BGN-1, CBN-1 for 21 days at 500, 900 and 1500 ppm respectively whereas 87% mortality rate was determined for 21 days exposure of Silicosec® at the highest concentrations on paddy. Athanassiou et all. (2004), reported that Silicosec was't reached complete mortality at 750,1000 and 1500 ppm concentration on rye, oats and triticale againt *T.confusum* after 21 days application but decrased to number of insect on F_1. In a similar study conducted on rice with *T. confusum* adults, Alagöz (2016) found that Silicosec® commercial diatom was found to be 20% at the end of 7th day, 75% at the end of 14th day and 99% at the end of 21st day, at the end of the day, did not find a new generation of adult outbreaks, including the control group, in all diatoms used in experiments. Ziaee et al. (2012), a study conducted on wheat with *T. confusum* adults, found 51% mortality with Silicosec after 2days at 2000ppm concentration and complete mortality was recorded at 1000,1500 and 2000 ppm after 7 days and more. In conclusion, this study indicated that Turkish DE deposits, AG2N-1, BGN-1 and CBN-1 had high insecticidal efficacy in comparison with the commercial Silicosec® and would have potential to be used against insects in the pest management of stored paddy.

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Twelve years (2005-2017) of scientific and professional work in the field of stored products pests protection in Slovenia

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Abstract

Scientific and professional work in the field of stored products pests protection in Slovenia began in 2005, when we tested the efficacy of entomopathogenic nematodes against the granary weevil (*Sitophilus granarius*) and the sawtoothed grain beetle (*Oryzaephilus surinamensis*) adults under laboratory conditions. In 2007, we participated as partners in the project SEE-ERA.NET "Development of a non-toxic, ecologically compatible, natural-resource based insecticide from diatomaceous earth deposits of South Eastern Europe to control stored-grain insects pests" (coordinated by C. Athanassiou), and we thus became acquainted with the research work in the field of investigation the efficacy of diatomaceous earth in controlling beetles from the *Sitophilus* genus. We have continued the research of different aspects of diatomaceous earth (the influence of geochemical composition and abiotic factors on its efficiency, the effects of individual and combined application, the effects on various harmful insect pests, etc.). In search for comparable substances to diatomaceous earth (regarding the efficacy), we have studied insecticidal effects of quartz sand and entomopathogenic nematodes from Slovenia,

plant powders and essential oils on various harmful beetles. In the recent years, our research work has been mainly dedicated to studying the efficacy of wood ash and zeolites as natural insecticides, which have demonstrated sufficient efficiency in suppressing *Sitophilus* beetles. In the same period, we studied the seasonal dynamics of the Indian mealmoth (*Plodia interpunctella*), the Mediterranean flour moth (*Ephestia kuehniella*) and the Angoumois grain moth (*Sitotroga cerealella*) in cereal stores, where we were also searching for possible indigenious natural enemies of stored product insects pests. We have confirmed the occurrence of two parasitoids, *Anisopteromalus calandrae* and *Dibrachys microgastri*. In 2017, we have organized the 11th Conference of the IOBC/wprs Working Group on Integrated Protection of Stored Products (Ljubljana, 3-5 July), which was attended by 136 participants from 25 countries. We also transfer knowledge to Slovenian agricultural specialists about the harmfulness and possible ways of controlling stored products insects pests. In 2014, we have organized a workshop on this topic ("From Technological Maturity to Storing of Cereals and Legumes"). In 2015, we have hosted C. Athanassiou as an invited lecturer at the 12th Slovenian Conference on Plant Protection with international participation in Ptuj. In recent years, we have been working with experts from other countries with the aim of studying the efficacy of environmentally acceptable insecticides (spinosad, spinetoram) and the influence of cereal production technologies on grains' susceptibility to attack by *Sitophilus* beetles. Furthermore, we participate in the research regarding the efficiency of new formulations of insecticidal preparations. The paper presents the chronology of activities in this area of our work.

Keywords: stored products pests, beetles, inert dusts, essential oils, biological control, Slovenia

1. Introduction

In Slovenia, the systematic research and professional work in the field of stored product pest control began in 2005, when in laboratory conditions we exposed the selected stored products beetles to entomopathogenic nematodes, whose effects were then tested on different species of insect pests. In the next 12 years, also with the help of foreign experts, we expanded the scope of stored product pest research to include other fields, primarily the fields of natural products, and physical and other techniques for stored products pest control. Bellow, we present the results of our work and the complete overview of references in this field.

