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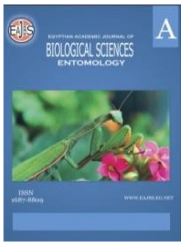

Insecticidal Activity of Pyriproxyfen, A Juvenoid, and Its Suppressive Effect on Growth and Development of The Black Cutworm, *Agrotis ipsilon* (Hufnagel) (Lepidoptera: Noctuidae)

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ABSTRACT

The black cutworm *Agrotis ipsilon* (Hufnagel) (Lepidoptera: Noctuidae), is generally considered to be worldwide in distribution. It is one of the destructive pests attacking nearly all vegetables and different field crops. The objective of the present study was to evaluate the toxicity of pyriproxyfen and its effect on the growth, development, metamorphosis and morphogenesis of this insect. Both the 4th instar and 5th instar larvae were treated with 6 concentrations of this juvenoid (800, 400, 200, 100, 50 & 25 ppm) *via* fresh discs of castor bean leaves. The most important results could be summarized as follows. Pyriproxyfen exhibited strong acute toxic activity against larvae and chronic toxicity against pupae and adults, after treatment of 4th instar or 5th instar larvae. LC_{50} values were calculated in 65.95 and 99.90ppm, after treatment of 4th instar and 5th instar larvae, respectively, i.e., the 4th instar larvae were found more sensitive to pyriproxyfen than 5th instar larvae. The larval body weight gain was remarkably reduced and the growth was considerably inhibited. The larval and pupal durations were considerably prolonged, in a dose-dependent course. Failure of ecdysis, as a criterion of the disrupted developmental program, was observed only after treatment with certain concentrations, but other features of the disrupted program had not been observed. The pupation was detrimentally suppressed after treatment of 4th or 5th instar larvae with pyriproxyfen. No deformed pupae were observed. Therefore, pyriproxyfen could be recommended as an eco-friendly alternative to synthetic insecticides for the IPM program of *A. ipsilon*.

INTRODUCTION

The black cutworm, *Agrotis ipsilon* (Hufnagel) (Lepidoptera: Noctuidae), is widely distributed all over the world, particularly in moderate and subtropical countries of the northern and southern hemispheres (Kononenko, 2003; Harrison, and Lynn, 2008; Binning *et al.*, 2015; Mishra, 2020; Rodingpuia and Lalthanzara, 2021). It is one of the most serious species of underground pests and can destroy more than 100 species of host plants (e.g., corn, wheat, cotton, soybean, vegetables and a variety of weeds) (Abd El-Aziz *et al.*, 2007; Binning *et al.*, 2015; Liu *et al.*, 2015).

This pest is a nocturnal insect. During the day, larvae remain buried in the ground, which hinders its viewing field and consequently its control is difficult (Bento *et al.*, 2007).

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Therefore, *A. ipsilon* is one of the most challenging agricultural pests when it comes to control and management (Andersch and Schwarz, 2003). Although integrated pest management (IPM) strategies are increasingly being developed (Veres et al., 2020), the majority of treatments for pest insects still rely exclusively on the use of neurotoxic insecticides (Jeschke *et al.,* 2011; Meslin *et al.,* 2021). Some studies have focused on the effectiveness of various insecticides to control *A. ipsilon* (Shakur *et al.,* 2007). InEgypt, the control measure of this insect pest depends mainly on the application of conventional insecticides, particularly organophosphates (Vattikonda and Sangam, 2017).

Over the years, the intensive and improper uses of conventional insecticides usually cause serious toxicological problems to the ecosystems (Haq*et al.,* 2004; Tiryaki and Temur, 2010; Chowański*et al.,* 2014). Many insecticides are not soluble in water, so large quantities of organic solvents are required and most of these solvents increase the environmental pollution, as well as contamination of ground waters, plants and soil (Arias-Estevez *et al.,* 2008; Holoubek *et al.,* 2009; Sanni and Mutta, 2014; Adrees *et al.,* 2015). In addition, the widespread use of neurotoxic insecticides exhibits negative effects on the physiology and behavior of non-target beneficial insects, such as honeybees (Davies *et al.,* 2007; Blacquière *et al.,* 2012; Vattikonda and Sangam, 2017). Unfortunately, the majority of current agrochemicals have adverse effects on human health (Shahzad *et al.,* 2020).
Therefore, the agrochemical research institutions have focused on the discovery of alternative selective compounds which interfere with the pest insect growth and development and areless toxic to non-target organisms and with negligible effects on the ecosystem (Dhadialla et al., 2005; Dubey et al., 2010; Chandler *et al*., 2011; Korrat *et al*., 2012; Derbalah *et al.,* 2014).Among the alternative control, agents are the insect growth regulators (IGRs) which have been classified as 'biorationals' to distinguish these compounds from the conventional insecticides. This term implies that IGRs are selective and specific to the target pests (Ishaaya *et al.,* 2005; Horowitz *et al.,* 2009; Sarwar, 2015). IGRs are now used to control various insect pests and can assist in the development of sustainable agriculture (Raslan, 2002; Zhou *et al.,* 2003; Wang and Wang, 2007; Sabry and Abdu, 2016). Such compounds have much greater metabolic and environmentally more stable than earlier analogs and are much better suited to insect pest control (for some detail, see reviews of Dhadialla *et al.,* 1998; Dhadialla and Jansson, 2000; Dhadialla *et al.,* 2005). Depending on the specific mode of action, IGRs had been classified into three categories: (i) juvenile hormone analogues (JHAs, also called Juvenoids), (ii) Ecdysteroid agonists and (iii) Chitin synthesis inhibitors (CSIs) or moult inhibitors (Dhadialla et al., 1998; Oberlander and Silhacek, 2000**)**. They had been, also, grouped in CSIs and substances that interfere with the action of insect hormones (i.e. JHAs, and ecdysteroids)(Tunaz and Uygun, 2004). Since juvenile hormone does not occur in vertebrates, the juvenoid IGRs are considered safe to humans (Jindra and Bittova, 2020). JHAs are excellent tools for studying endocrinological mechanisms in insects (Ramaseshadri *et al.,* 2012), since disrupting metamorphosis is the main insecticidal activity of juvenoid IGRs (Jindra and Bittova, 2020).

Pyriproxyfenis cited as 2-[1-methyl-2-(4-phenoxyphenoxy) ethoxy] pyridine or 4-Phenoxyphenyl (*R/S*)-2-(2-pyridyloxy) propyl ether or 2-[1-(4-Phenoxyphenoxy) propan-2-yloxy] pyridine.Its molecular formula is $C_{20}H_{19}NO_3$. It was first registered as KNACK®, SUMILARV®, and ADMIRAL®; Sumitomo Chemical Co., Japan in 1991 for controlling public health pests (Yokoyama and Miller, 1991). It is a relatively stable compound (Mohandass et al., 2006). Due to the widespread use of pyriproxyfen worldwide, it is important to know how this IGR behaves in the terrestrial environment and the effect on non-target organisms. For the fate of pyriproxyfen in soil and plants, see the review of Devillers (2020). Pyriproxyfen has been reported to be safe for a variety of predatory arthropods (Naranjo et al., 2003) and compatible with natural enemy conservation (Liu and Chen, 2000; Liu and Stansly, 2004) as well as much less toxic to the ecosystem (Korrat*etal.*, 2012). Also, it has a relatively low mammalian toxicity (Mohandass*et al.,* 2006) and mild toxicity to some aquatic organisms but is non-toxic to bees (Dhadialla *et al.,* 2005).

Pyriproxyfen is a potent JHA available today affecting the hormonal regulation of different vital processes in insects (Devillers, 2009; Hatakoshi, 2012; Chłopecka *et al.*, 2018) resulting thereby in a strong suppression of embryogenesis (Maharajan et al., 2018), metamorphosis (Barbosa *et al.,* 2018) and adult metamorphosis in several insect orders (Aribi*et al.,* 2006). Also, it was reported to suppress oviposition, reduce the viability of eggs (Ghasemi *et al.*, 2010; Ohba *et al.*, 2013) and reduce thefecundity of insects (Singh and Kumar, 2015; Meng *et al.,* 2018). Therefore,Pyriproxyfen, as a broad-spectrum IGR, is usually applied against many public health insect pests (Korrat *et al.*, 2012), and has been successfully used to control important pests of many agricultural crops all over the world (Sazo *et al.,* 2008; Moadeli *et al.,* 2014). The objective of the present study was to evaluate the toxicity of pyriproxyfen and its effect on the growth, development, metamorphosis and morphogenesis of *A. ipsilon*.

MATERIALS AND METHODS

1. Experimental Insect:

A culture of the black cutworm *Agrotis ipsilon* (Hufnagel) (Lepidoptera: Noctuidae) was raised under constant conditions (27±2°C and 65±5% R.H.) at Department of Zoology and Entomology, Faculty of Science, Al-Azhar University, Cairo, Egypt. It was originated by a sample of eggs from the susceptible strain culture maintained for several generations in Plant Protection Research Institute, Doqqi, Giza, Egypt. The rearing technique was carried out according to Abdin (1979) with the improvement of El-Shershaby (2010). The eggs were kept in wide-mouth plastic jars (1000 ml) fitted with filter paper until hatching. Newly hatched larvae were kept into new jars andprovided with clean castor bean leaves *Ricinus communis*as food every day. After the first molt, a sawdust layer was put on the floor to avoid moisture, and renewed daily. At reaching the 4th instar, larvae were reared in few numbers in separate jars to avoid crowding and cannibalism. These jars were covered with pieces of cloth for preventing larval escape. Sawdust and fresh castor bean leaves were renewed daily until pupation. The pupae were then placed in plastic jars (10 x 25 cm) covered with muslin and fitted with filter paper, as an oviposition site for future moths. After the adult emergence, a piece of cotton wool soaked in 10% sugar solution was suspended from the top of each jar and renewed every 48 hrs for feeding moths. The plastic jars were examined daily for collecting papers containing eggs.

2. Pyriproxyfen Concentrations and Larval Treatment:

Pyriproxyfen (S-3113) is cited as 2-[1-methyl-2-(4-phenoxyphenoxy) ethoxy] pyridine or 4-Phenoxyphenyl (*R/S*)-2-(2-pyridyloxy) propyl ether or 2-[1-(4-Phenoxyphenoxy) propan-2-yloxy] pyridine.Its molecular formula is $C_{20}H_{19}NO_3$ It was first registered as KNACK®, SUMILARV®, and ADMIRAL®; Sumitomo Chemical Co., Japan. It was purchased from Milipore Sigma, Burlington, MA 01803, USA Merk Ltd., Egypt. A series of 6 concentrations of pyriproxyfen was prepared by diluting with distilled water in volumetric flasks:800.0, 400.0, 200.0, 100.0, 50.0 and 25.0ppm.

Bioassay test was carried out against 4th and 5th instar larvae of *A. ipsilon* using the dipping technique. Discs of fresh castor bean leaves were dipped in each concentration for 5 minutes and air dried before the introduction to larvae as food for 24 hr under the aforementioned laboratory conditions. Control larvae were provided with water-treated castor leaves. Thirty larvae in three replicates (10 larvae/replicate) of treated and control larvae were kept separately in plastic vials. After 24 h feeding on treated leaves, larvae were provided with fresh untreated castor bean leaves and all results were recorded daily.

3. Criteria of Study:

3.1. Toxicity and Insecticidal Effect:

All mortalities of treated and control (larvae, pupae and adults) of *A. ipsilon* were recorded every day and corrected according to Abbott's formula (Abbott, 1925) as follows:

$$\textbf{Corrected Mortality\%} = \frac{\textbf{Observed Mortality \%} - \boldsymbol{Control\ Mortality}\ \%}{\mathbf{100} - \boldsymbol{Control\ Mortality}\ \%} \times \mathbf{100}$$

The LC_{50} values were calculated for general mortality by Microsoft® office Excel (2007), according to Finny (1971).

3.2. Growth, Development and Metamorphosis:

Larval Body Weight Gain: Each individual larva (treated and control) was carefully weighted every day using a digital balance for calculating the body weight gain as follows: Initial weight (before the beginning of the experiment) - final weight (at the end of the experiment).

Larval Growth Rate: Growth rate (GR) can be calculated according to (Waldbauer, 1968) as follows:

GR = fresh weight gain during feeding period of larvae / feeding period x mean fresh body weight of larvae during the feeding period.

Developmental Duration and Rate: Dempster's equation (1957) was applied for calculating the developmental duration, and Richard's equation (1957) was used for calculating the developmental rate.

Pupation Rate: Pupation rate was calculated according to Jimenez-Peydro et al. (1995) as follows:

P.R. = [No. pupated larvae / No. treated larvae] × 100

Deranged Metamorphosis: Deranged metamorphosis program of *A. Ipsilon* was observed and calculated in larval-pupal or pupal-adult intermediates (%). Also, pupal deformation was calculated in %. Features of impaired development were recorded in photos.

4. Statistical Analysis of Data:

Data obtained were analyzed by the Student's *t*-distribution, and refined by Bessel correction (Moroney, 1956) for the test significance of the difference between means using GraphPad InStat© v. 3.01 (1998).

RESULTS

In the present study, toxicity and bio-efficacy of pyriproxyfen (a juvenoid) were evaluated against *A. ipsilon* after treatment of 4^{th} and 5^{th} instar larvae. For achieving this aim, six concentrations of pyriproxyfen were prepared: 800, 400, 200, 100, 50 & 25 ppm. Using the dipping technique discs of fresh clean castor bean leaves were treated with each concentration and then air-dried. Groups of newly molted larvae of both instars were allowed to no-choice feed on these discs for 24 hr. Control larvae were allowed to feed on untreated leaf discs. The insecticidal activity and effect on growth, development, metamorphosis, morphogenesis, adult performance and reproductive potential were recorded as follows.

