Journal of Pure and Applied Agriculture (2020) 5(2): 52-58
ISSN (Print) 2617-8672, ISSN (Online) 2617-8680
http://jpaa.aiou.edu.pk/
RESEARCH PAPER

Antixenotic and antibiotic impact of synthetic and plant extracted chemicals against *Rhyzopertha dominica* (Fabricius) (Coleoptera: Bostrichidae) at different storage periods in stored wheat

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Received: 4 March 2020; Accepted: 18 June 2020; Published online: 29 June 2020

Key Message: Jute sacks treated with pyrethroids and botanicals were found to show maximum antixenotic and antibiotic activity against lesser grain borer at 15 days interval in wheat. However, pyrethroids showed greater effect as compared to botanicals.

Abstract: Lesser grain borer, *Rhyzopertha dominica* (Fabricius) (Coleoptera: Bostrichidae) is a major pest of stored products. A research work was conducted to evaluate the efficacy of the two pyrethroids i.e. deltamethrin, and cypermethrin @ 2.5 ml/liter and three botanicals, i.e. leaf extracts of *Azadirachta indica*, *Moringa oleifera* and seed extract of *Datura stramonium* @ 5% concentration by dipping the jute sacks into their solutions (50 ml solution per bag) to check the repellant action of these chemicals against the *R. dominica* in wheat stored for four storage intervals (15, 30, 45, and 60 days). Different treatments of the chemicals tested, and storage periods showed a significant effect on the penetration of insects into the bags and mortality of insects. Degree of antixenosis and antibiosis showed a negative correlation with the storage periods. Among the two pyrethroids and three botanicals, deltamethrin and cypermethrin conferred an effective control of the target insects for one month which lessened gradually in the second month. Maximum antixenosis of 62.13% and 61.63% were shown due to application of deltamethrin and cypermethrin, respectively at 15 days of the storage interval, while a minimum of 49.60% and 49.71%, respectively were shown due to same treatments at 90 days of the storage period. Similarly, the decreasing order of antixenosis percentage (non-preference) against botanicals at 15 days interval was 40.04%>35.17%>28.31% against *D. stramonium*, *A. indica* and *M. oleifera*, respectively. The application of deltamethrin and cypermethrin induced maximum antibiosis of 94.83% and 94.86%, respectively against *R. dominica* after 15 days of storage period as compared to botanicals and control treatment. © 2020 Department of Agricultural Sciences, AIOU

Keywords: Antibiosis, Antixenosis, Chemicals, *Rhyzopertha dominica*, Storage, Wheat

To cite this article: Khan, M. N., Din, N., Afzal, M. B. S., Ashraf, M., Khan, U., Iqbal, Z., Hayat, F. & Rehman, M. A. (2020). Antixenotic and antibiotic impact of synthetic and plant extracted chemicals against *Rhyzopertha dominica* (Fabricius) (Coleoptera: Bostrichidae) at different storage periods in stored wheat. *Journal of Pure and Applied Agriculture, 5*(2), 52-58.

Introduction

Common wheat *Triticum aestivum* L. (Cyperales: Poaceae) is an essential cereal grain that constitutes a significant proportion of the global diet in Pakistan and many other countries (Giraldo et al., 2019; Government of Pakistan [GOP], 2018). In Pakistan, wheat is grown over about 8,734 thousand hectares, with an annual production of about 25.492 million tons (GOP, 2018). It is important to store wheat in order to maintain its uninterrupted supply during off-season (Abubakar et al., 2019). In Pakistan, farmers from rural areas are mostly unaware about the importance of properly built long-term storages and usually rely on poor and unhygienic storage structures; thus suffer storage losses (Atta et al., 2020). The wheat grains, during storage, may suffer substantial losses due to the attack of the insect pests as a result of poor storage conditions and inadequate safety measures. The aggregate losses, during the postharvest operations in the food supply chain, vary significantly among different crops, areas, and economies (Ahmad, 2009; Aulakh et al., 2013). Post-harvest loss accounts for direct physical and quality losses that reduce the economic value of the crop or may make it unsuitable for human consumption. In severe cases, these losses can be up to 80% of the total production (Fox, 2013).