2. Chronology of scientific and professional work in the field of stored products pests protection

2.1. First attempts or entomopathogenic nematodes against stored products beetles

Four entomopathogenic nematode species (*Steinernema feltiae, Steinernema carpocapsae, Heterorhabditis bacteriophora*, and *Heterorhabditis megidis*) were tested in a laboratory bioassay with the aim of studying their efficacy in control of the adults of two stored grain pests, *Sitophilus granarius* and *Oryzaephilus surinamensis*. Activity of the biological agents studied was determined at three different concentrations (500, 1000, and 2000 infective juveniles [IJs] per adult) and temperatures (15, 20, and 25°C). The granary weevil mortality rate was higher than the mortality rate of the saw-toothed

grain beetle. *Heterorhabditis megidis* proved to be the least efficient in control of both pests, while no significant differences were recorded between any of the other three nematode species. The experiment demonstrated that the entomopathogenic nematodes were most efficient in the control of *S. granarius* at 20°C (LC_{50} after 7-day exposure 803-1195 IJs/adult) and 25°C (LC_{50} 505-1175 IJs/adult). A satisfactory level in control of the pest *O. surinamensis* was reached at 20°C (LC_{50} 921-1335 IJs/adult). The concentration of the suspension used in our experiment was shown to be a less important factor affecting the biological activity of nematodes against the adults of both stored grain pests. Though the use of entomopathogenic nematodes for control of the tested pests is not possible at the present time, it may be possible to combine this approach with some other (biotechnical) methods in the future (Trdan et al., 2005; Trdan et al., 2006).

The efficacy of three new strains (B30, B49 and 3162) of the entomopathogenic nematode *Steinernema feltiae* in controlling rice weevil (*Sitophilus oryzae*) adults was tested in a laboratory bioassay. The aim of the study was to determine the activity of selected biological control agents

against one of the most important primary stored product pests to prevent the occurrence of rice weevil resistance to insecticides. The pathogenicity of biological agents was studied at four different temperatures (15, 20, 25 and 30°C) and for five concentrations of nematode suspension (125, 250, 500, 1000 and 2000 IJs per adult). Beetle mortality was determined on 4, 6 and 8 days after treatment. The results showed that all studied strains were most pathogenic (42-72% mortality) at 25°C and the highest concentration of the nematode suspension, while the lowest pathogenicity (from 6 to 11%) was found at 30°C and the lowest concentration of the nematode suspension. Besides, at higher concentrations the suspension of entomopathogenic nematodes can be an effective biological agent in controlling adult rice weevils. The lowest LC_{50} value (1165 IJs/adult after an 8-day exposure) was obtained for the Hungarian strain 3162 at 25°C, while the highest (2533 IJs/adult after an 8-day exposure) was obtained for the Slovenian strain B30 at 30°C (Laznik et al., 2010; Laznik and Trdan, 2010).

2.2. Seasonal dynamics of stored products lepidopteran pests

In the period 2004-2006 seasonal dynamics of Mediterranean flour moth (*Ephestia kuehniella*), Indianmeal moth (*Plodia interpunctella*) and Angoumois grain moth (*Sitotroga cerealella*) was studied in the mills and grain warehouses in central Slovenia. For this purpose pheromone traps were used from April until December, and the males of all three lepidopteran pests were counted in two week intervals. The three insect pests under investigation developed two peaks in capture per year that might represent two distinct generations per year. In the maize open air storage *Ephestia kuehniella* was the most numerous, while *Plodia interpunctella* was more frequent in the closed storage in mills and warehouses, *Sitotroga cerealella* was slightly less common in these latter closed warehouses (Trdan et al., 2010).