1. Insecticidal Activity of Pyriproxyfen Against *A. ipsilon*:

After treatment of the newly molted 4^{th} instar larvae of *A. ipsilon* with 6 concentrations of pyriproxyfen, data of the insecticidal activity were assorted in Table (1). Depending on these data, the treated larvae with the highest concentration completely died. At other concentrations, the larval mortalities were recorded in a dose-dependent course (56.7, 50.0, 50.0, 20.0 & 6.7% larval mortality at 400, 200, 100, 50 & 25 ppm, respectively, *vs*. 0.0% mortality of control larvae). According to the data listed in the same table, pyriproxyfen exhibited chronic toxicity against the successfully developed pupae, in a dose-dependent trend (46.7, 37.2, 17.8, 12.5 & 14.1% of pupal mortalities, at 400, 200, 100, 50 & 25 ppm, respectively, *vs*., 3.3% mortality of control pupae). Also, the successfully emerged adults suffered the toxic action of pyriproxyfen, almost in a dose-dependent manner (38.9, 19.4, 25.0, 14.3 & 8.3% mortality of treated adults, at 400, 200, 100, 50 & 25 ppm, respectively, *vs*. 0.0% mortality of control adults). However, the corrected mortality was determined in a dose-dependent course. LC_{50} value was calculated at 65.95 ppm.

After treatment of the newly molted 5th instar larvae with pyriproxyfen concentrations, data of the insecticidal activity were arranged in Table (2). Depending on these data, pyriproxyfen exhibited a strong acute toxicity against larvae, in a dose-dependent course (100, 50.0, 43.3, 30.0, 6.7 & 3.3% larval mortality, at 800, 400, 200, 100, 50 & 25 ppm, respectively, *vs*. 0.0% mortality of control larvae). As obviously shown in the same table, pyriproxyfen displayed chronic toxicity against the successfully developed pupae of which mortality increased with the increasing concentration (46.7, 23.3, 19.3, 14.4 & 3.3% pupal mortality, at 400, 200, 100, 50 & 25 ppm, respectively, compared to 0.0% mortality of control pupae). Also, the tested IGR displayed chronic toxicity against the successfully emerged adults of which mortality was found almost in a dose-dependent course (33.3, 38.3, 22.9, 7.9 & 7.0% mortality of treated adults, at 400, 200, 100, 50 & 25 ppm, respectively, compared to 0.0% mortality of control adults). As clearly seen in the aforementioned table, the corrected mortality was found in a dose-dependent course. LC_{50} was calculated at 99.90ppm.

Depending on the data of both tables (1 & 2), pyriproxyfen exhibited stronger insecticidal potency against the 4th instar larvae than the 5th instar larvae, i.e., the 4th instar larvae were found more sensitive to pyriproxyfen than 5th instar larvae.

Table 1: Toxicity (%) of pyriproxyfen on *A. ipsilon*after treatment of the 4th instar larvae.

Conc. (ppm)	Larval mortality	Pupal mortality	Adult mortality	Total mortality	Corrected mortality	LC_{50} (ppm)
800	100	---	---	100	100	**65.95**
400	56.7	46.7	38.9	86.7	86.2	
200	50.0	37.2	19.4	80.0	79.3	
100	50.0	17.8	25.0	73.3	72.4	
50	20.0	12.5	14.3	40.0	38.0	
25	6.7	14.1	8.3	26.7	24.2	
Control	0.0	3.3	0.0	3.3	00.00	

Conc.: concentration. ---: no developed pupae oremerged adults.

Table 2: Toxicity (%) of pyriproxyfen on *A. ipsilon* after treatment of the 5th instar larvae.

Conc. (ppm)	Larval mortality	Pupal mortality	Adult mortality	Total mortality	Corrected mortality	LC_{50} (ppm)
800	100	---	---	100	100	**99.90**
400	50.0	46.7	33.3	83.3	83.3	
200	43.3	23.3	38.3	73.3	73.3	
100	30.0	19.3	22.9	56.7	56.7	
50	6.7	14.4	7.9	26.7	26.7	
25	3.3	3.3	7.0	13.3	13.3	
Control	0.0	0.0	0.0	0.0	0.0	

Conc., ---: see footnote of Table (1).

2. Effect of Pyriproxyfen on Growth, Development, Metamorphosis and Morphogenesis of *A. ipsilon*:

After treatment of the newly molted 4th instar larvae with 5 concentrations of pyriproxyfen, data of the somatic weight gain, growth rate, larval and pupal duration, developmental rate, corrupted larval-pupal transformation, pupation rate and pupal morphogenesis were assorted in Table (3). After treatment of the newly molted 5th instar larvae with 5 concentrations of pyriproxyfen, data of the previously mentioned criteria were listed in Table (4).

2.1. Effect of Pyriproxyfen on Weight Gain and Growth:

Data of Table (3) clearly revealed that pyriproxyfen considerably reduced the larval somatic weight gain (wtg), in a dose-dependent course (264.81±10.54, 238.52±9.64, 208.24±1.73, 202.42±3.61 & 181.02±3.61mg of treated larvae, at 25, 50, 100, 200 & 400ppm, respectively, *vs*. 286.67±4.51mg of control larvae) after-treatment of the newly molted 4th instar larvae. Also, the growth was greatly inhibited, since the growth rate (GR) of treated larvae was drastically regressed, in a dose-dependent course (15.53±0.62, 12.53±0.51, 10.95±0.09, 9.18±0.16 & 8.23±0.16, at 25, 50, 100, 200 & 400ppm, respectively, *vs*. 23.89±0.38 of control larvae).

After treatment of the newly molted 5th instar larvae with pyriproxyfen, data of Table (4) obviously showed the dramatically reduced wtg, in a dose-dependent course (121.00±8.19, 105.32±2.08, 101.27±4.93, 89.62±12.50 & 71.33±13.32, at 25, 50, 100, 200 & 400ppm, respectively, *vs*. 126.05±8.19 mg of control larvae). Also, GR was severely regressed, in a dose-dependent course (9.31±0.63, 7.55±0.15, 6.35±0.31, 5.27±0.74 & 3.96±0.74, at 25, 50, 100, 200 & 400ppm, respectively, *vs*. 10.50±0.68 of control larvae).

2.2. Effect of Pyriproxyfen on Developmental Durations and Rate:

After treatment of the newly molted 4th instar larvae with pyriproxyfen, data of Table (3) clearly demonstrated remarkable prolongation of the larval duration, in a dose-dependent course (18.1±0.45, 20.4±0.50, 23.9±1.01, 24.0±0.05 & 27.9±1.27 days of treated larvae, at 25, 50, 100, 200 & 400ppm, respectively, *vs*. 15.2±0.23 days of control larvae). Also, the developmental rate (DR) was considerably regressed (5.52, 4.90, 4.18, 4.17 & 3.58, at 25, 50, 100, 200 & 400ppm, respectively, *vs*. 6.57 of control larvae).

After treatment of the newly molted 5th instar larvae with pyriproxyfen, data of Table (4) obviously showed significantly prolonged larval duration, in a dose-dependent course (14.4±0.97, 16.9±0.66, 18.3±1.02, 22.1±1.71 & 25.7±0.30 days of treated larvae, at 25, 50, 100, 200 & 400ppm, respectively, *vs*. 11.2±0.76 days of control larvae). Also, DR was greatly regressed (6.94, 5.92, 5.46, 4.52 & 3.89, at 25, 50, 100, 200 & 400ppm, respectively, *vs*. 8.93 of control larvae).

With regard to the pupal duration, treatment of the newly molted 4th instar larvae with pyriproxyfen, resulted in a significant prolongation, in a dose-dependent course, with no exception (12.0±0.17, 12.1±0.06, 13.1±0.36, 13.7±0.58 & 14.9±0.55 days,at 25, 50, 100, 200 & 400ppm, respectively, *vs*. 09.6±0.26 days of control pupae, Table 3). A similar result was recorded for pupae after-treatment of the newly molted 5th instar larvae with pyriproxyfen, since the pupal duration was remarkably prolonged, in a dose-dependent course (12.1±0.15, 14.2±0.21, 14.7±0.64, 14.0±0.44 & 15.5±0.41days, at 25, 50, 100, 200 & 400ppm, respectively, *vs*. 09.9±0.40 days of control pupae, Table, 4).

2.3. Effect of Pyriproxyfen on The Developmental Program:

Data of Table (3) displayed a criterion of the disrupted developmental program, Failure of ecdysis, after treatment of 4th instar larvae only with the higher two concentrations of pyriproxyfen (20.00 & 26.66% failed larvae to molt, at 200 & 400ppm, respectively, compared to 0.0% failure of control larvae to molt). Plate (1) demonstrated photos of incompletely ecdysed 5th instar larvae with attached 4th instar cuticles. A similar result was obtained after treatment of 5th instar larvae only with the highest concentration of Pyriproxyfen (13.3% failure of ecdysis, Table 4). Plate (2) contains photos of failure of 5th instar larvae to moult into 6th instar, since old 5th instar cuticle remained with the 6th instar larvae, in addition to some abdominal constrictions. However, no larval-pupal intermediates were produced, as another feature of the disrupted developmental program, irrespective of the treated larval instar with pyriproxyfen.

2.4. Effect of Pyriproxyfen on The Metamorphosis:

As shown in Table (3), treatment of 4th instar larvae with pyriproxyfen resulted in considerably suppressed pupation rate, since pupation % remarkably decreased, in no certain trend (93.3, 80.0, 40.0, 40.0 & 43.3% pupation, at 25, 50, 100, 200 & 400ppm, respectively, *vs*. 100% pupation of control larvae. Data of Table (4) revealed that the pupation was adversely hindered proportional to the Pyriproxyfen concentration (96.7, 93.3, 70.0, 56.7 & 50.0% pupation, at 25, 50, 100, 200 & 400ppm, respectively, *vs*. 100% pupation of control larvae).

2.5. Effect of Pyriproxyfen on The Morphogenesis Program:

As clearly seen in Table (3) and Table (4), pyriproxyfen failed to affect the pupal morphogenesis, since no malformed pupae were observed, regardless the treated larval instar.

Table 3: Influenced growth and development of *A. ipsilon* after treatment of 4th instar larvae with pyriproxyfen.

Conc. (ppm)	Larval stage						Pupal stage		
	Weight gain (mg) (mean ± SD)	Growth rate (mean± SD)	Duration (days) (mean ±SD)	Develop. rate (%)	Failure of ecdysis (%)	Larval-pupal Inter. (%)	Pupation (%)	Deformed pupae (%)	Duration (days) (mean ±SD)
400	181.02±3.61 d	8.23±0.16 d	27.9±1.27 d	3.58	26.66	0.0	43.3	0.0	14.9±0.55 d
200	202.42±3.61 d	9.18±0.16 d	24.0±0.05 d	4.17	20.00	0.0	40.0	0.0	13.7±0.58 d
100	208.24±1.73 d	10.95±0.09 d	23.9±1.01 d	4.18	00.00	0.0	40.0	0.0	13.1±0.36 d
50.0	238.52±9.64 c	12.53±0.51 d	20.4±0.50 d	4.90	00.00	0.0	80.0	0.0	12.1±0.06 d
25.0	264.81±10.54 b	15.53±0.62 d	18.1±0.45 d	5.52	00.00	0.0	93.3	0.0	12.0±0.17 d
Control	286.67±4.51	23.89±0.38	15.2±0.23	6.57	00.00	0.0	100.0	0.0	09.6±0.26

Conc.: See footnote of Table (1). Develop.: Developmental.Mean±SD followed with letter a: insignificant (P >0.05), b: significant (P<0.05), c: highly significant (P<0.01), d: very highly significant (P<0.001).

Table 4: Influenced growth and development of *A. ipsilon* after treatment of 5th instar larvae with pyriproxyfen.

Conc. (ppm)	Larval stage						Pupal stage		
	Weight gain (mg) (mean ± SD)	Growth rate (mean± SD)	Duration (days) (mean ± SD)	Develop. rate (%)	Failure of ecdysis (%)	Larval-pupal Inter. (%)	Pupation (%)	Deformed pupae (%)	Duration (days) (mean ± SD)
400	71.33±13.32 c	3.96±0.74 d	25.7±0.30 d	3.89	13.3	0.0	50.0	0.0	15.5±0.41 d
200	89.62±12.50 b	5.27±0.74 c	22.1±1.71 d	4.52	00.0	0.0	56.7	0.0	14.0±0.44 d
100	101.27±4.93 b	6.35±0.31 b	18.3±1.02 d	5.46	00.0	0.0	70.0	0.0	14.7±0.64 d
50	105.32±2.08 b	7.55±0.15 b	16.9±0.66 d	5.92	00.0	0.0	93.3	0.0	14.2±0.21 d
25	121.00±8.19 a	9.31±0.63 a	14.4±0.97 b	6.94	00.0	0.0	96.7	0.0	12.1±0.15 d
Control	126.05±8.19	10.50±0.68	11.2±0.76	8.93	00.0	0.0	100.0	0.0	09.9±0.40

Conc.: See footnote of Table (1). Develop., a, b, c, d,: see footnote of Table (3).

