Brazilian Journal of Biology®

ISSN 1519-6984 (Print)
ISSN 1678-4375 (Online)

Original Article

Effect of three insect growth regulators on certain biological aspects of the lesser grain borer, *Rhyzopertha dominica* (Coleoptera: Bostrichidae)

Efeito de três reguladores de crescimento de insetos em certos aspectos biológicos da broca-do-grão, *Rhyzopertha dominica* (Coleoptera: Bostrichidae)

M. A. Mahmoud[a]*, I. E. AbdElrahman[b], O. A. A. Zedan[a], Y. A. Abdel-Rahman[a], R. M. Saba[a], G. F. Abo Laban[b] and I. S. Ibrahim[b]

[a]Al-Azhar University, Faculty of Agriculture, Plant Protection Department, Assiut, Egypt
[b]Al-Azhar University, Faculty of Agriculture, Plant Protection Department, Cairo, Egypt

Abstract

The current study was performed to evaluate the efficacy of certain insect growth regulators (IGRs), buprofezin, hexaflumuron, and lufenuron, at different concentrations (0.2, 0.4, and 0.8 ppm) against *Rhyzopertha dominica* in wheat grains. Our data showed that the three IGRs tested at different concentrations significantly affected the mortality of adults to varying extents. The percentage mortality of adults increased with increasing concentrations and time of exposure. After 21 days of treatment, the highest mortality (80.00%, 78.33%, and 60.00%) was observed at the highest concentration (0.8 ppm) and the lowest mortality (58.33%, 46.66%, and 30.00%) was observed at the lowest concentration (0.2 ppm) of lufenuron, buprofezin, and hexaflumuron, respectively. The tested IGRs reduced fecundity, hatchability, adult emergence, and weight loss in treated wheat grains and increased the developmental period of *R. dominica* compared with the control.

Keywords: lesser grain borer, IGR, mortality, fecundity, adult emergence, weight loss.

Resumo

O presente estudo foi realizado para avaliar a eficácia de certos Reguladores de Crescimento de Insetos (RCIs), buprofezin, hexaflumuron e lufenuron, em diferentes concentrações (0,2, 0,4 e 0,8 ppm) contra *Rhyzopertha dominica* em grãos de trigo. Nossos dados mostraram que os três RCIs, testados em diferentes concentrações, afetaram significativamente a mortalidade de adultos em graus variados. A mortalidade percentual de adultos cresceu com o aumento das concentrações e do tempo de exposição. Após 21 dias de tratamento, a maior mortalidade (80,00%, 78,33% e 60,00%) foi observada na maior concentração (0,8 ppm) e a menor mortalidade (58,33%, 46,66% e 30,00%) foi observada na menor concentração (0,2 ppm) de lufenuron, buprofezin e hexaflumuron, respectivamente. Os RCIs testados reduziram a fecundidade, eclodibilidade, emergência de adultos e perda de peso em grãos de trigo tratados, bem como aumentaram o período de desenvolvimento de *R. dominica* em comparação com o controle.

Palavras-chave: broca-do-grão, RCI, mortalidade, fecundidade, emergência de adultos, peso.

1. Introduction

Wheat (*Tritium aestivum* L.) is considered the most important cereal crop because of its high production and consumption. It is the leading staple in human foods (Ileke, 2011). Wheat is attacked in the field and in storage by several pests that attack the stored grains and grain produce. Among them, the lesser grain borer, *Rhyzopertha dominica* (F.) (Coleoptera: Bostrichidae), is one of the major pests of cereals stored in many regions of the world (Edde, 2012). This pest is present both in the field at harvesting time and in granaries (Naseem and Khan, 2011). It is one of the most important pests of stored wheat, and it also attacks other crops (e.g., barley, beans, chickpeas, millet, malt, oats, sorghum, rice, peanuts, and pearl) (Perisic et al., 2018; Chandel et al., 2019). The beetle is especially prevalent in tropical and subtropical regions (Obretenchev et al., 2020). Adults and larvae cause major qualitative and quantitative losses to several crops (Banga et al., 2018). The total grain damage this insect causes annually around the world is estimated to be 10% to 40% (Matthews, 1993). The presence of this pest in stored grain reduces not only the quantity but also the quality of the grains and reduces their nutritional value as well as the market value, making them unfit for human consumption (Astuti et al., 2013).

*e-mail: MahmoudAli.49@azhar.edu.eg
Received: September 7, 2022 – Accepted: October 16, 2022

Chemical pesticides carry health risks and can cause environmental pollution (Grewal et al., 2017) because of their toxicity to humans and wildlife (Paoletti and Pimentel, 2000). The presence of insecticide residues in food (Phillips and Throne, 2010) and the development of insecticide resistance (Boyer et al., 2012) are of major concern around the world. To overcome these problems, safe alternative approaches are required for the management of insect pests of stored products. Insect growth regulators (IGRs) are receiving more attention because of their efficacy against insects in stored grain. In addition, they are environmentally safe, biodegradable, and nontoxic to humans and nontarget organisms (Ishaaya et al., 2007). These features of IGRs increase acceptance of products treated with IGRs by the food industry (Phillips and Throne, 2010). IGRs are effective in suppressing the development of insects for the entire life cycle (Gelbic et al., 2011). IGRs aim to affect mating efficiency and reduce egg production in emerging adults (Segura et al., 2009). Chitin synthesis inhibitors (CSIs), a group of IGRs, are very effective against several pests of stored grain by treating either the commodities that contain eggs or the adults (Mishra et al., 2013; Trostanetsky et al., 2015; Ali et al., 2016). CSIs have been widely used to impair the reproduction and development of insects (Arthur and Hartzer, 2018). CSIs interfere with chitin synthesis in insects and thus prevent molting or cause production of an imperfect cuticle (Abdel Rahman et al., 2007). Buprofezin, hexaflumuron, and lufenuron are some CSIs that affect oviposition, egg hatchability, adult emergence, and development of stored grain insect pests (Sohrabi et al., 2011; Kavallieratos et al., 2012; Ali et al., 2016, 2018, 2019; Fiaz et al., 2018; Yasir et al., 2019). IGRs are considered ecofriendly in the control of insect pests.

