moratlity) (Mwangangi and Mutisya, 2013), which is in conformity with the results of the present work.

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Effects of chlorpyrifos-methyl and pirimiphos-methyl applied with 5°C temperature on *Sitophilus oryzae* (L.) (Coleoptera: Curculionidae) in wheat grain

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Abstract

The effects of the insecticides chlorpyrifos-methyl and pirimiphos-methyl in combination with low temperature treatment at 5°C were tested in the laboratory to improve the existing pest management programs for *S. oryzae* control. Adults were released into wheat grain pretreated with three insecticide doses: 0.08, 0.12 and 0.16 mg/kg of chlorpyrifos-methyl, and 0.125, 0.19 and 0.25 mg/kg of pirimiphos-methyl, and exposed to 5°C temperature over intervals of 5, 6, 7 and 8 days. Mortality after low temperature only, insecticides only, and their combinations, was assessed after 1, 2, 7 and 14 days of recovery at 25±1°C and 60±5% r.h., as well as their impact on F1 progeny production/reduction (PR) after 8 weeks. The combined application of 0.16 mg/kg chlorpyrifos-methyl and 5°C temperature (5-7 days of exposure) caused a significantly higher mortality of *S. oryzae* after 1, 2, 7 and 14 days of recovery than the activity of low temperature alone, as well as the combined application of 0.12 mg/kg chlorpyrifos-methyl and 5°C after 7 and 14 days of recovery. Adults mortality and progeny reduction of *S. oryzae* was ≥92% after 14 days of recovery from an interaction of 0.16 mg/kg dose of chlorpyrifos-methyl and exposure for 6 days to 5°C, as well as all doses in combination with 7 days exposure to 5°C. Combined application of 0.25 mg/kg pirimiphos-methyl and 5, 6 and 7 days of exposure to 5°C caused a significantly higher mortality of *S. oryzae* after 7, 2 and 1 day of recovery, respectively, compared to temperature-only exposure. High mortality (91-95%) and progeny reduction >92% were caused by the same pirimiphos-methyl rate in combination with 6 and 7 days of exposure to 5°C after 7 days of recovery as the combination of 5, 6 and 7 days of exposure to 5°C after 14 days of recovery.

Keywords: *S. oryzae*, chlorpyrifos-methyl, pirimiphos-methyl, 5°C temperature, combined effects.

1. Introduction

Since the 1960s, residual grain protectants, chiefly organophosphorus and pyretroid insecticides, have been used in management programs for insect pest control in stored raw agricultural commodities. Protectants are usually applied when commodities are loaded into storage, and residues from this single application are expected to protect grain throughout the storage period (Arthur, 1996). Malathion, first registered in the United States in 1958, received extensive use as a storage spray and grain protectant (Arthur and Subramanyam, 2012). The use of malathion decreased significantly after control failures in stored grain (because the extensive use of this compound has resulted in a worldwide resistance of several species). Thus, malathion has been replaced by other organophosphorous insecticides, such as chlorpyrifos-methyl and pirimiphos-methyl (Boyer et al., 2012). Chlorpyrifos-methyl and pirimiphos-methyl are the most common organophosphate insecticides, and both are used as chemical protectants of stored grain throughout the world, either alone or in combination with some pyirethroid compound, e.g. chlorpyrifos-methyl plus deltamethrin in the United States (White and Leesch, 1996; Arthur and Subramanyam, 2012). This class of insecticides is favored for use in stored grains because of relatively low mammalian toxicity and suitable degradation rates that are directly influenced by temparature and product moisture content (White and Leesch, 1996). Compared to contact insecticides, treatments with extreme temperatures as a physical method of controlling stored-product insects have a number of advantages: they leave no residues on products, they are effective against populations resistant to contact insecticides, and the risk for operators is minimal (Fields, 1992, 2001; Burks et al., 2000; Beckett and Morton, 2003; Hagstrum and Subramanyam, 2006; Beckett et al., 2007; Fields et al., 2012). Over the past three decades, low temperatures have been largely used to disinfest either commodities or storage facilities from stored product pests, or for quarantine purposes (Fields, 1992, 2001; Donahaye et al., 1995; Burks et al., 2000; Loganathan et al., 2011; Fields et al., 2012).

