VOLUME 9 ISSUE 2 2023

ISSN 2454 – 3055

INTERNATIONAL JOURNAL OF ZOOLOGICAL INVESTIGATIONS

Forum for Biological and Environmental Sciences

Published by Saran Publications, India

International Journal of Zoological Investigations Vol. 9, No. 2, 1105-1113 (2023)

International Journal of Zoological Investigations
Contents available at Journals Home Page: www.ijzi.net
Editor-in-Chief: Prof. Ajai Kumar Srivastav
Published by: Saran Publications, Gorakhpur, India

ISSN: 2454-3055

Methoxyfenozide Induced Management of Stored Cereal Pest, *Corcyra cephalonica* (Stainton)

Mishra A.*, Singh K. and Tiwari S.K.

Department of Zoology, D.D.U. Gorakhpur University, Gorakhpur, 273009, Uttar Pradesh, India

**Corresponding Author*

Received: 14th September, 2023; **Accepted:** 22nd October, 2023; **Published online:** 20th November, 2023

https://doi.org/10.33745/ijzi.2023.v09i02.123

Abstract: Application of methoxyfenozide to the different instar larvae of rice-moth, *Corcyra cephalonica* severely influenced their ontogeny resulting into a significant enhancement in larval and pupal mortality and a significant reduction in pupation and adult emergence. The highest concentration i.e. 30 ppm of methoxyfenozide when exposed to 1st instar larvae of *C. cephalonica* caused 100% larval mortality preventing recurrence of this pest. Effect of this IGR was found exposure time-dependant to the larvae i.e. it was highest in 1st instar larvae and then gradually decreased to 2nd, 3rd and 4th instar larvae. Methoxyfenozide affects growth, development and metamorphosis of *C. cephalonica* larvae by accelerating larval ecdysis resulting into emergence of premature adults as well as formation of larval-pupal and pupal-adult intermediates. It may be used for the effective control of rice-moth and other Lepidopteran pests.

Keywords: Rice-moth, *Corcyra cephalonica,* Ontogeny, Larva, Pupa, Adult, Methoxyfenozide

Citation: Mishra A., Singh K. and Tiwari S.K.: Methoxyfenozide induced management of stored cereal pest, *Corcyra cephalonica* (Stainton). Intern. J. Zool. Invest. 9(2): 1105-1113, 2023.

https://doi.org/10.33745/ijzi.2023.v09i02.123

Introduction

The rice-moth, *Corcyra cephalonica* Stainton (Lepidoptera:Pyralidae) is one of the most destructive pests of stored cereals and cereal commodities in Asia, Africa, Europe, North America and other tropical and subtropical regions of the world (Munro and Thomson, 1929). Rice, gram, sorghum, maize, wheat and milled products are severely damaged by its larval phases (Atwal, 1976; Piltz, 1977). Insect pest management in stored cereals is still a puzzling problem of the world. Application of organic pesticides i.e. organochlorines, organophosphates and synthetic pyrethroids develop resistance in insect pests (Boyer *et al.*, 2012), kill beneficial organisms (Fields, 1992; Hagstrum and Subramanyam, 2006) and of course pollute the whole environment (Relyea, 2009). One of the suitable alternative to rid off these problems in management of stored cereal pests is the application of insect growth hormone analogues

that affect the growth, development and metamorphosis of insect pests resulting into non-arrival of the future generation.

Methoxyfenozide (RH-2485) is a suitable ecdysone hormone analogue that accelerates the moulting of the test organism in Lepidopteran insects (Enriquez *et al.*, 2010). In addition, it is biodegradable in the environment (Stall, 1975), possesses low mammalian toxicity and is harmless to non-target organisms (Stall, 1975; Oberlander *et al.*, 1997).

Hence, as an objective of the present programme, attempts have been made to investigate the role of methoxyfenozide on the growth, development and metamorphosis of various developmental stages of rice-moth, *Corcyra cephalonica*. This study may of course provide knowledge to control the pest population of *C. cephalonica* in particular and Lepidopteran pests in general in eco-friendly way.

Materials and Methods

Collection and culture of rice-moth, Corcyra cephalonica Stainton:

Adults of *Corcyra cephalonica* were obtained from Central Integrated Pest Management Centre, Gorakhpur 273009, Uttar Pradesh, India. A stock laboratory culture was maintained on normal dietary medium composed of coarsely ground jowar (*Sorghum vulgare)* mixed with 5% (w/w) powdered yeast inside large glass containers (150 mm diameter, 200 mm height) at temperature 26 ± 1ºC, relative humidity (R.H.) 93 ± 5% and a light regime of 12 h light and 12 h darkness.