This study aimed to evaluate the effects of buprofezin, hexaflumuron, and lufenuron on mortality in adult *R. dominica*; determine the effects of these IGRs on the fecundity, hatchability, progeny, and developmental period of *R. dominica*; and determine the effects of these IGRs on weight loss in wheat grains.

2. Materials and methods

2.1. Rearing of insects

Adults of *R. dominica* were collected from the naturally infested wheat grains from the local market in Assiut Governorate, Egypt. In each glass jar of 1 liter capacity, fifty pairs of adult *R. dominica* were released into 500 g of disinfected wheat grains. The mouths of the jars were covered with muslin cloth fastened with rubber bands to ensure ventilation while preventing the escape of the insects, and the jars were incubated at 30°C ± 2°C and 70% ± 5% relative humidity. The beetles were left in the culture for about 10 days for egg-laying. Newly emerged adults (0 to 24 hours old) were placed in glass jars containing sterilized grain for oviposition in order to maintain a stock culture for a continuous fresh supply of the insects.

Male and female adults were identified according to the description of Hagstrum and Subramanyam (2006). The last exposed abdominal tergum was usually uniformly brown in males and pale yellow in females.

2.2. IGRs

Three locally available IGRs (buprofezin [Applaud 25% SC] from Nihon Nohyaku Company Japan, hexaflumuron [Dimeuron 10% EC] from the national company for Agrochemicals Productions Egypt, and lufenuron [Match, 5% EC] from Syngenta Agro Company Switzerland) were used at concentrations of 0.0, 0.2, 0.4, and 0.8 ppm.

2.3. Experimental design

To determine the effects of buprofezin, hexaflumuron, and lufenuron on *R. dominica*, 30 g of sterilized wheat grains were placed in glass jars of 200 ml capacity and sprayed by hand sprayer with 1 ml each of buprofezin, hexaflumuron, and lufenuron at concentrations of 0.2, 0.4, and 0.8 ppm prepared in distilled water. Distilled water was used as the control. The sprayed grain was then left to air-dry. Ten pairs of 1- to 2-day-old adult *R. dominica* were then placed in each jar. The jars were covered with muslin cloth to prevent the insects from escaping and maintained at 30°C ± 2°C and 70% ± 5% relative humidity. Three replicates were used for each treatment. Mortality of adults was recorded after 7, 14, and 21 days of treatment application. Corrected mortality (PT) was calculated by Abbotts's (Abbott, 1925) using the Formula 1

$$PT = (Po - Pc / 100 - Pc) \times 100 \quad (1)$$

where Po = Observed mortality, Pc = Control mortality.

The numbers of eggs laid and hatched were recorded after 10 days of treatment. The number of days taken by the insects to complete their life cycle from the egg to the adult stage was calculated according to Howe (1971).

After 50 days of treatment, we counted and recorded the number of F1 adults emerged and determined the weight loss of the wheat grains. The percent inhibition rate (% IR) in fecundity, eggs hatched, and adults emerged were calculated according to Silassie and Getu (2009) using the Formula 2

$$\% IR = Cn - Tn / Cn \times 100 \quad (2)$$

where Cn is the number of eggs laid, eggs hatched, and newly emerged insects in the control group, and Tn is the number of eggs laid, eggs hatched, and newly emerged insects in the treatment group.

Percent weight loss (PWL) was calculated according to Odeyemi and Daramola (2000) as (Equation 3)

$$PWL = IW - FW / IW \times 100 \quad (3)$$

where IW is the initial weight and FW is the final weight.

2.4. Statistical analysis

The data were analyzed by two-way analysis of variance using the Statistical Analysis System at a significance level of 5%. The mean differences were separated using the least significant difference and shown as means ± SE.

3. Results

3.1. Effect of IGRs on adult mortality

The results in Table 1 show the effects of different concentrations of IGRs on mortality in adult *R. dominica* after 7, 14, and 21 days of treatment. The mean percentages of adult mortality after 7, 14, and 21 days of treatment at 0.2 ppm concentration were 26.66%, 40.00%, and 46.66% for buprofezin, 16.66%, 21.66%, and 30.00% for hexaflumuron, and 35.00%, 53.33%, and 58.33% for lufenuron, respectively. Increasing the IGR concentration to 0.8 ppm increased the percentage of adult mortality after 7, 14, and 21 days of treatment to 40.00%, 61.66%, and 78.33% for buprofezin, 41.66%, 46.66%, and 60.00% for hexaflumuron, and 53.33%, 73.33%, and 80.00% for lufenuron, respectively. In general, the percentage of adult mortality increased vertically with increased concentration of IGRs and horizontally with increased time of exposure to IGRs. The highest percentage of adult mortality was 80.00% for lufenuron at 0.8 ppm after 21 days of treatment. The lowest percentage of adult mortality was 16.66% for hexaflumuron at 0.2 ppm after 7 days of treatment. In general, the results showed that lufenuron was the most effective IGR against *R. dominica*, followed by hexaflumuron and then buprofezin.