2.3. Diatomaceous earth, quartz sand, plant powders, wood ashes, and zeolites in single and combined use

Laboratory experiments were carried out to evaluate the impact of diatomaceous earth (DE) samples of different origin with their insecticidal properties to control *Sitophilus oryzae*. We tested the efficacy of three local DEs, from Serbia, Greece and Slovenia, and commercial formulation SilicoSec against the adults in stored wheat. The experiments were carried out at three temperatures (20, 25 and 30 °C) and two relative humidity (RH) levels (55 and 75 %). Mortality of pest was counted 7, 14 and 21 days after exposure (DAT) at the following DE dose rates: 100, 300, 500 and 900 ppm. The mortality of adults normally increased with increasing dose rates and DAT. In all samples the mortality of rice weevil adults (dose rate 900 ppm, 21 DAT) was above 90 %, except at Slovenian DE (at 20 °C and 55 % RH) and Greek DE (at 25 °C and 75 % RH), when the mortality was 85.3 and 67.6 %, respectively. With 100 % mortality (14 DAT and at 900 ppm) the most effective was SilicoSec. Slovenian DE was more effective at 55 % RH than at 75 % RH (7 DAT at all temperatures) (Rojht et al., 2008, 2010a; Rojht et al., 2012a).

Laboratory experiments were done to determine the effect of geochemical composition of diatomaceous earth (DE) on insecticidal activity of DE against adults of the rice weevil, *Sitophilus oryzae* (L.) (Coleoptera: Curculionidae). Samples of DE were mined from DE-deposits in Slovenia, Greece, and Serbia. In addition, a commercially available DE formulation (SilicoSec®) was used in the tests and served as a positive control. The bioassays were carried out at temperatures 20, 25, and 30°C, relative humidity levels of 55 and 75%, and at application rates of 100, 300, 500, and 900 ppm. Adult mortality was recorded after 7, 14, and 21 days of exposure. Prior to bioassays with *S. oryzae*, the geochemical composition of all DEs that were used in the tests was determined by whole rock ICP geochemical analyses. Silica (in the form of SiO_2 or opal-A) was the DE ingredient that was significantly correlated with efficacy in most of the bioassays. Some weak positive correlation was observed between *S. oryzae* mortality and MnO or CaO content. All significant correlations between mortality and Al_2O_3, Fe_2O_3, K_2O, TiO_2, Cr_2O_3, P_2O_5, and MgO content were negative, while correlation between Na_2O content and mortality was generally not significant (Rojht et al., 2010b).

The efficacy of Slovenian quartz sands admixed with stored wheat was tested against rice weevils (*Sitophilus oryzae*) in laboratory conditions. Five different samples of quartz sand of different ages were tested. Samples from the location Raka-Ravno (with admixture and clean) and the location Moravče (with admixture and clean) and commercially available cleaned quartz sand from the locality of Puconci (Plantella) each were used at six concentrations: 100, 300, 500, 900, 1200, and 1500 ppm. The amount of SiO_2 in all sand samples was high and varied from 91.52 to 99.24%. For each dose rate, the treated wheat grains were placed at four temperatures (20, 25, 30 and 35°C) and at 55 and 75% relative humidity level. After 7, 14 and 21 days of exposure dead adults were counted. All samples showed only a slight insecticidal effect on adults of rice weevil and are not appropriate for wider use against rice weevil adults in stored wheat. The highest mortality (15%) of rice weevil adults was confirmed 21 days after treatment at 900 ppm, 30°C and 55% RH level for quartz sand with admixture from the Moravče location (Rojht et al., 2010c; Rojht et al., 2011).

In the search for an effective and sustainable control method against the bean weevil, *Acanthoscelides obtectus* (Say), three different powders were tested against adults under laboratory conditions. The three powders were diatomaceous earth (DE) (commercial product SilicoSec®), common lavender (*Lavandula angustifolia*) powder and field horsetail (*Equisetum arvense*) powder. The substances were tested at five temperatures (15, 20, 25, 30, and 35°C), two relative humidity levels (RH) (55 and 75%), and four concentrations (100, 300, 500, and 900 ppm). The mortality of adults was measured after the 1st, 2nd, 4th, and 7th days of exposure. The efficacy of the powders increased with the temperature, whereas in general, RH did not have a significant effect on the adults' survival. According to common practice of storing common beans, we recommend the use of DE against the pest in question, as this inert powder showed the highest efficacy at lower temperatures and concentrations. Concerning the wider use of common lavender and field horsetail powders, we suggest studying their combined use with other environmentally friendly methods with the aim of achieving the highest synergistic effect possible (Trdan and Bohinc, 2011; Bohinc et al., 2013).