Egg laying and their hatching:

Newly emerged males and females from above culture were kept in oviposition glass chambers (35 mm diameter, 200 mm height). No food was given to these pairs in oviposition vessels because they do not feed in their adult stage during their confinement in these vessels. Eggs laid by the females were collected and transferred in glass chambers (250 ml beakers) for hatching by using zero number hair brush of camel.

Ecdysone hormone analogue used:

Methoxyfenozide ($C_{22}H_{28}N_2O_3$) (Fig. 1), N-tert-butyl-N′-(3-methoxy-o-toluoyl)-3,5xylohydrazide, an ecdysone analogue (Catalogue Number M262765, Lot- 16-SCC-7-1) used in the present study was obtained from Toronto Research Chemicals Inc., 2 Brisbane Road, Toronto, ON, Canada M3J 2J8.

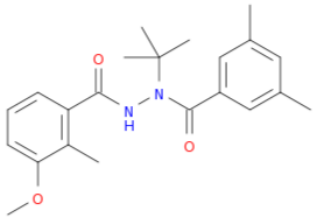

Fig. 1: Methoxyfenozide

Preparation of different concentrations of methoxyfenozide in dietary media:

Stock solution of known concentration of methoxyfenozide was prepared in acetone and then adjusted via serial dilutions to achieve its required concentrations. Then required volume of different concentrations of methoxyfenozide was thoroughly mixed with the required quantity of normal food (roughly ground jowar mixed with 5% w/w yeast powder) to get different desired concentrations i.e. 1, 5, 10, 15, 20, 25 and 30 ppm of methoxyfenozide in dietary media. This treated food was then air dried at room temperature to eliminate completely the acetone. For control purposes, the normal food was thoroughly mixed with a required volume of acetone similar to that of treated food and then air dried in the same way.

Evaluation of effect of methoxyfenozide against the developmental stages of C. cephalonica:

To investigate the toxicity of various concentrations of methoxyfenozide at different life stages of rice-moth, four sets of experiments were designed. In each set, eight rearing chambers (consisting of 250 ml beakers) containing 50 g of food were used, out of which 7 rearing chambers contained 1, 5, 10, 15, 20, 25 and 30 ppm of methoxyfenozide treated food separately, whereas

one chamber contained normal food, serving as control. In the first set of experiment, freshly hatched larvae of *C. cephalonica* were allowed to feed on a normal dietary medium for exactly four days and on the fifth day, a group of 25 first instar larvae were transferred to each rearing chamber containing 50 g of dietary medium mixed and treated separately with different known concentrations of methoxyfenozide and similarly in the 2nd, 3rd and 4th sets of experiment, the second instar, third instar and fourth instar larvae were kept, respectively. All the four sets of experiments were kept at temperature, relative humidity and photoperiod, as mentioned earlier. When life cycle was completed per cent adult emergence and pupal mortality were noted and per cent pupation and per cent larval mortality were determined (Tripathi and Tiwari, 2014). The developmental course and external morphology of larvae, pupae and adults were also observed.

Statistical analysis:

Experiments were replicated six times and the data obtained were analysed statistically. Student's t-test was applied to determine the significant differences from control and corresponding treated groups. LD_{50} values (µg/larva), 95% confidence limits (lower and upper confidence limits) of LD_{50}, slope value and heterogeneity of methoxyfenozide were calculated by Polo Plus, Probit and Logit Analysis, version: 2.0, LeOra Software based on Probit analysis (Finney, 1971).

Results and Discussion

Effect of methoxyfenozide on larval motality:

In the present investigation, methoxyfenozide an ecdysone hormone analogue caused a significant enhancement in the percentage larval mortality when exposed to each instars i.e. 1st, 2nd, 3rd and 4th instars. Methoxyfenozide exposure caused 100% larval mortality at its 30 ppm concentration in comparison to control i.e. 3.20 ± 0.42% (Table 1). Larval mortality in 2nd, 3rd and 4th instar larvae, at each concentration was found to be decreased significantly, possibly due to comparatively shorter duration of exposure of methoxyfenozide from 2nd to 4th instars. Similar findings have also been reported in newly hatched larvae of European corn borer, *Ostrinia nubilalis,* when exposed to 0.125 ppm concentration of methoxyfenozide and 0.5 ppm concentration of tebufenozide which resulted 100% larval mortality (Trisyono and Chippendale, 1997). Methoxyfenozide at a concentration of 10 ppm caused 44% larval mortality when exposed to last instar larvae of *Plodia interpunctella* while tebufenozide at the same concentration resulted 65% larval mortality when treated to same larvae (Oberlander *et al.*, 1998). The 2nd, 3rd and 4th instar larvae of *C. cephalonica* fed at a concentration of 80 ppm tebufenozide (RH-5992) resulted maximum mortality i.e. 74.33, 66.33 and 67.5% respectively on 5th day after larval treatment while the same larvae when administered with the same concentration of halofenozide (RH- 0345) to 2nd, 3rd and 4th instar larvae showed a maximum mortality of 76.33, 71.5 and 69.0%, respectively on the 5th day after larval treatment (Chakravarthy *et al.*, 2012). Methoxyfenozide induced larval mortality has also been reported in *Tribolium castaneum* which caused 28.33, 48.33, 63.33 and 78.33% larval mortality at the concentrations of 2.5, 10, 15 and 20 ppm, respectively in 1st instar larvae (Ali *et al.*, 2016). In addition, chromafenozide at the concentrations of 2.4, 5.3 and 11.8 (mg L^{-1}) has also been reported to cause 10, 25 and 50% larval mortality, respectively after 96 h of treatment of 6th instar *Spodoptera littoralis* larvae (El-Sabrout *et al.*, 2019).