3.2. Effect of IGRs on oviposition

Table 2 shows the mean number of *R. dominica* eggs laid on wheat grains treated with different concentrations of IGRs, compared with control. The number of eggs laid on untreated grains was 163.33 eggs / female. The number of eggs laid on grains treated with buprofezin at 0.2 ppm concentration was 72.00 eggs / female, decreasing with increasing concentration of buprofezin to 16.33 eggs / female at 0.8 ppm. The number of eggs laid on grains treated with hexaflumuron at 0.2 ppm concentration was 100.33 eggs / female, decreasing with increasing concentration of hexaflumuron to 58.66 eggs / female at 0.8 ppm. The number of eggs laid on grains treated with

Table 1. Mortality of *Rhyzopertha dominica* adults exposed for 7, 14, and 21 days to wheat grains treated with different concentrations of insect growth regulators (IGRs).

IGR	Concentration (ppm)	Mean ± SE mortality (%)		
		7 days	14 days	21 days
Buprofezin	**0.2**	26.66 ± 1.66^{e}	40.00 ± 2.89^{e}	46.66 ± 3.33^{d}
	0.4	$31.66 \pm 3.33d^{e}$	48.33 ± 1.66^{cde}	70.00 ± 5.78^{ab}
	0.8	$40.00 \pm 0.00b^{c}$	61.66 ± 3.33^{ab}	78.33 ± 1.66^{a}
Hexaflumuron	**0.2**	16.66 ± 1.66^{f}	21.66 ± 4.41^{f}	30.00 ± 2.89^{e}
	0.4	$28.33 \pm 1.66d^{e}$	36.66 ± 6.67^{e}	51.66 ± 3.33^{cd}
	0.8	41.66 ± 4.41^{bc}	46.66 ± 3.33^{de}	60.00 ± 2.89^{bc}
Lufenuron	**0.2**	35.00 ± 2.89^{cd}	53.33 ± 4.41^{bcd}	58.33 ± 3.33^{c}
	0.4	43.33 ± 1.66^{b}	60.00 ± 2.89^{bc}	71.66 ± 2.89^{a}
	0.8	53.33 ± 3.33^{a}	73.33 ± 4.4^{a}	80.00 ± 5.00^{a}
F-value		17.2	14.6	19.5

Values within a column sharing the same superscript letter are not significantly different at $P < 0.05$ (df = 8).

Table 2. Oviposition of *Rhyzopertha dominica* on wheat grains treated with different concentrations of insect growth regulators (IGRs).

IGR	Concentration (ppm)	Mean ± SE	
		No. of eggs/female	% reduction
Control	**0.0**	163.33 ± 3.18^{a}	–
Buprofezin	**0.2**	72.00 ± 3.46^{c}	55.96 ± 1.26
	0.4	57.66 ± 4.63^{de}	64.77 ± 2.14
	0.8	16.33 ± 4.26^{f}	90.08 ± 2.45
Hexaflumuron	**0.2**	100.33 ± 1.45^{b}	38.53 ± 1.19
	0.4	82.00 ± 3.60^{c}	49.69 ± 3.01
	0.8	58.66 ± 1.85^{d}	64.04 ± 1.42
Lufenuron	**0.2**	83.00 ± 3.00^{c}	49.13 ± 2.10
	0.4	47.33 ± 2.02^{e}	70.94 ± 1.80
	0.8	21.66 ± 6.96^{f}	86.88 ± 3.02

Values within a column sharing the same letter are not significantly different at $P < 0.05$ ($F = 125$; df = 9).

lufenuron at 0.2 ppm concentration was 83.00 eggs / female, decreasing with increasing concentration of lufenuron to 21.66 eggs / female at 0.8 ppm. The highest percentage reduction of the number of eggs laid (90.08%) was recorded for buprofezin at a concentration 0.8 ppm, while the lowest percentage reduction of the number of eggs laid (38.53%) was recorded for hexaflumuron at a concentration of 0.2 ppm.

3.3. Effect of IGRs on hatchability

The results in Table 3 show the mean number of hatched eggs of *R. dominica* on grain treated with different concentrations of IGRs, compared with control. The mean number of eggs hatched on untreated grains was 160.66. The lowest number of hatched eggs was recorded in grain treated with lufenuron at 0.8 ppm concentration (0.00 eggs); the number increased gradually with decreasing concentrations of lufenuron to 75.00 eggs at a concentration 0.2 ppm. For grain treated with hexaflumuron, 87.33 eggs were hatched at 0.2 ppm, and the number decreased gradually to 40.33 eggs at 0.8 ppm. The mean number of eggs hatched on grains treated with 0.2 ppm of buprofezin was 60.00, decreasing gradually with increased concentration of buprofezin concentration to 3.66 eggs at a concentration of 0.8 ppm. The highest percent reduction in hatchability (100%) was recorded with lufenuron at a concentration of 0.8 ppm, decreasing gradually with decreased concentration of lufenuron to 53.30% at a concentration 0.2 ppm; the lowest percent reduction in hatchability (45.59%) was recorded with hexaflumuron at a concentration of 0.2 ppm. In general, increasing concentration of the tested IGRs resulted in a decrease in the number of eggs hatching.