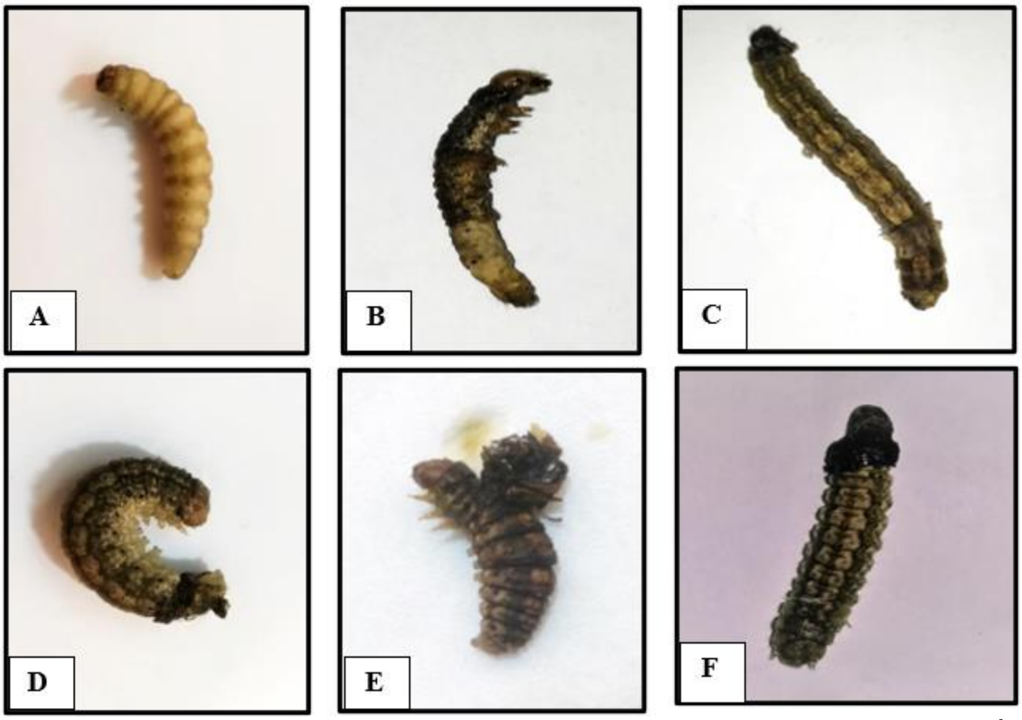

Plate 1: Failure of ecdysis of *A. ipsilon* after treatment of the newly moulted 4th instar larvae with pyriproxyfen. A: Normal 5thinstar larva. B, C, D, E & F: photos of incompletely ecdysed 5th instar larva with attached 4th instar cuticle.

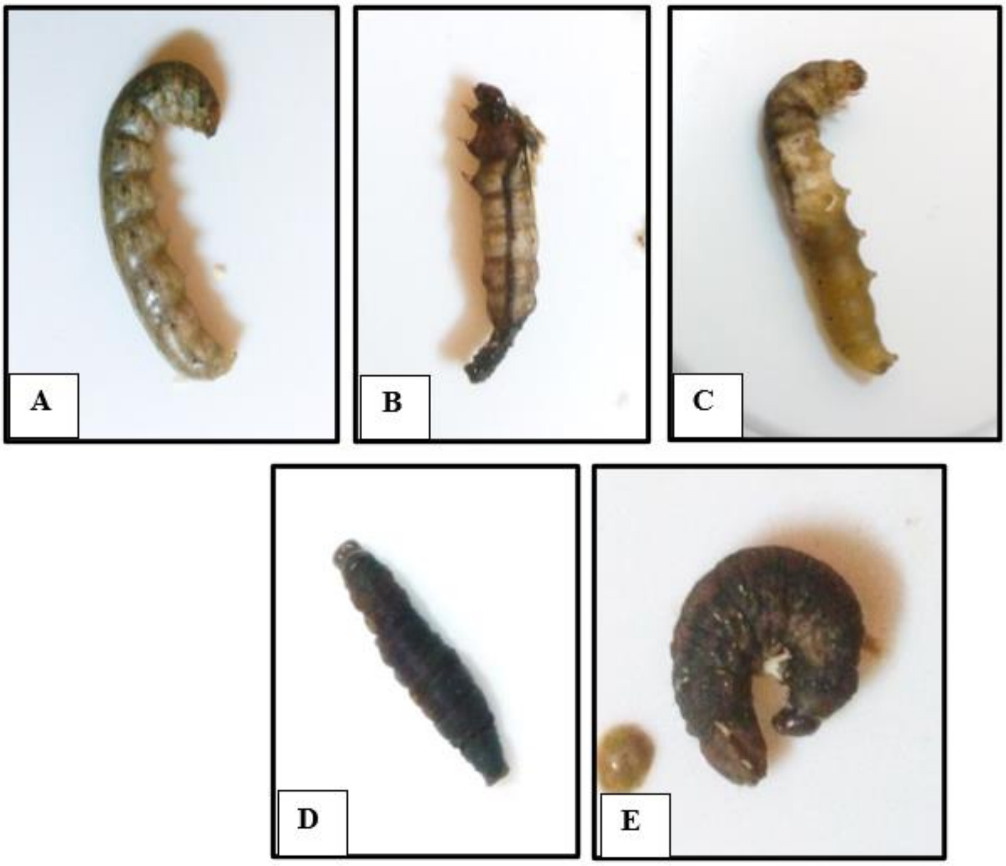

Plate 2: Failure of ecdysis of *A. ipsilon* after treatment of the newly moulted 5th instar larvae with pyriproxyfen. A: Normal 6th instar larva. B, C, D & E: photos of incompletely moulted 6th instar larvae with old 5th instar cuticles and abdominal constrictions.

DISCUSSION

Insecticidal Activity of Pyriproxyfen against *A. ipsilon*:

Toxic effects of various insect growth regulators (IGRs) on the black cutworm *Agrotis ipsilon* had been reported, such as flufenoxuron and methoprene (Khatter, 2014), chlorfluazuron and triflumuron (Fahmy, 2014), methoprene (Abdou and Abdel-Hakim, 2017), chlorfluazuron and flufenoxuron (Shaurub *et al*., 2018) and chlorantraniliprole (He *et al.*, 2019). Results of the present study were in agreement with these reported results, since pyriproxyfen exhibited strong acute insecticidal activity against larvae of *A. ipsilon*, in a dose-dependent course, after treatment of 4th instar or 5th instar larvae. Also,the same IGR exhibited considerable chronic toxicity against the pupae and adults, in a dose-dependent trend, regardless of the treated larval instar.

Also, the present results were in corroboration with various reported results of toxicity of different IGRs against several insects, other than *A. ipsilon*, such as methoprene against the common house mosquito *Culex pipiens* (Gelbic *et al.*, 2002), the Asian tiger mosquito *Aedes albopictus* (Khan *et al.*, 2016), therice meal moth *Corcyra cephalonica* (Tripathi and Tiwari, 2006), the yellow fever mosquito *Aedes aegypti* (Braga *et al.*, 2005) and the flesh fly *Sarcophagaruficornis* (Singh *et al.*, 2017); Flufenoxuron (El-Naggar, 2013), Lufenuron (Bakr *et al.*,2013), Buprofezin (Nasr *et al.*, 2010), Cyromazine (Tanani*et al.*, 2015), Teflubenzuron (Mead and Khedr, 2018) and chlorfluazuron (Shaurub *et al.*, 2020) against the Egyptian cotton leafworm *Spodoptera littoralis*; pyriproxyfen against the Sunn pest *Eurygaster integriceps* (Mojaver and Bandani, 2010) and the lawn armyworm *Spodoptera mauritia* (Resmitha and Meethal, 2016); kinoprene against *C. pipiens* (Hamaidia and Soltani, 2014); Lufenuron against the red flour beetle *Tribolium castaneum* (Gado*et al.*, 2015); Tebufenozide (RH-5992) againstthe Mediterranean flour moth *Ephestia kuehniella* (Tazir*et al.*, 2016); Lufenuron against the lesser mulberry snout moth *Glyphodes pyloalis* (Aliabadi *et al.*, 2016) and the corn earworm *Helicoverpa armigera* (Vivan *et al.*, 2017); Fenoxycarb against *C. Cephalonica* (Begum and Qamar, 2016); Cyromazine against the flies *Musca domestica*, *Stomoxys calcitrans* and *Fannia canicularis* (Donahue *et al.*, 2017); Novaluron against the pink bollworm *Pectinophora gossypiella* (Ghoneim*et al.*, 2017a) and the mosquito *Aedes aegypti* larvae (Gunathilaka *et al.*, 2020); Novaluron (Ghoneim *et al.*, 2017b) and Methoxyfenozide (Hamadah and Abo Elsoud, 2018) against olive leaf moth *Palpita unionalis*; Pyriproxyfen against the false stable fly *Muscina stabulans* (Hamadah, 2018); *etc*.

In the current investigation, 4th instar larvae of *A. ipsilon* were found more sensitive to the pyriproxyfen toxicity than 5th instar larvae. This result was consistent with the results of larval sensitivity of the same insect to some IGRs, such as some chitin synthesis inhibitors (El-Kady *et al.*, 1990; Abou El-Ghar *et al.*, 1994) and methoprene (a juvenoid) (Abdou and Abdel-Hakim, 2017).

It is important to discuss the variation of LC_{50} values in the present study, compared to various values, as reported for other insects. In thecurrentstudy on *A. ipsilon*, LC_{50} values of pyriproxyfen were calculated at 65.95 and 99.90ppm, after treatment of 4th instar and 5th instar larvae, respectively. Various LC_{50} values against *A. ipsilon* were reported for different IGRs, such as 3.5 and 4.0 ppm for triflumuronand chlorfluazuron, respectively (Fahmy, 2014); 1.00 and 4.68 mg/L for chlorfluazuron and flufenoxuron, respectively (Shaurub *et al.*, 2018) and 0.187 $\mu g.g^{-1}$ for chlorantraniliprole (He *et al.*, 2019).

Apart from *A. ipsilon*, the available literature contains many reported results of LC_{50} values of different IGRs against several insects, such as LC_{50} values of novaluron and lufenuron against the tobacco cutworm *Spodoptera litura* larvae were 350.45 and 453.78

ppm, respectively (Sharma and Pathania, 2014); LC_{50} of Pyriproxyfen was found to be 0.025% against *S. litura* larvae (Kaur and Chandi, 2015); LC_{50} of hexaflumuron against *H. armigera* was 8.47 mg /L (Taleh *et al.*, 2015); LC_{50} values of lufenuron and chlorfluazuron against 4th instar larvae of *S. littoralis* were 1.7 and 2.2 ppm, respectively (Aboutaleb *et al.*, 2015). LD_{50} values of the ecdysone agonists RH-5849 and RH-5992 (tebufenozide) against *E. kuehniella* were 0.05 and 0.005 µg/insect, respectively (Tazir *et al.*, 2016); LC_{50} of the ecdysone agonist methoxyfenozide against *Cx. pipiens* was 24.54 µg/L (Hamaidia and Soltani, 2016); LC_{50} of Lufenuron against *G. pyloalis* was 19 ppm (Aliabadi et al., 2016); LC_{50} values of chlorfluazuron, cyromazine, lufenuron and precocene I against the cat flea *Ctenocephalides felis* were 0.19, 2.66, 0.20, and 10.97 ppm, respectively (Rust and Hemsarth, 2016); LD_{50} values of RH-5849 and tebufenozide against *E. kuehniella* were 0.05 and 0.005 µg/insect, respectively (Tazir*et al.*, 2016); LC_{50} of teflubenzuron against *P. gossypiella* was 78.59 ppm (Said et al., 2017); LC_{50} values of Novaluron against *P. gossypiella* were 0.187 ppm and 0.765 ppm, after treatment of newly hatched and full grown larvae, respectively (Ghoneim *et al.*, 2017a); LC_{50} values of flufenoxuron, chlorfluazuron and triflumuron against 4th instar larvae of *S. littoralis* were 0.14 ppm, 0.42 and 1661.58 ppm, respectively (Abdel-Mageed et al., 2018); LC_{50} of pyriproxyfen against the mosquitoes *Aedes aegypti* and *Aedes albopictus* were 1.63ppm and 1,56ppm, respectively (Sucipto *et al.*, 2018); LC_{50} values of diofenolan against *P. gossypiella* were 0.028 ppm and 0.036 ppm, after treatment of newly hatched and full grown larvae, respectively (Tanani and Bakr, 2018); LC_{50}value of methoxyfenozide against last instar (6th) larvae of *P. unionalis* was 0.176 ppm (Hamadah and Abo Elsoud, 2018); LD_{50} values of pyriproxyfen against the false stable fly *Muscina stabulans* were 0.242 & 0.444µg/stage, after treatment of early last (3rd) instar larvae and prepupae, respectively (Hamadah, 2018); LD_{50} of novaluron against 9th instar larvae of the red palm weevil *Rhynchophorus ferrugineus* was 14.77 ppm (Hussain *et al.*, 2019); LC_{50} values of hexaflumuron, lufenuron and chlorfluazuron against *H. armigera* larvae were 6.16, 61.31 and 31.75 mg ai/l, respectively (Khorshidi *et al.*, 2019); LC_{50} of fenoxycarb against 4th instar larvae of *S. littoralis* was 25.943 ppm (Gad *et al.*, 2019); LC_{50} values of novaluron and methoxyfenozide against 3rd instar *S. litura* larvae were 29.56 mg/l and 21.06 mg/l, respectively (Khan *et al.*, 2021); *etc*. However, LC_{50} value depends on several factors, such as susceptibility of the insect and its treated stage or instar, lethal potency of the tested compound and its concentration levels, method and time of treatment, source of stock insect referring to potential genetical/geographical variations, as well as the experimental conditions.

To explicate the recorded toxic effect of pyriproxyfen on larvae, pupae and adults of *A. ipsilon*, in the current study, IGRs exhibit their toxic effects on insects with a mode of action other than that of conventional insecticides. It was suggested that the tested juvenoid IGR interfered with the transport system of UDP-N-acetyl amine across the membrane (Eto, 1990). For some detail, the larval deaths of *A. ipsilon* by pyriproxyfen, in the current study, might be due to the failure of larvae to moult owing to the inhibition of chitin formation (Abdel Rahman *et al.*, 2007; Adel, 2012) or the prevention of molting larvae to swallow volumes of air for splitting the old cuticle and expand the new one during ecdysis (Linton *et al*., 1997) or to the inability of the molting larvae to shed their exocuticle (Zorzetti *et al.,* 2015). Also, these larval deaths might be due to the prevented feeding and continuous starvation of the present insect (Ghoneim *et al.,* 2000).