Insect growth, development and moulting processes depends upon the titre balance of the principal moulting hormones, 20-hydroxyecdysone (E) and juvenile hormones (Gilbert and Warren, 2005; Palli *et al.*, 2005). The higher dose of ecdysteroid led to higher larval mortality that may be due to alteration in the storage proteins of *C. cephalonica* at the time of larval development. It has been reported that larval *C. cephalonica* storage proteins can be sequestered at the time of larval-pupal

Table 1: Toxicity of methoxyfenozide on the larval mortality of *Corcyra cephalonica,* when exposed at 1st, 2nd, 3rd and 4th instar larval stages at temperature 26º ± 1ºC, relative humidity (r.h.) 93 ± 5% and a light regime of 12 h light and 12 h darkness

Methoxyfenozide concentrations [ppm]	Per cent Larval Mortality			
	1st instar#	2nd instar#	3rd instar#	4th instar#
0	3.20 ± 0.42	3.20 ± 0.42	3.20 ± 0.42	3.20 ± 0.42
1	9.60 ± 1.19[a]	8.00 ± 1.00[a]	6.40 ± 1.14	4.8 ± 0.35
5	24.0 ± 2.11[aa']	25.60 ± 1.56[aa']	21.60 ± 2.07[ab']	16.80 ± 1.45[aa']
10	48.0 ± 3.44[aa']	44.00 ± 4.32[aa']	41.60 ± 3.31[aa']	32.00 ± 2.98[aa']
15	63.20 ± 6.69[ab']	58.40 ± 5.29[ab']	52.00 ± 4.00[ab']	41.60 ± 3.29[ab']
20	78.60 ± 6.91[ab']	71.20 ± 5.22[ab']	65.60 ± 4.56[ab']	57.60± 4.89[aa']
25	85.60 ± 7.80[a]	80.00 ±7.48[ac']	72.80 ± 5.93[ac']	64.00 ± 4.52[a]
30	100	94.40 ± 5.37[ab']	88.80 ± 5.93[ab']	72.80 ± 5.16[a]

Values are expressed as the mean ± SD of six replicates. [a] Significantly different $p<0.001$ compared with control; [a', b'] and [c'] significantly different $p<0.001$, $p<0.01$ and $p<0.05$, respectively from the corresponding treated group when t-test was applied.

development due to ecdysteroid functions (Kiran Kumar *et al.*, 1997).

The present study indicates that methoxyfenozide disrupts the normal growth and development of insects. Similar observations have also been noticed in 4th instar larvae of *Ostrinia nubilalis* treated with methoxyfenozide that ceased feeding 8h after ingestion, indicating that larvae had prematurely entered a molting cycle (Trisyono and Chippendale, 1997). This effect is important for the control potential of methoxyfenozide because larval feeding damage to stored cereals would be limited. Feeding cessation and malformation of the mouth parts (Smagghe and Degheele, 1992) may cause starvation, which eventually leads to death. The failure of treated larvae to shed the old cuticle may be the result of inhibition of eclosion hormone caused by residue of methoxyfenozide in the larval body. This hormone is released as a result of a decline in ecdysteroid titer following the peak titer before ecdysis (Truman *et al.*, 1993). Our findings suggest that application of methoxyfenozide at the time of 1st instar larval stage should inhibit the successive moulting, thus larvae would fail to pupate and so the arrival of the adult may not occur controlling the pest population. It was observed that in the present study methoxyfenozide exposed larvae that do not receive a lethal concentration may show sublethal chronic effects, including lower larval growth rate, decreased pupal weight and adult emergence. This finding is in accordance with that of methoxyfenozide and tebufenozide exposed *Ostrinia nubilalis* larvae (Trisyono and Chippendale, 1997).