In the search for an effective and sustainable control method against the maize weevil (*Sitophilus zeamais* Motschulsky), an important insect pest affecting stored grain, different inert dusts were tested under laboratory conditions. We treated wheat grains with quartz sand, zeolites, and diatomeaceous earth. Inert dusts of different origins were used, namely diatomaceous earth from Slovenia and SilicoSec, quartz sands from two locations from Slovenia, and three different zeolites (two types of natural zeolite from location in Slovenia, and synthetic zeolite Asorbio®). Untreated winter wheat grains served as control treatment. The substances were tested at three different temperatures (15, 20 and 25 °C) and two different relative humidity levels (55 and 75%). Mortality was measured 7th, 14th and 21st day after exposure. Inert dusts were applied at two different concentrations, 450 and 900 ppm. The analysis of pooled results provoked significantly the highest mortality of beetles in treatments with SilicoSec® (52.31 ± 2.07%), and in treatment with one type of Slovenian zeolite (31.48 ± 1.42%). The lowest mortality was recorded in treatments with quartz sands from both Slovenian locations, Moravče (18.84 ± 1.31%), and Raka (9.12 ± 0.66%). Mortality of *S. zeamais* was significantly the highest in treatments exposed to 25 °C (28.32 ± 1.16%), and in treatments exposed to higher concentrations (900 ppm) of inert dusts (27.30 ± 0.87%). The use of diatomaceous earth is well established in stored products pest management, however the knowledge on the efficacy of zeolites is very week and offers a lot of opportunities for future researchers (Trdan et al., 2015).

The effectiveness of three different wood ashes from black locust (*Robinia pseudoacacia*), beech (*Fagus sylvatica*), and Norway spruce (*Picea abies*) were evaluated on maize weevil (*Sitophilus zeamais*) regarding adult (2-4 weeks old) mortality. Diatomaceous earth served as positive control. We have tested wood ashes as surface treatment (10 and 20 g/m2) and as admixtures (2.5 and 5 w%). Mortality of weevils, when wood ashes were applied as surface treatment was evaluated every day till 7th day of application, and every day till 14th day of application (as delayed mortality). When wood ashes were admixed, we have evaluated mortality after 7, 14 and 21st day. Research was

performed at two different relative humidty values (55 and 75%) and at three different temperatures (15, 20 and 25 °C). Based on the results of our survey we conclude that mortality of *Sitophilus zeamais* adults was influenced by wood ash species, air temperature and relative humidity. As surface treatment, 99.69 ± 0.31% mortality was achived at treatment with Norway spruce on day 7 at 25 °C. When admixed, 100% mortality was achieved on day 14, when Norway spruce's wood ash has been applied at 25 °C. Use of wood ash as stored product protectant proved to be efficient in our survey, although additional reseach should be made (Bohinc et al., 2017a).

Laboratory experiment was carried out to evaluate the impact of zeolites of different origin on the mortality of the maize weevil (*Sitophilus zeamais* Motschulsky) adults. We have tested the efficacy of natural zeolites (Slovenian and Serbian) and synthetic zeolites ('Asorbio'). Diatomaceous earth (product SilicoSec® was used as positive control). We have applied zeolites as surface treatment (at concentrations 10 and 20 g/m2) and as admixtures (at concentrations 450 and 900 ppm). Mortality of weevils, when zeolites were applied as surface treatment was evaluated everyday till 7th day after application, and everyday till 14th day after application (as delayed mortality). When zeolites were admixed, we have evaluated mortality after 7th, 14th and 21st day. Research was performed at two different relative humidty values (55 and 75%), and at three different temperature (15, 20 and 25 °C). We conclude that mortality of maize weevil adults was influenced by higher temperature values and lower relative humidity value. When we have applied 'Zeolite Slovenia' (at 900 ppm, 15 °C, 55% Rh) as admixture we have recorded 69.69 ± 7.04% after day 21, meanwhile mortality reached 83.66 ± 3.21% after day 21, when 'Zeolite Slovenia' was applied at 25 °C. 100% mortality of maize weevil adults was recorded, when 'Zeolite Slovenia' (after day 7 at 25 °C) was applied at surface. There was no impact of zeolite's dose on mortality of maize weevils. Mortality of weevils was alike in two natural zeolites (Slovenian and Serbian), meanwhile mortality of maize weevils was the lowest in treatments with 'Asorbio'. Use of natural zeolites proved to be efficient as stored product protectant in our research, although additional surveys should be made (Bohinc et al., 2017b).