Another area of potential benefits from low temperature treatments is their combination with some other pest control methods, such as chemical protectants as part of an integrated approach to manage stored products pests and their resistance to insecticides (Kljajic et al., 2014). Cold pre-treatment at -5°C of adults of granary weevil, *Sitophilus granarius* (L.), has consistently increased the insecticide efficacy of deltamethrin, compared to an unexposed weevil population. Deltamethrin toxicity to field and selected populations after 24 h recovery, following exposure to -5 °C, was 12.1 and 11.0 times higher, respectively, while it was 6.9 and 36.6 times higher, respectively, after 72 h of recovery (Kljajic et al., 2014).

However, insufficient information is available about the influence of the lethal supra-optimal extreme temperature of 5°C on insecticide effectiveness. Research of the interactions between insecticides and temperature in recent years have been mostly based on testing temperatures that ranged from 10 to 30 °C. Organophosphate compounds were found to be more toxic at higher temperatures (≥ 30 °C), in contrast to pyrethroids, which were more toxic at lower temperatures (≤

20 °C) (Tyler and Binns, 1982; Watters et al., 1983; Thaung and Collins, 1986; Subramanyam and Cutkomp, 1987; Longstaff, 1988; Subramanyam and Hagstrum, 1996; Fleurat-Lessard et al., 1998). Wilkin et al. (1999) exposed *Sitophilus oryzae* (L.) adults to treated wheat for five days and reported pirimiphos-methyl (4.0 mg/kg) effectiveness of 64 % at 5 °C, and 100% efficacy at 10° C, revealing the insecticide's higher effectiveness at higher temperature. However, almost none of these studies examined how the combination of treatments affected the survival of insects at low temperatures. However, the effects of acclimation on their survival at low temperatures are well documented (Andreadis and Athanassiou, 2017).

Working on potential improvements of current pest management programmes for *S. oryzae* control, we focused our present laboratory study on examining the effects of a combination of 5° C temperature with the contact insecticides/grain protectants chlorpyrifos-methyl and pirimiphos-methyl on a lab population of rice weevil, *Sitophilus oryzae* (L.) in wheat grain. The effects on its progeny production/ reduction in F1 generation were also examined, and all data compared with the effects of extreme temperature and independent insecticide treatments.

2. Materials and methods

Test insects and insecticides applied

Adults of a laboratory population of *S. oryzae*, reared at the institute were used as test insects in experiments as described by Harein and Soderstrom (1966) and Davis and Bry (1985). The weevils were reared on whole soft wheat grain of 12% moisture, in 2.5 L glass jars at 25 ± 1°C temperature and 60 ± 5% relative humidity. Unsexed 2-5 week old adults were used in all trial variants. The following insecticide products were used in tests: chlorpyrifos-methyl (Reldan EC 40 with 400 g/L a.i., Dow AgroSciences, Austria) and pirimiphos-methyl (Actellic EC 50 with 500 g/L a.i., Galenika-Fitofarmacija, Serbia).

Bioassays

Moisture content in the soft wheat grain variety NS 40 S was 11.0 ± 0.5% and was measured by a DickeyeJohn Mini GAC (DickeyeJohn Co., USA) device before the experiment. Based on a preliminary experiment, three application rates were determined for each insecticide, i.e. chlorpyrifos-methyl (0.08, 0.12 and 0.16 mg/kg) and pirimiphos-methyl (0.125, 0.19 and 0.25 mg/kg), as well as four intervals of exposure to 5° C temperature: 5, 6, 7 and 8 days, in order to test the combined activity of the insecticides and low temperature. Four standard solutions were prepared for each insecticide and diluted into dose series, so that each insecticide dose was used for four treatments (replications) of 500 g lots (one treatment included a single replication of each interval of grain exposure to 5° C temperature: 0, 5, 6, 7 and 8 days. Each 1000 mL glass jar was filled with 500 g of wheat grain and treated with 5 mL of water solution of one of the insecticides, or 5 mL of water for control grain. After hand shaking the treated wheat grain for 30 s, it was mixed on a rotary shaker for 10 min. Plastic 200 mL bottles were then filled with 50 g of treated wheat grain and untreated control grain, and 25 *S. oryzae* adults, previously acclimed in a refrigirator at 15 °C over 24 h, were added into each bottle and the bottle was topped with cotton cloth and fixed with a rubber band. The lots representing each time interval were then independently placed in an incubator (LE-519, MRC, Israel) set to 5 ± 0.5 °C temperature. Temperature in all trial variants was recorded by a data logger (Kestrel 4000, USA). The bottles had a completely randomized arrangement in the incubator. They were transferred after each interval to laboratory conditions (25 ± 1° C and 60 ± 5% r. h), and lethal effects were determined after 1, 2, 7 and 14 days. The same procedure was used to determine the independent effects of both insecticides. After the last assessment, insects were seaved out (seive density 2.0 mm) to enable F1 progeny counts eight weeks after the adults made contact with treated wheat grain and the bottles were kept in the laboratory at 25 ± 1° C and 60 ± 5% r. h.