Although the disturbance of hormonal regulation or the disruption of the normal activity of the endocrine system in insects by IGRs was reported (Oberlander *et al*., 1997; Mulla *et al.,* 2003; Djeghader *et al.,* 2014), the pupal deaths in *A. ipsilon*, in the present study, could be due to some causes, such as suffocation, bleeding and desiccation due to imperfect exuviation, failure of vital homeostatic mechanisms, *etc*. (Smagghe and Degheele, 1994).

In addition, the adult mortality of *A. ipsilon* after treatment of newly moulted 4th and 5th instar larvae with pyriproxyfen, in the current study, could be explained by the retention and distribution of this juvenoid IGR in the insect body as a result of rapid transport from the gut of treated larvae into other tissues, by the direct and rapid transport *via* the haemolymph to other tissues, and/or by lower detoxification capacity of adults against the tested compound (Osman *et al.*, 1984).

Disrupted Growth, Development, Metamorphosis and Morphogenesis of *A. ipsilon* by Pyriproxyfen:

1. Reduced Weight Gain and Inhibited Growth:

In the present study, treatment of 4th instar or 5thinstar larvae of *A. ipsilon* with pyriproxyfen resulted in a remarkable reduction of the larval somatic weight gain, in a dose-dependent course. Also, the growth was considerably inhibited, since the growth rate of treated larvae was drastically regressed, in a dose-dependent course. These results were in accordance with the reported results of reduced body weight and inhibited the growth of the same insect after treatment of chlorfluazuron or triflumuron (Fahmy, 2014) and chlorantraniliprole (He *et al.*, 2019).

Also, the current results were concomitant with many reported results of reduced body weight and/or inhibited growth of other insects by various IGRs, such as *S. littoralis* by flufenoxuron (Bakr *et al.*, 2010), lufenuron (Adel, 2012), and novaluron (Ghoneim et al., 2015); the common lime butterfly *Papiliodemoleus* by diofenolan (Singh and Kumar, 2011); *S. litura* by chlorfluazuron (Perveen, 2012); *Cx. pipiens* by novaluron (Djeghader*et al.*, 2014) and kinoprene (Hamaidia and Soltani, 2014); the bean aphid *Aphis craccivora* (Vadja and Kalasariya, 2015), the brown planthopper *Nilaparvata lugens* (Alam and Das, 2017) and *S. litura* (Khatun *et al.*, 2017) by buprofezin; the mosquitoes *A. aegypti* and *Aedes albopictus* by pyriproxyfen (Sucipto *et al.*, 2018); *P. unionalis* by Methoxyfenozide (Hamadah and Abo Elsoud, 2018); *H. armigera* by hexaflumuron, lufenuron and chlorfluazuron (Khorshidi *et al.*, 2019); the okra jassid *Amrasca biguttula* by pyriproxyfen, lufenuron and buprofezin (Joarder *et al*., 2020); *etc*.

On the other hand, the present results disagreed with some reported results of increased body weight and/or enhanced growth of some insects by certain IGRs, such as *A. ipsilon* by fenoxycarb (Abdel-Hakim and El-Mandarawy, 2017) and methoprene (Abdou and Abdel-Hakim, 2017) and *S. littoralis* by cycloheximide (Basiouny and Ghoneim, 2018). In addition, some IGRs failed to affect the growth of different insects, such as the house fly *Musca domestica* (Ghoneim *et al.*, 1991), the American cockroach *Periplaneta americana* and the large milkweed bug *Oncopeltus fasciatus* (Darvas *et al.*, 1992), the African armyworm *Spodoptera exempta*, the beet armyworm *Spodoptera exigua* and the Colorado potato beetle *Leptinotarsa decemlineata* (Smagghe and Degheele, 1994). For the interpretation of body weight gain reduction and growth inhibition of *A. ipsilon* after treatment with pyriproxyfen, in the presentstudy, it may be important to mention that Lepidoptera belongs to the most sensitive groups of insects regarding the growth-regulating effects of IGRs. The reduction of the body weight and inhibition of larval growth of *A. ipsilon* might be a result of the blocked release of morphogenic peptides, causing alteration in the ecdysteroid and juvenoid titers (Barnby and Klocke, 1990), disrupted tissues and cells undergoing mitosis (Nasiruddin and Mordue, 1994), disruption of chitin synthesis and loss of body fluid during the molting stage (Vojudi *et al.*, 2017) or might be due to the reduced food intake during the larval period or high metabolic costs required for the detoxification of ingested xenobiotic compounds (Khorshidi *et al.*, 2019).

2. Prolonged Developmental Duration and Regressed Developmental Rate of *A. ipsilon* by Pyriproxyfen:

In the present study, treatment of 4^{th} instar or 5^{th} instar larvae of *A. ipsilon* with pyriproxyfen resulted in remarkable prolongation of the larval and pupal durations, in a dose-dependent course. Also, the developmental rate was considerably regressed, in a dose-dependent course. These results were in agreement with some reported results of prolonged larval and pupal durations of the same insect after treatment of larvae with different IGRs, such as chlorfluazuron or triflumuron (Fahmy, 2014), methoprene and flufenoxuron (Khatter, 2014), methoprene (Abdou and Abdel-Hakim, 2017), fenoxycarb (Abdel-Hakim and El-Mandarawy, 2017), chlorfluazuron or flufenoxuron (Shaurub *et al.,* 2018) and chlorantraniliprole (He *et al.,* 2019).

Also, the present results were in accordance with many reported results of prolonged larval and pupal durations indicatingregressed developmental rate of other insects after treatment with IGRs of various categories, such as *Cx. pipiens* after treatment with kinoprene (Hamaidia and Soltani, 2014) and methoxyfenozide (Hamaidia and Soltani, 2016); the diamondback moth *Plutella xylostella* after treatment with Pyriproxyfen (Mahmoudvand *et al.,* 2015); *S. littoralis* after treatment with diflubenzuron (Aref *et al*., 2010), Lufenuron (Gaaboub *et al.,* 2012), novaluron (Ghoneim *et al.,* 2015), methoxyfenozide (Khaled and Farag, 2015) and cyromazine (Tanani *et al.,* 2015); *G. pyloalis* after treatment with lufenuron (Aliabadi *et al.,* 2016); *C. cephalonica* after treatment with methoprene (Tripathi and Tiwari, 2006) and fenoxycarb (Begum and Qamar, 2016); *P. gossypiella* after treatment with buprofezin (Al-Kazafy, 2013), teflubenzuron (El-Khayat *et al*., 2015; Said *et al.,* 2017), chromafenozide (Salem, 2015), pyriproxyfen (Sabry and Abdou, 2016), novaluron (Hamadah and Ghoneim, 2017;Ghoneim*et al.,* 2017a) and diofenolan (Tanani and Bakr, 2018); the false stable fly *Muscina stabulans* after topical application of pyriproxyfen onto the early last (3^{rd}) instar larvae (Hamadah, 2018); *H. armigera* after feeding on diet mixed with hexaflumuron, lufenuron or chlorfluazuron (Khorshidi *et al.,* 2019); *etc*.

On the contrary, the present results disagreed with the reported results of shortened larval and pupal duration of some insects after treatment with different IGRs, such as *A. ipsilon* after treatment with flufenoxuron (El-Sheikh, 2002); *Rh. ferrugineus* after treatment with lufenuron and diofenolan (Tanani,2001**)**; the desert locust *Schistocerca gregaria* after treatment with lufenuron (Bakr *et al.,* 2008); *P. gossypiella* after treatment with methoxyfenozide (Sabry and Abdou, 2016); *P. unionalis* after treatment with novaluron (Ghoneim *et al.,* 2017b); *Cx. pipiens* after treatment with halofenozide (Bouaziz *et al.,* 2017); *M. stabulans* after topical application of Pyriproxyfen onto the prepupae (Hamadah, 2018) and *S. littoralis* after treatment with chlorfluazuron (Shaurub *et al.,* 2020). In addition, the larval duration of *S. littoralis* was not affected after treatment with flufenoxuron or pyriproxyfen (Shaurub *et al.,* 2020).

To explicate the remarkable prolongation of larval and pupal duration and considerably regressed developmental rate after treatment4^{th} instar or 5^{th} instar larvae of *A. ipsilon* with pyriproxyfen, in the present study, pyriproxyfenmight affect the tissues and cells undergoing mitosis (Nasiruddin and Mordue, 1994) or might exhibit a delaying effect on the ecdysis and transformation (Linton *et al.,* 1997). Also, pyriproxyfenmight exhibit a delaying effect on the pupation of *A. ipsilon*. On the other hand, the final step of the chitin biosynthesis pathway was inhibited by this juvenoid IGR and the precursor was not converted into chitin leading to a prolongation of the developmental duration (Djeghader *et al.,* 2014). In general, the prolongation of pupal duration might be due to the persistence of juvenile hormone (JH) and its elevated level in the haemolymph where it is only in the absence of JH that ecdysone could be activated and lead to the formation of the next stage

(Kuwano *et al.,* 2008). In addition, because the pyriproxyfen-treated *A. ipsilon* larvae must spend more resources on detoxification rather than development, larval development takes significantly longer duration (Hannig *et al.,* 2009). In other words, the pyriproxyfen-treated larvae should divert the energy stream from development and reproduction to detoxification or rehabilitation of tissues following possible damages. Moreover, hormonal imbalances after IGR treatment may cause diverse physiological discrepancies to be taken care of by the survived larvae which require energy (Khorshidi *et al.,* 2019).

3. Disrupted Developmental Program of *A. ipsilon*:

Depending on the available literature, the major symptoms and features of the impaired developmental program of an insect after treatment with various IGRs had been described as failure of larval ecdysis, production of larval-pupal and/or pupal-adult intermediates, production of supernumerary larval instars (superlarvae). However, all or some of these features were observed in various insects by the disruptive effects of IGRs. However, all or some of these features were observed in various insects as responses to the disruptive effects of different IGRs, such as *S. littoralis* by flufenoxuron (El-Naggar, 2013), novaluron (Ghoneim *et al.,* 2015) and cyromazine (Tanani *et al.,* 2015). Also, some or all of these symptoms of the impaired developmental program were recorded after treatment of different insects with several IGRs, such as the American serpentine leafminer *Liriomyza trifolii* (Saryazdi*et al.,* 2012) and the cowpea weevil *Callosobruchus maculates* (Al-Mekhlafi *et al.,* 2012) by cyromazine; *H. armigera* (Murthy and Ram, 2002), *A. aegypti* (Nwankwo *et al.,* 2011) and*M. domestica* (Lohmeyer *et al.,* 2014) by novaluron; the mustard aphid *Lipaphis erysimi* by pyriproxyfen (Liu and Chen, 2001); *Rh. ferrugineus* (Tanani, 2001) and the lime butterfly *Papilio demoleus* (Singh and Kumar, 2011) by diofenolan; the European grapevine moth *Lobesia botrana* by lufenuron (Saenz-de-Cabezon *et al.,* 2005); *Cx. pipiens* by kinoprene (Hamaidia and Soltani, 2014); *P. gossypiella* (Ghoneim*et al.,* 2017a) and *P. unionalis* (Ghoneim *et al.,* 2017b) by novaluron; etc.

In the present study on *A. ipsilon*, ecdysis failure of larvae, as a criterion of the disrupted developmental program, was observed only after treatment of 4th instar larvae with two concentrations and after treatment of 5th instar larvae with the highest concentration of pyriproxyfen. The major symptom of this failure was observed as incompletely ecdysed larvae with the attached old cuticle of the previous instar and some abdominal constrictions.

For the interpretation of this ecdysis failure of treated *A. ipsilon* larvae, it may be important to mention that the molting hormone "ecdysone" plays a major role in the shedding of old cuticles in a phenomenon called "ecdysis" or "molting". Pyriproxyfen might exhibit serious disturbances during larval molting, indicating that it disrupted the function of the larval endocrine system, thereby preventing the completion of molting (Ben Hamouda *et al.,* 2015). For some detail, pyriproxyfenmight suppress the activity of ecdysone in larvae leading to the failure of moult and ultimately died (Baskar *et al.,* 2009; Baskar *et al.,* 2011; Jeyasankar *et al.,* 2013; Sivaraman *et al.,* 2014). On the other hand, failure of ecdysisof *A. ipsilon*larvae, in the current work, may be attributed to an inhibitory effect of pyriproxyfen on the chitin formation (Abdel Rahman *et al.,* 2007; Adel, 2012) or to the inability of larvae to shed their exocuticle during ecdysis (Linton *et al*., 1997).

On the other hand, other features of the disrupted developmental program of *A. ipsilon,* such as larval-pupal intermediates, permanent larvae, giant larvae of supernumerary larvae, had not been observed in the present study after treatment with pyriproxyfen. However, the production of larval-pupal intermediates had been reported for some insects by various IGRs, such as *H. armigera* by hexaflumuron (Taleh *et al.,* 2015), *S. littoralis* by novaluron (Ghoneim *et al.,* 2015) and cyromazine (Tanani *et al.,* 2015), *C.*

cephalonica by fenoxycarb (Begum and Qamar, 2016); *P. gossypiella* (Ghoneim *et al.,* 2017a) *P. unionalis* (Ghoneim *et al.,* 2017b) by novaluron; and *P. unionalis* by methoxyfenozide (Hamadah and Abo Elsoud, 2018).