3.4. Effect of IGRs on adult emergence

The results in Table 4 show the mean number of adults of *R. dominica* emerging from wheat grain treated with different IGRs compared with untreated grain. The mean

Table 3. Hatchability of *Rhyzopertha dominica* eggs on wheat grains treated with different concentrations of insect growth regulators (IGRs).

IGR	Concentration (ppm)	Mean ± SE	
		No. of eggs hatched	% reduction
Control	**0.0**	160.66 ± 3.28^{a}	–
Buprofezin	**0.2**	60.00 ± 1.52^{d}	62.66 ± 0.19
	0.4	45.00 ± 2.31^{e}	71.92 ± 1.85
	0.8	3.66 ± 3.67^{g}	97.69 ± 2.30
Hexaflumuron	**0.2**	87.33 ± 3.93^{b}	45.59 ± 2.71
	0.4	65.00 ± 2.00^{d}	59.52 ± 1.33
	0.8	40.33 ± 2.02^{ef}	74.85 ± 1.54
Lufenuron	**0.2**	75.00 ± 2.08^{c}	53.30 ± 1.18
	0.4	34.66 ± 2.90^{f}	78.33 ± 2.22
	0.8	0.00 ± 0.00^{g}	100 ± 0.00

Values within a column sharing the same superscript letter are not significantly different at $P < 0.05$ ($F = 311$; $df = 9$).

Table 4. Adult emergence of *Rhyzopertha dominica* from wheat grains treated with different concentrations of insect growth regulators (IGRs).

IGR	Concentration (ppm)	Mean ± SE	
		No. of adults emerged	% reduction
Control	**0.0**	150.66 ± 1.20^{a}	–
Buprofezin	**0.2**	47.00 ± 1.00^{c}	68.65 ± 0.38
	0.4	22.00 ± 3.21^{e}	85.36 ± 2.21
	0.8	1.33 ± 1.33^{g}	99.11 ± 0.89
Hexaflumuron	**0.2**	63.33 ± 1.85^{b}	57.97 ± 0.92
	0.4	43.66 ± 2.60^{cd}	71.03 ± 1.51
	0.8	11.00 ± 1.15^{f}	92.49 ± 0.
Lufenuron	**0.2**	39.33 ± 2.60^{d}	73.86 ± 1.92
	0.4	16.00 ± 2.89^{f}	89.38 ± 1.91
	0.8	0.00 ± 0.00^{g}	100 ± 0.00

Values within a column sharing the same superscript letter are not significantly different at $P < 0.05$ ($F = 477$; $df = 9$).

number of adults emerging from untreated wheat grain was 150.66. The mean numbers of adults emerging from wheat grain treated with IGRs at a concentration of 0.2 ppm were 63.33, 47.00, and 39.33 for wheat grain treated with hexaflumuron, buprofezin, and lufenuron, respectively. Adult emergence decreased significantly to 11.00, 1.33, and 0.00 for wheat grain treated with hexaflumuron, buprofezin, and lufenuron, respectively, with increase of the concentration of the three IGRs to 0.8 ppm. The highest percentage reduction of adult emergence (100%) was recorded for lufenuron at a concentration of 0.8 ppm. The lowest percentage reduction of adult emergence (57.97%) was recorded for hexaflumuron at a concentration of 0.2 ppm.

3.5. Effect of IGRs on developmental period

The mean developmental period of *R. dominica* on untreated grain was 27.33 days (Figure 1). The mean developmental period was longer on grains treated with IGRs. The mean developmental period was 29.66, 31.00, and 35.00 days for grains treated with hexaflumuron, buprofezin, and lufenuron, respectively, at 0.2 ppm concentration. The developmental period increased significantly to 34.66, 36.33, and 44.66 days, respectively, with increase of the concentrations of hexaflumuron, buprofezin, and lufenuron to 0.8 ppm.

Statistical parameters: buprofezin ($F = 27.3$; $P < 0.05$; $df = 3$); hexaflumuron ($F = 9.91$; $P < 0.05$; $df = 3$); lufenuron ($F = 46.6$; $P < 0.05$; $df = 3$).

3.6. Effect of IGRs on weight loss

Figure 2 shows the mean loss in weight of wheat grain treated with IGRs at three concentrations, compared with untreated grain. The mean loss in weight of untreated grains was 13.36%. In grain treated with 0.2 ppm lufenuron, the loss in weight was 1.68%, decreasing to 0.00% in grain treated with 0.8 ppm lufenuron. Buprofezin at 0.2 ppm was second to lufenuron in its efficacy in reducing grain weight loss; the mean loss was 2.41%, decreasing gradually to 0.09% with increase of buprofezin concentration to 0.8 ppm. Hexaflumuron at 0.2 ppm was the least effective at reducing grain weight loss; the mean loss was 2.87%, decreasing gradually to 0.44% with hexaflumuron at a concentration of 0.8 ppm.

Statistical parameters: buprofezin ($F = 2224$; $P < 0.05$; $df = 3$); hexaflumuron ($F = 1997$; $P < 0.05$; $df = 3$); lufenuron ($F = 2303$; $P < 0.05$; $df = 3$).