Effect of methoxyfenozide on pupation:

In the present study, each concentration of Methoxyfenozide exposure to the larvae of 1st, 2nd, 3rd and 4th instars showed a significant reduction in percentage pupation. A concentration of 30 ppm that caused 100% larval mortality in 1st instar, resulted 5.60 ± 1% pupation in 2nd instar treated larvae but in 3rd and 4th instars percentage pupation enhanced due to the shorter tenure of exposure of larvae (Table 2). Such results have also been observed in 5th instar larvae of *Spodoptera frugiperda* following the exposure ofmethoxyfenozide that resulted 91.7 ± 1.74 and 71.6 ± 3.09% pupation at its 0.24 and 0.35 mg

Table 2: Toxicity of methoxyfenozide on the pupation of *Corcyra cephalonica,* when exposed at 1st, 2nd, 3rd and 4th instar larval stages at temperature 26º ± 1ºC, relative humidity (r.h.) 93 ± 5% and a light regime of 12 h light and 12 h darkness

Methoxyfenozide concentrations [ppm]	Per cent Pupation			
	1st instar#	2nd instar#	3rd instar#	4th instar#
0	96.80 ± 3.35	96.80 ± 3.35	96.80 ± 3.35	96.80 ± 3.35
1	90.40 ± 2.19^{b}	92.00 ± 4.00^{c}	93.60 ± 3.58	95.20 ± 3.35
5	76.00 ± 4.00$^{aa'}$	74.40 ± 4.56$^{aa'}$	78.40 ± 6.07$^{ab'}$	83.20 ± 3.35$^{aa'}$
10	52.00 ± 4.88$^{aa'}$	56.00 ± 4.42$^{aa'}$	58.40 ± 5.37$^{aa'}$	68.00 ± 4.0$^{aa'}$
15	36.80 ± 3.92$^{aa'}$	41.60 ± 3.24$^{aa'}$	48.00 ± 4.00$^{ab'}$	58.40 ± 4.29$^{ab'}$
20	21.60 ± 3.11$^{aa'}$	28.80 ± 3.00$^{aa'}$	34.40 ± 3.14$^{aa'}$	42.40 ± 3.76$^{aa'}$
25	14.40 ± 1.72$^{ab'}$	20.00 ± 2.14$^{aa'}$	27.20 ± 2.18$^{ab'}$	36.00 ± 3.12$^{ac'}$
30	00	5.60 ± 1.00$^{aa'}$	11.20 ± 2.46$^{aa'}$	27.20 ± 2.81$^{ab'}$

Values are expressed as the mean ± SD of six replicates. ^{a} and ^{b} Significantly different $p<0.001$ and $p<0.01$ respectively compared with control; $^{a'}$, $^{b'}$ and $^{c'}$ significantly different $p<0.001$, $p<0.01$ and $p<0.05$, respectively from corresponding treated group when the t-test was applied.

a.i./kg concentration (Zarate *et al.*, 2010). These authors also observed the formation of deformed pupae also i.e. 8.2 ± 0.74 and 28.3 ± 3.09% following the exposure of 0.24 and 0.35 mg a.i./kg concentrations of methoxyfenozide, respectively. Ecdysone induces rapid moulting so the larva does not get sufficient time for transformation of larva to pupa. Thus non-viable forms like larval-pupal and pupal-adult intermediates get formed (Tateishi *et al.*, 1993; Eizaguirre *et al.*, 2007).

Effect of methoxyfenozide on pupal mortality:

Pupal mortality increases significantly with increase in the methoxyfenozide concentration on each developmental instars. 100% pupal mortality was recorded in 1st instar larvae when exposed to 25 ppm concentration of methoxyfenozide. But, as the exposure duration decreases in 2nd, 3rd and 4th instars, their mortalities decreases (Table 3). Similar observation have also been observed in 5th instar treated larvae of *S. frugiperda* which showed 78.6 ± 1.80% pupal mortality at a concentration of 0.35 mg a.i./kg of methoxyfenozide (Zarate *et al.*, 2010). Newly ecdysed pupal treatement of *E. kuehniella* Zellar with concentration of 0.02 and 0.04 µg/pupa also exerted 60.41 ± 2.81 and 88.00 ± 4.36% pupal mortality, respectively (Soltani *et al.*, 2012).

Our findings pertaining to methoxyfenozide induced pupal mortality in *C. cephalonica* resumbles to that of methoxyfenozide exposed *Spodoptera frugiperda* (Zarate *et al.*, 2010) and *Ephestia kuehniella* Zellar. These results, can be explained by the accumulation and persistence of ecdysone agonists in the larval tissue until the pupal molt, at which point agonist kills the insects (Zarate *et al.*, 2010; Soltani *et al.*, 2012). In addition, Sundaram *et al.* (2002) reported the presence of an ecdysone receptor complex in the Lepidopteran pupae, so it is clear that this life stage is just as susceptible to ecdysone agonists as larval stage.

