Research Article

Evaluation of Spinosad Applied to Grain Commodities for the Control of Stored Product Insect Pests

Muhammad Yasir*, Mansoor ul Hasan, Muhammad Sagheer, Amer Rasul, Rameesha Amjad Ali and Habib ur Rehman

Department of Entomology, University of Agriculture, Faisalabad, Pakistan.

Abstract | The insect pests of stored food commodities are not only the pests of bulk grains but also of many value-added food products in mills, processing plants and storage facilities where these products are stored. The residual efficacy of spinosad was assessed by exposing the *Oryzaephilus surinamensis, Tribolium castaneum* and *Trogoderma granarium* to the treated commodities (wheat, maize, rice and oats) at concentrations of 0.25, 0.50 and 1 mg Kg^{-1} under laboratory conditions maintained at 28 ± 2°C, 65 ± 5% RH and continuous darkness. Seven bioassays were conducted by releasing the insects on treated commodities after different post treatment periods (0,1, 2, 3, 4, 5 and 6 months). The mortality of three insect species was recorded at tested concentrations in all the treated commodities after the exposure period of 3 and 7 days. Overall results of all bioassays show that residual efficacy of spinosad was reduced with the increase of post treatment period. At 1 mg Kg^{-1}, at the exposure period of 7 days, the mortality was more than 97% at month 0 and it was > 47.7% at month 5 in all the tested insect species on all grain types. Spinosad was more effective in oats followed by wheat, maize and rice in all the tested species. Results show that spinosad possess great potential for residual control of *O. surinamensis, T. castaneum* and *T. granarium*, and can be used for replacement of conventional neurotoxic insecticides for managing the insect pests of stored commodities.

Received | January 08, 2020; **Accepted** | October 25, 2020; **Published** | January 09, 2021
***Correspondence** | Muhammad Yasir, Department of Entomology, University of Agriculture, Faisalabad, Pakistan; **Email:** yasiruca@gmail.com
Citation | Yasir, M., M. Hasan, M. Sagheer, A. Rasul, R.A. Ali and H. Rehman. 2021. Evaluation of spinosad applied to grain commodities for the control of stored product insect pests. *Sarhad Journal of Agriculture,* 37(1): 24-31.
DOI | http://dx.doi.org/10.17582/journal.sja/2021/37.1.24.31
Keywords | Microbial-derieved insecticide, Spinosad, Residual efficacy, Grain commodities, Stored grain insects

Introduction

Synthetic insecticides are the currently used pest control method that causes quick mortality of the insects but there are harmful effects of these insecticides on the health (Arthur, 1996), environment (Phillips and Throne, 2010) and on non-targeted organisms (Fields, 1992). Stored grain insects also have developed resistance to these insecticides (Wijayaratne *et al*., 2018; Nayak *et al*., 2020). As the treated grains are consumed by human, there is a need to use reduced risk insecticides as an alternate to conventional insecticides (Arthur, 2007). Addionaly, these alternative options may be proven to have no harmfull effects on the respiratory and nervous system of humans (Phillips and Throne, 2010). Spinosad is an insecticide derived from soil borne bacteria *Saccharopolyspora spinosa* Mertz and Yao (1990). It is registered in several countries as a grain protectant at the maximum labelled use rate of 1 mg/Kg of grain and its Maximum Residue Limit (MRL) established at 1.5 ppm (Hertlein *et al*., 2011). The spinosad can persist from 6-12 months on the stored grain commodities (Fang *et al*., 2002a; Flinn *et al*., 2004; Subramanyam *et al*., 2007; Vayias *et al*., 2010; Dissanayaka *et al*., 2020).

Links Researchers

The most desired character of a grain protectant is that it should provide the protection for longer period of time. Various pyrethroids (alpha cypermethrin, beta cyfluthrin and deltamethrin) have provided control of *S. Oryzae* on wheat for more than four months (Athanassiou *et al*., 2004). Persistance of traditionaly used grain protactants can cause serious health hazards for human beings, and therefore, these insecticides are not preffered. High persistance of reducded risk insecticides can be used in controlling stored grain insects. It has been recognized that breakdown of spinosad occur after its exposure to ultraviolet light (Saunders and Bret, 1997). Therefore, it could be ideal to protect grains in stored ecosystems where in darkness its breakdown will occur very slow and it would remain effective for longer period of time.