The lesser grain borer *Rhyzopertha dominica* (Fabricius) (Coleoptera: Bostrichidae) is one of the severe and primary pests of stored grains such as paddy rice, wheat, maize and sorghum but it also infests various other commodities including pulses (Edde, 2012; Perisic et al., 2018; Chandel et al., 2019). This pest is distributed throughout the world mainly in tropical regions and causes serious damages to dried stored products (Obretenchev et al., 2020). Besides cereals, the infestation of *R. dominica* has also been recorded at raw materials and some other food products such as cassava, cocoa beans, tobacco, nuts, peanuts, spices, beans, biscuits, dried fruits, dried and fish and meat (Obretenchev et al., 2020). The adult beetle is a strong flyer and may rapidly migrate to begin a new infestation elsewhere (Mahroof et al., 2010). The adults and larvae of this pest cause damage to sound grains by consuming the starchy matter of endosperm and leaving behind the hollow grains with irregular holes accompanied by the formation of fine dust which produces unpleasant smell and makes grain un-consumable (Obretenchev et al., 2020).

In the commercial and house-hold wheat storages, the infestation of this pest is checked by the use of phosphine gas, a toxic fumigant (Mahla, 2001; Anwar et al., 2003; Groote et al., 2013). Showering the grains and storing them in polypropylene bags after proper application of actellic super (pirimiphos-methyl and permethrin can efficiently evade the pest infestation for a few months of storage (Kimenju & Groote, 2010). But chemical control measures have been proven as costly and environmentally hazardous, therefore the use of grain protectants, entomopathogenic fungus such as genus *Trichoderma* as biological weapon and application of botanical extracts were also evaluated as best management options for *R. dominica* (Kaoud et al., 2013; Ahad et al., 2016). Kaoud et al. (2013) reported that *Trichoderma album* caused 20 % mortality at the lowest concentration of 10 spores and 100% mortality at the highest concentration of 107 spores ml^{-1} of strain of fungus/100 g of grains at 7 days post spraying. In the developing countries like Pakistan, the plant based extracts having insecticidal activity can be cheaper, safer and effective method for the management of stored grain pests by farmers and processors (Regnault-Roger et al., 2012). Various studies have reported the effectiveness of botanical insecticides against several species of stored grain pests. Odeyemi and Ashamo (2005) observed the reduction in population build-up of khapra beetle *Trogoderma granarium* Everts (Coleoptera: Dermestidae) when feeding substrate was sprayed with extracts of neem *Azadirachta indica* A. Juss (Sapindales: Meliaceae). Similarly leaf extract of *Datura alba* has also been reported effective against *T. granarium*, and rice weevil *Sitophilus oryzae* (L.) (Coleoptera: Curculionidae) (Ali et al., 2012).

Antibiosis resistance often results in an increased mortality or reduced longevity and reproduction of the insects. Antibiosis due to toxic chemicals such as plant extracts and pyrethroids, against the target insect pests, has been assessed from the percent-mortalities in the toxicity studies (Jilani and Saxena, 1990; Hondelmann et al., 2020). Antixenosis resistance affects the behaviour of an insect pest and is expressed as non-preference of the insect for a resistant material or plant-based extracts compared with a susceptible one (Mitku et al., 2019). It is a relative term and cannot be expressed in an absolute manner. It is described as a percentage difference between the efficiencies of two different insect repellents (Anwar, 2009; Kumar et al., 2018).

In this study, two pyrethroids and three botanicals (chemicals extracted from plants) were used to assess the antixenosis and antibiosis effects as a result of the application of synthetic and plant-based chemicals for the control of *R. dominica* with the help of pre-storage disinfestations of insect-free packing materials, under the natural conditions. Furthermore, this study also evaluated the safe storage-periods for wheat grains with different chemicals to save the commodity from direct contact with the insecticidal material, so that the flavour of the foodstuff may not be affected.