Effect of methoxyfenozide on adult emergence:

In the present investigation, the adult emergence was 96.80 ± 3.35% in control and 00 and 12.00 ± 1.14% in 1st and 4th instar larvae, respectively following treatment with 30 ppm of methoxyfenozide (Table 4). These findings revealed that longer exposure of *C. cephalonica* larvae to methoxyfenozide has a greater effect on the rate of adult emergence. Such findings have also been observed in case of *Ostrinia nubilalis* exposed to tebufenozide that resulted 44% adult

Table 3: Toxicity of methoxyfenozide on the pupal mortality of *Corcyra cephalonica,* when exposed at 1st, 2nd, 3rd and 4th instar larval stages at temperature 26º ± 1ºC, relative humidity (r.h.) 93 ± 5% and a light regime of 12 h light and 12 h darkness

Methoxyfenozide concentrations [ppm]	Per cent Pupal Mortality			
	1st instar#	2nd instar#	3rd instar#	4th instar#
0	00	00	00	00
1	1.80 ± 0.14[a]	2.70 ± 0.91[a]	1.70 ± 0.21[a]	0.00 ± 0.00
5	4.21 ± 0.18[aa']	4.20 ± 0.64[ac']	2.90 ± 0.19[aa']	2.90 ± 0.19[aa']
10	9.60 ± 1.01[aa']	8.70 ± 1.86[aa']	6.60 ± 0.52[aa']	5.88 ± 0.45[aa']
15	17.39 ± 1.26[aa']	12.70 ± 1.60[ab']	8.30 ± 1.07[ac']	8.00 ± 0.82[aa']
20	33.70± 3.29[aa']	22.60 ± 2.09[aa']	16.50 ± 1.09[aa']	22.20 ± 1.82[aa']
25	100	79.30 ± 6.50[aa']	44.20 ± 3.24[aa']	41.20 ± 2.76[aa']
30	-	100[aa']	75.30 ± 4.46[aa']	56.50 ± 3.82[aa']

Values have been expressed as the mean ± SD of six replicates. [a] Significantly different p<0.001 compared with control; [a', b'] and [c'] significantly different p<0.001, p<0.01 and p<0.05, respectively from the corresponding treated group when the t-test was applied.

Table 4: Toxicity of methoxyfenozide on the adult emergence of *Corcyra cephalonica,* when exposed at 1st, 2nd, 3rd and 4th instar larval stages at temperature 26º ± 1ºC, relative humidity (r.h.) 93 ± 5% and a light regime of 12 h light and 12 h darkness

Methoxyfenozide concentrations [ppm]	Per cent Adult Emergence			
	1st instar#	2nd instar#	3rd instar#	4th instar#
0	96.80 ± 3.35	96.80 ± 3.35	96.80 ± 3.35	96.80 ± 3.35
1	88.80 ± 3.42[b]	89.60 ± 6.07[c]	92.00 ± 2.83[c]	95.20 ± 3.35
5	72.80 ± 3.55[aa']	71.20 ± 3.35[aa']	76.00 ± 4.0[aa']	80.80 ± 4.38[aa']
10	47.20 ± 4.82[aa']	53.60 ± 4.21[aa']	54.40 ± 3.58[aa']	64.00 ± 4.90[aa']
15	30.40 ± 2.74[aa']	36.00 ± 3.06[aa']	44.00 ± 4.90[ab']	53.60 ± 4.27[ab']
20	13.60 ± 1.14[aa']	22.40 ± 2.14[aa']	28.80 ± 2.22[aa']	33.60 ± 2.81[aa']
25	00	4.00 ± 0.16[aa']	15.20 ± 1.22[aa']	21.60 ± 2.04[aa']
30	00	00	3.20 ± 0.34[aa']	12.00 ± 1.14[aa']

Values have been expressed as the mean ± SD of six replicates. [a, b] and [c] Significantly different p<0.001, p<0.01, and p<0.05, respectively compared with control; [a'] and [b'] significantly different p<0.001 and p<0.01, respectively from the corresponding treated group when the t-test was applied.

emergence at its 0.031 ppm concentration (Trisyono and Chippendale, 1997). A similar observation was also reported in case of *Tribolium castaneum* at 2.5 ppm concentration of methoxyfenozide treated pupae that resulted 73.33% adult emergence (Ali *et al.*, 2016). Exposure of tebufenozide has been shown to decrease the percentage of adult emergence in *Spodoptera littoralis* possibly due to the fact that it blocks the maturation of imaginal discs which are primordial for adult integumentary structures in endopterygote insects (Schneidermann, 1972; Suh *et al.*, 2000). In the present investigation, similar reasons may be assigned for decrease of adult emergence in *C. cephalonica* following exposure of methoxyfenozide.

LD_{50} values (µg/larva), 95% confidence limits (lower and upper confidence limits) of LD_{50}, slope values and heterogeneity of methoxyfenozide to the first to fourth instar larvae are presented in Table 5. It is evident from the table that methoxyfenozide is more effective on the first instar larvae than second, third and fourth instar larvae.

