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Effect of temperature and relative humidity on the efficacy of spinetoram for the control of three stored product beetle species

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ABSTRACT

The effect of temperature and relative humidity (r.h.) on the efficacy of spinetoram on wheat was investigated against three stored product insect species. Laboratory bioassays were conducted on wheat in all combinations of three temperatures (20, 25 and 30 °C) and two r.h. levels (55 and 75%). The rates used were 0.1, 0.5 and 1 ppm, and the insects tested were adults of *Rhyzopertha dominica*, *Sitophilus oryzae* and *Tribolium confusum*. Mortality was assessed after 7, 14 and 21 d of exposure, and progeny production of the first two species was recorded 65 d later. Based on both mortality and progeny production counts, *R. dominica* was highly susceptible to all doses of spinetoram. Moreover, the test temperature and r.h. had little effect on *R. dominica* adult mortality. *Sitophilus oryzae* was also susceptible to spinetoram at dose rates ≥0.5 ppm. For this species, mortality increased significantly with an increase of temperature, but not in all dose–r.h. combinations. Adult mortality of *T. confusum* was low, which indicated that this species was not susceptible to spinetoram, regardless of the conditions examined. The results of the present study suggest that over the range tested, temperature and r.h. affected spinetoram efficacy only in the case of *S. oryzae*, and not significantly in *R. dominica* and *T. confusum*.

1. Introduction

In the stored grain ecosystem, of the abiotic environmental variables, firstly temperature and then moisture and gas composition are the most important factors for insect development (Hagstrum and Milliken, 1988; Muir, 2000). The interaction of insecticides with temperature and relative humidity (r.h.) has been examined extensively with often contradictory results (Arthur, 1999, 2000; Fields and Korunic, 2000; Fang and Subramanyam, 2003). Toxicity of most organophosphate (OP) insecticides increases with the increase of temperature, while the opposite occurs for pyrethroids (Johnson, 1990). Inconsistent effects of temperature have been observed for carbamates (Snelson, 1987). The effect of temperature on phosphine efficacy is positive (Nayak and Collins, 2008).

One of the most recent alternatives over the use of traditional contact insecticides in stored-grain protection is spinosad (Thompson et al., 2000). So far spinosad has been proved effective against a number of different stored product insects (Hertlein et al., 2011). Spinosad can be used effectively for OP and pyrethroid resistant strains of several stored product insects (Daglish, 2008). Also, in comparison with OPs and pyrethroids, Pozidi-Metaxa and Athanassiou (2012), reported that spinosad was more effective than chlorpyriphos-methyl and equally effective as deltamethrin and pirimiphos-methyl against the larger grain borer, *Prostephanus truncatus* (Horn) (Coleoptera: Bostrychidae). The effect of temperature and r.h. on spinosad efficacy has been examined by Athanassiou et al. (2008). The authors, working with four stored grain beetles, reported positive correlation of temperature with adult mortality in most of the species tested.

Recently, spinetoram, a new member of the spinosyns family, has been tested against stored-product beetles and proved effective against several species (Vassilakos et al., 2012; Vassilakos and Athanassiou, 2012). Spinetoram is a mixture of two synthetically modified spinosyns (spinosyn J and spinosyn L), which are metabolites of the bacterium *Saccharopolyspora spinosa* Mertz and Yao (Bacteria: Actinobacteridae). Spinetoram has the same mode of action as spinosad, acting on the insect nervous system at a unique site on the nicotinic acetylcholine (nACh) receptor that is distinct from neo-nicotinoids or any other nicotinic ingredients, and is active through contact or ingestion (Dripps et al., 2011). It is generally considered that spinetoram is more effective than spinosad (Dripps et al., 2008; Sparks et al., 2008).

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In the present study, we investigated the influence of temperature and r.h. on the efficacy of spinetoram against three major stored product insect species, the lesser grain borer, *Rhyzopertha dominica* (F.) (Coleoptera: Bostrychidae), the rice weevil, *Sitophilus oryzae* (L.) (Coleoptera: Curculionidae), and the confused flour beetle, *Tribolium confusum* Jacquelin du Val (Coleoptera: Tenebrionidae).

2. Materials and methods

2.1. Insects

Adults of mixed age and sex were used in the tests. All adults were reared at 25 °C, 60% r.h. and continuous darkness on whole wheat for *S. oryzae* and *R. dominica* or on wheat flour for *T. confusum*.