4. Discussion

Our findings regarding the effects of IGRs against *R. dominica* showed that lufenuron had a strong effect, with 80% adult mortality after 21 days exposure to treated grain. Similar results regarding mortality in *R. dominica* exposed to IGR-treated grain were reported by Kavallieratos et al. (2012). Other studies have also reported an increase in mortality with increased exposure to IGR-treated diets (Sagheer et al., 2012; Yasir et al., 2012; Ali et al., 2016).

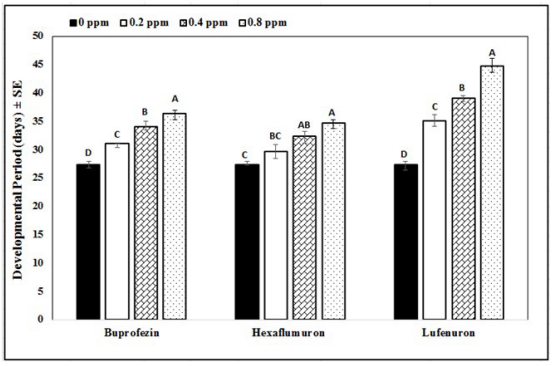

Figure 1. Mean developmental period of *Rhyzopertha dominica* on wheat grains treated with different concentrations of insect growth regulators (IGRs).

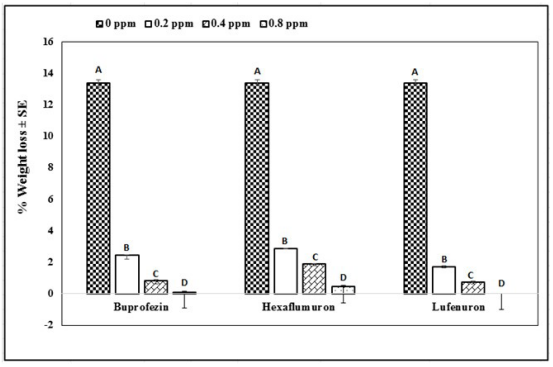

Figure 2. Mean percent weight loss in wheat treated with different concentrations of insect growth regulators (IGRs).

The results of this study showed the inhibitory effects of IGRs on fecundity and egg hatchability in *R. dominica*. The highest percent reductions in fecundity and egg hatchability were recorded for buprofezin and lufenuron at 0.8 ppm, respectively. Other studies also report the ovicidal activity of the CSIs triflumuron, flufenoxuron, and lufenuron against *Tribolium castaneum* (Parween et al., 2001; Salokhe et al., 2003). Similar results have been reported by Arthur (2004) against the adults of *R. dominica* by the application of *s*methoprene. Abo-Elghar et al. (2004) reported the ovicidal and developmental inhibition activity of CSIs against cowpea weevil. Hexaflumuron reduced the fecundity and affected the growth and development of oocytes and egg viability of *Callosobruchus maculatus* (Kellouche and Soltani, 2006). Egg production in *R. dominica* was significantly reduced by treatment with methoprene, which simultaneously affected egg hatchability (Chanbang et al., 2008). Our findings are also in line with the results of the studies on the effect of lufenuron against *T. castaneum,* which found significant reductions in fecundity and hatchability (Ali et al., 2019; Awais et al., 2019; Yasir et al., 2019).

Our results showed that lufenuron was the most effective compound against *R. dominica* among the three IGRs tested. At 0.8 ppm, it completely inhibited the F1 adult emergence

of *R. dominica*. For example, exposure of adults of *R. dominica* to pyriproxyfen- and methoprene-treated grains resulted in reduction in F1 adult emergence (Kostyukovsky et al., 2000; Daglish and Wallbank, 2005). Mahanthi (2006), tested lufenuron as a stored-maize protectant and showed that it completely inhibited the adult emergence of *Sitophilus oryzae* and completely controlled *Corcyra cephalonica*. Arthur et al. (2009) reported inhibition of adult emergence of stored-product insect pests due to larval exposure to IGRs. Ali et al. (2016) reported reduced adult emergence when adults of *T. castaneum, Tribolium confusum,* and *Ephestia cautella* were exposed to methoprene-treated diets. Similar results of inhibition of adult emergence had been reported (Ioni et al., 2011; Kavallieratos et al., 2012; Ali et al., 2018; Fiaz et al., 2018) when stored grain insect pests were exposed to IGR-treated food media.

The effects of the tested IGRs on the developmental period were similar to the findings of Kostyukovsky et al. (2000), who found that methoprene, pyriproxyfen, RH-5849, and tebufenozide affected the development of susceptible and actellic-resistant strains of *T. castaneum* and susceptible strains of *R. dominica* and *S. oryzae* Our results agree with those of Trostanetsky and Kostyukovsky (2008), who also found that the development of progeny was affected when adults of *T. castaneum* were treated with CSIs. Our findings are also supported by the work of Arora et al. (2012), who reported the effects of sublethal concentrations of lufenuron against different developmental stages of *T. castaneum.* Lufenuron had very little effect against adults when it was fed in the diet. These results are supported by the findings of Kavallieratos et al. (2012), who investigated the efficacy of seven IGRs as grain protectants in wheat, rice, and maize against *Prostephanus truncates* and *R. dominica*.

References

ABBOTT, W.S., 1925. A method of computing the effectiveness of an insecticide. *Journal of Economic Entomology*, vol. 18, no. 2, pp. 266-267. http://dx.doi.org/10.1093/jee/18.2.265a.