The residual efficacy of spinosad varies with the type of grain commodity. It has been evaluated on different grain types (Fang *et al*., 2002b; Daglish and Nayak, 2006; Vayias *et al*., 2009, 2010; Dissanayaka *et al*., 2020; Gad *et al*., 2020). Furthermore, the residual efficacy of spinosad varies among insect species (Vayias *et al*., 2010; Bajracharya *et al*., 2013). However, further studies are needed for determining the residual efficacy of spinosad again different stored grain insects.

In current study, insecticidal efficacy and persistance of spinosad was evaluated against the adults of *Oryzaephilus surinamensis* (Coleoptera: Silvanidae), *Tribolium castaneum* Herbst (Coleoptera: Tenebrionidae) and larvae of *Trogoderma granarium* Everts (Coleoptera: Dermestidae) by determining the adult/ larvae mortality for the time period of 6 months. Bioassays were conducted on various type of grain commodities (wheat, rice, maize and oats) in order to determine the differences in the efficacy and persistance of spinosad against these three insect pest species.

Materials and Methods

Insects and insecticide

The heterogeneous cultures of *O. surinamensis*, *T. castaneum* and *T. granarium* were collected from household granaries, grain markets and stores of Punjab food department located at Faisalabad, Pakistan. The collected insect species were reared in sterilized glass jars at 30 ± 2 °C and 65 ± 5% relative humidity to obtain uniform-aged first generation (F_1) adults. The culture medium was sterilized wheat flour, whole wheat grains and cracked wheat grains for rearing of *O. surinamensis*, *T.castaneum* and *T. granarium* respectively. The spinosad 240 SC (Tracer®) was obtained from Arysta Life Science, Pakistan.

Grain commodity and treatment

Untreated, clean and infestation free four different grain commodities wheat, maize, rice and oats were obtained from local grain market for use in the treatments. The treatments of grains with concentrations of 0.25, 0.50 and 1.00 mg Kg^{-1} spinosad diluted in distilled water were performed according to Yasir *et al*. (2020) with few modifications. Briefly, a total of 4.2 Kg grains from each commodity were treated with the each desired spinosad concentrations. Control treatment was performed with 4.2 Kg grain each commodity treated with distilled water. These treatments were performed on plastic sheet with thin layer of gains. All the treated grains were kept in a growth chamber at 25 ± 2°C, 65 ± 5% RH and continuous darkness to dry for 24 hours. Then, the grains were placed in separate 5 L plastic sealed containers and stored at the above conditions for the total period of 6 months. For bioassays, the grains samples were obtained at the 0 (24 hours after treatment), 1, 2, 3, 4, 5 and 6 months.

Bioassays

Three samples of 50 g each grain treated with different concentrations of spinosad and control were placed in glass jars with aerated lids. Thirty individuals of each insect species (two-week-old adults for *O. surinamensis* and *T. castaneum*, and three-week-old larvae for *T. granarium*) were released and maintained at 28 ± 2°C, 65 ± 5% RH and continuous darkness. The adult or larvae mortality was recorded after 3 and 7 days of exposure to treated grains. Separate trials were conducted at the 0 (24 hours), 1, 2, 3, 4, 5, and 6 months post treated grains, as described above. All the treatments were replicated four times and performed with factorial under Completely Randomized Design (CRD).

Statistical analysis

The data of adult/larvae mortality was corrected by Abbott's formula (Abbott, 1925) and was statistically analyzed by using the R-software (version 3.5.2) (R Core Team, 2013). The means of adult/larvae mortality for each treatment were compared by Tukey-Kramer HSD test at $P < 0.05$ significance level (Sokal and Rohlf, 1995).

