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A Review on the Use of Synthetic Insecticides for the Control of the Lesser Grain Borer *Rhyzopertha dominica* (FAB.).

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Abstract: The lesser grain borer Rhyzopertha dominica (Fab.) is a cosmopolitan pest feeding on wide varieties of food produce attacking sound and wholesome grains. Management of this insect in storage using chemicals may lead to insecticide residues in grains and insecticide resistance development in insect. The search for alternative insect pest control methods and materials have therefore become essential however, understanding of the biology of this pest is one of the means through which the control of this insect will be easily achieved. Effects of plant product such as Azadirachtin indica, fumigant toxicity of essential plant oils, treatment with combination of different protectants as well as treatment of grains with Pirimiphos-methyl synergized, Pirimiphos-methyl plus synergized pyrethrins and combination of two or more formulations of DEs efficacy in the control of R. dominica are discussed. This review has also shown that botanical insecticide alone and in combination with synthetic insecticides is effective in the control of R. dominica. The review has shown that synthetic insecticides used at the proper doses could be a better option against the R. dominica than most botanicals so far tested in various control measures against most stored grain pests. The processes of obtaining botanicals through the raw materials can be available, cheap to obtain but difficult to process in quantities that can reasonably be used in large scale storage facilities like silos and ware-houses of thousands of tonnes capacity.
Keywords: Grain Borer, Insecticides Synthetic, use

INTRODUCTION

Taxonomy and identification

The lesser grain borer *Rhyzopertha dominica* (Fab.) is a cosmopolitan pest feeding on wide varieties of food produce. It is a small 2.5-3mm long, reddish-brown to black-brown in colour, slim and cylindrical in shape[1]. The hood is round in shape and the neck shield extends over the head hiding it while some pits on the shield become gradually smaller towards the rear. The last three antennal segments form club and adults are less powerful fliers[2-4].

Life History and Behaviors of the Study Insect

Female lay up to 500 eggs on kernels or loose in the frass produced by the insect. Oviposition is greatly influenced by moisture contents of the grains as well as the developmental rates. For example, no eggs are laid on wheat with moisture content below 8% and larval development is more rapid on whole grain than on flour of same grain. Immature larvae cannot penetrate undamaged kernels and normally moult four to five times, while in flour meal, they will moult two to seven times and larval development usually takes 27-31 days at normal temperature of below 30^{o}C. Pupation takes place in an enlarged cacoon cells as the larval feeding tube and the duration of the pupal stage range between 5-6 days at the normal temperature.

Adults remain in the kernel for 3-5 days before beginning to feed and tunnel out of the kernel. Oviposition starts approximately 15 days later and can last up to 4 months. Females survive for several days after oviposition[5]. Adult lesser grain borers fly though they are not strong fliers and often carried through air currents. They can cause considerable damage using their powerful jaws which is powerful enough to bore into wood[5].

R. dominica is a major, primary and cosmopolitan pest of stored-grain commodities worldwide and attacks sound and wholesome grains[6-9]. It is a serious pest of several stored grains such as rough stored rice causing weight loss through their feeding damage[10]. Both adult and larvae are voracious feeders and they cause serious damage to produce through boring and tunneling activities. The adult feeds on the germs while the larvae devour the endosperm. The infested grains are riddled with hollow and irregular hole with characteristic tunnels leading to severe powdering[11]. However, preferred grains include wheat, rye, corn, rice, and millet but oilseeds and spices are not suitable for larval development[12].

Development of the Study Insect

Developments of the life cycle of the insect under controlled environment are presented in Table 1. The minimum (18.2ºC) and maximum (39.0ºC) temperatures for development of the beetles reared on wheat grain at 14% moisture content and 70% RH are indicated [13]. Brood development is impaired at relative humilities below 30% at any temperature[13], however the beetles were able to complete development in wheat kernels of 9% moisture content (approximately 20% RH) at 34ºC, indicating that different strains of *R. dominica* might respond differently to the effects of temperature and humidity in their development. The optimum moisture contents of grains required for the development of *R. dominica* are between 12 and 14% and at temperatures of 26ºC – 34ºC[14]. Under any combination of temperature and relative humidity, mortality of the first instar is higher in undamaged grain than in damaged grain, due to difficulties encountered by the first instar in entering the kernels[14]. Many of the larvae that enter the grain die in the first instar because the hazards of entering the grain apparently weakening the larvae considerably.

Control of the Study Insect

Relative to other stored pests, *R. dominica* is one of the most difficult insect pests to control with insecticides or grain protectants in many countries[15-17]. This could be due to ineffectiveness against the insect, or the insect has developed resistance to all approved organophosphorus insecticides – chlorpyrifos methyl, fenitrothion, Pirimiphos-methyl and malathion [15-17]. Resistance of *R. dominica* to pyrethroid based grain protectants is widespread[15, 16]. However, a formulation of methoprene composed of only the S-isomers was registered in 2002, and both the dust and EC formulations of S-methoprene gave 100% suppression of F1 adult progeny of *R. dominica* at application rates of 1 ppm[18].