Materials and Methods

Layout of experiment

The experiment was conducted in Stored Grains Laboratory, Entomological Research Institute (ERI), Faisalabad, Pakistan. There were four treatments, including control. Each treatment was tested in four replications.

Insects

Mix culture (adults and larvae) of *R. dominica* was collected randomly from different gowdowns in Faisalabad region of Pakistan. These storage gowdowns were often treated with different chemicals such as deltamethrin and methyl bromide to prevent the infestation of stored grain pests. The insect culture obtained from different storages was maintained in sterilized plastic jars (15 cm in diameter and 30 cm in length) of 2 L capacity filled with 2 kg of wheat grains and covered with a muslin cloth in a stored grain laboratory at 30±2°C temperature with a relative humidity of 65±5% and light:dark photoperiod 14:10 h.

Chemicals and their application

Two pyrethroids i.e. deltamethrin (Decis Super 2.5 EC, Bayer Crop Sciences, Pakistan) @ 2.5 ml/L and cypermethrin (Arrivo 10% EC, FMC United Pvt. Ltd) @ 2.5 ml/L and three botanicals i.e. leaf extract of *A. indica*, and drumstick tree *Moringa oleifera* Lam. (Brassicales: Moringaceae) and seed extract of jimson weed *Datura stramonium* L. (Solanales: Solanaceae) @ 5% were used against *R. dominica*. These were applied before storage of grains by dipping jute sacks (2.5 kg capacity) of mesh size 0.1 × 0.1 mm into solutions of these chemicals. After drying, each sack was filled with 2 kg infestation free wheat grains. The grains in all treated sacks were placed under favourable conditions at 30±2°C temperature with a relative humidity of 65±5%, near opened rearing jars of *R. dominica*. Mortalities (%) were determined at 15, 30, 45 and 60 days post treatment.

Parameters studied

Data regarding the number of alive and dead insects, % mortality, penetration of insects into the treated and untreated bags, antixenosis and antibiosis were recorded at specified intervals.

Penetration of the insects

The total population of the insects (dead and alive), inside the bags, was inversely proportional to the deterrent effect of the oil used (Anwar, 2009)

Deterrence α 1/Population build-up

Assessment of the antixenosis

Antixenosis of the chemicals and botanicals was assessed, following the formula given below (Anwar, 2009):

Antixenosis= Cn –Tn/Cn × 100

Where

Cn = Number of insects in control

Tn = No. of insects in a treatment

Toxicity

The total number of insects (dead and alive) inside the treated bags was counted, and the percent mortality was calculated as a measure of insecticidal activity of the chemicals and botanicals as compared to the control. In the present study, insect mortality was caused due to the direct toxicity and growth-inhibiting effect of chemicals and botanicals, by their contact action on the insect bodies. The toxicity and deterrence of these chemicals and botanicals against *R. dominica* were determined at four storage-intervals of 15, 30, 45 and 60 days, at ambient temperature and relative humidity, that generally prevailed under store-house conditions.

Assessment of the antibiosis

Antibiosis was assessed from the percent-mortalities determined in the toxicity studies by using the following formula (Anwar, 2009):

Antibiosis = Tm-Cm/Tm × 100

Where Cm = % mortality in control

Tm = % mortality under treatment

Data analysis

The data were analyzed using statistical software version 8.1. Analysis of Variance (ANOVA) for each parameter and their interactions were carried out to determine the levels of significance by using Completely Random Design (CRD). The mean values of different treatments were compared by Least Significance Difference (LSD) test and were considered statistically significant at $P<0.05$. During analysis, the control-values were compared with other treatments, at all levels.

Results

Population build-up

The means of the population build-up of *R. dominica* against the different treatments at four storage periods of 15, 30, 45 and 60 days were presented in Table 1. Mean maximum population (47.00) was observed in control at a storage time of 60 days, whereas the minimum population (9.5) was recorded in jute sacks treated with deltamethrin and cypermethrin at a dose of 2.5 ml/liter of water at 15 days interval. Overall means of the insect population in treated jute sacks were found to be 16.00, 16.64, 28.07, 28.81, 25.63 and 37.38 against deltamethrin, cypermethrin, *A. indica*, *M. oleifera*, *D. stramonium*, and control, respectively.