4. Impaired Metamorphosis of *A. ipsilon*:

Pupation is a crucial process in the life of insects for transformation from one stage to the next one. Depending on the current literature, the pupation rate of *A. ipsilon* was reported to be reduced after treatment with some IGRs, such as chlorfluazuron and triflumuron (Fahmy, 2014), chlorfluazuron and flufenoxuron (Shaurub *et al.,* 2018) and chlorantraniliprole (He *et al.,* 2019). Results of the present study were consistent with those reported results, since treatment of 4th or 5th instar larvae of *A. ipsilon* with a series of pyriproxyfen concentrations led to detrimentally suppressed pupation, proportional to the concentration. The present result was, also, in agreement with many reported results of reduced pupation of different insects, other than *A. ipsilon*, after treatment with various IGRs, such as such as *P. xylostella* after treatment with Hexaflumuron (Mahmoudvand *et al.,* 2012); *S. littoralis* after treatment with novaluron (Ghoneim *et al*., 2015), cyromazine (Tanani *et al.,* 2015), methoxyfenozide (Khaled and Farag, 2015) and cycloheximide (Basiouny and Ghoneim, 2018); *G. Pyloalis* after treatment with lufenuron (Aliabadi*et al.,* 2016)and fenoxycarb (Singh and Tiwari, 2016); the whitefly parasitic wasp *Encarsia formosa* after treatment with pyriproxyfen and fenoxycarb (Wang and Liu, 2016); *P. gossypiella* after treatment with novaluron (Ghoneim et al., 2017a), teflubenzuron (Said *et al.,* 2017), noviflumuron (Hamadah and Ghoneim, 2017) and diofenolan (Tanani and Bakr, 2018); *P. unionalis* after treatment with novaluron (Ghoneim *et al*., 2017b); *M. stabulans* after treatment with pyriproxyfen(Hamadah, 2018); *etc*.

To understand the regressed pupation rate of *A. ipsilon*, in the current investigation, pyriproxyfen might exert a suppressive action on the chitin synthesis and prevented the normal deposition of the new cuticle during apolysis (Retnakaran *et al.,* 1985). For some detail, pyriproxyfen might exert an inhibitory action on the prothoracic gland (ecdysone-producing gland) and hence the ecdysone could not be synthesized and/or released. In other words, pyriproxyfen might block the release of morphogenic peptides, causing a disturbance in titers of both ecdysteroids and juvenoids (Barnby and Klocke, 1990). Also, pyriproxyfen might disrupt the ecdysteroid metabolism or might alternatively act directly to inhibit the release of an ecdysis-triggering hormone (Gaur and Kumar, 2010). In addition, reduction of the pupation rate of *A. ipsilon* might be due to an inhibitory effect of pyriproxyfen on the synthesis of specific storage proteins in the fat body during the last larval instar and their deposition at the time of pupation (Gupta, 1985**)**.

2.5. Impaired Morphogenesis Program of *A. ipsilon*:

According to the currently available literature, there are some reported results of impaired pupal morphogenesis of a number of insects, since deformed pupae were observed after treatment with different IGRs, such as the red flour beetle *Tribolium castaneum* and the confused flour beetle *Tribolium confusum* after treatment with cyromazine (Kamaruzzaman *et al*., 2006); the fall armyworm *Spodoptera frugiperda* after feeding of 5th instar larvae on a diet treated with methoxyfenozide (Zarate *et al*., 2011); *C. cephalonica* after topical application of fenoxycarb onto last instar larvae (Begum and Qamar, 2016); *P. gossypiella* after-treatment of the full-grown larvae with novaluron (Ghoneim *et al.,* 2017a) and *P. unionalis* after treatment of newly moulted last instar larvae with novaluron (Ghoneim *et al.,* 2017b). In contrast, the results of the present study disagreed with the previously reported results, since pyriproxyfen failed to affect the pupal morphogenesis and no malformed pupaewere observed after treatment of the 4th instar or 5th instar larvae of *A. ipsilon* with a series of its concentrations.

Conclusion:

Depending on the results of the present study, pyriproxyfen exhibited a considerably toxic effect on different development stages of *A. ipsilon*, caused a drastic reduction of the larval weight gain and detrimental inhibition of growth. Also, it remarkably suppressed the pupation and disturbed development program. Therefore, pyriproxyfen could be recommended as an eco-friendly alternative to synthetic insecticides for the management of this dangerous insect.

REFERENCES

Abbott, W.S. (1925): A method of computing the effectiveness of insecticide. *Journal of Economic Entomology*, 18(2): 265-267.

Abdel Rahman, S.M.; Hegazy, E.M. and Elweg, A.E. (2007): Direct and latent effect of two chitin synthesis inhibitors on *Spodoptera littoralis* larvae (Boisd.). *American Eurasian Journal of Agricultural and Environmental Sciences*, 2(4): 454-464.

Abdel-Hakim, E.A. and El-Mandarawy, M.B. (2017): Effects of juvenile hormone mimic on growth, morphogenesis and morphology of hemocytes of the black cutworm, *Agrotis ipsilon* larvae (Lepidoptera: Noctuidae). *Current Science International*, 6(3): 662-669.

Abdel-Mageed, A.; El-bokl, M.; Khidr, A. and Said, R. (2018): Disruptive effects of selected chitin synthesis inhibitors on cotton leafworm *Spodoptera littoralis* (Boisd.). *Australian Journal of Basic and Applied Sciences*, 12(1): 4-9. DOI: 10.22587/ajbas.2018.12.1.2

Abdin, M.I. (1979): Standard technique for mass rearing of the black cutworm, *Agrotis ipsilon*. M.Sc. Thesis, Faculty of Agriculture, Al-Azhar University, Egypt.

Abdou, W.L. and Abdel-Hakim, E.A. (2017): Some biological and biochemical aspects of *Agrotis ipsilon* (Lepidoptera: Noctuidae) larvae as Influenced by Methoprene (JHA). *Current Science International*, 06: 631-639.

Abo El-Ghar, G.E.S.; Khalil, M.S. and Eid, T.M. (1994): Effects of plant extracts on development and fecundity of *Agrotis ipsilon* (Lepidoptera: Noctuidae). *Bulletin of Entomological Society of Egypt (Economic Series)*, 21: 171-190.

Aboutaleb, H.K.; Eldin, H.; Zahran, M. and Gad, A.A. (2015): Biochemical and physiological effects of lufenuron and chlorfluazuron on *Spodoptera littoralis* (Boisd.) (Lepidoptera: Noctuidae). *Journal of Entomology*, 12: 77–86.

Adel, M.M. (2012): Lufenuron impair the chitin synthesis and development of *Spodoptera littoralis* Bosid. (Lepidoptera: Noctuidae). *Journal of Applied Science Research*, 8(5): 27-66.

Adrees, M.; Ali, S.; Rizwan, M.; Ibrahim, M.; Abbas, F. and Farid, M. (2015): The effect of excess copper on growth and physiology of important food crops: a review. *Environmental Science and Pollution Research*, 22: 8148–8162.

Alam, M.J. and Das, G. (2017): Laboratory evaluation of Buprofezin on the mortality of Brown plant hopper, *Nilaparvata lugens* (Delphacidae: Hemiptera). *Journal of Entomology and Zoology Studies, 5*(6): 2172-2175.

Aliabadi, F.P.; Sahragard, A. and Ghadamyari, M. (2016): Lethal and sublethal effects of a chitin synthesis inhibitor, lufenuron, against *Glyphodes pyloalis* Walker (Lepidoptera: Pyralidae). *Journal of Crop Protection,* 5(2): 203-214. http://journals. modares. ac.ir/article-3-522-en.html.

Al-Kazafy, H.S. (2013): Effect of some pesticides with different target sites on the pink bollworm, *Pectinophora gossypiella* (Saunders). *Archives of Phytopathology and Plant Protection*, 46(8): 942-951.

Al-Mekhlafi, F.; Mashaly, A.M.; Wadaan, M.A. and Al-Mallah, N.M. (2012): Effect of different applicable conditions of the insect growth regulator (Cyromazine) on the southern cowpea weevils, *Callosobruchus maculatus* reared on peas. *Pakistan Journal of Zoology*, 44(2): 481-488.

Andersch, W. and Schwarz, M. (2003): Clothianidin seed treatment (PonchoReg.) - the new technology for control of corn rootworms and secondary pests in US-corn production. *Pflanzenschutz Nachrichten Bayer*, 56(1):147-172.

Aref, S.A.; Bayoumi, O.Ch. and Soliman, H.A.B. (2010): Effect of certain insecticides on the biotic potential of the cotton leafworm, *Spodoptera littoralis* (Boisd.). *Egyptian Journal of Agricultural Researches*, 88(1): 31-40.

Arias-Estevez, M.; Lopez-Periago, E.; Martinez-Carballo, E.; Simal-Gandara, J.; Mejuto, J.C. and Garcia-Rio, L. (2008): The mobility and degradation of pesticides in soils and the pollution of groundwater resources. *Agriculture, Ecosystems & Environment*, 123:247–260.

Aribi, N.; Smagghe, G.; Lakbar, C.; Soltani-Mazouni, N. and Soltani, N. (2006): Effect of pyriproxyfen a juvenile hormone analogue, on development of the mealworm, *Tenebrio molitor*. *Pesticide Biochemistry and Physiology*, 84: 55–62.

Bakr, R.F.; Ghoneim, K.S.; Al-Dali, A.G.; Tanani, M.A. and Bream, A.S. (2008): Efficiency of the chitin synthesis inhibitor lufenuron (CGA-184699) on growth, development and morphogenesis of *Schistocerca gregaria* (Orthoptera: Acrididae). *Egyptian Academic Journal of Biological Sciences, (A.Entomology),* 1(1): 41-57.

Bakr, R.F.A.; El-barky, N.M.; Abd Elaziz, M.F.; Awad, M.H. and Abd El-Halim, H.M.E. (2010): Effect of Chitin synthesis inhibitors (flufenoxuron) on some biological and biochemical aspects of the cotton leaf worm *Spodoptera littoralis* Bosid. (Lepidoptera: Noctuidae). *Egyptian Academic Journal of Biological Sciences (A. Entomology)*,2(2): 43-56.

Bakr, R.F.A.; Abd Elaziz, M.F.; El-barky, N.M.; Awad, M.H. and Abd El-Halim, H.M.E. (2013): The activity of some detoxification enzymes in *Spodoptera littoralis* (Boisd.) larvae (Lepidoptera Noctuidae) treated with two different insect growth regulators. *Egyptian Academic Journal of Biological Sciences (C.Physiology and Molecular Biology),* 5(2):19-27.

Barbosa, P.R.R.; Oliveira, M.D.; Barros, E.M.; Michaud, J.P. and Torres, J.B. (2018): Differential impacts of six insecticides on a mealybug and its coccinellid predator. *Ecotoxicology and Environmental Safety*, 147: 963–971. DOI: 10.1016/j.ecoenv.2017.09.021.

Barnby, M.A. and Klocke, J.A. (1990): Effects of azadirachtin on levels of ecdysteroids and prothoracicotropic hormone-like activity in *Heliothis virescens* (Fabr) larvae. *Journal of Insect Physiology*, 36: 125-131.

Basiouny, A. and Ghoneim, K. (2018): Impairment of development and reproductivity of Egyptian cotton leafworm *Spodoptera littoralis* Boisduval (Noctuidae: Lepidoptera) by cycloheximide (Acti-Dione). *Egyptian Academic Journal of Biological Sciences (A. Entomology),* 11(5): 31-58.

Baskar, K.; Kingsley, S.; Vendan, S.E.; Paulraj, M.G.; Duraipandiyan, V. and Ignacimuthu, S. (2009): Antifeedant, larvicidal and pupicidal activities of *Atalantia monophylla* (L) Correa against *Helicoverpa armigera* Hubner (Lepidoptera: Noctuidae). *Chemosphere,* 75(3): 355–359.

Baskar, K.; Sasikumar, S.; Muthu, C.; Kingsley, S. and Ignacimuthu, S. (2011): Bioefficacy of *Aristolochiatagala* Cham. Against *Spodoptera litura* Fab. (Lepidoptera: Noctuidae). *Saudi Journal of Biological Sciences,* 18: 23-27.

Begum, R. and Qamar, A. (2016): Fenoxycarb- a potent inhibitor of metamorphosis and reproduction in Rice Moth, *Corcyra cephalonica* (Stainton). *Journal of Entomology and Zoology Studies*, 4(4): 572-577.

Ben Hamouda, A.; Mechi, A.; ZarradKh.; Laarif A. and Chaieb, I. (2015): Disruptive effects of pomegranate *Punica granatum* Linn. (Lythraceae) extracts on the feeding, digestion and morphology of *Spodoptera littoralis* (Boisduval) (Lepidoptera: Noctuidae). *Entomology and Applied Science Letters*, 2(2): 1-6.

Bento, F.M.M.; Magro, S.R.; Fortes, P.; Zério, N.G. and Parra, J.R.P. (2007): Biologia e tabela de vida de fertilidade de *Agrotis ipsilon* e mdieta artificial. *Pesquisa Agropecuária Brasileira*, 42: 1369-1372.

Binning, R.R.; Coats, J.; Kong, X. and Hellmich, R.L. (2015): Susceptibility to *Bt*proteins is not required for *Agrotis ipsilon* a version to *Bt* maize. *Pest management science*, 71: 601–606. doi:10.1002/ps. 3901PMID:25186105.

Blacquière, T.; Smagghe, G.; Van Gestel, C.A.M. and Mommaerts, V. (2012): Neonicotinoids in bees: A review on concentrations, side-effects and risk assessment. *Ecotoxicology*, 21: 973–992.

Bouaziz, A.; Amira, K.; Djeghader, N.; Aïssaoui, L. and Boudjelida, H. (2017): Impact of an insect growth regulator on the development and the reproduction potency of mosquito. *Journal of Entomology and Zoology Studies*, 5(3): 1662-1667.

Braga, I.A.; Mello, C.B.; Peixoto, A.A. and Valle, D. (2005): Evaluation of methoprene effect on *Aedes aegypti* (Diptera: Culicidae) development in laboratory conditions. *Memórias do Instituto Oswaldo Cruz, Brasil*, 100(4): 435-440.

