

Article

The Role of the Analogue Hormone Insegar 25 WP (Fenoxycarb) in Controlling *Trogoderma Granarium* (Everts)(Coleoptera: Dermistidae)

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Abstract: This study aimed to evaluate the effect of the insect growth regulator Insegar 25 WP (Fenoxycarb) on some life traits and population dynamics of the Khapra grain beetle *Trogoderma granarium* (Everts) , one of the most serious pests of stored grains. Three concentrations of the insecticide (0.2, 0.4, and 0.6 g/L) were used, along with a control treatment. Life table parameters were evaluated, including larval stage duration (Ld), pupal stage duration (Pd), adult lifespan (Al), probability of survival to adulthood (lx), fecundity (mx), generation time (T), net reproduction rate (R_0), self-increase rate (r), finite rate of increase (λ), total reproduction rate (GRR), generational survival rate (GMR), and some derived population indicators. The results showed that all concentrations significantly prolonged the duration of both the larval and pupal stages, and progressively decreased survival and fertility until reproductive capacity ceased at a concentration of 0.6 g/L. The net reproduction rate (R_0) decreased from 16.17 in the control treatment to 0.25 and then to 0.10, reaching zero at the highest concentration. Meanwhile, the self-increase rate (r) shifted from a positive value (0.063) to negative values, indicating population collapse. Comparison between GRR and R_0 revealed that reduced survival to adulthood was the primary factor in population collapse, rather than a decrease in theoretical reproductive capacity. These results confirm that fenoxycarb is a promising and relatively safe growth regulator for the environment and public health, and can be incorporated into integrated storage pest management (IPM) programs, particularly when combined with non-chemical preventative measures.

Keywords: Fenoxycarb, IGR, Insegar 25 WP, IPM , Life table ,*Trogoderma granarium*

Introduction

The Field crops are one of the most important sources of human food and constitute the most important strategies of countries to maintain the stability of their people. Therefore, the stock of these crops must be preserved from damage and infestation by harmful pests, which lead to large economic losses that cannot be compensated. Hence, the Khapra grain beetle *T. granarium*, belonging to the family

of leather beetles Dermestidae, order Coleoptera, is considered one of the important insects that infect grains, especially in stores, and causes direct damage that affects their nutritional and agricultural value, as it feeds on grains of all kinds, seeds, animal foodstuffs, and dried fruits [1]. The Food and Agriculture Organization (FAO) estimated global losses from infestation by stored pests at about 30.1 million tons in various types of grains [2]. Chemical methods using pesticides, especially fumigants, are among the most common methods for controlling this pest in the world and Iraq, despite the negative effects caused by such control [3], [4]. It is also controlled by other means such as sterilization and killing with gamma rays [5]. Traditional chemical methods, particularly fumigants (phosphine and others), have long been the most common means of controlling this pest both locally and globally. However, continuing with this classic approach entails serious health and environmental risks, most notably: Acute health damage: The use of traditional pesticides leads to the accumulation of toxic chemical residues in grains and stored materials intended for direct human consumption. This accumulation poses a direct threat to human health and increases the likelihood of acute poisoning or chronic diseases in the long term. Environmental degradation: These chemicals pollute the environment surrounding storage facilities, in addition to their severe negative impact on non-target organisms. Furthermore, excessive use leads to the development of resistant insect strains, creating a vicious cycle of increased dosage and increased pollution. Therefore, this study is of paramount health and environmental importance, aiming to provide advanced alternatives that ensure the disruption of the pest's life cycle while fully preserving human health and the ecosystem. The current study focuses on evaluating the effectiveness of the hormone-like agent Insegar 25 WP (Fenoxycarb). This substance is distinguished by its complete safety from both an environmental and health perspective. Its safety lies in its highly specialized mechanism of action, mimicking the insect's juvenile hormone and targeting only its physiological development without possessing any direct toxicity that could harm the consumer or pollute the environment. Accordingly, this study was conducted to determine the effect of this safe hormone-mimicker on the life cycle parameters and population dynamics of the khapra beetle, and to test the sensitivity of its various life stages, thus establishing a sustainable health and environmental foundation for integrated pest management (IPM) programs in storage facilities.