Table 1: *ANOVA for main effects and interactions for mortality of Oryzaephilus surinamensis, Tribolium castaneum and Trogoderma granarium (Error df: 504).*

Source	df	*O. surinamensis*		*T. castaneum*		*T. granarium*	
		F	P	F	P	F	P
Month	6	129.51	< 0.01	73.401	< 0.01	209.86	< 0.01
Exposure Period	1	209.44	< 0.01	201.212	< 0.01	206.41	< 0.01
Concentration	2	1390.30	< 0.01	1288.12	< 0.01	1621.96	< 0.01
Commodity	3	27.92	< 0.01	18.07	< 0.01	36.82	< 0.01
Month × Exposure Period	6	2.26	0.04	1.11	0.32	5.11	< 0.01
Month × Concentration	12	6.48	< 0.01	2.98	< 0.01	13.70	< 0.01
Exposure Period × Concentration	2	12.95	< 0.01	7.78	< 0.01	15.98	< 0.01
Month × Commodity	18	2.22	< 0.01	3.00	< 0.01	2.40	< 0.01
Exposure Period × Commodity	3	0.21	0.84	0.16	0.90	0.72	0.54
Concentration × Commodity	6	2.21	< 0.01	1.44	0.13	4.12	< 0.01
Month × Exposure Period × Concentration	12	0.21	0.99	0.16	0.99	0.20	0.99
Month × Exposure Period × Commodity	18	0.16	1.00	0.13	0.99	0.26	0.99
Month × Concentration × Commodity	36	0.71	0.84	0.41	0.99	1.19	0.18
Exposure Period × Concentration × Commodity	6	0.19	0.98	0.16	1.00	0.57	0.72
Month × Exposure Period × Concentration × Commodity	36	0.06	0.99	0.04	0.99	0.12	1.00

Table 2: *Percentage corrected mortality of Oryzaephilus surinamenis adult mean (± SE) exposed for 3 and 7 days on treated grain commodities with different concentrations of spinosad for 6 month period.*