Chandler, D.; Bailey, A.S.; Tatchell, G.M.; Davidson, G.; Greaves, J. and Grant, W.P. (2011): The development, regulation and use of biopesticides for integrated pest management. *Philosophical Transactions of the Royal Society B*, 366: 1987–1998.

Chłopecka, M.; Mendel, M.; Dziekan, N. and Karlik, W. (2018): The effect of pyriproxyfen on the motoric activity of rat intestine—*in vitro* study. *Environmental Pollution*, 241: 1146–1152. doi: 10.1016/j. envpol.2018.06.046

Chowański, S.; Kudlewska, M.; Marciniak, P. and Rosiński, G. (2014): Synthetic insecticides- is there an alternative? *Polish Journal of Environmental Studies*, 23(2): 291-302.

Darvas, B.; Polgar, L.; El-Din, H.T.; Eröss, K. and Wing, K.D. (1992): Developmental disturbances in different insect orders caused by an ecdysteroid agonist, RH 5849. *Journal of Economic Entomology*, 85: 2107-2112.

Davies, T.G.E.; Field, L.M.; Usherwood, P.N.R. and Williamson, M.S. (2007): DDT, pyrethrins and insect sodium channels. *IUBMB Life*, 59: 151-162.

Dempster, C. (1957): The population dynamic of Moroccan locust *Dociostarusmurcocamus* in Cyprus. *Anti-Locust Bulletin*, p.27.

Derbalah, A.S.; Khidr, A.A.; Moustafa, H.Z. and Taman, A. (2014): Laboratory evaluation of some non-conventional pest control agents against the pink bollworm *Pectinophora gossypiella* (Saunders). *Egyptian Journal of Biological Pest Control*, 24(2): 363-368.

Devillers, J. (2009): Endocrine disruption modeling; CRC Press: Boca Raton, FL, USA, ISBN 9781138111912.

Devillers, J. (2020): Fate of pyriproxyfen in soils and plants. Toxics, 8, 20. 15pp. doi:10.3390/toxics8010020

Dhadialla, T.S. and Jansson, R.K. (2000): non-steroidal ecdysone agonists: new tools for IPM and insect resistance management. Insecticide Discovery Group, Rohm and Haas Company, 727 Norristown Road, Spring House, PA 19477.

Dhadialla, T.S.; Carlson, G.R. and Le, D.P. (1998): New insecticides with ecdysteroidal and juvenile hormone activity. *Annual Review of Entomology,* 43:545-569.

Dhadialla, T.S.; Retnakaran, A. and Smagghe, G. (2005): Insect growth and development disrupting insecticides. In: "Comprehensive Insect Molecular Science" (Gilbert, L.I.; Kostas, I. and Gill, S., eds.). Pergamon Press, New York, NY. Vol. 6, pp. 55-116.

Djeghader, N.E.H.; Aïssaoui, L.; Amira, K. and Boudjelida, H. (2014): Impact of a chitin synthesis inhibitor, Novaluron, on the development and the reproductive performance of mosquito *Culex pipiens*. *World Applied Sciences Journal,* 29(7): 954-960.

Donahue, Jr.; W.A.; Showler, A.T.; Donahue, M.W.; Vinson, B.E. and Osbrink, W.L.A. (2017): Lethal effects of the insect growth regulator Cyromazine against three species of filth flies, *Musca domestica*, *Stomoxys calcitrans*, and *Fannia canicularis* (Diptera: Muscidae) in Cattle, Swine, and Chicken Manure. *Journal of Economic Entomology,* 1; 110(2): 776-782. doi: 10.1093/jee/tow294. tow294.

Dubey, N.K.; Shukla, R.; Kumar, A.; Singh, P. and Prakash, B. (2010): Prospect of botanical pesticides in sustainable Agriculture. *Current Science, India,* 98(4): 479-480.

Abd El-Aziz, A.; Omer, E.A. and Sabra, A.S. (2007): Chemical composition of *Ocimum americanum* essential oil and its biological effects against *Agrotis ipsilon* (Lepidoptera: Noctuidae). *Research Journal of Agriculture and Biological Sciences,* 3(6): 740-747.

El-Kady, M.B.; Tayeb E.H.; Mesbah H.A. and Saad A.A. (1990): The relative efficiency of the pregnancy inhibitory hormone medroxy progesterone acetate (MPA) and the insect growth inhibitor (XRD) on the greasy cutworm *Agrotis ipsilon* (Hfn.) (Noctuidae: Lepidoptera). *Bulletin of Entomological Society of Egypt (Econ. Ser.),* 18: 93-104.

El-Khayat, E.F.; Rashad, A.M.; Abd-El Zaher, T.R.; Shams El-Din, A.M. and Salim, H.S. (2015): Toxicoloical and biological studies of some pesticidal formulations against *Pectinophora gossypiella* (Saunders) (Lepidoptera: Gelechiidae). *American-Eurasian Journal of Toxicological Sciences,* 7(1): 01-06.

El-Naggar, J.B.A. (2013): Sublethal effect of certain insecticides on biological and physiological aspects of *Spodoptera littoralis* (Boisd.). *Nature and Science,* 11(7): 19-25.

El-Sheikh, T.A.A. (2002): Effects of application of selected insect growth regulators and plant extracts on some physiological aspects of the black cutworm, *Agrotis ipsilon* (HUF.). Ph. D. Thesis, Faculty of Science, Ain Shams University, Egypt, 224pp.

El-Shershaby, M.M.A. (2010): Toxicity and biological effect of *Capparis* leaves extracts to the black cutworm, *Agrotis ipsilon* (Hufn.). *Egyptian Academic Journal of Biological Sciences (F. Toxicology & Pest Control),* 2(1): 45-51. DOI: 10.21608/eajbsf.2010.17462

Eto, M. (1990): Biochemical mechanism of insecticidal activities. In: "Chemistry of Plant Protection"(Haug, G. and Hoffman, H. eds.). Springer Verlag, 6: 65- 107.

Fahmy, A.R. (2014): Toxicological, biological and biochemical impact of some chitin synthesis inhibitors on the black cutwom, *Agrotis ipsilon* (Lepidoptera: Noctuidae) (Hufn.). *Egyptian Academic Journal of Biological Sciences (A. Entomology),* 7(2): 119-128.

Finney, D.J. (1971): Probit analysis. 3rd ed. Cambridge, England: Cambridge University Press, 318 pp.

Gaaboub, I.; Halawa, S. and Rabiha, A. (2012): Toxicity and Biological Effects of Some Insecticides, IGRs and Jojoba oil on Cotton Leafworm *Spodoptera littoralis*

(Boisd.). *Journal of Applied Sciences Research,* 2: 131-139.
Gäde, G. (2004): Regulation of intermediary metabolism and water balance of insects by neuropeptides. *Annual Review of Entomology,* 49: 93-113.
Gad, M.A.; Elwassimy, M.M.; Aref, S.A. and Abdelhamid, A.A. (2019): Chemical Design and Effects of New Insect Growth Regulators as Potential Insecticidal Agents on *Spodoptera littoralis* (Boisd.). *Novel Research in Sciences,* 2(3): 4pp.
Gado, P.; Salokhe, S.G. and Deshpande, S.G. (2015): Impact of Lufenuron (5.4% EC) on reproductive end points of *Tribolium castaneum*. *World Journal of Pharmaceutical Research,* 4(3): 1593-1599.
Gaur, R. and Kumar, K. (2010): Insect growth-regulating effects of *Withania somnifera* in a polyphagous pest, *Spodoptera litura*. *Phytoparasitica,* 38(3): 237–241. https://doi.org/10.1007/s12600-010- 0092-x
Gelbic, I.; Olejnicek, J. and Grubhoffer, L. (2002): Effects of insect hormones on hemagglutination activity in two members of the *Culex pipiens* complex. *Experimental Parasitology,* 100:75-79.
Ghasemi, A.; Sendi, J.J. and Ghadamyari, M. (2010): Physiological and biochemical effect of pyriproxyfen on Indian meal moth *Plodia interpunctella* (Hübner) (Lepidoptera: Pyralidae). *Journal of Plant Protection Research,* 50: 416-422.
Ghoneim, K.S.; Fouda, M.A. and Bream, A.S. (1991): Effectiveness of the non-steroidal ecdysone mimic, RH-5849 for the control of *Musca domestica vicina*. *Journal of Egyptian Society of Parasitology,* 21:723-733.
Ghoneim, K.S.; Mohamed, H.A. and Bream, A.S. **(**2000): Efficacy of the neem seed extract, Neemazal, on growth and development of the Egyptian cotton leafworrn, *Spodoptera littoralis* Boisd. (Lepidoptera: Noctuidae). *Journal of Egyptian German Society of Zoology,* 33: 161-179.
Ghoneim**,** K.; Tanani, M.; Hamadah, Kh.; Basiouny, A. and Waheeb, H. (2015):Bioefficacy of Novaluron, a chitin synthesis inhibitor, on survival and development of *Spodoptera littoralis* (Boisd.) (Lepidoptera: Noctuidae). *Journal of Advances in Zoology,* 1(1): 24-35.
Ghoneim, K.; Hassan, H.A.; Tanani, M.A. and Bakr, N.A. (2017a): Toxic and disruptive effects of Novaluron, a chitin synthesis inhibitor, on development of the pink bollworm *Pectinophora gossypiella* (Saunders)(Lepidoptera: Gelechiidae). *International Journal of Entomology Research,* 2(2): 36-47.
Ghoneim, K.; Hamadah, Kh.; Mansour, A.N. and Abo Elsoud, A.A. (2017b): Toxicity and disruptive impacts of Novaluron, a chitin synthesis inhibitor, on development and metamorphosis of the olive leaf moth *Palpita unionalis* (Hübner) (Lepidoptera: Pyralidae). *International Journal of Trend in Research and Development,* 4(3): 184-193.
GraphPad InStat© v. 3.01 (1998): GraphPad Software, Inc.7825 Fay Avenue, Suite 230 La Jolla, CA 92037 USA. Available online at: http://www.graphpad.com/scientific-software/instat/
Gunathilaka, N.; Ranathunga, T.; Hettiarachchi, D.; Udayanga, L. and Abeyewickreme, W. (2020): Field-based evaluation of novaluron EC10 insect growth regulator, a chitin synthesis inhibitor against dengue vector breeding in leaf axils of pineapple plantations in Gampaha District, Sri Lanka. Parasites Vectors, 13:228, 9pp. https://doi.org/10.1186/s13071-020-04109-y
Gupta, A.P. (1985): Cellular Elements in the Hemolymph. In: "Comprehensive Insect Physiology Biochemistry Pharmacology" (Kerkut, G.A. and Gilbert, L.I., eds.). Pergamon Press, New York, pp: 400-451.
Hamadah, Kh.Sh. (2018): Impaired survival and development of the false stable fly,

Muscina stabulans (fallen) (Diptera: Muscidae) by pyriproxyfen (a juvenile hormone analogue). *Journal of the Egyptian Society of Parasitology,* 48(3): 677-688.

Hamadah, Kh. and Ghoneim, K. (2017): Ovicidal activities and developmental effects of the chitin synthesis inhibitors, Noviflumuron and Novaluron, on the pink bollworm *Pectinophora gossypiella* (Saunders) (Lepidoptera: Gelechiidae). *Scholars Academic Journal of Biosciences,* 5(6):412-424. DOI: 10.21276/sajb

Hamadah, Kh. and Abo Elsoud, A.A. (2018): Deteriorating effects of methoxyfenozide on survival, development and metamorphosis of the olive leaf moth, *Palpita unionalis* (Hübner) (Lepidoptera: Pyralidae). *Egyptian Academic Journal of Biological Sciences (A. Entomology),* 11(5): 59– 78.

Hamaidia, K. and Soltani, N. (2014): Laboratory evaluation of a biorational insecticide, Kinoprene, against *Culex pipiens* larvae: effects on growth and development. Annual Research *Review of Biology,* 4(14): 2263-2273. DOI:10.9734/ ARRB/2014/9729

Hamaidia, K. and Soltani, N. (2016): Ovicidal activity of an insect growth disruptor (methoxyfenozide) against *Culex pipiens* L. and delayed effect on development. *Journal of Entomology and Zoology Studies*, 4(4): 1202-1207.

Hannig, G.T.; Ziegler, M. and Marçon, P.G. (2009): Feeding cessation effects of chlorantraniliprole, a new anthranilic diamide insecticide, in comparison with several insecticides in distinct chemical classes and mode-of-action groups. *Pest management science,* 65: 969-974.

Haq, H.S.; Shaikh, M.A. and Khan, R.H. (2004): Protein proteinase inhibitor genes in combat against insects, pests and pathogens: natural and engineered phytoprotection. *Archives of Biochemistry and Biophysics,* 431: 145-159.

Harrison, R.L. and Lynn, D.E. (2008): New cell lines derived from the black cutworm, *Agrotisipsilon*, that support replication of the *A. ipsilon* multiple nucleopolyhedrovirus and several group I nucleopolyhedroviruses. *Journal of Invertebrate Pathology,* 99: 28–34.

Hatakoshi, M. (2012): Pyriproxyfen: a new juvenoid. In:"Modern Crop Compounds" (Kramer, W.; Schirmer, U.; Jeschke, P. and Witschel, M., eds.). 2nded., Wiley-VCH, Weinheim, pp.: 963–998.