Diatomaceous Earth (DE) applied as a surface or "top-dress" treatment immediately after grain is stored could provide a protective barrier from migrating insects that may enter grain bins from the top[19]. *R. dominica* could move deeper in grain mass than most other grain beetles[20], and are able to penetrate the DE-treated top layer and oviposit on the untreated wheat below [21-22]. Fumigation is the effective method of control of this storage pest which causes heavy damages on large quantities of grains, to kill both the larval and pupal stages. Heat treatment at 60˚C can also kill larvae but have the disadvantages of reducing viability and flour quality. Heavily infested grains has a sweet and slightly pungent odor and unsuitable for consumption. Phosphine is by far the most important fumigant to control *R. dominica* [23-24] and controls all insect life stages. Two major genes are believed to be responsible for resistance to phosphine in *R. dominica* [24, 25]. These two genes act in synergist resulting in increased expression of resistance to phosphine compared to any one of the resistance genes on their own [25].

Prevention is by far the best control option, but may be impractical given the ability of *R. dominica* to migrate into grain storage. As the search continue for alternatives, it is important that every effort should be made to conduct fumigations according to recommended procedures to ensure that the established dosage rates continue to provide effective control of the insect. The natural rate of increase of *R. dominica* is about 20 times per month under optimum condition of 34ºC and 70% RH in wheat kernels. This rate is higher than the rate reported for *P. truncatus* similar to observation in another internal feeding grain insect *Sitophilus oryzae* L. (Coleoptera: Curculionidae).

R. dominica is a holometabolus and eggs are deposited in clusters on grain or singly among frass produced by the insect. The eggs are opaque, whitish in colour with a waxy appearance when freshly laid, but after a little while takes on a pinkish colour are oval-shaped about 0.5-0.6 mm in length and 0.2-0.25 mm in diameter. The egg surface appears smooth, but micrograph scanning (SEM) and magnification reveals a distinct granulated microstructure. The chorion, which has two layers, is about 2.7µm in thickness. The dark rusty tips of the mandibles and the abdominal thorn of the larva are visible through the chorion at the end of egg development[26].

Mean longevity of adult male and female *R. dominica* fed on wheat kernels at 28ºC and 65% RH is 26 and 17 weeks respectively. Other researchers reveal that about 4% of the male and 3% of female beetles could live for 52 weeks[27]. However, mean longevity of male beetles in the experiment was 20 weeks, which is 6 weeks shorter than observed. This difference may relate to the fact that Birch kept males and females together while Edde and Phillips kept them separately. Mean longevity values of starved adult male and female were 5.7 and 4.7 days, respectively[27]. Negative effects on reproduction and movement of adult *R. dominica* may occur after 4 days of starvation[28, 29]. The effects of starvation are more pronounced on female *R. dominica* presumably due to the greater energy demand on them for reproduction[29].

The use of colour, however, was found to be unreliable for the separation of *R. dominica* sexes from other geographical areas [30] and recorded the existence of a distinct transverse, punctuate groove on the firth abdominal sternite of the male *R. dominica* which is never present in females. Sinclair [31]did not observe the groove in *R. dominica* strains, but colour characteristics or punctuate groove were easily discernible in laboratory-reared or field-collected beetles in USA. Since most insect pests of stored products are repeatedly transported around the world by transits, the use of such external characters may prove useful in identification of possible origins of infestation. Potential breeding resources for *R. dominica* is the family Poaceae(= *Gramineae*) (rice, wheat, sorghum, oat, pearl millet, malt barley) and *Leguminosae* (chickpeas, peanuts, beans). Other alternative hosts are stored pharmaceuticals, leather stuffing, mud plaster, packaging materials made from wood, paper, bound books and cork. However, *R. dominica* achieves its maximum reproductive success on dry grains, especially on wheat[30]. Recent studies have shown that while *R. dominica* can tunnel in many woody plants, reproduction in most of them is generally poor [3].

R. dominica may locate potential host by chance as the beetles fly about to look for suitable potential host materials. This flight behavior is likely to assist the insect in locating potential host at long distance using olfactory-guided mechanisms (primary attraction) or the male produced aggregation pheromones (secondary attraction). Although the two mechanisms (random flight and olfactory-guided) are not mutually exclusive and either could operate separately as the primary mode for host location. Dispersal and host location behavior of *R. dominica* has been reported in detail [27] and volatiles fumes from grains which saturate the atmosphere in grain storage environment[suggested the ability of *R. dominica* to orient to the volatiles. The manner in which *R. dominica* response showed that the insect is stimulated to move towards and in the direction of plant odors. The secondary attractant is a far stronger stimulus relative to primary attractant for host plant location in *R. dominica* and in the bruchids [27, 30].