Data analysis

Mortality data were analyzed using one-way ANOVA. Means were separated by Fisher's LSD test at P=0.05 (Sokal & Rohlf, 1995). *S. oryzae* progeny production/reduction in wheat grain was determined using the formula PR (%) = (K-T) 100/K (Tapondjou et al., 2002), where K - number of progeny in the untreated control, and T - number of progeny in treatments.

3. Results

In the variant without exposure to 5°C, none of the adults in grain treated with all rates of chlorpyrifos-methyl and pirimiphos-methyl (Tab. 1) died after 1 day of contact, while 1% and 5% mortality, respectively, occurred only under the highest doses of chlorpyrifos-methyl and pirimiphos-methyl (0.16 and 0.25 mg/kg, respectively) after 2 days of exposure. Adult mortality increased significantly after 7 and 14 days of contact with both insecticides, the highest being after 14 days of contact with 0.16 mg/kg chlorpyrifos-methyl (87%), and 0.25 mg/kg of pirimiphos-methyl (91%). Average counts of *S. oryzae* progeny in wheat decreased nominally with increasing rates of the tested insecticides. The highest number of progeny (around 530 and 400) and lowest progeny reduction (10.5 and 32.1%) were detected after treatment with the lowest rates of chlorpyrifos-methyl and pirimiphos-methyl (0.08 and 0.125 mg/kg, respectively), while the highest rates of chlorpyrifos-methyl and pirimiphos-methyl (0.16 and 0.25 mg/kg) allowed the lowest average number of progeny (207 and 232, respectively), i.e. the greatest progeny reduction (65.0 and 60.8%, respectively).

Tab. 1. Effects of chlorpyrifos-methyl and pirimiphos-methyl applied alone on *S. oryzae* in wheat grain.

Insecticide	Dose (mg/kg)	Mortality (%±SE) after exposure (days)				Mean No. of progeny (±SE)	PR[b] (%)
		1	2	7	14		
CPM	0.08	0.0±0.0a[a]	0.0±0.0a	0.0±0.0a	2.0±1.0a	530.0±123.6d	10.5
	0.12	0.0±0.0a	0.0±0.0a	43.0±2.1b	46.0±1.9b	227.5±159.5c	61.6
	0.16	0.0±0.0a	1.0±0.5b	78.0±3.0c	87.0±2.6c	207.5±44.2b	65.0
PM	0.125	0.0±0.0a	0.0±0.0a	4.0±1.4a	9.0±2.6a	402.5±213.3c	32.1
	0.19	0.0±0.0a	0.0±0.0a	40.0±0.8b	61.0±2.4b	375.0±118.5c	36.7
	0.25	0.0±0.0a	5.0±1.3b	87.0±1.7c	91.0±3.3c	232.5±61.8b	60.8
Control	0.00	0.0±0.0a	0.0±0.0a	0.0±0.0a	0.0±0.0a	592.5±149.1d	-

[a] For each insecticide separately, means within columns followed by the same letter are not significantly different, Fisher's
LSD test at P > 0.05; b Progeny reduction; CPM- chlorpyrifos-methyl; PM- pirimiphos-methyl

The mortality of S. oryzae adults after 1 and 2 days of recovery from exposure to 5° C temperature in grain untreated with insecticides (Tab. 2) ranged from 15- 83% and 26-86%, respectively, depending on exposure duration, and increased after 7 and 14 days of recovery to 41-96%. Regardless of the period of recovery, a significant increase in adult mortality occurred after 7 and 8 days of exposure to 5° C (43-96%), compared to the shortest exposure periods of 5 and 6 days (15-49%), and 7 and 8 days of exposure (43-74% and 83-96%), while no statistical difference was detected between the shortest exposure periods of 5 and 6 days (15-42% and 20-49%).