He, F.; Sun, S.; Tan, H.; Sun, X.; Qin,C.; Ji, S.; Li, X.; Zhang, J. and Jiang, X. (2019): Chlorantraniliprole against the black cutworm *Agrotis ipsilon* (Lepidoptera: Noctuidae): From biochemical/physiological to demographic responses. *Scientific Reports,* 9: 10328, 17pp.https://doi.org/10.1038/s41598-019-46915-0

Holoubek, I.; Dusek, L.; Sánka, M.; Hofman, J.; Cupre, P.; Jarkovsy, J.; Zbíeal, J. and Klánová, J. (2009): Soil burdens of persistent organic pollutants–their levels, fate and risk: part I. Variation of concentration ranges according to different soil uses and locations. *Environmental Pollution,* 157 (12): 3207–3217.

Horowitz, A.R.; Ellsworth, P.C. and Ishaaya, I. (2009): Biorational pest control: an overview. In: "Biorational control of arthropod pests: application and resistance management" (Ishaaya, I. and Horowitz, A.R., eds). Heidelberg (Dordrecht, London, New York): Springer; p. 1–20

Hussain, A.; A.M. AlJabr, and H. Al-Ayedh, (2019): Development-disrupting chitin synthesis inhibitor, novaluron, reprogramming the chitin degradation mechanism of red palm weevils. *Molecules*, 2019, 24(23), 4304; https://doi.org/ 10. 3390/molecules24234304

Ishaaya, I.; Kontsedalov, S. and Horowitz, A.R. (2005): Biorational insecticides: mechanism and cross-resistance. *Archives of Insect Biochemistry and*

Physiology,58(4):192–199. doi:10.1002/()1520-6327

Jeschke, P.; Nauen, R.; Schindler, M. and Elbert, A. (2011): Overview of the status and global strategy for neonicotinoids. *Journal of Agriculture and Food Chemistry,* 59: 2897–2908.

Jeyasankar, A.; Elumalai, K.; Raja, N. and Ignacimuthu, S. (2013): Effect of plant chemicals on oviposition deterrent and ovicidal activities against female moth, *Spodoptera litura* (Fab.) (Lepidoptera: Noctuidae). *International Journal of Agricultural Science Research,* 2(6): 206-213.

Jimenez-Peydro, R.; Gimeno-Martos, C.; Lopez-Ferror, J. Serrano- Delgado, C. and Moreno-Mari, J. (1995): Effects of the insect growth regulator, cyromazine, on the fecundity, fertility and offspring development of Mediterranean fruit fly, *Ceratitis capitata* Wied (Diptera, Tephritidae). *Journal of Applied Entomology*, 119: 435-438.

Jindra, M. and Bittova, L. (2020): The juvenile hormone receptor as a target of juvenoid "insect growth regulators". *Archives of Insect Biochemistry and Physiology,* 2020;103: e21615, 7pp. DOI: 10.1002/arch.21615

Joarder, J.; Khan, M.A. and Das, G. (2020): Relative efficacy of some chitin synthesis inhibitors in reducing growth and development of okra jassid, *Amrasca biguttula biguttula* (Ishida). *Insectia: Journal of Entomology*, 1(1): 16pp.

Kamaruzzaman, A.; Reza, A.; Mondal, K. and Parween, S. (2006): Morphological abnormalities in *Tribolium castaneum* (Herbst) and *Tribolium confusum* Jacquelin du Val Duval due to cyromazine and pirimiphos-methyl treatments alone or in combination. *Invertebrate Survival Journal*, 3:97-102.

Kaur, K. and Chandi, A.K. (2015): Toxicity of Pyriproxyfen against tobacco caterpillar, *Spodoptera litura* (Fabricius). International Journal of Science and Research, 4(11): 481-483. DOI: 10.15373/22778179

Khaled, A.S. and Farag, S.M. (2015): Toxicological, biological and biochemical impacts of Indoxacarb and Methoxyfenozoid on the larvae of the Cotton leafworm, *Spodoptera littoralis* (Boisd.) (Lepidoptera: Noctuidae). *Egyptian Academic Journal of Biological Sciences (F. Toxicology & Pest control),* 7(1): 25-36.

Khan, G.Z.; Khan, I.; Khan, I.A.; Alamzeb; Salman, M. and Kalim Ullah, (2016): Evaluation of different formulations of IGRs against *Aedes albopictus* and *Culex quinquefasciatus* (Diptera: Culicidae). *Asian Pacific Journal of Tropical Biomedicine*, 6(6): 485-491.

Khan, R.R.; M. Arshad, A. Aslam, and M. Arshad, (2021): Additive interactions of some reduced-risk biocides and two entomopathogenic nematodes suggest implications for integrated control of *Spodoptera litura* (Lepidoptera: Noctuidae). *Scientific Reports,* 11:1268, 9pp. https://doi.org/10.1038/s41598-020-79725-w

Khatter, N.A. (2014): Effect of two insect growth regulators on the development of *Agrotis ipsilon* Hufn. (Lepidoptera: Noctuidae). *Journal of Harmonized Research in Applied Sciences*, 2(1): 20-28.

Khorshidi, M.; Abad, R.F.P.; Saber, M. and Zibaee, A. (2019): Effects of hexaflumuron, lufenuron and chlorfluazuron on certain biological and physiological parameters of *Helicoverpa armigera* (Hübner) (Lepidoptera: Noctuidae). *Biocatalysis and Agricultural Biotechnology,* 21, 101270: 8pp. https://doi.org/10.1016/j.bcab.2019.101270

Kononenko, V.S. (2003): Noctuidae. In: "Keys to the insects of the Russian Far East" (Ler P.A., ed.). V. 5(4). Trichoptera and Lepidoptera. Vladivostok: Dal.nauka. 688pp. (In Russian)

Korrat, E.E.E.; Abdelmonem, A.E.; Helalia, A.A.R. and Khalifa, H.M.S. (2012):

Toxicological study of some conventional and nonconventional insecticides and their mixtures against cotton leaf worm, *Spodoptera littoralis* (Boisd.) (Lepidoptera: Noctuidae). *Annals of Agricultural Sciences,* 57(2): 145-152.https://doi.org/ 10.1016/j.aoas.2012.08. 008

Kuwano, E.; Fujita, N.; Furuta, K. and Yamada, N. (2008): Synthesis and biological activity of novel anti-juvenile hormone agents. *Journal of Pesticide Science,* 33(1): 14–16. https://doi.org/10.1584/jpestics.R07-08

Linton, Y.M.; Nisbet, A.J. and Mordue (Luntz), A.J. (1997): The effect of azadirachtin on the testes of the desert locust *Schistocerca gregaria* (Forskal). *Journal of Insect Physiology,* 43: 1077-1084. https://doi.org/10.1016/ S0022-1910(97)00060-7

Liu, T.X. and Chen, T.Y. (2000): Effects of the chitin synthesis inhibitor buprofezin on survival and development of immatures of *Chrysoperla rufilabris* (Neuroptera: Chrysopidae). *Journal of Economic Entomology,* 93: 234–239.

Liu, T.-X.and Chen, T.-Y. (2001): Effects of the insect growth regulator fenoxycarb on immature *Chrysoperla rufilabris* (Neuroptera: Chyrsopidae). *Florida Entomologist,* 84(4): 628-633. DOI: 10.2307/ 3496394

Liu, T.X. and Stansly, P.A. (2004): Effects of two insect growth regulators on *Delphastus catalinae* (Coleoptera: Coccinellidae), predator of whiteflies (Homoptera: Aleyrodidae). *Biological Control,* 30: 298-305.

Liu, Y. Q.; Fu, X.W.; Feng, H. Q.; Liu, Z. F.; and Wu, K.M. (2015): Trans-regional migration of Agrotisipsilon (Lepidoptera: Noctuidae) in north-East Asia. *Annals of the Entomological Society of America,* 108: 519–527.

Lohmeyer, K.H.; Pound, J.M.; Yeater, K.M.; May, M.A. (2014): Efficacy of Novaluron as a feed-through for control of immature horn flies, house flies, and stable flies (Diptera: Muscidae) developing in cow manure. *Journal of Medical Entomology,* 51(4): 725-906. https://doi.org/10.1603/ME13196

Maharajan, K.; Muthulakshmi, S.; Nataraj, B.; Ramesh, M. and Kadirvelu, K. (2018): Toxicity assessment of pyriproxyfen in vertebrate model zebra fish embryos (*Danio rerio*): a multi biomarker study. *Aquatic Toxicology,* 196:132–145. DOI: 10.1016/j.aquatox. 2018.01.010.

Mahmoudvand, M.; Moharramipour, S. and Iranshahi, M. (2015): Effects of pyriproxyfen on life table indices of *Plutella xylostella* in multigenerations. Psyche, Article ID 453701,7 pp. http://dx.doi.org/ 10.1155/2015/453701

Mead, H.M.I. and Khedr, M.M. (2018): Role of Teflubenzuron as a chitin synthesis inhibitor against *Spodoptera littoralis* larvae. *Egyptian Academic Journal of Biological Sciences (F. Toxicology & Pest control),* 10(1): 49-58.

Meng, Q-W.; Xu, Q-Y.; Deng, P.; Fu, K-Y.; Guo, W-C. and Li, G-Q. (2018): Transcriptional response of Methoprene-tolerant (Met) gene to three insect growth disruptors in *Leptinotarsa decemlineata* (Say). *Journal of Asia-Pacific Entomology,* 21(2):466–473. DOI: 10.1016/j.aspen.2018.02.011.

Meslin, C.; Bozzolan, F.; Braman, V.; Chardonnet, S.; Pionneau, C.; François, M.-C.; Severac, D.; Gadenne, C.; Anton, S.; Maibèche, M.; Jacquin-Joly, E. and Siaussat, D. (2021): Sublethal exposure effects of the neonicotinoid clothianidin strongly modify the brain transcriptome and proteome in the male moth *Agrotis ipsilon*. Insects, 12, 152, 19 pp. https://doi.org/10.3390/insects12020152

Microsoft® office Excel (2007): Microsoft Corporation,One Microsoft Way Redmond, WA, 98052-7329 USA. Available online at: http://www.microsoft.com/en-us/download/ details .aspx?id=9396

Mishra, V.K. (2020): Insect pests of cumin and their management. In "Management of Insect Pests in Vegetable Crops: Concepts and Approaches"(Vishwakarma, R. and

Kumar, R. eds.), p. 73, 1st ed., 344pp.

Moadeli, T.; Hejazi, M.J. and Golmohammadi, G. (2014): Lethal effects of pyriproxyfen, spinosad, and indoxacarb and sublethal effects of pyriproxyfen on the 1st instar larvae of beet army-worm, *Spodoptera exigua* Hübner (Lepidoptera: Noctuidae) in the laboratory. *Journal of Agricultural Science and Technology,* 16:178–189.

Mohandass, S.M.; Arthur, F.H.; Zhu, K.Y. and Throne, J.E. (2006): Hydroprene: mode of action current status in stored-product pest management, insect resistance and future prospects. *Crop Protection,* 9: 902–909.

Mojaver, M. and Bandani, A.R. (2010): Effects of the insect growth regulator pyriproxyfen on immature stages of sunn pest, *Eurygaster integriceps* Puton (Heteroptera: Scutelleridae). *Munis Entomology and Zoology,* 5(1): 187-197.

Moroney, M.J. (1956): Facts from figures. (3rded.). Penguin Books Ltd., Harmondsworth, Middlesex, 228 pp.

Mulla, M.S.; Tawatsin, A.; Chompoosri, J.; Zaim, M. and Su,T. (2003):Laboratory and field evaluation of novaluron a new acylurea insect growth regulator against *Aedes aegypti* (Diptera: Culicidae). *Journal of Vector Ecology,* 4: 241-254.

Murthy, K.S.R.K. and Ram, G.M. (2002): Studies on the efficacy of a new chitin synthesis inhibitor Rimon (novaluron 10 EC) on American bollworm *Helicoverpa armigera* Hubn. attacking cotton. In: "Resources management in plant protection during twenty first century", Hyderabad, India, 14-15 November 2002 (Babu, B.S.; Varaprasad, K.S.; Anitha, K.; Prasada Rao, R.D.V.J.; Chakrabarty, S.K.; Chandurkar, P.S., eds.). Vol. II, pp.: 165-168.

Naranjo, S.E.; Hagler, J.R. and Ellsworth, P.C. (2003): Improved conservation of natural enemies with selective management systems for *Bemisia tabaci* in cotton. *Biocontrol Science and Technology,* 13: 571-587.

Nasiruddin, M. and Mordue (Luntz), A.J. (1994): The protection of barley seedlings from attack by *Schistocerca gregaria* using azadirachtin and related analogues. *Entomologia Expermentalis et Applicata,* 70: 247-252.https://doi.org/ 10.1111/j.1570-7458. 1994. tb00753.x

Nasr, H.M.; Badawy, M. and Rabea, E.I. (2010): Toxicity and biochemical study of two insect growth regulators, buprofezin and pyriproxyfen, on cotton leafworm *Spodoptera littoralis*. *Pesticide Biochemistry and Physiology,* 98(2): 198-205. https://doi.org/ 10.1016/j.pestbp.2010.06.007

Nwankwo, E. N.; Okonkwo, N. J.; Ozumba, N. A.; Okafor, E. G. (2011): Comparative studies on the larvicidal action of Novaluron (Mosquiron®100 EC) and *Moringa oliefera* (LAM) seed oil against *Aedes aegypti* (Diptera: Culicidae) larvae. *African Research Review,* 5(1): 424-437.http://dx.doi.org/10. 4314/ afrrev. v5i1.64539

Oberlander, H. and Silhacek, D. (2000): Insect growth regulators, In: "Alternatives to pesticides in stored-product IPM" (Subramanyam, B. and Hagstrum, D.W., eds.). Kluwer Academic Publishers, Boston, pp.: 147-163.

Oberlander, H.; Silhacek, D.L.; 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. *Journal of Stored Products Research,* 33: 1-6.