Laboratory experiment was carried out to evaluate the insecticidal efficacy of different environmentally acceptable substances on the mortality of the granary weevil (*Sitophilus granarius*) adults. We treated wheat grains with diatomaceous earth (commercial formulation SilicoSec®), quartz sand, leaf powder of neem tree (active ingredient azadirachtin, commercial formulation Neem listni prah®), and wood ash. Wheat grains were also treated with combination of diatomaceous earth and wood ash, combination of leaf powder and wood ash, quartz sand and wood ash and with a combination of four different substances (diatomaceous earth, wood ash, leaf powder and quartz sand). Substances were applied at different concentrations. Mortality of the granary weevil adults was tested at 3 different temperatures (20, 25 in 30°C) and at 2 different relative humidity levels (55 and 75%). Mortality was evaluated 7, 14 and 21 days after exposure. We have detected significant impact of different substances on the mortality of the beetles. Significantly the highest mortality of the beetles was evaluated in treatments with wood ash in single or combined use, i.e. individual use of 2,5 w% wood ash (69.73±2.52%), and combined uses of diatomaceous earth (450 ppm) and 2.5 w% wood ash (71.94±2.40%), quartz sand (450 ppm) and 2.5 w% wood ash (68.72±2.80%), and diatomaceous earth (225 ppm), wood ash (1.25w%), leaf powder (0.625 w%), and quartz sand (225 ppm) (68.76±2.75%). We established that wood ash in single or combined use can perform environmentallyacceptable alternative to synthetic insecticides in controlling granary weevil adults, however for final confirmation of this thesis we have to study the activity of the substances against the eggs and the larvae of the pest (Trdan and Bohinc, 2013, 2014; Bohinc and Trdan, 2017).

2.4. Essential oils and helbal extracts

Fumigant toxicity of essential oils from *Rosmarinus officinalis, Salvia officinalis, Laurus nobilis, Citrus bergamia*, and *Cinamomum camphora* against *Acanthoscelides obtectus* adults reared on common bean seeds was assessed. Properties of essential oils were tested at two different dose rates (245 and 980µl/l). Insecticidal efficacy was tested at five different temperatures (15, 20, 25, 30, and 35°C)

and two relative humidity (RH) levels (55 and 75%). Responses varied with type of essential oil, time of exposure, dose of essential oil, as well as with temperature and relative humidity levels. Three days after treatment over 90% adult mortality was achieved. An essential oil from rosemary gave over 94% efficacy after three days. At 75% relative humidity essential oils were significantly more effective than at 55% relative humidity level. The plant essential oils described in this paper could be useful for managing populations of *A. obtectus* in warehouses (Trdan and Bohinc, 2012; Bohinc and Trdan, 2013).

A trial was conducted to assess the fumigant toxicity of the essential oils from *Rosmarinus officinalis* L., *Salvia officinalis* L., *Lavandula angustifolia* Mill. and *Mentha balsamea* Willd. against the adults of *Sitophilus granarius* (L.). The relationships between the time after treatment (1, 2, and 3 days), temperature (20, 25, 30, 35, and 40°C), concentration of essential oils (2.4 and 7.4 ml/L air) and mortality were investigated. In the experiment, the efficacy of the essential oils at 40°C was 95%, whereas their efficacy was considerably lower at lower temperatures (from 12 to 36%). Throughout the experiment, the essential oil of rosemary proved to be the most effective fumigant, causing more than 60% mortality of the granary weevil adults. When applying the essential oil of rosemary, more than 50% mortality in the adults of granary weevil was attained at 35°C (89%) and 40°C (99%). A satisfactory efficacy of the other essential oils, common lavender (90%), peppermint (97%) and common sage (94%), was attained only at the highest temperature. The activities of the essential oils were better at higher concentrations (36%) than at lower concentrations (32%). When assessing the effect of the concentration on the adult mortality, we achieved more than 50% efficacy only with rosemary (2.4 ml/L of air, 58%; 7.4 ml/L of air, 63%). The data for the other essential oils ranged between 19% (peppermint, 2.4 ml/L of air) and 34% (common sage, 7.4 ml/L of air). The calculated values for the LC_{50} and LC_{90} showed that only rosemary produced satisfactory fumigant activity on the adult granary weevils, especially in relation to the temperature. However, the positive efficacy identified in our laboratory experiments needs to be validated under conditions similar to those of the applied conditions, that is, warehouses (Laznik et al., 2012).