Month	Concentration ($mgKg^{-1}$)	Exposure period (days)							
		3				7			
		Wheat	Maize	Rice	Oats	Wheat	Maize	Rice	Oats
0	0.25	19.9±0.42Ac	18.2±0.34Ac	19.6±0.20Ac	19.0±0.16Ac	30.0±0.22Ac	31.7±0.43Ab	30.4±0.26Ac	28.1±0.36Ac
	0.50	41.3±0.29Ab	38.9±0.30Ab	39.6±0.38Ab	39.7±0.42Ab	56.4±0.44Ab	57.7±0.42Ab	52.1±0.34Ab	52.0±0.33Ab
	1.00	80.2±0.35Aa	76.9±0.48Aa	76.0±0.20Aa	74.6±0.12Aa	99.0±0.10Aa	100.0±0.00Aa	97.1±0.12Aa	98.0±0.12Aa
1	0.25	15.1±0.22Ac	13.4±0.34Ac	13.0±0.26Ac	16.0±0.18Ac	25.1±0.22Ac	25.0±0.52Ac	24.9±0.20Ac	26.0±0.18Ac
	0.50	37.1±0.24Ab	35.5±0.38Ab	35.0±0.32Ab	38.8±0.18Ab	50.2±0.66Ab	49.0±0.56Ab	48.2±0.42Ab	51.2±0.62Ab
	1.00	72.1±0.36Aa	71.2±0.20Aa	71.0±0.14Aa	74.4±0.42Aa	92.0±0.50Aa	90.7±0.22Aa	89.4±0.18Aa	92.8±0.18Aa
2	0.25	13.9±0.31Ab	11.1±0.33Ab	10.2±0.17Ab	15.0±0.42Ac	25.0±0.24Ac	24.0±0.16Ab	23.6±0.34Ab	25.9±0.31Ac
	0.50	33.2±0.38Ab	32.0±0.39Ab	31.1±0.41Ab	37.0±0.27Ab	46.2±0.62Ab	45.0±0.42Ab	43.8±0.50Ab	48.0±0.68Ab
	1.00	65.2±0.54Aa	63.8±0.62Aa	61.9±0.76Aa	69.1±0.52Aa	88.1±0.21Aa	83.6±0.30Aa	82.2±0.48Aa	91.0±0.28Aa
3	0.25	12.0±0.42Ab	10.2±0.29Ab	9.0±0.13Ab	14.8±0.49Ab	24.0±0.46Ab	22.8±0.62Ab	22.2±0.40Ab	25.1±0.28Ac
	0.50	32.2±0.21Ab	30.1±0.32Ab	29.2±0.48Aab	36.1±0.21Ab	44.6±0.46Ab	43.9±0.72Ab	43.0±0.28Ab	47.0±0.64Ab
	1.00	63.6±0.42Aa	61.2±0.71Aa	59.4±0.69Aa	71.1±0.68Aa	87.0±0.18Aa	83.1±0.42Aa	81.2±0.28Aa	89.6±0.18Aa
4	0.25	11.8±0.23Ab	8.2±0.20Ab	7.6±0.24Ab	14.0±0.29Ab	20.8±0.26Ab	16.2±0.19Ab	15.0±0.22Ab	23.3±0.69Ac
	0.50	28.2±0.41Ab	22.9±0.40Ab	22.1±0.61Ab	33.2±0.43Ab	37.9±0.23Ab	34.6±0.28Aab	32.8±0.18Ab	42.1±0.34Ab
	1.00	62.2±0.24Aa	58.2±0.71Aa	57.7±0.83Aa	67.1±0.52Aa	82.1±0.40Aa	72.5±0.19Aa	71.4±0.68Aa	85.8±0.54Aa
5	0.25	6.8±0.21Ab	0.0±0.00Ab	0.0±0.00Ab	10.1±0.19Ab	17.6±0.42Ab	6.2±0.10Ab	1.2±0.08Ab	19.1±0.11Ab
	0.50	18.0±0.16Ab	11.1±0.21Ab	9.7±0.16Ab	25.1±0.13Ab	33.0±0.28Ab	24.0±0.29Ab	23.1±0.32Ab	34.7±0.21Ab
	1.00	56.1±0.49Aa	52.2±0.64Aa	48.1±0.37Aa	61.0±0.32Aa	73.2±0.36Aa	57.3±0.31Aa	55.8±0.40Aa	77.1±0.22Aa
6	0.25	0.0±0.00Ab	0.0±0.00Ab	0.0±0.00Ab	2.4±0.11Ac	3.3±0.21Ab	0.0±0.00Ab	0.0±0.00Ab	9.0±0.17Ac
	0.50	16.4±0.32Ab	6.7±0.40Aab	4.5±0.22Aab	22.1±0.20Ab	24.1±0.66Ab	14.1±0.24Ab	13.2±0.31Aab	28.1±0.08Ab
	1.00	42.1±0.31Aa	17.2±0.32Ba	16.1±0.31Ba	49.2±0.30Aa	60.2±0.38Aa	30.1±0.24Ba	26.6±0.47Ba	68.4±0.58Aa

Significant difference between treatments (columns) denoted by different lower-case letters, significant difference between commodities (rows) denoted by different upper-case letters.

Table 3: *Percentage corrected mortality of Tribolium castaneum adult mean (± SE) exposed for 3 and 7 days on treated grain commodities with different concentrations of spinosad for 6 month period.*