Materials and Methodology

The hormone analogue, Insegar 25wp, was obtained from the Swiss company Syngenta, Iraq branch. The insect was reared in the Entomology Laboratory, College of Agriculture, University of Karbala, on a wheat-based medium. Pure cultures were obtained and placed in 1.5-liter glass bottles, their mouths covered with tightly packed muslin cloth, tightened with rubber bands. These were placed in an incubator at a temperature of $33 \pm 2^\circ\text{C}$, a humidity of 75%, and a photoperiod of (1) light: (2) dark. Three concentrations of the analogue were prepared, (0.6, 0.4, and 0.2) g/liter of water, for treatment as follows:

1- Egg treatment.

Effect of the hormone analogue on egg hatchability.

Fresh, one-day-old eggs were prepared from the reared colony. The eggs were collected using a small, soft brush and divided into four groups, each containing 30 eggs (each replicate containing 10 eggs) in a dish (8) cm in diameter and (1.2) cm in height. The egg groups were treated with concentrations of (0.2, 0.4, and 0.6) g/liter of water for the control, while the control treatment was sprayed with water only using a (1) liter hand sprayer, one spray per replicate. The treatments were then transferred to an incubator at a temperature of $33 \pm 2^\circ\text{C}$ and a relative humidity of 75%. The percentage of egg hatching was calculated after 24 hours, and each treatment was repeated three times.

2- Larval Treatment

A- The effect of the hormonal analogue Insegar 25wp on the mortality of the various larval stages.

Ten newly hatched first instar larvae, one day old, were taken from each replicate and concentration and placed in plastic dishes of 8 cm diameter and 1.2 cm height, each containing 3 g of broken wheat. The dishes were sprayed with the different concentrations using a hand sprayer with a capacity of (1 liter). The control treatment was sprayed with water only and the dishes were placed in

the incubator conditions indicated in three replicates. The mortality rates of the first instar larvae were recorded daily and the total mortality rates were calculated after one week. The same process was repeated for the fourth and final larval instars, each separately. The instar was determined by the number of molts.

B- The effect of the hormonal analogue on the duration of the larval stage.

Ten newly hatched first-instar larvae, one day old, were taken from each replicate and sprayed with the hormonal analogue concentrations, while the control treatment was sprayed with water only after being placed in the dishes indicated above. The treatments were then placed in the incubator under the same conditions, and the duration of the larval stage was recorded upon larval pupation. The experiment was repeated three times.

C- The effect of the hormonal analogue on the pupal stage.

One day after pupation, 50 pupae were randomly taken from the first-instar larvae treated with the analogue and placed in the incubator under the same conditions. The duration of the pupal stage, the weights of the pupae using a sensitive balance, and the percentage of emerging adults were recorded. The experiment was repeated three times.

D- The effect of the hormonal analogue on the adult stage.

The resulting adults were taken from the pupae that were treated in the first larval stage with different concentrations of the hormone analogue and were kept in a plastic dish at a rate of (3 males + 3 females). They were left to feed naturally and then placed in the incubator under the same conditions and (the lifespan of the adult, the number of eggs per female, and the percentage of egg hatching) were recorded. The experiment was carried out with three replications.

3 - Adult Treatment.

To determine the effect of the hormonal analogue on the adult stage of the insect, particularly the females, female and male insects were confined immediately after emerging from the pupal stage, at a rate of (5 males + 5 females) per dish. The dishes containing the adults were treated with the aforementioned hormonal analogue concentrations. The control dishes were sprayed with water only, and the dishes were placed in an incubator under the same conditions. The duration of the adult stage, the average number of eggs laid per female, and the hatching percentages of these eggs were recorded. The experiment was repeated three times.