Ethanol extracts of *Rosmarinus officinalis*, *Lavandula angustifolia* and *Ruta graveolens* were tested against adults of *Acanthoscelides obtectus*, an important insect pest affecting stored common beans and other legumes. Using a newly developed computer tracking system, a choice test revealed that all of the extracts have a repellent action. The highest repellent activity against the bean weevils adults showed the ethanol extract of rue. We suggested that a cocktail of volatile components in the ethanol extracts was responsible for the observed repellent action. All three of the extracts have insecticidal effects on bean weevils, reducing F1 adult emergence, with no side effects on the germination of the bean plants (Rojht et al., 2012b).

2.5. Biological control agents of stored products pests

In Slovenia, biological control agents, whose introduction, rearing and use are permitted according to Rules on biological control of plant pests (Official Gazette RS No 45/06), are classified in the List of indigenous biological control agents. Since 2006, when the first List was composed, until 2015 the number of indigenous biological control agents increased for 11 species (to present 25 species). The knowledge about occurrence and distribution of indigenous natural enemies is the key factor for their implementation in food and ornamental plants production systems (Trdan and Bohinc, 2016).

In 2012, we established the first record of parasitoid wasp *Dibrachys microgastri* (Boche, 1834) in Slovenia. The wasp was detected in the Laboratory of Entomology (Biotechnical Faculty in Ljubljana) in the rearing containers filled with wheat grains, which are used for reproduction of population of the granary weevil (*Sitophilus granarius*) (Trdan et al., 2013). During 2013 and 2014, we first recorded nine beneficial organisms in Slovenia, among them also parasitic wasp *Anisopteromalus calandrae* Howard. In our opinion this insect species has the potential for future implementation in plant production, since it is already used in some European countries in biological control of some stored products beetles like *Sitophilus* species and *Rhyzopertha dominica* (Bohinc and Trdan, 2015).

2.6. Environmentally acceptable insecticides

The efficacy of spinetoram and spinosad against 2-4 weeks old *Sitophilus* adults has been tested under laboratory conditions. Spinetoram and spinosad were applied at three different dose rates (0.5., 1 and 2 mg/kg). Experiment was performed at 25 °C and 65% rh, on four different winter wheat varieties. Mortality counts were assessed on day 7, day 24 and day 21. Our research demonstrated impact of grain type, dose of exposure, day of evaluation and *Sitophilus* species on mortality of weevils. Mortality of weevils was higher in treatments treated with spinetoram (90.19 ± 0.48%). After day 21, spinosad caused 91.64 ± 0.93% mortality, meanwhile 96.13 ±0.51% mortality was detected in spinetoram treatment after day 21. When applied spinosad as 2 mg/kg, 96.35 ± 0.44% was detected. Spinetoram caused 96.79 ± 0.38% at 2 mg/kg. Efficacy of spinosad (69.47 ± 1.87%) and spinetoram (78.23 ± 0.83%) was the lowest on variety 'Fidelius'. Spinosad caused the highest mortality in treatments with Serbian maize weevil (96.64 ± 0.31%), meawhile spinetoram prooved to be the most efficient in treatments with Serbian rice weevil (94.58 ± 0.77%) and Serbian granary weevil (94.07 ± 0.64%). Our resarch on the efficacy of spinetoram and spinosad against stored product insect pests is the first one for Slovenian agriculture. It presents good basics for further studies on implementation of tested insecticides as protectant of stored grains in Slovenia (Trdan et al., 2017).