Month	Concentration ($mgKg^{-1}$)	Exposure period (days)							
		3				7			
		Wheat	Maize	Rice	Oats	Wheat	Maize	Rice	Oats
0	0.25	20.2±0.30Ac	18.8±0.44Ac	20.4±0.22Ac	19.2±0.18Ac	30.2±0.34Ac	32.1±0.61Ab	29.8±0.21Ac	27.9±0.29Ac
	0.50	42.3±0.19Ab	39.7±0.34Ab	40.2±0.32Ab	40.0±0.27Ab	57.2±0.44Ab	58.2±0.40Ab	53.9±0.45Ab	52.9±0.43Ab
	1.00	82.5±0.32Aa	78.1±0.28Aa	77.4±0.26Aa	76.4±0.42Aa	99.1±0.09Aa	100.0±0.00Aa	97.4±0.12Aa	98.4±0.10Aa
1	0.25	16.0±0.23Ac	14.9±0.37Ac	14.0±0.17Ac	17.1±0.19Ac	26.9±0.30Ac	26.7±0.22Ac	26.0±0.20Ac	27.2±0.41Ac
	0.50	39.0±0.46Ab	37.1±0.19Ab	37.0±0.32Ab	39.4±0.12Ab	52.4±0.59Ab	51.2±0.56Ab	50.0±0.56Ab	53.0±0.42Ab
	1.00	75.0±0.46Aa	74.8±0.41Aa	74.0±0.18Aa	75.9±0.48Aa	95.0±0.22Aa	93.8±0.32Aa	92.2±0.28Aa	95.9±0.18Aa
2	0.25	14.2±0.32Ab	12.0±0.34Ab	11.2±0.18Ab	16.0±0.44Ac	26.0±0.36Ac	25.0±0.36Ab	24.9±0.46Ab	26.8±0.28Ac
	0.50	35.2±0.30Ab	34.0±0.38Ab	33.1±0.42Ab	38.0±0.20Ab	48.2±0.44Ab	47.0±0.52Ab	45.8±0.50Ab	50.0±0.48Ab
	1.00	68.2±0.56Aa	66.8±0.66Aa	64.9±0.77Aa	70.1±0.50Aa	91.1±0.42Aa	86.6±0.40Aa	85.2±0.38Aa	94.0±0.38Aa
3	0.25	13.0±0.40Ab	11.2±0.28Ab	10.0±0.14Ab	15.8±0.46Ab	25.0±0.58Ab	24.1±0.52Ab	23.2±0.22Ab	26.1±0.18Ac
	0.50	34.2±0.20Ab	32.1±0.30Ab	31.2±0.46Aab	37.1±0.20Ab	46.6±0.46Ab	45.9±0.72Ab	45.0±0.28Ab	49.0±0.64Ab
	1.00	66.2±0.46Aa	64.2±0.72Aa	62.4±0.68Aa	73.0±0.38Aa	90.1±0.16Aa	86.0±0.40Aa	84.6±0.22Aa	92.9±0.20Aa
4	0.25	12.1±0.28Ab	9.2±0.22Ab	8.4±0.28Ab	15.0±0.28Ab	21.2±0.16Ab	17.0±0.10Ab	16.2±0.40Ab	24.2±0.18Ac
	0.50	30.0±0.42Ab	24.9±0.42Ab	24.0±0.62Ab	35.1±0.44Ab	39.9±0.33Ab	36.4±0.28Aab	34.0±0.32Ab	45.2±0.54Ab
	1.00	65.1±0.26Aa	61.2±0.72Aa	59.6±0.83Aa	71.8±0.58Aa	85.2±0.48Aa	75.4±0.72Aa	74.2±0.48Aa	89.1±0.21Aa
5	0.25	7.2±0.30Ab	0.0±0.00Ab	0.0±0.00Ab	12.2±0.42Ab	18.6±0.42Ab	9.3±0.12Ab	4.2±0.30Ab	21.2±0.16Ab
	0.50	20.2±0.41Ab	14.2±0.32Ab	11.1±0.64Ab	27.4±0.18Ab	35.2±0.31Ab	26.1±0.48Ab	24.0±0.60Ab	37.0±0.40Ab
	1.00	60.7±0.52Aa	55.0±0.68Aa	51.4±0.34Aa	64.0±0.33Aa	76.7±0.30Aa	63.0±0.37Aa	60.4±0.64Aa	80.2±0.42Aa
6	0.25	0.0±0.00Ab	0.0±0.00Ab	0.0±0.00Ab	4.2±0.42Ac	4.0±0.18Ab	1.1±0.09Ab	0.0±0.00Ab	9.9±0.44Ac
	0.50	18.8±0.31Ab	7.2±0.40Aab	5.4±0.22Aab	24.2±0.20Ab	27.0±0.66Ab	16.2±0.44Ab	16.0±0.50Aab	30.2±0.48Ab
	1.00	46.2±0.62Aa	20.4±0.34Ba	18.2±0.32Ba	55.1±0.32Aa	66.2±0.40Aa	33.2±0.52Ba	30.1±0.47Ba	76.0±0.34Aa

Significant difference between treatments (columns) denoted by different lower-case letters, significant difference between commodities (rows) denoted by different upper-case letters.