In all investigated combinations of insecticide treatment with 5° C temperature (Tab. 2), adult mortality significantly increased with the duration of exposure to extreme temperature, with increasing insecticide doses, and duration of insect exposure to treated wheat grain. Excepting the 8 day exposure, which caused high adult mortality (83-100%) and progeny reduction (92-100%) regardless of recovery period and insecticide, both independently and in all combinations, high adult mortality (>89%) and high progeny reduction (>92%) was also revealed for the combination of 0.16 mg/kg chlorpyrifos-methyl and 6 days of exposure to 5° C temperature, after 14 days of recovery, and for all combinations of chlorpyrifos-methyl treatment and 6 and 7 days of exposure to 5° C after 7 and 14 days of recovery. Adult mortality (>91%) and progeny reduction (>92%) were also high in the combination of the highest dose of pirimiphos-methyl (0.25 mg/kg) with 6 and 7 days of exposure to 5° C after 7 days of recovery, and with 5, 6 and 7 days of exposure to 5° C after 14 days of recovery.

Tab.2. Combined effects of chlorpyrifos-methyl and pirimiphos-methyl, and 5°C temperature on *S. oryzae* in wheat grain after 1, 2, 7 and 14 days of recovery/exposure.

Exposure (days)/ Dose (mg/kg)	Mortality (% ± SE) 1	2	7	14	Mean progeny production (±SE)	PR[b] (%)	PR[c] (%)
			Chlorpyrifos-methyl				
5 d							
0.00	15.0±2.6ab[a]	26.0±2.4bc	41.0±3.4bc	42.0±4.0bc	226.0±27.2c	-	61.9
0.08	22.0±1.3cd	27.0±1.3bc	35.0±1.0ab	38.0±1.3ab	285.7±36.7d	-26.4	51.8
0.12	14.0±1.0ab	20.0±1.4ab	25.0±1.7a	31.0±1.9a	313.5±75.3d	-38.7	47.1
0.16	26.0±2.6cd	41.0±2.5d	76.0±1.8e	83.0±1.5ef	128.7±31.3b	43.0	78.3
6 d							
0.00	20.0±0.0ab	29.0±1.5bc	46.0±3.3c	49.0±2.6c	219.2±11.1c	-	63.0
0.08	18.0±2.6ab	15.0±1.3a	40.0±0.8abc	46.0±2.1bc	213.7±50.2c	2.5	63.9
0.12	9.0±2.6a	24.0±1.4bcd	64.0±1.6d	65.0±1.7d	190.0±29.4c	13.3	67.9
0.16	21.0±1.3c	31.0±1.0c	84.0±0.8ef	92.0±0.8fg	45.5±16.7a	79.2	92.3
7 d							
0.00	43.0±2.6d	56.0±1.8e	74.0±1.0de	74.0±1.0de	119.5±52.0b	-	79.8
0.08	55.0±1.3e	61.0±1.3ef	89.0±2.7fg	92.0±1.8fg	30.0±24.6a	74.9	95.0
0.12	79.0±1.3e	79.0±1.0g	97.0±1.0gh	100g	20.0±37.4a	83.3	96.6
0.16	64.0±1.6e	66.0±2.1f	89.0±2.2fg	93.0±1.3g	38.0±39.5a	67.6	93.5
8 d							
0.00	83.0±2.5f	86.0±2.4gh	96.0±0.8gh	96.0±0.8g	47.5±33.6a	-	92.0
0.08	94.0±0.6f	95.0±0.5h	99.0±0.5gh	100g	8.0±16.0a	83.2	98.6
0.12	83.0±2.7f	83.0±2.7g	97.0±1.0gh	100g	27.0±31.3a	43.2	95.4
0.16	88.0±0.8f	92.0±0.8h	100h	100g	0.0±0.0a	100	100
			Pirimiphos-methyl				
5 d							
0.00	15.0±2.6a	26.0±2.4b	41.0±3.6bc	42.0±4.0bc	226.0±27.2de	-	61.9
0.125	12.0±0.8a	12.0±0.0a	26.0±3.1a	29.0±2.6a	293.7±138.0e	-30.0	50.4
0.19	12.0±0.8a	16.0±0.8a	33.0±3.2ab	35.0±2.9ab	220.2±111.4de	2.5	62.8
0.25	16.0±1.1a	26.0±1.7b	87.0±2.5fg	95.0±1.0gh	90.7±45.1bc	59.8	84.7
6 d							
0.00	20.0±0.0a	29.0±1.5bc	46.0±3.3c	49.0±2.6c	219.2±11.1de	-	63.0
0.125	16.0±2.2a	20.0±0.8ab	45.0±1.3c	48.0±1.8c	152.2±30.1cd	30.6	74.3
0.19	21.0±2.4a	37.0±1.7cd	62.0±2.4d	66.0±1.7d	163.7±56.2cd	25.3	72.4
0.25	19.0±1.0a	41.0±1.9d	91.0±1.7gh	93.0±1.3fgh	43.0±54.9ab	80.4	92.7
7 d							
0.00	43.0±2.6b	56.0±1.8ef	74.0±1.0e	74.0±1.0de	119.5±52.0bc	-	79.8
0.125	47.0±1.0b	52.0±0.8e	78.0±2.1ef	83.0±3.5ef	152.2±46.3cd	-27.4	74.3
0.19	60.0±1.6c	63.0±2.1f	85.0±1.5efg	86.0±1.7fg	102.0±55.4bc	14.6	82.8
0.25	63.0±1.7c	73.0±2.2g	92.0±0.8gh	92.0±0.8fgh	43.0±7.5ab	64.0	92.7
8 d							
0.00	83.0±2.5d	86.0±2.4h	96.0±0.8gh	96.0±0.8gh	47.5±33.6ab	-	92.0
0.125	93.0±1.3d	91.0±1.3h	99.0±0.5h	100h	0.0±0.0a	100	100
0.19	89.0±2.1d	91.0±2.2h	100h	100h	0.0±0.0a	100	100
0.25	87.0±1.0d	88.0±0.8h	100h	100h	0.0±0.0a	100	100