The objective of this paper is to review the use of synthetic insecticides for the control the lesser grain borer *R. dominica* (Fab).

Table 1 shows the residual activity of Azadirachtin with and without piperonyl butoxide (PB) in reducing the F1 and F2 progeny in each treatment. A summary of the statistical analyses in percent of the overall reduction in F1 progeny are presented. All test doses produced a high (>80%) level of control of F1progeny throughout the 48 weeks storage period. All treatments appeared to persist on the wheat grain as reflected by the absence of decline in the biological activity with increasing time after application. Addition of the synergist PB did not appear to greatly improve the efficacy. The statistics showed that the variability in the numbers of F1 progeny within treatments using azadirachtin alone, or in comparison with treatment PB, is not significant. The statistical parameters indicate that the data on reduction of adult emergence are homogeneous and in accordance with the assumptions that observations are normally distributed[32-33]. The inhibition of the F1 progeny was consistently higher at application rates of 50 mg kg^{-1} and above, with or without PB, as evident from the average F1 emergence. At 75mg kg^{-1}, or above, the few adults that emerged were found dead, presumably due to behavioral and physiological effects of azadirachtin. F2 progeny reductions are not presented but at doses of 10-50 mg kg^{-1}, the level of suppression of progeny was similar to that of F1. However, doses of 75mg kg^{-1} or above almost invariably produced no adults.

Table 1: Adult F1 and F2 progeny of *R. dominica* emerging from wheat treated with azadirachtin enriched neem kernel extract, with and without piperonyl butoxide (PB) (Mean + SEM) during 48 weeks storage period

	F1 progeny		F2 progeny	
Azadirachtin (mgkg^{-1})	Without PB	With PB	Without PB	With PB
0	692.0+262.0	590.9+228.7	589.0+254.0	585.0+161.0
10	23.1+16.0	37.8+23.9	24.6+11.6	51.0+10.5
25	22.8+14.1	7.5+10.7	20.1+6.5	6.8+2.5
50	4.7+2.7	2.5+3.2	6.4+1.6	2.5+1.2
75	3.2+2.5	2.6+2.7	0.6+0.04	0.6+0.8
100	2.7+1.9	2.9+1.5	0.3+0.2	0
200	3.4+2.4	3.1+1.8	0.7+0.4	0

*Mean of PB levels (2.20mg kg^{-1}).
Source: [34]

In table 2 other various oils extracted from many spice and herb plants[35], ZP 51 oil was found to be the most potent fumigant of all the oils tested against *R. dominica*. A concentration of 4.5µ/l or less was enough to obtain 90% kill of all the test insects within 24h in space tests. ZP 51 was also active in studies conducted in 600 ml fumigation chamber and in pilot tests in 1.2m – high columns, either 20 or 70% filled with wheat. The 5µ/l and at 7 days exposure were needed to obtain 94-100% kill of *R. dominica* tested when the study was conducted under conditions similar to those present in bulk storage.

Spices and medicinal plants of the Mediterranean areas which have essential oils (from a Labiatae sp) which found to be active as a fumigant against *R. dominica* in grains and as low as 50-70g oil/m^3 of concentration is needed to obtain effective control of the insects, compared to the recommended concentration for methyl bromide of 30g/m^3. Among the different plants tested, *Rauwoltia serpentina* was found to be most effective as it completely inhibited feeding and breeding of *R. dominica* at all the three concentrations. This plant is known to contain 27 physiologically active compounds. The results indicate that powder of *R. serpentina* can be used for the protection of stored wheat at farm level in tropical and subtropical countries and in highly *R. dominica* infested areas.

Acorus calamus and *M. Ferrea* protected the grain at high concentrations. *Acorus calamus* has been found to be effective against several stored grain insects. Reports indicate that powder of this plant is mixed with paddy and other grains for their protection in India and some other African countries. Complete mortality of *R. dominica* in 9.9 and 11 days at 1.0, 0.5 and 0.25% respectively has been reported. Only 45.0, 23.3 and 11.7% of adults were killed within 14 days at the respective concentrations as indicated on the table. *Albizia lebback* is mildly effective against *R. dominica*. Sorbic acid is known to suppress the population of several insects at 0.3 and 1.0%. It is generally regarded as safe at the level of (0.3% (w. w)) at which it is used as an insecticide and fungicide. These findings clearly indicate that powders of *R. serpentina*, *A. calamus* and *M. Ferrea* can be used as grain Protectants against *R. dominica*.

Table 2: Fumigant Toxicity of Essential Oils against *R. dominica* Insect in Space Test.