Antixenosis

Table 2 includes the information about percent antixenosis at different treatments against *R. dominica* at four storage periods of 15, 30, 45 and 60 days. Maximum antixenosis of 62.13 and 61.63% were induced by deltamethrin and cypermethrin, respectively at 15 days of the storage interval, while with the increase in a time interval, antixenosis decreased and a minimum of 49.60 and 49.71%, respectively were shown by the same treatment at 90 days of the storage period. Similarly, percent antixenosis for botanicals was also maximum at 15 days interval i.e. 40.04, 35.17 and 28.31% in *D. stramonium, A. indica* and *M. oleifera,* respectively. Hence, antixenosis (deterrence) of the test material and decline in population has a positive correlation between them. However, storage durations and decrease in population have a negative correlation between them.

Percent mortalities

The mean percent mortalities were 65.27, 63.90, 29.19, 25.14, 31.71 and 8.13% against deltamethrin, cypermethrin, *D. stramonium, A. indica* and *M. oleifera,* respectively. The maximum mortality (99.75 %) was observed due to deltamethrin and cypermethrin at 15 days interval, compared with the control (5.15%) (Table 3).

Antibiosis

The calculated percent antibiosis due to application of deltamethrin, cypermethrin, *D. stramonium, A. indica* and *M. oleifera* at 15, 30, 45 and 60 days of the storage period were presented in Table 4. Antibiosis due to deltamethrin (94.83 and 93.03%) and cypermethrin (94.86 and 92.98%) was maximum against *R. dominica* till 30 days of storage period; similarly, the botanical extracts of *A. indica* (89.82 and 86.11%), *M. oleifera* (89.24 and 83.42%) and *D. stramonium* (90.63 and 87.18%) also resulted in maximum antibiosis till 30 days after application. However, after 30 days, this effect was reduced significantly in all treatments. Significant variations in antibiosis over time are quite logical because chemicals and botanicals fade away with time.

Table 1 Effect of different treatments on build-up of *Rhyzopertha dominica* at different storage periods

Duration (days)	Treatments±SE					
	Deltamethrin	Cypermethrin	*A. indica*	*M. oleifera*	*D. stramonium*	Control
15	9.50±0.64[c]	9.50±0.64[c]	16.25±1.030[c]	18.00±1.291[c]	15.00±0.81[c]	25.50±2.25[b]
30	13.75±1.70[bc]	14.50±1.32[bc]	23.50±2.53[bc]	25.00±2.97[bc]	22.00±2.73[bc]	34.25±4.76[ab]
45	18.00±1.95[ab]	19.50±1.32[ab]	33.00±4.14[ab]	33.00±3.69[ab]	29.75±3.68[ab]	42.75±5.79[ab]
60	22.75±1.43[a]	23.00±1.77[a]	39.50±4.78[a]	39.25±4.51[a]	35.75±4.11[a]	47.00±6.31[a]
Mean	16.00[c]	16.64[c]	28.07[b]	28.81[b]	25.63[b]	37.38[a]
ANOVA	P = 0.003	P = 0.0001	P=0.0023	P = 0.0039	P = 0.0027	P = 0.0439
	DF = 312	DF = 312	DF = 312	DF = 312	DF = 312	DF = 312
	F-value = 14	F-value = 19.6	F-value = 8.85	F-value =7.72	F-value = 8.84	F-value = 3.67
	LSD = 6.372	LSD = 5.589	LSD = 14.481	LSD =14.017	LSD = 13.049	LSD = 21.121

Table 2 Antixenotic effect (%) of different treatments on *Rhyzopertha dominica* at different storage periods