[a] For each insecticide separately, means within columns followed by the same letter are not significantly different, Fisher's LSD test at P > 0.05.
[b] Progeny reduction compared to control 1 (weevil progeny in untreated wheat grain exposed to 5°C).
[c] Progeny reduction compared to control 2 (weevil progeny in untreated wheat grain not exposed to 5°C).

The lowest doses of both insecticides (0.08 and 0.12 mg/kg of chlorpyrifos-methyl and 0.125 mg/kg of pirimiphos-methyl) stimulated progeny production of treated parents by 26-38.7%, compared untreated wheat exposed to 5° C temperature over 5 days, and 5 and 7 days, respectively.

4. Discussion

Our results showed that the mortality of *S. oryzae* lab adults exposed to 5 °C temperature in untreated cold grain increased with exposure duration (5-8 days) and recovery duration (1-14 days), while weevil mortality after 7 and 8 days of exposure and 7 days of recovery were roughly the same as they were after 14 days of recovery (74% and 96%, respectively). Experimental data have shown variable effects of low temperatures on this species. A survey by Fields (1992) of the then available data on lethal effects of low temperatures on *S. oryzae*, cited a 50% survival of adults exposed for 10-16 days to 4.5 °C temperature, while other data showed no (0%) surviving adults after exposure to the same temperature, or survival of 4-6% adults after 14 days of exposure to 4.4 °C, the data depending on conditions in each particular experiment and on acclimation. On the other hand, when Pražić Golić et al. (2013) tested lethal effects of 5° C temperature in wheat grain on *Sitophilus* species, they found that *S. oryzae* adults mortality after 1-7 days of recovery from exposure to 5 °C for 5, 6, 7 and 8 days was 27-58, 33-61, 58-90 and 64-93%, which is similar to the present research data.

Our data on *S. oryzae* mortality caused by the insecticides chlorpyrifos-methyl and pirimiphos-methyl without cold treatment at 5°C showed that mortality increased with insecticide concentration and exposure interval, which generally agrees with many other studies on *S. oryzae* and some other stored-product insect pests (Wilkin et al., 1999; Arthur et al., 2004; Kavallieratos et al., 2009; Kljajić and Perić, 2009; Andrić et al., 2011; Athanassiou et al., 2008). In our present study, the highest mortality of *S. oryzae* adults of 87 and 91% was detected after 14 days of exposure to wheat treated with 0.16 mg/kg chlorpyrifos-methyl and 0.25 mg/kg pirimiphos-methyl, respectively. Some earlier studies had shown high efficacies (100%) of chlorpyrifos-methyl at 1.0 mg/kg and 5.0 mg/kg rate against *S. oryzae* after 7 and 14 days of exposure, respectively (Fleurat-Lessard et al., 1998; Daglish, 2008) and high efficacies (100%) of pirimiphos-methyl at 1.0 mg/kg and 4.0 mg/kg rates against *S. oryzae* after 7 days exposure (Huang and Subramanyam, 2005; Rumbos et al., 2013). In our research, 0.25 mg/kg pirimiphos-methyl caused 0.0, 5.0, 87.0 and 91.0% adult mortality after 1, 2, 7 and 14 days, respectively. In a study with the same exposure intervals conducted by Rumbos et al. (2013), a double dose of pirimiphos-methyl (0.5 mg/kg) caused a significantly lower mortality, 0.4, 1.2, 66.6 and 69.2%, respectively. The inconsistent data may be attributed to a higher susceptibility to insecticides of our lab population.