It was observed that adults emerged from the 1st instar treated larvae of *C. cephalonica* indicated different types of pupal-adult intermediates or

Table 5: LD_{10}, LD_{50} and LD_{90} values, Confidence limits (LCL and UCL) of LD_{10}, LD_{50} and LD_{90}, Slope values and Heterogeneity of methoxyfenozide to the 1st, 2nd , 3rd and 4th instars larvae of *C. cephalonica*

Insecticide	Instars	Effective doses (µg/ larva)		95% Confidence limits of LD_{50}		Slope values	Heterogeneity
				LCL	UCL		
Me	First	LD_{10}	3.839	2.649	4.924	2.989 ± 0.254	1.4723
		LD_{50}	10.303	8.906	11.555		
		LD_{90}	27.652	23.839	34.054		
Me	Second	LD_{10}	1.949	1.324	2.596	1.873 ± 0.130	1.3393
		LD_{50}	9.418	8.078	10.830		
		LD_{90}	45.520	36.312	61.340		
Me	Third	LD_{10}	2.229	1.616	2.854	1.809 ± 0.133	0.988
		LD_{50}	11.392	10.075	12.813		
		LD_{90}	58.214	46.744	77.276		
Me	Fourth	LD_{10}	2.761	1.959	3.564	1.663 ± 0.138	0.803
		LD_{50}	16.291	14.354	18.646		
		LD_{90}	96.105	71.588	143.276		

Me = Methoxyfenozide; LCL = Lower Confidence Limit; UCL = Upper Confidence Limit

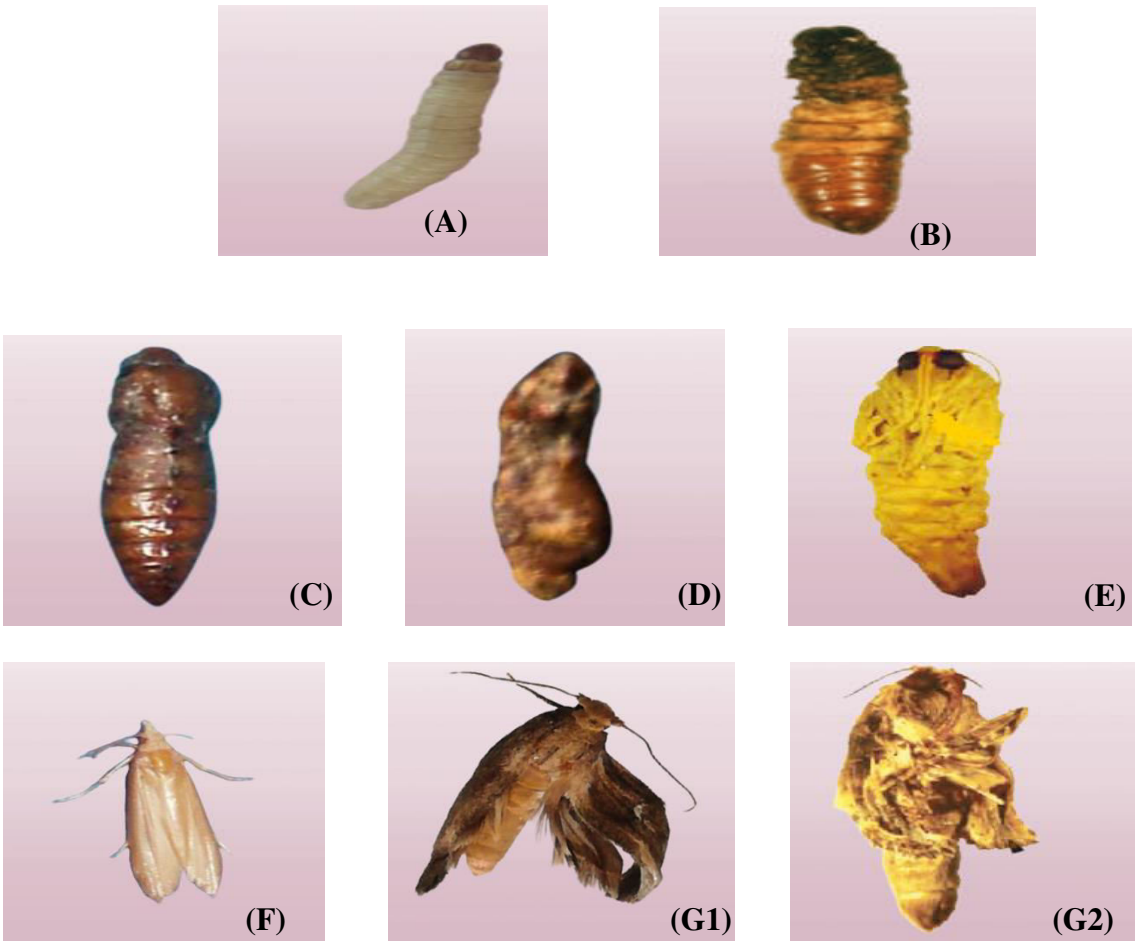

Fig. 2: (A) Normal larva; (B) Larval-pupal intermediate; (C) Normal pupa; (D) Abnormal pupa; (E) Pupal-adult intermediate; (F) Normal adult; (G1) Abnormal adult with crumpled wings; (G2) Adult with reduced wings and abnormal legs.