Results and Discussion

The data analysis for *O. surinamensis* showed that all the main effects and some interactions (month × exposure period, month × concentration, exposure period × concentration, month × commodity, and concentration × commodity) were significant while other interactions were non-significant (Table 1). From month 0 to 6, the effect of concentration on mortality was significant on all the commodities (Table 2). However, the effect of commodity on mortality was only significant at month 6 at 1 mg Kg^{-1} (Table 2). At month 0, at the highest concentration (1 mg Kg^{-1}), the adult mortality was 99.0, 100.0, 97.1 and 98.0 % in wheat, maize, rice and oats respectively at the exposure period of 7 days (Table 2). With the passage of time, the residual efficacy of spinosad decreased mainly in maize and rice. Similarly, at month 6, among the tested grain commodities, the mortality was maximum (68.4 %) in oats and followed by wheat (60.2%), maize (30.1%) and rice (26.6%) at 1 mg Kg^{-1} after the exposure period of 7 days (Table 2).

The data analysis for *T. castaneum* showed that all the main effects and some interactions (month × concentration, exposure period × concentration, and month × commodity) were significant while other interactions were non-significant (Table 1). From month 0 to 6, the effect of concentration on mortality was significant on all the commodities (Table 3). However, the effect of commodity on mortality was only significant at month 6 at 1 mg Kg^{-1} (Table 3). At month 0, at the highest concentration (1 mg Kg^{-1}), the adult mortality was 99.1, 100.0, 97.4 and 98.4 % in wheat, maize, rice and oats respectively at the exposure period of 7 days (Table 3). With the passage of time, the residual efficacy of spinosad decreased mainly in maize and rice. Similarly, at month 6, among the tested grain commodities, the mortality was maximum (76.0 %) in oats and followed by wheat (66.2%), maize (33.2%) and rice (30.1%) at 1 mg Kg^{-1} after the exposure period of 7 days (Table 3).

The analysis of data for *T. granarium* showed that all the main effects and some interactions (month × exposure period, month × concentration, exposure period × concentration, month × commodity, and concentration × commodity) were significant while other interactions were non-significant (Table 1). From month 0 to 6, the effect of concentration on mortality was significant on all the commodities (Table 4). However, the effect of commodity on mortality was only significant at month 6 at 1 mg Kg^{-1} (Table 4). At month 0, the larvae mortality was 100.0, 100.0, 97.0 and 98.2 % in wheat, maize, rice and oats respectively at the exposure period of 7 days (Table 4). With the passage of time, the residual efficacy of spinosad decreased mainly in maize and rice. Similarly, at month 6, among the tested grain commodities, the mortality was maximum (55.2 %) in oats and followed by wheat (48.8%), maize (20.3%) and rice (16.1%) at 1 mg Kg^{-1} after the exposure period of 7 days (Table 4).

Long term protection of stored grains against insect pests can be achieved by using various grain protectants. Although, a grain protectant should be persistent, use of toxic insecticides that have high persistence are not allowed in stored grain protection. So, insecticide like spinosad which has very low toxicity to mammals i.e. LD50 > 5000 mg/kg could be thought to be safe in this regard (Vayias *et al*., 2010).

Spinosad was found effective against the adults of *O. surinamensis*, *T. castaneum* and larvae of *T. granarium*. With respect to species the spinosad was more effective on *T. castaneum* and least effect on *T. granarium*. Regardless of grain commodity tested, mortality was more at higher concentrations.