Generally, very little is known about the effects of insecticide treatments of storage insects in combination with extreme low temperatures in wheat grain. The results in our present study on wheat grain showed that the exposure of *S. oryzae* adults to combinations of insecticide treatment and 5° C cold treatment over a period of 7 days caused, in almost all cases, a mortality that significantly exceeded the independent activities of either component, i.e. insecticide or low temperature. For example, regardless of the recovery period (1-14 days), Weevil mortality was 55-92%, 79-100% and 64-93% in grain treated with 0.08, 0.12 and 0.16 mg/kg chlorpyrifos-methyl, respectively, while adult mortality in wheat treated only with the insecticides was 0-2%, 0-46% and 0-87%, respectively, and 43-74% in untreated wheat after exposure at 5°C. Similarly, each individual component (insecticide and temperature) an interaction with 0.125, 0.19 and 0.25 mg/kg of pirimiphos-methyl and 7 days exposure to 5° C caused a statistically significant difference in adult mortality, i.g. mortality in wheat treated with pirimiphos-methyl was regardless of the recovery period 47-83%, 60-86% and 63-92%, respectively, while mortality in wheat treated with the insecticides only was 0-9%, 0-61% and 0-91%, respectively. After exposing *S. oryzae* (L.) adults to treated wheat for five days, Wilkin et al. (1999) found that pirimiphos-methyl applied at 4.0 mg/kg rate and 5 °C temperature achieved 64 % efficacy, while our 16 times lower dose (0.25 mg/kg) caused 4 times lower mortality (16 %), which demonstrates how the insecticide application rate greatly determines the effects of combined application of insecticide and low temperature.

As data on the effectiveness of insecticides as grain protectants vary, Subramanyam and Roesli (2000) insisted on the importance of checking their effects on progeny production of various storage insects. High progeny reduction of *S. oryzae*, >92%, was reported after the application of 0.16 mg/kg chlorpyrifos-methyl in combination with 6 days of exposure to 5° C, and all application rates of that insecticide (0.08, 0.12 and 0.16 mg/kg) in combination with 7 days of low temperature exposure. The same rate of progeny reduction was detected for the combination of the highest dose of chlorpyrifos-methyl (0.25 mg/kg) and 6 and 7 days of exposure to 5° C. Individual exposure of *S. oryzae* adults to 5° C over 8 days caused 92% progeny reduction. However, the highest doses of both chlorpyrifos-methyl and pirimiphos-methyl (0.16 and 0.25 mg/kg) caused a significantly lower progeny reduction in the laboratory, 65.0 % and 60.8 %, respectively. Kljajić and Perić (2010) found that contact of laboratory *S . granarius* weevils with sublethal doses of pirimiphos-methyl caused increases in progeny counts of 40%, while contact of weevils selected with a sublethal dose of chlorpyrifos-methyl caused 127% increase. In our present experiment, the lowest doses of chlorpyrifos-methyl, 0.08 and 0.12 mg/kg, combined with exposure to 5°C over 5 days, compared to the control not treated with insecticides but exposed to 5°C, increased the number of progeny 26.4 and 38.7%, respectively, while the lowest dose of pirimiphos-methyl (0.125 mg/kg) applied with 5°C temperature over 5 and 7 days, resulted in 30% and 27.4% increase, respectively. The data in our own and some earlier studies show evidently that there is a risk of lower or recommended insecticide doses, applied either alone or in combination with other control methods, becoming sublethal to stored product insects in certain situations, which may then further reflect on their survival and progeny production.

In conclusion, our findings show that the existing pest management programmes for *S. oryzae* control in wheat grain can be significantly improved through highly effective combinations of lower doses of the insecticides chlorpyrifos-methyl (0.08-0.16 mg/kg) and pirimiphos-methyl (0.25 mg/kg) with cold treatment at 5°C for 7 days.

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Residual efficacy of deltamethrin applied on porous and non-porous surfaces against *Sitophilus granarius* (L.), *Plodia interpunctella* (Hübner) and *Blattella germanica* (L.)

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Abstract

Residual efficacy of the insecticide deltamethrin, EC formulation with 25 g/L AI + 225 g/L PBO (synergist piperonyl butoxide), against lab populations of *S. granarius* and *P. interpunctella* by applying product water solutions (12.5 mg AI/m^2) to porous surface, and against *B. germanica* by applying them to non-porous surface,