table. 1). Variant II with 1 mg of pheromone had the highest results among the selected doses and control (*F*=4,76).

Tab. 1 Number of male insects caught during the period of flight.

variants	pheromone doses	average number of male beetles caught per one trap	significance
I (control)	0 mg	*1.4*	n.s.
II	1 mg	*2.4**	s.
III	2 mg	*1.1*	n.s.
IV	3 mg	*1.1*	n.s.

LSD_{05} = 0.94

Storage trials

Results of trials in 2015 showed that the largest number of caught male insects recorded in traps were with dispenser IV, with 27.3 individuals per trap during the flight period. Average number of male beetles per one trap in variants I, II and III were 12.7, 18.7 and 10.3 individuals, respectively (Table 2). At the same time, the average number for all variants (x_{avg}) was =17.25 male individuals per trap. The ratio of females (f) and males (m) in different variants was: I – 19 f:m 38, II - 5 f:m 56, III - 10 f:m 31 and IV - 17 f:m 82. The ratio of the total number of caught insects - 207 males and 51 females, i.e. 80.2% and 19.8%, respectively.

A long period of monitoring allowed us to estimate the dynamics of flight and the number of beetles of *C. maculatus*, it was stable and quite high.

Tab. 2 Trials in 2015: Number of male and female insects caught during the period of flight.

variants	pheromone doses	average catching of male beetles per one trap	significance	total number of caught males per one trap	total number of caught females per one trap
I	2 mg	*12.7*	n.s.	38	19
II	10 mg	*18.7*	n.s.	56	5
III	6 mg	*10.3*	n.s.	31	10
IV	20 mg	*27.3**	s.	82	17

LSD_{05} = 2.58

Statistical data processing has shown that there was a significant difference in insects caught among the tested variants. At the same time, variants I and II had the lowest attractiveness and number of caught insects was at the same level. Thus, for quarantine monitoring of the four-spotted bean weevil we can recommend the dispenser in the form of a spongy material wick with a dose of 20 mg of pheromone per dispenser.

Results of the trial conducted in 2017 did not reveal significant differences in the attractiveness among pheromone traps with tested types of dispensers: nearly the same number of insects was caught in variants with doses of 2, 4 and 8 mg (from 1.6 to 1.9 beetles per trap). The total number of captured insects was 67, of which 64 males and 3 females, representing 95.5% males and 4.5% females. The ratio of female (f) and male (m): I – 1:15, II - 2:12, and III and IV variants caught only males, 16 and 10, respectively. At the same time average number for all variants was 2.3 individuals per trap.

Tab. 3 Trials in 2017: Number of male and female insects caught during the period of flight.

variants	pheromone doses	average catching of male beetles per one trap	significance	total number of caught males per one trap	total number of caught females per one trap
I	2 mg	*2,7*	n.s.	15	1
II	4 mg	*2,3*	n.s.	12	2
III	8 mg	*2,7*	n.s.	16	0
IV	16 mg	*1,7*	n.s.	10	0

LSD_{05} = 8.47

Most attractive type of trap was Delta with variants IV (8 mg) and I (2 mg). The "Book" type trap caught significantly fewer insects than Delta. Average number of caught insects in "Book" type trap was extremely low (0.3 males per trap for the entire period of flight), while the trap Delta consistently showed high results compared to the latter and the number of caught males on average for all variants was 2.3 individuals, that is 2 times more than for the "Book" trap type.

Traps with variants IV and I caught only males of *C. maculatus*, 16 and 15 individuals respectively. Pheromone dispensers with doses of 8 mg and 2 mg were the best attractive substance for catching insect males. In variants II (4 mg) and V (16 mg), the number of captured males was 12 and 10, respectively. It is possible to make the assumption that under conditions of closed spaces (storages) these dispensers may cause an effect of insect disorientation.

The attractiveness of all pheromone traps used in the trials was high enough throughout the research period; therefore, dispensers were not replaced.

Discussion

Trials were carried out according to the original method developed at All-Russia Plant Quarantine Center. It allowed us to draw a conclusion that the synthetic sex pheromone of the four-spotted bean weevil *C. maculatus* possesses biologically active properties and is attractive for males of this pest species. Based on results of the field trials in 2014, it can be concluded that variant II (1 mg of pheromone per dispenser) showed the highest results among the selected doses (F=4,76). It should be assumed that variant II is most effective for attracting individuals of the four-spotted bean weevil into traps in early flight of insects in the field during the ripening of beans.

Evaluation of attractiveness of various doses of pheromone showed the possibility of disorientation of the four-spotted bean weevil in storage during the trial in 2015. At the same time, in a closed room with a constant temperature and humidity the dose of applied pheromone may vary in dependence on dispenser type used in traps. For example, capture efficiency was the optimum when using Delta type traps with a wick and applied pheromone in dose of 20 mg rather than when using an insulin cork as dispenser.

Storage trial in 2017, taking into account the dynamics of male numbers of *C. maculatus* attracted by pheromone, Delta traps with variants 4 (8 mg) and 1 (2 mg) were the best options in terms of attractiveness. In almost all cases, the "Book" trap type attracted significantly fewer insects than the Delta. In all variants, average number of caught insects in the "Book" trap type was 2 times lower than for Delta trap.

A long period of monitoring allowed us to estimate the dynamics of flight and the number of beetles of *C. maculatus*, during the trial it was stable and quite high.

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A Multi-parameter Grain Detection System Based on Industry 4.0

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Abstract

A multi-parameter grain detection system based on industry 4.0 was used to map all kinds of sensors and devices into multiple network addresses through the integration of equipment, to realize the local visual perception and the network transmission of various grain data, using software plug-in architecture technology to build online extension of the software to achieve the corresponding grain multi-parameter monitoring plug-ins; setting sensor and device communication protocol standards to achieve remote monitoring of various grain situation data on the scene equipment Remote debugging and maintenance work to form a remote data center and equipment maintenance center. The system is compatible with a wide range of heterogeneous sensors and devices online and with a high degree of online scalability.

Keywords: grain detection system; Industry 4.0; the integration of equipment

Introduction

The grain detection system is a system that uses modern electronic technology to detect, store and analyze ecological parameters of stored grain. The current system has major problems such as single function, poor compatibility, poor extension capability, and low level of intelligence. The design architecture lacks systemic considerations. It is difficult for different manufacturers and different kinds of data to be integrated in one system. The system integration of different sensors and equipment is difficult and incompatible, and it is unable to achieve integrated collection, control and data transmission, and it is no longer adaptable to new demands.

The stored grain detection system implemented in this paper is an information system under the Industry 4.0 architecture. It relies on the heterogeneous sensor universal access hardware platform and integrated equipment deployed in the field to achieve real-time perception of multiple stored grain condition data and cooperative control field equipment, intelligent system based on this platform can achieve continuous evolution and upgrade of the system, use of big data technology to analyze the correlation relationship between sensor data, accurately extract characteristics of stored grain, and form an online extension and maintenance of the stored grain detection application system, the core of which is compatible with a variety of heterogeneous sensors and devices online, has a high degree of online scalability.