Table 4: *Percentage corrected mortality of Trogoderma granarium larvae mean (± SE) exposed for 3 and 7 days on treated grain commodities with different concentrations of spinosad for 6 month period.*

Month	Concentration (mgKg^{-1})	Exposure period (days)							
		3				7			
		Wheat	Maize	Rice	Oats	Wheat	Maize	Rice	Oats
0	0.25	19.8±0.62Ac	18.6±0.44Ac	19.2±0.31Ac	19.1±0.18Ac	30.1±0.36Ac	30.0±0.48Ab	29.6±0.19Ac	28.8±0.26Ac
	0.50	41.1±0.36Ab	38.0±0.42Ab	39.2±0.28Ab	38.9±0.52Ab	55.8±0.19Ab	56.4±0.22Ab	53.4±0.15Ab	52.1±0.40Ab
	1.00	69.4±0.31Aa	77.2±0.26Aa	75.4±0.38Aa	74.9±0.42Aa	100.0±0.00Aa	100.0±0.00Aa	97.0±0.11Aa	98.2±0.06Aa
1	0.25	15.0±0.20Ac	13.1±0.24Ac	12.6±0.22Ac	15.1±0.14Ac	24.3±0.37Ac	23.8±0.42Ac	22.2±0.26Ac	25.1±0.19Ac
	0.50	37.2±0.21Ab	35.2±0.30Ab	34.1±0.22Ab	38.0±0.27Ab	49.7±0.46Ab	49.0±0.26Ab	48.1±0.32Ab	51.0±0.36Ab
	1.00	70.2±0.30Aa	68.1±0.68Aa	66.2±0.44Aa	72.6±0.32Aa	87.4±0.20Aa	86.2±0.42Aa	85.1±0.26Aa	89.6±0.12Aa
2	0.25	13.2±0.21Ab	11.0±0.43Ab	10.1±0.19Ab	14.1±0.32Ac	24.0±0.20Ac	23.1±0.18Ab	22.0±0.54Ab	24.6±0.41Ac
	0.50	33.0±0.30Ab	32.1±0.29Ab	31.2±0.33Ab	35.9±0.22Ab	45.1±0.42Ab	43.1±0.22Ab	43.0±0.40Ab	46.1±0.47Ab
	1.00	62.4±0.44Aa	61.2±0.42Aa	60.3±0.64Aa	66.7±0.42Aa	86.2±0.47Aa	82.4±0.38Aa	82.0±0.28Aa	89.2±0.48Aa
3	0.25	11.1±0.42Ab	10.0±0.22Ab	9.0±0.23Ab	12.4±0.19Ab	23.0±0.66Ab	22.1±0.22Ab	21.2±0.32Ab	24.2±0.22Ac
	0.50	30.5±0.32Ab	28.2±0.42Ab	27.1±0.21Aab	33.0±0.20Ab	42.2±0.66Ab	41.8±0.42Ab	41.0±0.30Ab	45.1±0.24Ab
	1.00	62.1±0.21Aa	60.3±0.41Aa	59.0±0.44Aa	65.2±0.37Aa	84.1±0.22Aa	82.1±0.42Aa	81.2±0.28Aa	86.2±0.28Aa
4	0.25	10.2±0.34Ab	8.0±0.34Ab	7.2±0.44Ab	11.0±0.20Ab	20.2±0.26Ab	15.1±0.29Ab	14.2±0.18Ab	23.0±0.29Ac
	0.50	27.1±0.21Ab	20.8±0.32Ab	19.2±0.64Ab	31.0±0.44Ab	37.9±0.23Ab	34.6±0.28Aab	32.8±0.18Ab	42.1±0.34Ab
	1.00	60.1±0.42Aa	57.3±0.41Aa	56.4±0.33Aa	64.2±0.32Aa	77.2±0.22Aa	70.4±0.26Aa	68.2±0.66Aa	80.2±0.33Aa
5	0.25	3.7±0.22Ab	0.0±0.00Ab	0.0±0.00Ab	8.2±0.39Ab	11.2±0.40Ab	3.3±0.13Ab	0.0±0.00Ab	16.2±0.12Ab
	0.50	16.1±0.20Ab	9.3±0.24Ab	8.1±0.16Ab	20.2±0.23Ab	27.2±0.22Ab	20.1±0.11Ab	17.2±0.30Ab	29.5±0.22Ab
	1.00	49.4±0.40Aa	40.1±0.66Aa	38.2±0.33Aa	55.1±0.22Aa	60.3±0.33Aa	50.1±0.21Aa	47.7±0.29Aa	66.2±0.54Aa
6	0.25	0.0±0.00Ab	0.0±0.00Ab	0.0±0.00Ab	0.0±0.00Ac	0.0±0.00Ab	0.0±0.00Ab	0.0±0.00Ab	2.1±0.10Ac
	0.50	5.2±0.13Ab	0.0±0.00Aab	0.0±0.00Aab	10.2±0.12Ab	10.3±0.40Ab	6.2±0.22Ab	4.3±0.11Aab	16.2±0.20Ab
	1.00	36.2±0.27Aa	11.1±0.21Ba	6.2±0.10Ba	41.3±0.33Aa	48.8±0.42Aa	20.3±0.21Ba	16.1±0.09Ba	55.2±0.68Aa