Plant source	LC 50	LC 90
Peppermint	9.6	16.0
Sage	6.7	10.8
Oregano	8.4	>15
Basil	10.0	16.7
Tree-lobed sage	6.8	10.8
Bay laurel	7.0	10.5
Rosemary	9.2	11.6
Lavender	11.4	13.8
Anise	8.8	21.3
ZP 51 (Labiatae sp.)	2.8	4.5

Sixty adults in three replicates were used for each experiment. The data are the average of 5-8 experiments. Exposure time 24 hr; the numbers are µ/L air.

Source [36]

Table 3 shows that methoprene was ineffective against adults even in those species where complete control of progeny was achieved. Synergized deltamethrin and combinations containing synergized deltamethrin gave protection against *R. dominica* for 30 weeks in wheat and 36 weeks in maize, during these periods the mortality was > 99% reduction in progeny. The organophosphorus (OP) protectants were not very effective against *R. dominica* in maize with > 50% progeny produced in each case, and tests of these treatments were terminated after 6 weeks of storage. In contrast, synergized deltamethrin and the combinations containing synergized deltamethrin gave complete control of the progeny in maize for 36 weeks. Although there was reduction in mean progeny production due to storage periods, the variation was narrow ranging from 97.2-99.0%. Efficacy of methoprene and the treatments containing methoprene against *R. dominica* may have been underestimated because of the difficulty in removing live parents insects from the maize kernels, those that were missed may have been recorded later as progeny. A mean of 47 out of 50 parents was recovered from the untreated maize and maize treated with methoprene and combinations containing methoprene. In contrast, parental mortality was high and recovery of parents was complete in maize treated with synergized deltamethrin combinations. The results for *R. dominica* in wheat were similar to the results for maize. The OP protectants were not very effective against this species in maize with > 50% progeny produced in each case, and tests of these treatments were discontinued after 6 weeks of storage. Synergised deltamethrin gave complete control of progeny for 30 weeks, as did the combinations containing synergised deltamethrin.

Experiments reported by Desmarchelier [37] and Daglish *et al*.,[38] provide data on the long term efficacy of a number of combination treatments against a range of species. This allows an assessment of the importance of the interactions between protectants in terms of control of progeny and this criterion is probably the most relevant for judging the ability of protectant treatments to prevent insect infestations. Based on periods of protection Desmarchelier [37] found no antagonism between OP protectants (dichlorvos, malathion, fenitrothion and pirimiphos-methyl) and pyrethroids (synergised or unsynergised Pyrethrins and bioresmethrin). Daglish, *et al*., [38] found strong synergism in paddy rice soon after treatment with chlorpyrifos-methyl+deltamethrin or chlorpyrifos-methyl synergised deltamethrin combinations, but based on the periods of protection there was no evidence of synergism or antagonism during long term storage. In the present study there was no synergism or antagonism between OP protectants and synergised deltamethrin during storage. These results support Desmarchellier's [37] generalization that during extended storage the effects of OP protectants and pyrethroids are additive, despite the fact that there may be substantial synergism in freshly treated grains [38, 39]. The rates were chosen with long term control in mind, and it is possible that if synergism occurred in freshly treated grain it might not have been detected in these experiments. This paper reports the efficacy of combinations of Methoprene with OP protectants even though there was no evidence of interactions. Similarly, Daglish *et al.*, [38] found no interactions between chlorpyrifos-methyl and methoprene in freshly treated paddy rice. These results support the additional generalization that during extended storage the effects of OP protectants and methoprene are additive.

The main use of protectants is to prevent infestations developing in stored grain from immigrating adults. Other studies involving long term experiments[37, 40], the level of potential mortality given by a treatment was not always a good indicator of the level of control of progeny and therefore any study looking for interactions between protectants should evaluate combination treatments during long term storage using control of progeny as the assessment criterion.

Table 3: Percentage Reduction of *R. dominica* Progeny Production in Maize at Different Times (weeks) after Treatment with Different Protectants

Treatment (mgkg^{-1})	Storage period (weeks)						
	0	6	12	18	24	30	36
Methoprene 1	95.3	97.6	99.2	98.8	99.6	99.0	98.1
Chlorpyrifos-methyl10+ methoprene 1	96.9	98.8	97.5	99.8	98.6	98.6	98.3
Fenitrothion 12+methoprene 1	98.4	98.2	99.1	99.2	99.2	98.6	98.3
Methacrifos 10+metheprene1	96.3	97.9	98.2	98.5	99.4	98.3	98.1
Pirimiphos-methyl6+methoprene1	99.1	97.9	98.2	97.4	98.2	99.2	97.9
Mean[a]	97.2	98.1	98.4	98.8	99.0	98.7	98.1

For storage period means the critical value of LSD (0.05) is 0.9 and LSD (0.01) is 1.2

Source: [41]

T**able 4** shows the efficacy of binary combinations of spinosad (1 mg kg^{-1}), chlorpyrifos–methyl (5 and 10 mg kg^{-1}) and s-methoprene (0.6 mg kg^{-1}) against resistant strains of *R. dominica, S. oryzae, T. castaneum, O. surinamensis,* and *C. ferrugineus* in wheat. Treatments are defined as effective if they caused >99% reduction in the number of live progeny relative to the control. Based on this criterion, there was no protectant combination that controlled all insect strains. The most effective combinations were chlorpyrifos–methyl at 10 mg kg^{-1}+ s-methoprene at 0.6 mg kg^{-1} which controlled all strains except methoprene-resistant *R. dominica*, and spinosad at 1 mg kg^{-1}+chlorpyrifos-methyl at 10 mg kg^{-1}, which controlled all strains except for OP-resistant *O. surinamensis*.