2.11 Other types of investigation

In a study the effects of the production systems of wheat from different production systems on the mortality, progeny production and preference of *Sitophilus zeamais* Motschulsky (Coleoptera: Curculionidae) were evalueted. The factors tested were production system (integrated [INT], organic [ORG], biodynamic [BD] and control), which differed in plant protection and fertiliser procedures during plant growth and development; exposure interval (7, 14 and 21 d); relative humidity (r.h.) (55% and 75%) and temperature (20°C, 25°C and 30° C). Mortality after 7 d increased with the temperature increase and decreased with the increase in r.h. in most of the tested combinations. The mortality of weevils was higher in ORG compared to INT-produced wheat after 7 d. Progeny production was recorded 56 d after removal of parental adults and was higher at 75% r.h. in comparison to 55% r.h. At 55% r.h. and 20°C, progeny was 60.8% higher when *S. zeamais* were exposed to ORG in comparison to INT-produced wheat. Wheat from different production systems influenced mortality rates which were higher in alternative compared to INT production systems under optimal conditions for wheat storage (low temperature and r.h.). The reverse was recorded for temperature and r.h. increase. Progeny was not affected by wheat from various production systems. Significantly more *S. zeamais* adults were found in traps containing wheat from BD and control in comparison to INT. An understanding of the agricultural processes, biotic and abiotic factors which alter the post-harvest response of storage pests could be useful for the development of efficient post-harvest strategies for ORG and BD farms and the processing industry (Turinek et al., 2016).

2.8 Organization of workshops for agricultural specialists and IOBC Conference

In 2017, we have organized the 11th Conference of the IOBC/wprs Working Group on Integrated Protection of Stored Products (Ljubljana, 3-5 July), which was attended by 136 participants from 25 countries (Trdan and Trematerra, 2017; Trematerra and Trdan, 2018). We also transfer knowledge to Slovenian agricultural specialists about the harmfulness and possible ways of controlling stored products insects pests. In 2014, we have organized a workshop on this topic ("From Technological Maturity to Storing of Cereals and Legumes") (Trdan, 2014ab), however even three years before we transfered our knowledge in the field of stored pests protection to Slovenian agricultural specialists in a siminal event (Trdan and Bohinc, 2011). In 2015, we have hosted C. Athanassiou as an invited lecturer at the 12th Slovenian Conference on Plant Protection with international participation in Ptuj (Athanassiou, 2015; Trdan, 2015ab).

2.9 Cooperation with foreign experts

In 2007, we participated as partners in the project SEE-ERA.NET "Development of a non-toxic, ecologically compatible, natural-resource based insecticide from diatomaceous earth deposits of South Eastern Europe to control stored-grain insects pests" (coordinated by C. Athanassiou), and we thus became acquainted with the research work in the field of investigation the efficacy of diatomaceous earth in controlling beetles from the *Sitophilus* genus (Athanassiou et al., 2009, 2011).

The opportunity to reduce the amount of pirimiphos-methyl applied to grain by formulating it in an electrostatic powder was investigated in a study of international research group. The insecticidal efficacy of pirimiphos-methyl in EC formulation or formulated using electrostatic powder (EP) as an inert carrier was investigated against *Sitophilus oryzae* (L.), *Oryzaephilus surinamensis* (L.), *Rhyzopertha dominica* (F.) and *Tribolium confusum* Jacquelin du Val. Furthermore, the adhesive properties of EP to rice, corn and wheat, together with the effect on bulk density and bread- and pasta-making properties, were investigated. The results showed that pirimiphos-methyl formulated with EP provided better efficacy against adultswhencompared with EC formulation for O. surinamensis and T. confusum, but there was no difference for R. dominica. Progeny production was consistently lower in grain treated with the EP formulation than in grain treated with the EC. Tests showed that EP adhered to the kernels for longer on hard wheat than on maize or rice. In most commodities, EP did not alter the bulk density. Finally, the addition of EP did not affect flour- and bread-making properties, nor the pasta-making properties. The results of the present study suggest that an EP could be used to reduce the amount of pirimiphos-methyl applied to grain for effective pest control, with no detrimental effects on grain quality (Athanassiou et al., 2016, 2017).