Significant difference between treatments (columns) denoted by different lower-case letters, significant difference between commodities (rows) denoted by different upper-case letters.

In addition to this, the higher concentrations were found to be effective for the time period of six months of grain storage. Similar results have been reported on wheat grains against *R. dominica* or *C. ferrugineus* (Fang *et al*., 2002a; Fang and Subramanyam, 2003; Subramanyam *et al*., 2007). However, spinetoram was found to be least effective on *O. surinamensis*, *T. castaneum* and *T. confusum* and more effective against *S. oryzae* and *S. granarius* (Rumbos *et al*., 2018).

Residual toxicity of spinosad decreased during the storage period of 6 months. So, based on the results it can be assumed that this insecticide degrade during the storage period and doesnt remain stable after 5 months. Spinosad and spinetoram have been reported to remain effective during the 5 months of rice storage (Dissanayaka *et al*., 2020). There are various studies in which more than 25 % reduction in the spinosad residues is reported on wheat grains soon after treatment; but the remaing spinosad residues were found to be effective for 12 months of storage (Fang *et al*., 2002a; Daglish and Nayak, 2006). In the current study, the spinosad residues have not been tested but it can be assumed that slower breakdown of spinosad made it effective for 6 months of storage.

Regarding the grain commodities, there were no significant differences in the mortality of the tested insect species on all grain commodities. However, the residual effects of spinosad become more prominet in later bioassays. In most of the cases, maximum residual efficacy of spinosad was found in oats followed by wheat, maize and rice. These results are similar with Vayias *et al*. (2010), who reported spinosad more persistent in barley and wheat than maize against different stored grain insects during storage period of 6 months. Similarly, IGRs methoxyfenozide and pyriproxyfen have been reported to be more effective in oats followed by wheat, maize and rice against *O. surinamensis* (Yasir *et al*., 2019, 2020). Methoprene was found more effective on maize as compared to wheat and rice while abamectin was reported more effective in maize than the wheat against tested stored grain insect species (Kavallieratos *et al*., 2009; Athanassiou *et al*., 2011). It can be suggested that certain interactions occure between the spinosd and physiochemical peoperties of the grains, that may be involved in the breakdown of the insecticide over the period of storage.

Conclusions and Recommendations

In the light of current study, the effectiveness of spinosad is dependent on the commodity, dose, exposure period and insect species. It can be used as grain protectant on oats, wheat, maize and rice for long term storage period of 5 months. Further studies should be done to assess spinosad effectiveness against other insect pests of stored grains. Residual efficacy of the spinosad in combination with other reduced risk insecticides should also be assessed in order to develop an integrated pest management program for insect pests of stored commodities.

Novelty Statement

In current study, the residual efficacy of spinosad was evaluated against the *O. surinamensis, T. castaneum* and *T. granarium* for the time period of 6 months.

Author's Contribution

MY wrote the manuscript, design and conducted the experiment. MH and MS design the experiment. AR and RAA helped in editing the manuscript. HR analyzed the data. All authors read and approved the final manuscript.

Conflict of interests

The authors have declared no conflict of interest.

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