adult deformities due to premature moulting and thus incomplete growth and metamorphosis of emerged moths (Fig. 2 A-H). Abnormal adult showing shortened crumpled fore and hind wings, shortened wings not totally covering the abdomen of the deformed moths due to the partially stretched wings; besides the abnormal thoracic legs and mouth parts. Such abnormal adults were reported in case of methoxyfenozide and tebufenozide exposed *Diatraea grandiosella* (Dyer) (Trisyono and Chippendale, 1998) as well as in methoxyfenozide influenced *S. exigua* (Carton *et al.*, 1998) and *S. littoralis* (El- Sabrout *et al.*, 2019).

Conclusion

On the basis of present investigation, it may be concluded that exposure of methoxyfenozide to the early instar larvae of *C. cephalonica* cause severe disruption of growth and development of this lepidopterous pest leading to failure of arrival of new generation.

Acknowledgements

Authors are thankful to Prof. Veena B. Kushwaha, Head, Department of Zoology, D.D.U Gorakhpur University, Gorakhpur, for providing laboratory facilities, Prof. Rajendra Singh, former Head, Department of Zoology, D.D.U Gorakhpur University, Gorakhpur for critical review of the manuscript, Prof. Ravi Kant Upadhyay, Prof V. K. Singh and Dr. Sushil Kumar for their kind cooperation and valuable suggestions. Thanks are also due to Toronto Research Chemicals Inc., Canada, M3J2J8 for providing methoxyfenozide.

References

Ali Q, Hasan M, Mason LJ, Sagheer M and Javed N. (2016) Biological activity of insect growth regulators, pyriproxyfen, lufenuron and methoxyfenozide against *Tribolium castaneum* (Herbst). Pakistan J Zool. 48(5): 1337-1342.

Atwal AS. (1976) Agricultural pests of India and South-East Asia. Kalyani Publ., Delhi, pp. 502.

Boyer S, Zhang H and Lemperiere G. (2012) A review of control methods and resistance mechanisms in stored-product insects. Bull Entomol Res. 102(2): 213-229.

Carton B, Smagghe G, Mourad K and Tirry L. (1998) Effect of RH-2485 on larvae and pupae of *Spodoptera exigua* (Hubner). Meded Fac. Landbouwkd Toegep Biol Wet Univ, Gent 63: 537-545.

Chakravarthy AK, Bhattacharya A, Shashank PR, Doddabasappa B, Chandrashekharaiah and Epidi TT. (2012) Effect of two ecdysteroid analogues (Tebufenozide - RH5992 and Halofenozide – RH0345) on the development of *Corcyra cephalonica* (Stainton) [Lepidoptera:Pyralidae]. Curr Biotica 6(2): 131-140.

Eizaguirre M, Lopez C, Schafellner C and Sehnal F. (2007) Effect of ecdysteroid agonist RH-2485 reveal interactions between ecdysteroid and juvenile hormones in the development of *Sesamiach nonagrioides.* Arch Insect Biochem Physiol. 65: 74-84.

El-Sabrout AM, Hassan SM and Eldesouky SE. (2019) Differential effects of some insect growth regulators on the reproductive potential of Lepidopteran pest, *Spodoptera littoralis.* J Basic Envr Sci. 6: 257-266.

Enriquez CLR, Pineda S, Figueroa JI, Schneider MI and Martinez AM. (2010) Toxicity and sublethal effects of methoxyfenozide on *Spodoptera exigua* (Lepidoptera: Noctuidae). J Eco Entomol. 103: 662-667.

Field PG. (1992) The control of stored- product insects and mites with extreme temperatures. J Stored Prod Res. 28: 89-118.

Finney DG. (1971) Probit analysis. Cambridge University Press, Cambridge, p. 333.

Gilbert LI and Warren JT. (2005) A molecular genetic approach to the biosynthesis of the insect steroid molting hormone. Vit Hormones 73: 31-57.

Hagstrum DW and Subramanyam B. (2006) Fundamentals of Stored- Product Entomology. AACC International, USA. ISBN-13: 978-1-891127-50-2.

Henrick CA, Staal GB and Siddall JB. (1973) Alkyl 3,7,11-trimethyl-2,4- dodecadienoates, a new class of potent insect growth regulators with juvenile hormone activity. J Agr Food Chem. 21(3): 354-359.