Duration (days)	Treatments±SE				
	Deltamethrin	Cypermethrin	*A. indica*	*M. oleifera*	*D. stramonium*
15	62.13±1.23[a]	61.63±3.97[a]	35.17±1.84[a]	28.31±2.21[a]	40.04±2.07[a]
30	59.56 ±1.23[a]	56.36 ±3.67[a]	30.27 ±2.81[ab]	26.08±2.73[ab]	35.25±1.41[ab]
45	57.37±1.75[a]	52.88 ±3.89[a]	22.34 ±2.02[bc]	21.79±3.29[ab]	30.02±1.13[b]
60	49.60 ±5.92[a]	49.71±3.69[a]	15.43±2.09[c]	15.62±3.10[b]	23.31±1.59[c]
ANOVA	P = 0.083	P = 0.2024	P = 0.002	P = 0.0398	P = 0.0001
	DF = 312	DF = 312	DF = 312	DF = 312	DF = 312
	F-value = 2.83	F-value = 1.79	F-value = 15.3	F-value = 3.80	F-value = 20.3
	LSD = 13.49	LSD = 16.02	LSD = 9.341	LSD = 12.03	LSD = 6.69

Table 3 Percent mortality of *Rhyzopertha dominica* against different treatments

Duration (days)	Treatments±SE					
	Deltamethrin	Cypermethrin	*A. indica*	*M. oleifera*	*D. stramonium*	Control
15	99.75±0.25[a]	99.75±0.02[a]	50.76±0.50[a]	47.82±0.54[a]	55.21±1.08[a]	5.15±0.25[c]
30	75.22±0.81[b]	74.69±0.51[b]	37.76±0.50[b]	31.64±0.64[b]	40.92±0.54[b]	5.23±0.02[c]
45	43.75±0.61[c]	45.75± 0.45[c]	16.26 ±0.50[c]	11.43 ±0.41[c]	17.15 ±0.64[c]	9.422±0.25[b]
60	42.36±0.70[c]	35.41±0.89[d]	11.98±0.30[d]	9.65±0.51[c]	13.54±0.41[d]	12.72±1.45[a]
ANOVA	P = 0.0001	P = 0.0001	P =0.0001	P = 0.0001	P =0.0001	P=0.0001
	DF = 312	DF = 312	DF = 312	DF = 312	DF = 312	DF = 312
	F-value = 1889	F-value = 2549	F-value = 1592	F-value = 1157	F-value = 770	F-value= 23.8
	LSD = 2.69	LSD = 2.42	LSD = 1.90	LSD =2.23	LSD =3.00	LSD =3.14

Table 4 Antibiotic effect (%) of different treatments to *Rhyzopertha dominica* at different storage periods

Duration (days)	Treatments±SE				
	Deltamethrin	Cypermethrin	*A. indica*	*M. oleifera*	*D.stramonium*
15	94.83±0.26[a]	94.86±0.25[a]	89.82±0.60[a]	89.24±0.67[a]	90.63±0.64[a]
30	93.03±0.098[a]	92.98±0.05[a]	86.11±0.23[a]	83.42±0.29[b]	87.18±0.21[a]
45	78.41±0.89[b]	79.41±0.47[b]	41.99±0.21[b]	20.91±1.78[c]	44.85±0.98[b]
60	69.78±3.90[c]	64.05±4.05[c]	9.65±4.54[c]	3.29±0.40[d]	13.17±5.37[c]
ANOVA	P = 0.0001	P= 0.0001	P = 0.0001	P = 0.0001	P = 0.0001
	DF = 312	DF = 312	DF = 312	DF = 312	DF = 312
	F-value = 35.7	F-value = 48.8	F-value = 277	F-value = 1950	F-value = 180
	LSD = 8.43	LSD = 8.59	LSD = 9.65	LSD = 4.13	LSD = 11.56