The study of Slovenian-Serbian research group focused on examining of spinosad and spinetoram efficacy after 21 days of *S. granarius* and *S. oryzae* adults exposure in treated wheat grain and their influence on weevils offspring production and wheat grain damage rates. Investigation was conducted under laboratory conditions at 25±1°C and 70±5% r.h. Both insecticides were applied to untreated wheat grain with 12.3±0.1% of m.c. at the rates of 0.5, 1.0 and 2.0 mg a.i./kg for both weevil species. Then, 25 adults were added to each plastic dish containing 50 g of treated wheat, in six replicates, for each insecticide/species tested. Mortality of weevils was determined after 21 days, and the effect on progeny production was determined seven weeks after parental exposure. When the offspring were counted, damage caused by the weevils were also assessed on 100 randomly selected kernels. Spinosad and spinetoram demonstrated the highest mortality (96-100%) of *S. granarius* and *S. oryzae* parents after 21 days of contact with 1-2 mg/kg and 2 mg/kg, respectively. The highest *S. granarius* offspring reduction (>90%) was found in wheat treated with 2 mg/kg spinosad and 1-2 mg/kg spinetoram, while S. oryzae offspring reduction was the greatest in wheat treated with 2 mg/kg spinetoram. In these experimental conditions, the percentage of grains damaged by *S. oryzae* was ≥50% in wheat treated with 0.5-1 mg/kg spinosad and 0.5 mg/kg spinetoram, while grain damage below 5% was found only in wheat treated with 2 mg/kg spinetoram. The results show that spinetoram was more effective than spinosad. Also, *S. granarius* was more susceptibility to both insecticides than *S. oryzae*. Under these experimental conditions, spinosad and spinetoram can be successfully used to control both weevil species at the rate of 2 mg/kg (Andrić et al., 2016, 2017).

Discussion

In 12 years of our work in the field of stored product pest control, our laboratory studies most often included three species from the genus *Sitophilus* (*S. granarius, S. oryzae* in *S. zeamais*) and the bean weevil (*A. obtectus*), i.e. harmful organisms which are in Slovenia of great economic significance. The economically harmful butterflies (E. *kuehniella, P. interpunctella* and *S. cerealella*) have been so far addressed in only one study. The main body of our research work included studying insecticidal properties of diatomaceous earth and other inert dusts, e.g. quartz sand, plant powders, wood ashes and zeolites. Diatomaceous earth was due to its efficiency often used as a positive control when studying the efficiency of other inert dusts. Considerable fumigant effects on harmful beetles were

in our laboratory experiments displayed also by some essential oils, particularly rosemary essential oil. In our professional work, in which we have been systematically sampling autochthonous natural enemies for more than 10 let years, we found two parasitoids of stored products beetles. In our view, the more important of these two is *Anisopteromalus calandrae*, which is already being systematically introduced in cereal storages in some European countries, while the Slovenian legislation in the field of biological control do not yet enable its use in practice. By organising expert meetings for the needs of the domestic experts who study the significance and control of stored product pests, we provide implementation of expert knowledge into practice, and we were delighted when the IOBC-WPRS entrusted us with the organisation of the 11th Conference of the IOBC/wprs (OILB/srop) Working Group on Integrated Protection of Stored Products (Ljubljana, Slovenia, 3-5 July 2017), which is also a result of our recognisability and our good cooperation with foreign experts. Studies in the field of monitoring and control of stored product pests will remain a part of our research-professional activities, as this group of harmful organisms will be also in future, due to the increasing world population, intense international trading in plant materials, climate changes and some other factors, one of the economically most important groups of plant pests.

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Investigations on the efficacy of Turkish diatomaceous earth comparing with SilicoSec? against the stored grain pests

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Abstract

In this research, both Turkish diatomaceous earth from Central Anatolia and SilicoSec? was evaluated against *Tribolium confusum* Jacquelin du Val (Tenebrionidae: Coleoptera), *Rhyzopertha dominica* (F.) (Bostrychidae: Coleoptera) and *Sitophilus granarius* (L.) (Curculionidae: Coleoptera) adults. Different rates (0, 250, 500, 750, 1000, 1500 ve 2000 mg/kg wheat) of diatomaceous earth from both sample mixed with wheat were evaluated for 1, 2, 3 and 4 -weeks exposure period at 55% r.h. and 25 adult/vial insect density in ten replicates. Mortalities were determined at the end of exposure, whereas F1 adult production were determined at 8 weeks after mortality