Early studies on alternative protectants showed that combinations of protectants (typically an OP protectants and a synergised pyrethroid) could give broad spectrum control. One combination that was used for many years was fenitrothion at 12 mg kg^{-1}+ bioresmethrin at 1 mg kg^{-1} + piperonyl butoxide at 8 mg kg^{-1}. The synergised pyrethroids targeted *R. dominica* and the OP targeted other species. Mortality was not always the best indicator of treatment efficacy because some treatments that had many adult survivors resulted in > 99% progeny reduction. The implication of results like these is that invading adults would be unable to produce sustainable populations in treated grain. This was particularly the case for some test strain exposed to wheat treated with s-methoprene or combinations containing s-methoprene. Mortality of OP-resistant *O. surrinamensis* was negligible in wheat treated with s-methoprene and the three combinations containing s-methoprene, but all four treatments resulted in no live progeny. In the case of *S. oryzae*, however, some treatments gave incomplete control of progeny despite giving 100% adult mortality. Efficacy in this study was determined in freshly treated wheat, it is possible that efficacy of treatments judged to be effective could decline during extended storage. The results of published studies suggest that any loss of efficacy is likely to be negligible[42-43].

Therefore binary combination of spinosad, chlorpyrifos-methyl and s-methoprene controlled a range of resistant strains of stored grain insects but each combination had specific strengths and weakness. The results demonstrate the difficulty of finding protectant combinations to control a broad range of pest species in the face of resistant development in Africa and potentially in other countries which use protectants.

Table 4: Percentage Mortality (mean ± S.E.) after 2 Weeks Exposure of Adults of Three Strains of *Rhyzopertha dominica* to Wheat Treated with Spinosad, Chlorpyrifos-methyl and S-methoprene alone or in Combination.

Treatment (Mgkg-1)	**QRD 788a**	**ORD551ab**	**Field a.c**
Control	0.7 ±9.7a	1.3 ± 0.7a	2.8 ± 2.8a
Spinosad (1)	100 ± 0.0b	100 ± 0.0b	98.7 ± 1.3b
Chlorpyrifos-methyl (5)	2.7 ± 1.3a	25.3 ± 2.4c	8.0 ± 7.00
Chlorpyrifos-methyl (10)	2.7 ± 1.3a	40.0 ± 4.0d	13.5 ± 9.0a
S-Methoprene (0.6)	6.7 ± 1.3a	0.0 ± 0.0a	10.2 ± 6.20a
Spinosad(1)+Chlorpyrifos-methyl (5)	100 ± 0.0b	100 ± 0.0b	100 ± 0.0b
Spinosad(1)+chlorpyrifos-methy(10)	100 ± 0.0b	100 ± 0.0b	100 ± 0.0b
Spinosad (1) + s-methoprene (0.6)	100 ± 0.0b	100 ± 0.0b	99.3 ± 0.7b
Chlorpyrifos-methyl(5)+S-methoprene (0.6)	2.7 ± 1.2a	40.7 ± 1.3d	10.7 ± 4.7a
Chlorpyrifos-methyl(10)+s-methoprene(0.6)	2.0 ± 1.2a	4.0 ± 1.3d	10.7 ± 4.7a

Means within columns are significantly different if followed by a different letter based on ANOVA of transformed data and the Boferroni multiple comparisons test (p<0.05).

[a] Organophosphorus Protectant- resistant

[b] Methoprene – resistant

[c] Contains pyrethroids – resistant insects

Source: [44].

Table 5 shows the results of treated sorghum with insecticides and indicated a strong impact throughout the trail on the reproduction of all three OP resistant strains of *R. dominica* including the strain QRD 551 which is also resistant to methoprene. There was no effect of storage period on QRD 788 which is resistant to OPs only, QRD 318 which is resistant to OPs and pyrethroids or QRD 551 which is resistant to OPs and methoprene. Similar response were for the three strains with mean progeny reduction during the trial of 5 months which give results of 99.9%, 99.8% and 99.9% for strains QRD 788, QRD 318 and QRD 551, respectively.