Discussion

Population build-up of *R. dominica* in wheat stored in jute sacks treated with different treatments was significantly lower as compared to control or untreated jute sacks, and the effect of treatment became less effective as the time interval increased. Similar results have also been reported by Saxena et al. (1989); Jilani & Saxena (1990); Mohiuddin et al. (1993); and Khan and Marwat (2003). Jilani and Saxena (1990) monitored the repellency of neem oil against *R. dominica* for eight weeks in a choice test on filter-paper-strips. It was observed that *R. dominica* showed significant repellence during the first two weeks, and after that their repellency decreased rapidly. *R. dominica* adults made significantly fewer and smaller feeding punctures in the filter paper discs, treated with 100, 500 and 1000 µg/cm² of the neem oil than those in control. Saxena et al. (1989) found that *A. indica* had shown anti-feedant effects against different insect pests of stored products during their investigations. Mohiuddin et al. (1993) evaluated plant oils i.e. *A. indica*, Fenugreek *Trigonella foenum-graecum* L. (Fabales: Fabaceae), nutmeg *Myristica fragrans*. Houtt (Magnoliales: Myristicaceae), black pepper *Piper nigrum* L. (Piperales: Piperaceae), black cumin *Nigella sativa* L. (Ranunculales: Ranunculaceae), and turmeric *Curcuma longa* L. (Zingiberales: Zingiberaceae) to test their toxicity and repellency against red flour beetle *Tribolium castaneum* (Herbst) (Coleoptera: Tenebrionidae) and *R. dominica* for two months. Botanical oils showed repellency as a surface treatment of the wheat grains. Khan and Marwat (2003) evaluated the powders made from leaves, seeds and bark of *A. indica* and oleander *Nerium oleander* L. (Gentianales: Apocynaceae) for their deterrent effects against *R. dominica* and got its repellency up to 96% from neem leaves and seeds.

Antixenotic impact or repellence with different treatments towards *R. dominica in* stored wheat were studied by determining the penetration and population build-up of insects, inside the treated bags, packed with insect-free wheat, kept for 15, 30, 45 and 60 days, at ambient temperature and relative humidity, in the stored grain laboratory. Our consideration of the antixenosis has been supported by the proved behaviour of the chemicals and botanicals, whose repellence reduces over time. Thus, the insect-population inside the treated bags seems to be negatively affected by antixenotic influence, while positively with the storage period. Kordan et al. (2019) studied the antixenosis and antibiosis effects of polyphenolic and lipophilic compounds present in six cultivars of bread wheat kernels against the infestation of granary weevil *Sitophilus granarius* L. (Coleoptera: Curculionidae). The kernels of different cultivars with highest sterol and lipid contents expressed lowest antixenosis effect against *S. granarius* one week after infestation. On contrary, the grains with higher total phenolic acids were least attractive to *S. granaries* infestation indicating strong antibiosis effect.

Similar to our study, Anwar (2009) also evaluated the antixenosis and antibiosis effect of different botanical oils obtained from *A indica*, castor bean *Ricinus communis* L. (Malpighiales: Euphorbiaceae), and Sweet flag *Acorus calamus* L. (Acorales: Acoraceae) at different concentrations against *T. castaneum*, *T. granarium*, *R. dominica*, and *S. granarius* at different storage intervals such as 30, 60 and 90 days using jute/cotton bags. Anwar (2009) found a linear correlation of antixenosis and antibiosis with the concentration of the botanical oils used but negative correlation with the storage periods was observed. Moreover, the mortality was directly proportional to the density of the packing materials used but penetration into the bags was inversely proportional. It was also observed that with the 20% concentration and fine packing material, mortalities occurred in *R. dominica* due to oils of *A. calamus*, *A. indica* and *R. communis* were 94, 90 and 82%, respectively up to one month. However, in second and third months, decrease in percent mortality was found gradually. Whereas, in cotton bags, having mesh size of 0.1 ×0.1 mm, 100, 95.55, and 91.55% mortality for 30, 60 and 90 days respectively, was observed using mixture of three oils in 10% concentration of each.