2.2. Commodity and insecticide treatment

Untreated whole hard wheat (*Triticum durum* L., var. Simeto), with moisture content 13.5%, as determined by a moisture meter (Multitest, GODE co., France) was used in the tests. The insecticide formulation used was spinetoram XDE-175 GF-1587 SC-NC suspension concentrate (11,7% active intergradient [AI], obtained from Dow AgroSciences, UK). Lots of 1.5 kg of grains were sprayed with spinetoram at the dose rate of 0.1 ppm, 0.5 ppm and 1 ppm (corresponding to 0.1, 0.5 and 1 mg of AI/kg of grain, respectively), using a volume rate of 1 ml of formulated spray per kg (1.5 ml of formulated spinetoram per 1.5 Kg of grain), Spraying was performed with a Mecafer AG4 artist's airbrush (Mecafer Co., France). Additional 1.5 kg lots of grain were sprayed with distilled water and used as control.

2.3. Bioassays

The bioassays were carried out in three replicates and each replicate had three subreplicates. All tests were performed in incubators set in all combinations of three temperatures (20, 25 and 30 °C) and two r.h. levels (55 and 75%), which corresponds to six combinations in total. For each temperature–r.h.–dose–species combination, there were three plastic cylindrical vials (3 cm in diameter, 8 cm in height) which were used as subreplicates. Each vial was filled with 20 g of treated or untreated grain and twenty adults of each species were placed into each vial, with separate vials for each species. The vials were then placed in separate incubators at the conditions mentioned above, and in continuous darkness. All vials were placed in plastic containers, with saturated salt solutions at the bottom, in order to maintain the r.h. at the desirable level. The r.h. in the plastic containers was continuously monitored with Temp/r.h. H08-003-02 HOBO data loggers (Onset co, USA). Mortality of the exposed individuals was assessed after 7, 14 and 21 d. After the 21 d morality counts, for *R. dominica* and *S. oryzae*, all adults (dead and alive) were removed and the vials were returned at the same conditions. Sixty-five days later, the vials were examined for progeny production. This was not done for *T. confusum*, given that progeny of this species cannot develop easily in sound grain kernels (Aitken, 1975). The entire procedure was repeated three times (replicates), by preparing new lots each time.

2.4. Data analysis

Control mortality was low, so no correction was considered necessary. Adult mortality was analyzed separately for each species by using the MANOVA Fit Repeated Measures Procedure with Wilk's lambda estimate of JMP software (Sall et al., 2001), with dose, temperature and r.h. as main effects, and time-mortality as the repeated variable. For progeny production, an one-way ANOVA was performed, by using the same software, with number of progeny as the response variable, and dose, temperature and r.h. as main effects. In this case, the number of progeny in the control vials was also included in the analysis. Means were separated by the Tukey–Kramer HSD test at 0.05 (Sokal and Rohlf, 1995).

3. Results

3.1. Rhyzopertha dominica mortality

From all main effects and their associated interactions only that of temperature and dose was significant (Table 1). *Rhyzopertha dominica* was highly susceptible to all doses of spinetoram regardless of the temperature and r.h. levels (Table 2). After 21 d of exposure, adult mortality was 100% to all temperatures and doses at 55% r.h. Similar mortality levels, for the same exposure interval, were also recorded at 75% r.h. with the exception of 20 °C where mortality was 98%. At shorter exposures, with some exceptions,

Table 1
Repeated-measures ANOVA parameters for the mortality counts of the species tested (in all cases error $df = 144$).

	df	*R. dominica*		*S. oryzae*		*T. confusum*	
		F	*P*	*F*	*P*	*F*	*P*
All between	17	3.9	<0.0001	21.0	<0.0001	1.6	0.0666
Intercept	1	211,357.0	<0.0001	9213.6	<0.0001	191.7	<0.0001
Dose	2	4.2	0.0170	113.7	<0.0001	2.1	0.1283
Temp	2	17.0	<0.0001	29.7	<0.0001	7.7	0.0006
r.h.	1	3.2	0.0760	14.4	0.0002	1.4	0.2326
Dose*temp	4	3.4	0.0108	7.1	<0.0001	0.4	0.8001
Dose*r.h.	2	0.6	0.5348	9.6	0.0001	0.8	0.4580
Temp*r.h.	2	1.2	0.3045	1.5	0.2267	1.1	0.3290
Dose*temp*r.h.	4	0.8	0.5180	1.5	0.2180	0.2	0.9171
All within	34	2.1	0.0008	7.0	<0.0001	2.9	<0.0001
Time	2	92.4	<0.0001	171.2	<0.0001	119.8	<0.0001
Time*dose	4	2.8	0.0269	32.1	<0.0001	7.4	<0.0001
Time*temp	4	7.1	<0.0001	12.2	<0.0001	5.5	0.0003
Time*r.h.	2	1.1	0.3512	3.4	0.0370	6.4	0.0023
Time*dose*temp	8	2.2	0.0305	3.2	0.0016	0.7	0.6518
Time*dose*r.h.	4	0.3	0.8703	3.8	0.0050	4.2	0.0026
Time*temp*r.h.	4	0.4	0.8337	2.6	0.0351	0.9	0.4772
Time*dose*temp*r.h.	8	1.3	0.2589	0.7	0.7306	1.2	0.2746