The results showed that the combination of diflubenzuron (1mg kg^{-1}) + methoprene (1mg kg^{-1}) was highly effective in protecting stored sorghum from *S. oryzae* and *R. dominica* despite low mortality of adults. The treatment resulted in 99-100% reduction in F1 progeny of *R. dominica* throughout the 7 months of trials and also greatly reduced the reproductive capacity of *S. oryzae*. Invading adults would be incapable of producing a sustainable population. Although the treated sorghum was not sampled for insects during storage, no live insects were detected in the samples prior to use in bioassay. In addition, the sorghum was sold within two weeks of the final sample collection, and no live insects were detected during off-loading using normal commercial methods.

Table 5: Percentage F1 Progeny Reduction (Mean ± SEM, n=3) of *R. dominica* in Sorghum Treated with Diflubenzuron (1 mg kg^{-1}) + methoprene (1mgkg^{-1}).

Storage Period[a] (Months)	Strain		
	QRD 788[b]	QRD 318[c]	QRD 551[d]
0.5	99.9 ± 0.1a	99.6 ± 0.2a	99.7 ± 0.3a
3.5	99.9 ± 0.1a	99.9 ± 0.2a	99.8 ± 0.0a
5	99.9 ± 0.2a	99.8 ± 0.1a	99.9 ± 0.1a
7	99.9 ± 0.1a	99.8 ± 0.1a	100 ± 0.0a

For each strain, means within columns are not significantly different (P>0.05) if followed by the same letter.

[a] Storage period includes 2 weeks of conditioning at relevant bioassay conditions.

[b] Resistant to OP compounds.

[c] Resistant to OP compounds and pyrethroids.

[d] Resistant to OP compounds and methoprene.

Source: [43].

In table 6, Wheat treated with pirimiphos – methyl at 4, 6 and 8mgkg^{-1} was effective against *R. dominica*, with pirimiphos – methyl proving more effective on *R. dominica* adult. On control wheat, 22.3 (± 0.3) *R. dominica* adults per container survived after, 7 days. Survival of adult *R. dominica* decreased significantly (< 0.05) as the rate of pirimiphos-methyl increased (Table 6). A few *R. dominica* adult [1.3 (± 0.7) adults per container] survived even the 8mg kg^{-1} rate. However, survival of *C. ferrugineus* and *S. oryzae* adults was significant although adult survival tended to decrease with an increase in insecticide rate.

Table 6: Survival of Adults of Four Beetle Species after 7 Days on Untreated Wheat and Wheat Treated with Pirimiphos-methyl Synergized pyrethrins, and Pirimiphos-methyl, plus synergized pyrethrins.

Insecticide rate(mg/kg)	Number of Survivors[b] (+SEM)	
Pirimiphos-methyl	**Synergized pyrethrins[a]**	***R. dominica***
0	0 0.38 0.75 1.13 1.5	22.3 (± 0.3)a 17.7 (± 1.8)a 13.7 (± 1 .2)a 10.7 (± 1.5)a 7.7 (± 0.7)a
4	0 0.38 0.75 1.13 1.5	6.3 (± 0.9)b 7.0 (± 1.5)b 3.0 (± 0.0)b 3.6(± 1.3)b 5.0 (± 0.6)b
6	0 0.38 0.75 1.13 1.5	2.0 (± 1.2)c 2.3 (± 0.3)c 2.3 (± 0.3)c 3.0 (± 0.6)c 2.0 (± 1.2)
8	0 0.38 0.75 1.13 1.5	1.3 (± 0.7)c 1.7 (± 01.2)c 2.3 (± 0.3)c 1.7 (± 0.3)c 0.7 (± 0.3)c

[a] pyrethrins were synergized with piperonyl butoxide in 1:10 ratio.
[b] Means within a vertical column followed by different letters are significantly different (P<0.05; by least squares means test).
Source;[45].

In table 7, Pirimiphos-methyl at all three rates effectively suppressed progeny production of *R. dominica*. A large number of progeny were observed on untreated wheat, whereas no progeny (Larvae, pupae or adults) were found on wheat treated with pirimiphos–methyl (Table 7). In general, progeny production decreased with increasing rates of synergized pyrethrins. Synergized pyrethrins at 1.5 mg kg^{-1} satisfactorily suppressed progeny production of *R. dominica*. However, Synergised Pyrethrins alone did not provide sufficient progeny suppression and combinations of pirimiphos-methyl and synergised Pyrethrins significantly suppressed progeny of all five species.

Table 7: Progeny Production of Five Insect Species after 49 Days on Untreated Wheat and on Wheat Treated with Pirimiphos-methyl Synergized pyrethrins and Pirimiphos-methyl plus synergized pyrethrins.