ABDEL RAHMAN, S.M., HEGAZY, E.M. and ELWEY, A.E., 2007. Direct and latent effect of two chitin inhibitors to *Spodoptera littoralis* larvae (Boisd). American-Eurasian. *Journal of Agriculture and Environmental Science*, vol. 2, pp. 457-464.

ABO-ELGHAR, G.E., EL-SHEIKH, A.E., EL-SAYED, F.M., EL-MAGHRABY, H.M. and EL-ZUN, H.M., 2004. Persistence and residual activity of an organophosphate, pirimiphosmethyl, and three IGRs, hexaflumuron, teflubenzuron and pyriproxyfen, against the cowpea weevil, *Callosobrushus maculatus* (Coleoptera: bruchidae). *Pest Management Science*, vol. 60, no. 1, pp. 95-102. http://dx.doi.org/10.1002/ps.783. PMid:14727746.

ALI, Q., UL HASAN, M., MASON, L.J., SAGHEER, M. and JAVED, N., 2016. Biological activity of insect growth regulators, pyriproxyfen, lufenuron and methoxyfenozide against *Tribolium castaneum* (Herbst). *Pakistan Journal of Zoology*, vol. 48, no. 5, pp. 1337-1342.

ALI, Q., UL HASAN, M., SALEEM, S., RANJHA, M.H., NAWAZ, R., QASIM, M.U. and ANJUM, N.A., 2019. Effect of reduced risk insecticides on the different developmental stages of *Tribolium castaneum* (Herbst). *Journal of Agricultural Research (Lahore)*, vol. 57, no. 3, pp. 159-166.

ALI, Q., UL HASAN, M., SHAKIR, H.U., ANJUM, N.A., SALEEM, S., IQBAL, M.Y., QASIM, M.U., REHMAN, H.U. and FAISAL, M., 2018. Transgenerational effect of insect growth regulators on the *Trogoderma granarium* (Everts) (Coleoptera: Dermestidae) under different abiotic factors. *Pakistan Journal of Agricultural Sciences*, vol. 55, no. 4, pp. 897-903.

ARORA, M.S., SALOKHE, S.G. and MUKHERJEE, S.N., 2012. Effect of sub-lethal concentrations of lufenuron on growth, development and reproductive performance of *Tribolium castaneum* (Herbst) (Coleoptera: tenebrionidae). *International Journal of Applied Biology and Pharmaceutical Technology*, vol. 3, pp. 111-122.

ARTHUR, F.H., 2004. Evaluation of methoprene alone and in combination with diatomaceous earth to control *Rhyzopertha dominica* (Coleoptera: Bostrichidae) on stored wheat. *Journal of Stored Products Research*, vol. 40, no. 5, pp. 485-498. http://dx.doi.org/10.1016/S0022-474X(03)00060-2.

ARTHUR, F.H. and HARTZER, K.L., 2018. Susceptibility of selected stored product insects to a combination treatment of pyriproxyfen and novaluron. *Journal of Pest Science*, vol. 91, no. 2, pp. 699-705. http://dx.doi.org/10.1007/s10340-017-0914-4.

ARTHUR, F.H., LIU, S., ZHAO, B. and PHILLIPS, T.W., 2009. Residual efficacy of pyriproxifen and hydroprene applied to wood, metal and concrete for control of stored-product insects. *Pest Management Science*, vol. 65, no. 7, pp. 791-797. http://dx.doi.org/10.1002/ps.1756. PMid:19360716.

ASTUTI, L.P., MUDJIONO, G., RASMINAH, C.S. and RAHARDJO, B.T., 2013. Susceptibility of milled rice varieties to the lesser grain borer (*Rhyzopertha dominica*, F.). *Journal of Agricultural Sciences*, vol. 5, pp. 145-149.

AWAIS, M., HASAN, M., SAGHEER, M., ASIF, M.U., ALI, Q. and ZAMAN, S., 2019. Efficacy of diatomaceous earth and insect growth regulators against *Tribolium castaneum* (Herbst) (Coleoptera: tenebrionidae). *Science Letters*, vol. 7, pp. 59-67.

BANGA, K.S., KOTWALIWALE, N., MOHAPATRA, D. and GIRI, S.K., 2018. Techniques for insect detection in stored food grains: an overview. *Food Control*, vol. 94, pp. 167-176. http://dx.doi.org/10.1016/j.foodcont.2018.07.008.

BOYER, S., ZHANG, H. and LEMPERIERE, G., 2012. A review of control methods and resistance mechanisms in stored-product insects. *Bulletin of Entomological Research*, vol. 102, no. 2, pp. 213-229. http://dx.doi.org/10.1017/S0007485311000654. PMid:22126937.

CHANBANG, Y., ARTHUR, F.H., WILDE, G.E., THRONE, J.E. and SUBRAMANYAM, B.H., 2008. Susceptibility of eggs and adult fecundity of the lesser grain borer, *Rhyzopertha dominica*, exposed to methoprene. *Journal of Insect Science*, vol. 8, pp. 1-5. http://dx.doi.org/10.1673/031.008.1601. PMid:20233095.

CHANDEL, R.K., NEBAPURE, S.M., SHARMA, M., SUBRAMANIAN, S., SRIVASTAVA, C. and KHURANA, S.M., 2019. Insecticidal and repellent activities of eucalyptus oil against lesser grain borer *Rhyzopertha dominica* (Fabricius). *Journal of Microbiology, Biotechnology and Food Sciences*, vol. 9, pp. 525-529. http://dx.doi.org/10.15414/jmbfs.2019/20.9.3.525-529.