The mean values of the percent mortality of *R. dominica* (65.27, 63.90, 29.19, 25.14, 31.71 and 8.13) in wheat stored in jute sacs treated with different synthetic chemicals such as deltamethrin, cypermethrin, and botanicals, such as *D. stramonium*, *A. indica*, *M. oleifera* and control, respectively at different time intervals indicates that it varied significantly in chemical and botanicals treatments. The maximum mortality (99.75%) was observed with deltamethrin and cypermethrin at 15 days interval as compared with *D. stramonium* (55.21%), *A. indica* (50.76%), *M. oleifera* (47.82) and control (5.15%). Our results are in accordance with previous studies (Daglish, 1998; Nayak et al., 2002; Athanassiou et al., 2004; Ali et al., 2014; Sehgal & Subramanyam, 2014) who found the effectiveness of deltamethrin against insects associated with stored grains. Our results that botanicals are effective against *R. dominica* have been confirmed by the work of Chander et al. (2000); Chandel et al. (2001) who found that extract of *A. calamus* rhizomes was highly effective, even at the lowest concentration of 2.5 mg/cm² of jute fabric. The concentrations exhibited repellency, even after three months of application at room temperature. Mansoor-ul-Hasan et al. (2006) found that the toxicity of deltamethrin was greater as compared to saxaul *Haloxylon recurvum* (Moq.) (Caryophyllales: Amaranthaceae) extract as deltamethrin induced 25% mortality while *H. recurvum* caused 17% mortality in *T. granarium*. Moreover, they also found that by increasing the concentrations of these chemicals and exposure time, pest mortality increased. At a concentration of 1.5% and with the high exposure time of 168 hours, the overall percent was 23% for *H. recurvum* and 39% for deltamethrin.

The calculated percent antibiosis of deltamethrin, cypermethrin, *D. stramonium*, *A. indica* and *M. oleifera* at 15, 30, 45 and 60 days of the storage period significantly varied over time. It is quite logical because chemicals and botanicals essentials fade away with the passage of time and our results are in agreement with those of Bloszyk et al. (1990) who reported that synthetic pyrethroids, natural botanical anti-feedants and silica gel are greatly effective if applied on stored grain packaging materials and could resist insect penetration. Lal & Dikshit (2001) conducted the studies on deltamethrin to track its possibilities for use as grain protectant in stored chickpea mainly against pulse beetle *Callosobruchus chinensis* L. (Coleoptera: Bruchidae). They sprayed deltamethrin at the rates 15 and 25 mg a.i. m^{-2} on jute sacks filled with chickpea to see its efficacy and persistence. Deltamethrin spray resulted in 76 to 78% mortality in *C. chinensis* up to six months and grains in spray treated sacks were found to have deltamethrin residues below MRL (maximum residue limit). The deltamethrin treatments also did not result in any changes in protein contents and viability of grains.

Conclusion

It is concluded from the results of this study that pyrethroids i.e. deltamethrin and cypermethrin have potential to be used as a management tool for *R. dominica* in storages and should be preferred over botanicals. Besides, it was also suggested that the safe storage-periods for wheat grains with different chemicals and botanicals was 15 days and a re-application might be needed after that. Moreover, the application of chemicals at the jute sacks might save the commodity from direct contact with the insecticidal material, so that the flavour of the food-stuff may not be affected. Although the chemical solutions of protectants such as deltamethrin and cypermethrin could provide long lasting protection against *R. dominica* and some other storage pests of wheat but they must be used judicially to avoid resistance development and residue accumulation in stored wheat grains. These chemicals must be used after proper calibration and according to the label directions to avoid their harmful effects on humans.

Author Contribution Statement: Misbah Ashraf and Zafar Iqbal conceived and designed the study. Misbah Ashraf conducted experiments. Naima Din generated and analyzed the data. Muhammad Nawaz Khan, Naima Din and Muhammad Babar Shahzad Afzal wrote the earlier version of manuscript. Muhammad Babar Shahzad Afzal, Ummara Khan,Faisal Hayat and Malik Abdul Rehman edited the manuscript and prepared its final version.

Conflict of Interest: The authors declare that they have no conflict of interest.

Acknowledgements: The authors highly acknowledge Director Entomological Research Institute, Faisalabad, Punjab, Pakistan for providing the necessary facilities to conduct research work.

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