Insecticide rate(mg kg^{-1})	Progeny [ab](+SEM)	
Pirimiphos-methyl	**Synergized pyrethrins[c]**	***R. dominica***
0	0 0.38 0.75 1.13 1.5	154. (+ 10.1)a 34.7 (+ 10.2)b 19.7 (+ 3.4)b 5.0 (+ 5.0)a 0.3 (+ 0.3)d
4,6, or 8	0 0.38 0.75 1.13 1.5	6.3 (+ 0.0)a 0.0 (+ 0.0)d 0.0 (+ 0.0)d 0.0(+ 0.0)d 0.0 (+ 0.0)d

[a] The number progeny for the four beetle species was the total number of insects observed minus the 25 beetle adults, which were originally released to infest the wheat. No live beetle were found from any treatment containing pirimiphos – methyl. The data are based on adult only.

[b] Means within a vertical column followed by different letters are significantly different (P,0.05; by least square means test).
[c] pyrethrins were synergized with piperonyl butoxide in 1:10 ratio.
Source: [45].

Table 8 shows Pirimiphos-methyl alone at 4-8mgkg^{-1} effectively prevented kernel damage by *R. dominica* synergized pyrethrins were effective in preventing kernel damage. In general, kernel damage decreased with increasing rate of synergized pyrethrins at 1.5mgkg^{-1} provided good kernel protection because < 2.3% of the kernels were damaged by *R. dominica*. The interaction was significant for *R. dominica* as the combination treatments provided 100% protection from kernel damage by *R. dominica* however, adult *R. dominica* survived the 7 day exposure to wheat treated with pirimiphos-methyl at 4-8 mg kg^{-1} , progeny production and kernel damage were completely suppressed at these rates. They lay eggs outside the kernel and larvae hatching from eggs enter the kernels and continue development within the kernels. The complete suppression of progeny production and kernel damage can be attributed to high susceptibility of neonate larvae to pirimiphos-methyl and all treatments containing pirimiphos-methyl killed 100% of exposed adults of the beetles of *R. dominica* and completely suppressed progeny production and kernel damage. Similarly, a combination of pirimiphos-methyl at < 4 mg kg-1 with the synergised pyrethrins was not deemed necessary to achieve high control efficacy against *R. dominica*. Pirimiphos-methyl appears to be a potential grain protectant for use on wheat at 4-8 mg kg^{-1} to manage the major stored product insects like *R. dominica*.

Table 8: Number of damaged kernel of untreated wheat and insecticide-treated wheat damaged by *R. dominica* of 49 days

Insecticide rate (mgkg^{-1})	Number of damaged Kernels[b] (+SEM)	
Pirimiphos-methyl	Synergized pyrethrins	*R. dominica*
0	0	14.7 (± 1.9)a
	0.38	8.3 (± 2.7)ab
	0.75	4.7 (± 1,5)b
	1.13	1.3 (± 0.7)c
	1.5	0.7 (± 0.3)cd
4	0	0.7 (± 0.7)cd
	0.38	0.7 (± 0.7)cd
	0.75	0.3 (± 0.3)cd
	1.13	0.3(± 0.3)cd
	1.5	0.0 (± 0.0)d
6	0	0.0 (± 0.0)d
	0.38	0.0 (± 0.0)d
	0.75	0.7 (± 0.7)cd
	1.13	0.0 (± 0.0)d
	1.5	0.3 (± 0.3)cd
8	0	0.0 (± 0.0)d
	0.38	0.3 (± 0.3)cd
	0.75	0.0 (± 0.0)d
	1.13	0.0 (± 0.0)d
	1.5	0.0 (± 0.0)d

[a] Pyrethrins were synergized with piperonyl butoxide in 1:10 ratio.
[b] Means within a vertical column followed by different letters are significantly different (P<0.05; by least-square means test).
Source: [45].

In table 9, an application of Dryacide® at the labeled rate of 1000ppm could effectively control *R. dominica* in stored wheat. The observed mortality level was about 98% and this happen as a result of amount of DE in the Dryacide® formulation. In general, this study the label rate of 1000ppm Dryacide® reduced penetration of *R. dominica* through the treated grain mass, as shown by the level of mortality in the initial adult population and collectively low number of live adults collected after each exposure intervals; the resultant population of live progeny was also very low. While increasing the rates of Insecto™ or Protec-It®, may or may not yield comparable results to those obtained for Dryacide® , the current rate of 1000ppm Dryacide® could be used as a surface treatment or in combination with other control strategist to suppress *R. dominica* populations in stored wheat.

Table 9 Percentages of Live and Dead Parental *R. dominica* within and Below the Layers of Wheat Treated with Three Commercial Formulations of Diatomaceous Earth (DE).