DAGLISH, G.J. and WALLBANK, B.E., 2005. Efficacy of diflubenzuron plus methoprene against *Sitophilus oryzae* and *Rhyzopertha dominica* in stored sorghum. *Journal of Stored Products Research*, vol. 41, no. 3, pp. 353-360. http://dx.doi.org/10.1016/j.jspr.2004.06.001.

EDDE, P.A., 2012. A review of the biology and control of *Rhyzopertha dominica* (F.) the lesser grain borer. *Journal of Stored Products Research*, vol. 48, pp. 1-18. http://dx.doi.org/10.1016/j.jspr.2011.08.007.

FIAZ, M., ALI, A., AHMAD, F., UL HASAN, M., SAGHEER, M., SERRAO, J.E., ZANUNCIO, J.C., SHAREEF, M. and LIU, J., 2018.

Comparative potential of chitin synthesis inhibitors against *Trogoderma granarium* (Coleoptera: Dermestidae) for stored wheat management in Pakistan. *Pakistan Journal of Agricultural Sciences*, vol. 55, no. 4, pp. 949-954.

GELBIC, I., ADEL, M.M. and HUSSEIN, H.M., 2011. Effects of nonsteroidal ecdysone agonist RH-5992 and chitin biosynthesis inhibitor lufenuron on *Spodoptera littoralis* (Boisduval, 1833). *Central European Journal of Biology*, vol. 6, no. 5, pp. 861-869.

GREWAL, A.S., SINGLA, A., KAMBOJ, P. and DUA, J.S., 2017. Pesticide residues in food grains, vegetables and fruits: a hazard to human health. *Journal of Medicinal Chemistry and Toxicology*, vol. 2, no. 1, pp. 40-46. http://dx.doi.org/10.15436/2575-808X.17.1355.

HAGSTRUM, D.W. and SUBRAMANYAM, B., 2006. *Fundamentals of stored-product entomology*. St. Paul, Minnesota: AACC International.

HOWE, R.W., 1971. A parameter for expressing the suitability of environment for insect development. *Journal of Stored Products Research*, vol. 7, no. 1, pp. 63-65. http://dx.doi.org/10.1016/0022-474X(71)90039-7.

ILEKE, K.D., 2011. Effect of *Sitophilus zeamais* Mot. and *S. oryzae* (L.) [Coleoptera: Curculionidae] infestation on grain quality of wheat (*Triticum aestivum*). *Journal of Physical Biological Science*, vol. 4, no. 1, pp. 7-12.

IONI, S., MOAREFI, M., FARAZMAND, H. and KARAMI, E., 2011. The effect of regulating compounds on the growth of *Tribolium confusum* du Val (Coleoptera: tenebrionidae). *Munis Entomology & Zoology*, vol. 6, no. 1, pp. 377-385.

ISHAAYA, I., BARAZANI, A., KONTSEDALOV, S. and HOROWITZ, A.R., 2007. Insecticides with novel mode of action: Mechanism, selectivity and cross-resistance. *Entomological Research*, vol. 37, no. 3, pp. 148-152. http://dx.doi.org/10.1111/j.1748-5967.2007.00104.x.

KAVALLIERATOS, N.G., ATHANASSIOU, C.G., VAYIAS, B.J. and TOMANOVIC, Z., 2012. Efficacy of insect growth regulators as grain protectants against two stored-product pests in wheat and maize. *Journal of Food Protection*, vol. 75, no. 5, pp. 942-950. http://dx.doi.org/10.4315/0362-028X.JFP-11-397. PMid:22564945.

KELLOUCHE, A. and SOLTANI, N., 2006. Impact of hexaflumuron, a chitin synthesis inhibitor, on growth, development and reproductive performance of the progeny in *Callosobruchus maculatus* (F.) after adult treatments. *African Journal of Agricultural Research*, vol. 1, no. 3, pp. 57-64.

KOSTYUKOVSKY, M., CHEN, B., ATSMI, S. and SHAAYA, E., 2000. Biological activity of two juvenoids and two ecdysteroids against three stored product insects. *Insect Biochemistry and Molecular Biology*, vol. 30, no. 8-9, pp. 891-897. http://dx.doi.org/10.1016/S0965-1748(00)00063-1. PMid:10876135.

MAHANTHI, V., 2006. Management of stored grain pests of maize using safer grain protectants. *Pestology*, vol. 30, pp. 23-31.

MATTHEWS, G.A., 1993. Insecticide application in stores. In G. A. Mathews and E. C. Hislop (Eds.), *Application technology for crop protection* (pp. 305-315). Wallingford: CAB International. http://dx.doi.org/10.1079/9780851988344.0000.

MISHRA, P.B., SALOKHE, S.G. and DESHPANDE, S.G., 2013. Biological and bio-chemical effects of lufenuron (IGR) on growth, development and reproductive performance of *Tribolium castaneum* (Herbst) (Coleoptera: Tenebrionidae) (Adults). *Research Journal of Pharmaceutical, Biological and Chemical Sciences*, vol. 4, pp. 802-810.

NASEEM, M.T. and KHAN, R.R., 2011. Comparison of repellency of essential oils againstred flour beetle *Tribolium castaneum* Herbst (Coleoptera: tenebrionidae). *Journal of Stored Products and Postharvest Research*, vol. 2, no. 7, pp. 131-134.