Kirankumar N, Ismail MS, Dutta-Gupta A. (1997) Uptake of storage protein in the rice moth *Corcyra cephalonica* : identification of storage protein binding proteins in the fat body cell membranes. Insect Biochem Mol Biol. 27(7): 671-679.

Munro JW and Thomson WS. (1929) Report on insect infestation of stored cocoa. H. M. Stationery Office, London.

Oberlander H, Silhacek DL, Shaaya E and Ishaaya I. (1997) Current status and future perspectives of the use of insect growth regulators for the control of stored product pests. J Stored Prod Res. 33: 1-6.

Oberlander H, Silhacek D and Leach CE. (1998) Interactions of ecdysteroid and juvenoid agonists in *Plodia interpunctella* (Hubner). Arch Insect Biochem Physiol. 38: 91-99.

Palli SR, Hormann RE, Schlattner U and Lezzi M. (2005) Ecdysteroid receptors and their applications in agriculture and medicine. Vit Hormones 73: 59-100.

Parween S. (1996) The effect of Triflumuron on malathion susceptible (FSS II) and malathion resistant (CTC 12) strains of *Tribolium castaneum* HERBST. Ph.D. Thesis, University of Newcastle, Tyne, UK.

Piltz H. (1977) *Corcyra cephalonica* (Staint.). In: Disease pests and weeds tropical crops, (eds.) Kranz J., Schmutterer H. and Koch W., Verlag Paul Parey, Berlin and Hamburg, pp. 439-440.

Relyea RA. (2009) A cocktail of contaminants: how mixtures of pesticides at low concentrations affect aquatic communities. Oecologia 159: 363-376.

Schneidermann HA. (1972) Insect hormone and insect control. In : Insect juvenile hormone, Chemistry and action, (eds.) Menn J.J. and Beroza M., Academic Press, New York, London. pp. 3-27.

Smagghe G and Degheele D. (1992) Effect of RH 5849, the first nonsteroidal ecdysteroid agonist, on larvae of *Spodoptera littoralis* (Boisd) (Lepidoptera: Noctuidae). Arch Insect Biochem Physiol. 21: 119-128.

Soltani–Mazouni N, Hami M and Gramdi H. (2012) Sublethal effects of methoxyfenozide on reproduction of Mediterranean flour moth, *Ephestia kuehniella* Zeller. Invetebr Reprod Devel. 56(2): 157-163.

Stall GB. (1975) Insect growth regulators with juvenile hormone activity. Ann Rev Entomol. 20: 417-460.

Suh CPC, Orr DB and Van Duyn JW. (2000) Effect of insectisides on *Trichogramma exiguum* (Hymenoptera:Trichogrammatidae) preimaginal development and adult survival. J Econ Entomol. 93: 577-583.

Sundaram M, Palli SR, Smagghe G, Ishaaya I, Feng QL, Primavera M, Tomkins WL, Krell PJ and Retnakaran A. (2002) Effect of RH-5992 on adult development in spruce budworm, *Choristoneura fumiferana.* Insect Biochem Mol Biol. 32: 225-231.

Tateishi K, Kiuchi M and Takeda S. (1993) New cuticle formation and moult inhibition by RH-5849 in the common cutworm *Spodoptera litura* (Lepidoptera: Pyralidae). Appl Entomol Zool. 28: 177-184.

Tripathi P and Tiwari SK. (2014) Potential of insect growth regulator in the management of rice moth *Corcyra cephalonica* Stainton, 1866 (Lepidoptera: Pyralidae). Polish J Entomol. 83(1): 79-97.

Trisyono A and Chippendale M. (1997) Effect of nonsteroidal ecdysone agonists, methoxyfenozide and tebufenozide, on the European corn borer (Lepidoptera:Pyralidae). J Econ Entomol. 90(6): 1486-1492.

Trisyno A and Chippendale M. (1998) Effect of ecdysone agonists, RH-2485 and tebufenozide, on the southwestern corn borer, *Diatraea grandiosella.* Pesticide Sci. 53: 177-185.

Trueman JW, Rountree DB, Reiss SE and Schwartz LW. (1993) Ecdysteroids regulate the release and action of eclosion hormone in the tobacco hornworm, *Manduca sexta* (L.). J Insect Physiol. 29: 895-900.

Zarate N, Diaz O, Matinez AM, Figuerao JI, Schneider MI, Smagghe G, Vinuela E, Budia F and Pineda S. (2010) Lethal and sublethal effects of methoxyfenozide on the development, survival and reproduction of the fall armyworm, *Spodoptera frugiperda* (J.E. Smith) (Lepidoptera:Noctuidae). Sociedade Entomol Do Brasil 40(1): 129-137.