	Live *R. dominica*		Dead *R. dominica*		% Total survival	
Treatment	Within DE	Below DE		Within DE	Below DE	
Untreated control	96.7±3.3	3.3±3.3c		3.3±3.3	96.6±3.3a	96.7±3.3a
Insecto™ 500ppm	9.0±1.6	91.0±1.6b		53.8±4.7	46.2±4.7b	27.4±3.7b
Protect-It® 400ppm	5.7±1.1	94.3±1.1ab		72.4±4.9	27.6±4.9c	16.6±2.8c
Dryacide®1000ppm	2.2±0.4	97.8±0.4a		97.5±2.3	2.5±2.3d	1.9±0.3d

Means within columns for below DE followed by different letter are significantly different (p<0.05).
Source:[22].

In table 10, the mixture of Insecto®, PyriSec®, and Protect-It® gave better mortality compared with each DE alone. Insecto® contains food additive compounds, PyriSec® contains natural pyrethrum and Protect-It® contains silica aerogel and their efficacy increased when mixed together. The DE combination takes advantage of the positive characteristics of each formulation and the presence of food additives, which may cause internal desiccation, can be combined with the high abrasive power of small doses of pyrethroids which increase the rate of mortality.

Table 10. Mean (%) Mortality (±SE) of *R. dominica* adults Exposed for 7 Days on Wheat and Maize Treated with Insect ®, PyriSec ®, and Protect-It ®, alone or in Combination, at Three Dose Rates (I: Insect ®, P: PyriSec ®, and P: Protect-It ®)[a]

DE Formulation/combination							
Dose rate(kg)	**I**	**P**	**R**	**I+P**	**I+R**	**P+R**	**I+P+R**
Wheat							
0.25	51.2±4.7a	86.5±3.3b	78.3±3.0c	89.3±2.3	88.3±3.9bd	80.1±3.0c	94.3±3.9d
0.50	92.0±2.7a	97.4±1.4b	98.5±0.6bc	99.0±0.7bc	99.2±0.5bc	98.3±4.6bc	100±0.0c
0.75	98.2±1.4ab	98.5±1.0ab	93.3±0.5ab	99.2±0.6ab	99.1±0.4ab	97.9±1.1a	100±0.00b
Maize							
0.25	62.2±4.3a	82.5±5.0bc	79.2±4.2b	81.3±2.6bc	83.2±3.9bc	89.4±2.8c	87.2±2.1c
0.50	75.3±4.8a	91.3±3.0bc	89.5±4.8bc	84.2±2.5b	88.2±2.9b	94.3±2.6c	95.1±2.8c
0.75	76.0±4.7a	90.3±4.0bc	90.2±2.4bc	90.4±4.6bc	89.0±3.7c	95.9±3.1b	96.1±2.6b

Means within each row followed by the same letter are not significantly different (HSD test at P< 0.05).
Source:[46].

In table 11, spinosad at the labeled rate of 1mg (a.i)/kg protected hard wheat from infestation and damage by *R. dominica*. Spinosad has low mammalian toxicity and is persistent on wheat for a period of 12 months [47]. These attributes makes an appealing grain protectant for organic or non-organic wheat growers.

Table 11. Adult Survival and Progeny Production of Kernel Damage Bystored-Product Beetle on Untreated and Spinosad-Treated Hard White Winter Wheat.

Specie	**Rate, mg(a.i)/kg**	**Number of live adult at: 7days[1]**	**14days[1]**	**Number of progeny[1,2]**	**Number of kernels damage[2,3] 7days[1]**	**14days[1]**	**49days[1]**
R. dominica	0	24.7±0.3[4]	23.3±1.7[4]	76.0±6.8[4]	0.7±0.3a	1.3±0.9a	8.7±1.3a
	0.1	0	0	0	0a	0a	1.0±0.6b
	0.5	0	0	0	0.7±0.3a	0.3±0.3a	0c
	1.0	0	0	0	0a	0.3±0.0a	0c

[1]Mean within a vertical column followed by different letters are significantly different (P < 0.05; by Fisher's protected least significant difference test).
[2]The number of progeny produced by the beetle was the total number of insects observed after subtracting the 25 beetle adults which were originally released to infest the wheat.
Source: [48].

CONCLUSION

The various synthetic and botanical insecticides such as diflubenzuron, Pirimiphos-methyl, synergised pyrethrins, spinosad, chlorpyrifos-methyl and methoprene proved effective against *R. dominica*. Azadirachtin and essential oils of several plants with insecticidal properties are also among the effective botanical insecticides. Diatomaceous earth (DE) applied as a surface or "top-dresses" or admixture treatment proved to be an effective protective barrier from migrating stored insect pests that may enter grain bins from the top and preventing spread of the insects within stored grain mass, the use of fumigants, manipulation of temperature and relative humidity has been key factors in the control of *R. dominica*. Combination of two or more formulations of Des increase efficacy against *R. dominica*. The use of synthetic insecticides as shown by this review has demonstrated that time and period (length) of storage also matters in the control of this pest in stored grains. Although, botanicals can be used but the time being, synthetic chemicals based on this review have shown to have longer residual active than botanicals which are biodegradable in nature.

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