OBRETENCHEV, D., ZIDAN, F. and ATANASOVA, D., 2020. Food specialization of the lesser grain borer, *Rhyzopertha dominica* F. (Coleoptera: bostrichidae). *Canadian Journal of Agriculture and Crops*, vol. 5, no. 1, pp. 52-58. http://dx.doi.org/10.20448/803.5.1.52.58.

ODEYEMI, O.O. and DARAMOLA, A.M., 2000. *Storage practices in the tropics: food storage and pest problems*. Nigeria: Dave Collins Publication, vol. 1.

PAOLETTI, M.G. and PIMENTEL, D., 2000. Environmental risks of pesticides versus genetic engineering for agricultural pest contro. *Journal of Agricultural & Environmental Ethics*, vol. 12, no. 3, pp. 279-303. http://dx.doi.org/10.1023/A:1009571131089.

PARWEEN, S., FARUKI, S.I. and BEGUM, M., 2001. Impairment of reproduction in the red flour beetle, *Tribolium castaneum* (Herbst) (Coleoptera: Tenebrionidae) due to larval feeding on triflumuron-treated diet. *Journal of Applied Entomology*, vol. 125, no. 7, pp. 413-416. http://dx.doi.org/10.1046/j.1439-0418.2001.00576.x.

PERISIC, V., VUKAJLOVIĆ, F., PEŠIĆ, S., PREDOJEVIĆ, D., ĐEKIĆ, V. and LUKOVIĆ, K., 2018. Feeding preferences and progeny production of *Rhyzopertha dominica* (Fabricius1792) (Coleoptera: Bostrichidae) in small grains. *Biologica Nyssana*, vol. 9, pp. 55-61.

PHILLIPS, T.W. and THRONE, J.E., 2010. Biorational approaches to managing stored-product insects. *Annual Review of Entomology*, vol. 55, no. 1, pp. 375-397. http://dx.doi.org/10.1146/annurev.ento.54.110807.090451. PMid:19737083.

SAGHEER, M., YASIR, M., HASAN, M. and ASHFAQ, M., 2012. Impact of triflumuron on reproduction and development of red flour beetle, *Tribolium castaneum* (Herbst) (coleoptera: tenebrionidae). *Pakistan Journal of Agricultural Sciences*, vol. 2, pp. 173-178.

SALOKHE, S.G., PAL, J.K. and MUKHERJEE, S.N., 2003. Effect of sublethal concentrations of flufenoxuron on growth, development and reproductive performance of *Tribolium castaneum* (Herbst) (Coleoptera: tenebrionidae). *Invertebrate Reproduction & Development*, vol. 43, no. 2, pp. 141-150. http://dx.doi.org/10.1080/07924259.2003.9652533.

SEGURA, D.F., CACERES, C., VERA, M.T., WORNOAYPORN, V., ISLAM, A., TEAL, P.E.A., CLADERA, J.L., HENDRICHS, J. and ROBINSON, A.S., 2009. Enhancing mating performance after juvenile hormone treatment in *Anastrepha fraterculus*: a different response in males and females acts as a physiological sexing system. *Entomologia Experimentalis et Applicata*, vol. 131, no. 1, pp. 75-84. http://dx.doi.org/10.1111/j.1570-7458.2009.00830.x.

SILASSIE, A. and GETU, E., 2009. Evaluation of botanical plants against *Zabrotes subfasciatus* (Boheman) (Coleoptera: Bruchidae) in stored haricot beans under laboratory condition. *African Journal of Agricultural Research*, vol. 4, pp. 1073-1079.

SOHRABI, F., SHISHEHBOR, P., SABER, M. and MOSADDEGH, M., 2011. Lethal and sublethal effects of buprofezin and imidacloprid on *Bemisia tabaci* (Hemiptera: aleyrodidae). *Crop Protection (Guildford, Surrey)*, vol. 30, no. 9, pp. 1190-1195. http://dx.doi.org/10.1016/j.cropro.2011.05.004.

TROSTANETSKY, A. and KOSTYUKOVSKY, M., 2008. Transovarial activity of the chitin synthesis inhibitor, novaluron on egg hatch and subsequent development of larvae of *Tribolium castaneum*. *Phytoparasitica*, vol. 36, pp. 38-41.</jrn>.

TROSTANETSKY, A., KOSTYUKOVSKY, M. and QUINN, E., 2015. Transovarial effect of Novaluron on *Tribolium castaneum* (Coleoptera: Tenebrionidae) after termination of direct contact. *Journal of Insect Science*, vol. 15, no. 1, pp. 125. http://dx.doi.org/10.1093/jisesa/iev109. PMid:26363061.

YASIR, M., SAGHEER, M., ABBAS, S.K., UL-HASAN, M., AHMAD, S. and IJAZ, M., 2019. Bioactivity of lufenuron against *Tribolium castaneum* (Herbst) (Coleoptera: tenebrionidae). *Sains Malaysiana*, vol. 48, no. 1, pp. 75-80. http://dx.doi.org/10.17576/jsm-2019-4801-09.

YASIR, M., SAGHEER, M., HASAN, M., ABBAS, S.K., AHMAD, S. and ALI, Z., 2012. Growth, development and reproduction inhibition in the red flour beetle, *Tribolium castaneum* (Herbst) (Coleoptera: Tenebrionidae) due to larval exposure to flufenoxuron-treated diet. *Asian Journal of Pharmaceutical and Biological Research*, vol. 2, pp. 51-58.