Ohba, S.; Ohashi, K.; Pujiyati, E.; Higa, Y., Kawada, H.; Mito, N. and Takagi, M. (2013): The effect of pyriproxyfen as a "population growth regulator" against *Aedes albopictus* under semi-field conditions. *PLoS ONE,* 8(7): e67045

Osman, E.E.; Rarwash, I. and El-Samadisi, M.M. (1984): Effect of the anti-moulting agent "Dimilin" on the blood picture and cuticle formation in *Spodopterea littoralis* (Boisd.) larvae. *Bulletin of Entomological Society of Egypt (Economic Series),* 14: 3-46.

Ramaseshadri, P.; Farkaš, R. and Palli, S.R. (2012): Recent progress in juvenile hormone analogs (JHAs) research. *Advances in Insect Physiology*, 43: 353–436.

Raslan, S.A.A. (2002): Preliminary report on initial and residual mortality of the natural product, spinosad for controlling cotton leaf worm egg masses. In: 2002 Cotton Season At Sharkia Governorate, Egypt. *2nd International Conference, Plant Protection Research Institute, Cairo, Egypt*, 21-24 December, 2002. Vol. 1: 635-637.

Resmitha, C. and Meethal, K. V. (2016): Toxicity of insect growth regulator, Pyriproxyfen, on larvae of *Spodoptera mauritia* Boisd. (Lepidoptera: Noctuidae). *International Journal of Agriculture Innovations and Research,* 5(1): 173-176.

Retnakaran, A.; Granett, J. and Andennis, T. (1985): Insect growth regulators. In: "Comprehensive Insect, Physiology, Biochemistry and Pharamacology"(Kerkut, G.A. and Gibert, L.I., eds.). *Pergamon, Oxford*, 12: 529-601.

Richard, A.G. (1957): Cumulative effects of optimum and suboptimum temperatures on insect development. In: "Influence of Temperature on Biological Systems" (Johnson, F.H., ed.). Ronald Press Comp., New York, pp: 145-162.

Rodingpuia, Ch. and Lalthanzara, H. (2021): An insight into black cutworm (*Agrotisipsilon*): A glimpse on globally important crop pest. *Science Vision,* 2021(2): 36–42. https://doi.org/10. 33493/scivis.21.02.02

Rust, M.K. and Hemsarth, W.L.H. (2016): Intrinsic Activity of IGRs against larval cat fleas. *Journal of Medical Entomology,* 54(2):tjw201. doi: 10.1093/jme/tjw201

Sabry, K.H. and Abdou, G.Y. (2016): Biochemical and toxic characterization of some insect growth regulators to the pink bollworm, *Pectinophora gossypiella* (Saunders). *American-Eurasian Journal of Sustainable Agriculture,* 10(1): 8-14.

Saenz-de-Cabezon, I.F.J.; Marco, V.; Salmo, F.G. and Perez- Moreno, I. (2005): Effects of methoxyfenozide on *Lobesia botrana* Den and Schiff (Lepidoptera: Tortricidae) egg, larval and adult stages. *Pest Management Science,* 11: 1133-1137.

Said, S.M.; Abd El-Raheem, A.M. and Kandel, M.A. (2017): Biochemical and biological effects of insect growth regulator, teflubenzuron on *Pectinophora gossypiella* (Saunders) Lepidoptera: Gelechiidae) and *Coccinella undecimpunctata* (l.) (Coleoptera: Coccinellidae). *Menoufia Journal of Plant Protection,* 2: 139 -152.

Salem, M.S.M. (2015): Latent effect of different compounds on *Pectinophora gossypiella* (Saunders). *Journal of Plant Protection and Pathology, Mansoura University, Egypt,* 6(2): 269-279.

Sanni, B.N. and Mutta, R.S. (2014): Impact of solvents leading to environmental pollution. *Journal of Chemical and Pharmaceutical Sciences,* 3: 49–52.

Sarwar, M. (2015): Biopesticides: an effective and environmental friendly insect-pests inhibitor line of action. *International Journal of Engineering and Advanced Research Technology,* 1(2): 10-15.

Saryazdi, G.A.; Hejazi, M.J. and Saber, M. (2012): Residual Toxicity of Abamectin, Chlorpyrifos, Cyromazine, Indoxacarb and Spinosad on *Liriomyza trifolii* (Burgess) (Diptera: Agromyzidae) in Greenhouse Conditions. *Pesticides and Phytomedicine (Belgrade),* 27(2): 107–116.

Sazo L.; Araya J.E. and Esparza S. (2008): Control of San Jose scale nymphs, *Diaspidiotus perniciosus* (Comstock), on almond and apple orchards with pyriproxyfen, phenoxycarb, chlorpyrifos, and mineral oil. *Chilean Journal of Agricultural Research,* 68: 284–289.

Shahzad, M.; Qu, Y.; Zafar, A.; Ur Rehman, S. and Islam, T. (2020): Exploring the influence of knowledge management process on corporate sustainable performance through green innovation. *Journal of Knowledge Management,* 24(9): 2079-2106. DOI: 10.1108/JKM-11-2019-0624

Shakur, M.; Ullah, F.; Naem, M.; Amin, M.; Saljoqi, A. and Zamin, M. (2007): Effect of various insecticides for the control of potato cutworm (*Agrotis ipsilon* Huf., Noctuidae: Lepidoptera) at Kalam Swat. *Sarhad Journal of Agriculture,* 23: 423–426.

Sharma, S.C. and Pathania, A. (2014): Susceptibility of tobacco caterpillar, *Spodoptera litura* (Fabricius) to some insecticides and biopesticides. *Indian Journal of Scientific Research and Technology,* 2: 24-30.

Shaurub, E.H.; Zohdy, N.Z.; Abdel-Aal, A.E. and Emara, S.A. (2018) Effect of chlorfluazuron and flufenoxuron on development and reproductive performance of the black cutworm, *Agrotis ipsilon* (Hufnagel) (Lepidoptera: Noctuidae), *Invertebrate Reproduction & Development,* 62:1, 27-34. DOI: 10.1080/07924259.2017.1384407

Shaurub, E.H.; Abdel Aal, A.E. and Emara, S.A. (2020): Suppressive effects of insect growth regulators on development, reproduction and nutritional indices of the Egyptian cotton leafworm, *Spodoptera littoralis* (Lepidoptera: Noctuidae), *Invertebrate Reproduction & Development*, 64(3): 178-187, DOI: 10.1080/ 07924259.2020. 1741454

Singh, S. and Kumar, K. (2011): Diofenolan: a novel insect growth regulator in common citrus butterfly, *Papilio demoleus*. *Phytoparasitica,* 39(3): 205-213.

Singh, S. and Kumar, K. (2015): Effects of juvenoid pyriproxyfen on reproduction and F1 progeny in myiasis causing flesh fly *Sarcophaga ruficornis* L. (Sarcophagidae: Diptera). *Parasitological Research,* 114: 2325–2331.

Singh, A. and Tiwari, S.K. (2016): Role of Fenoxycarb, a juvenile hormone analogue, on the developmental stages of rice-moth, *Corcyra cephalonica* Staint. (Lepidoptera: Pyralidae). *International Journal of Zoological Investigation,* 2(2): 267-280.

Singh, Z.; Singh, A.; Kaur, M. and Kaur, T. (2017): Assessment of barium carbonate Toxicity on the Developmental Stages of *Sarcophaga ruficornis* (Diptera: Sarcophagidae). *International Journal of Current Microbiology and Applied Sciences,* 6(5): 485-494.

Sivaraman, G.G.; Paulraj, M.; Ignacimuthu, S. and Al-Dhabi, N.A. (2014): Bioefficacy of *Cleome viscosa* L. and *Sinapis alba* L. seed extracts against *Helicoverpa armigera* (Hubner) (Lepidoptera: Noctuidae). *International Journal of Pure and Applied Zoology,* 2(3): 211-217.

Smagghe, G. and Degheele, D. (1994): The significance of pharmacokinetics and metabolism to the biological activity of RH-5992 (tebufenozide) in *Spodoptera exempta*, *Spodoptera exigua* and *Leptinotarsa decemlineata*. *Pesticide Biochemistry and Physiology,* 49: 224-234.

Sucipto, C.D.; Wahyudin, D.; Santoso, H.J.; Latho, I. and Gunawan, A.T. (2018): The effectiveness of insect growth regulator (IGR) on the growth and the development of *Aedes aegypti* and *Aedes albopictus* in Tangerang City, Indonesia. *Journal of Medical Science and Clinical Research,* 6(4): 890-902.

Taleh, M.; Pourabad, R.F.; Geranmaye, J.and Ebadollahi, A. (2015): Toxicity of Hexaflumuron as an insect growth regulator (IGR) against *Helicoverpa armigera* Hubner (Lepidoptera: Noctuidae). *Journal of Entomology and Zoology Studies,* 3(2): 274-277.

Tanani, A.M. (2001): Study the effects of certain IGRs and plant extracts on some physiological aspect of the red palm weevil *Rhyncophorus ferrugenius* (Curculionidae: Coleoptera). M.Sc. Thesis, Faculty of Science, Al-Azhar University, Egypt.

Tanani, M.A. and Bakr, N.A. (2018): Effectiveness of the chitin synthesis inhibitor, diofenolan, on survival and development of the pink bollworm, *Pectinophora gossypiella*(Saunders) (Lepidoptera: Gelechiidae). *Journal of Entomology and Zoology Studies,* 6(4): 1209-1219.

Tanani, M.; Hamadah, Kh.; Ghoneim, K.; Basiouny, A. and Waheeb, H. (2015): Toxicity and bioefficacy of Cyromazine on growth and development of the Cotton leafworm *Spodoptera littoralis* (Lepidoptera: Noctuidae). *International Journal of Research Studies in Zoology,* 1(3):1-15.

Tazir, A.; Kirane-Amrani, L. and Soltani, N. (2016): Impact of two bisacylhydrazines on development of *Ephestia kuehniella* Zeller, 1879 (Lepidoptera: Pyralidae) with respect to cuticular thickness and protein. *Journal of Entomology and Zoology Studies,* 4(6): 626-631.

Tiryaki, D. and Temur, C. (2010): The fate of pesticide in the environment. *Journal of Biological and Environmental Sciences,* 4(10): 29-32.

Tripathi, P. and Tiwari, S.K. (2006): Potential of an insect growth regulator in the management of the rice moth *Corcyra cephalonica* Stainton, 1866 (Lepidoptera: Pyralidae). *Polish Journal of Entomology,* 83: 79–97.

Tunaz, H. and Uygun, N. (2004): Insect growth regulators for insect pest control. *Turkish Journal of Agriculture and Forestry,* 28: 337-387.

Vadja D.J. and Kalasariya R.L. (2015): Bio-efficacy of newer pesticides against aphid *Aphis craccivora* Koch. on cluster bean. *Agricultural Research,* 4(2): 125-130.

Vattikonda, S.R. and Sangam, S.R. (2017): Effect of forskolin on the growth and differentiation of the ovary of *Papilio demoleus* L. (Lepidoptera: Papilionidae). *International Research Journal of Environmental Science,* 6: 13-17.

Veres, A.; Wyckhuys, K.A.G.; Kiss, J.; Tóth, F.; Burgio, G.; Pons, X.; Avilla, C.; Vidal, S.; Razinger, J. and Bazok, R. (2020): An update of the Worldwide Integrated Assessment (WIA) on systemic pesticides. Part 4: Alternatives in major cropping systems. *Environmental Science and Pollution Research,* 27: 29867–29899.

Vivan, L.M.; Torres, J.B. and Fernandes, P.L.S. (2017): Activity of selected formulated biorational and synthetic insecticides against larvae of *Helicoverpa armigera* (Lepidoptera: Noctuidae). *Journal of Economic Entomology,* 1;110(1):118-126. doi: 10.1093/jee/tow244.

Vojoudi, S.; Saber, M.; Gharekhani, G. and Esfandiari, E. (2017); Toxicity and sublethal effects of hexaflumuron and indoxacarb on the biological and biochemical parameters of *Helicoverpa armigera* (Hübner) (Lepidoptera: Noctuidae). *Iranian Crop Protection,* 91: 100–107.

Waldbauer, G.P. (1968): The consumption and utilization of food by insects. Advances in Insect Physiology, 5: 229-288. https://doi.org/ 10.1016/S0065-2806(08)60230-1

Wang, Q.L. and Liu, T.-X. (2016): Effects of three insect growth regulators on *Encarsia formosa* (Hymenoptera: Aphelinidae), an endoparasitoid of *Bemisia tabaci* (Hemiptera: Aleyrodidae). *Journal of Economic Entomology,* 109(6): 2290-2297. DOI: 10.1093/jee/tow216

Wang, Y. and Wang, M. (2007): The research of IGRs. *World Pesticides,* 29: 8-11.

Yokoyama, V.Y. and Millar, G.T. (1991): Potential of pyriproxyfen as a quarantine treatment for codling moth and oriental fruit moth (Lepidoptera: Tortricidae). *Journal of Economic Entomology,* 84: 942-947.

Zarate, N.; Diaz, O.; Martinez, A.M.; Figueroa, J.I.; Schneider, M.I.; Smagghe, G.; Vinuela, E.; Budia, F. and Pineda, S. (2011): Lethal and sublethal effects of Methoxyfenozide on the development, survival and reproduction of the fall armyworm, *Spodoptera frugiperda* (J.E. Smith) (Lepidoptera: Noctuidae).

Neotropical Entomology, 40(1): 129-137. DOI: 10.1590/S1519-566X 2011000100020

Zhou, Z.; Deng, G. and Luo, S. (2003): Study and application of IGRs. *Guangxi Agricultural Sciences*, 1: 34-36.

Zorzetti, J.; Constanski, K.; Santoro, P.H.; Fonseca, I.C.B. and Neves, P.M.O.J. (2015): Growth regulator insecticides for the control of the lesser mealworm beetle *Alphitobius diaperinus* (Coleoptera: Tenebrionidae). *Revista Colombiana de Entomología*, 41(1): 24-32.