After obtaining the results from the above experiments, a life table was designed that included the following criteria:

- Larval duration: L_d (number of days spent in the larval stage)
- Pupal duration: P_d (days from the start of pupation until adult emergence)
- Adult longevity (A_l) Average lifespan of an adult insect (number of days lived after emergence)
- l_x (survival to adulthood) Probability of an individual surviving from the start of the first instar until becoming a reproductive adult ,Calculated by (multiplying the pupal rate $\times$ the adult emergence rate) [6].
- m_x (females/female): The average number of females produced by a single female at reproductive stage , Calculated from: (Number of eggs/female $\times$ hatchability $\times$ 0.5 assuming a 1:1 sex ratio) [7].
- Generation time (T): The average time between the birth of the individuals and their production of the next generation
($L_d + P_d + 0.5 \times$ adult age)
- (Net reproductive rate): Net reproductive rate = sum of ($l_x \times m_x$) Across ages, R_0 represents the average number of females produced by a single female during her lifetime [8].
- r (Intrinsic rate of increase):
The inherent rate of natural increase (in days⁻¹) is calculated from : $r = \ln(R_0) / T$, $r > 0 \Rightarrow$ Population growth if $r < 0 \Rightarrow$ Population decline
- Finite rate of increase $\lambda = e^r$, If $\lambda > 1 \Rightarrow$ The population is growing, if $\lambda < 1 \Rightarrow$ The population is declining .
- Net Reproductive Rate per Unit Time was calculated from : (R_0/T) [7].

- Finite Generation Increase (ΔN) was also calculated using ($\Delta N = R_0 - 1$). It is used to determine whether the next generation is able to compensate for the losses of the previous generation [7].
- Doubling Time (DT) was calculated using ($DT = \ln 2 / r$) [9].
- The Gross Reproductive Rate (GRR) was also studied, which is the sum of m_x excluding survival (l_x) [6].
- The Generation Survival Rate (GNR) was calculated using ($GNR = \Sigma l_x / n$) .

Statistical Analysis

Data were analyzed using a completely randomized design (CRD), with each experimental unit considered an independent statistical unit, and at least three replicates per treatment. One-way ANOVA was performed to compare treatment means after verifying homogeneity of variance (Levene's test) and normality of distribution (Shapiro–Wilk test). Tukey's HSD test was used for post-hoc comparisons at a significance level of 0.05 ($P \geq 0.05$). When the assumptions of the ANOVA were not met, the Kruskal–Wallis test followed by the Dunn test was used. Percentage data were analyzed using a generalized linear model (GLM) with a binomial distribution. The life table parameters (R_0 , r , λ , GRR, T, GNR) were calculated using the Age–Stage, Two-Sex Life Table methodology [10], [11], with standard error and 95% confidence intervals estimated using the Bootstrap method (10,000 iterations) according to [12], [13]. Analyses were performed using SPSS v25 and R v4.2.2, while the life table analysis was performed using TWOSEX-MSChart [14].

Results and Discussion

Table 1. Life table parameters for the insect *Trogoderma granarium* treated with the insect hormone analogist Insegar 25 wp.

Con c. (g/L)	Ld(day s)	Pd (day s)	Al (day s)	l_x	m_x (e gg / femal e)	T (day s)	R_0	r)da y^{-1}	λ	R_0/T (female /female/ day)	ΔN	DT(day)	GRR	GNR ($\Sigma l_x /$ n)
0.0	28	7.0	18	0.8 5	18.9	44.0	16.1 7	0.063	1.0 6	0.37	+15.17	11.0	≈18.9	≈0.85
0.2	40	9.0	7	0.2 5	1.0	52.5	0.25	-0.02	0.9 7	0.0047	- 0.75	—	≈ 1.0	≈ 0.2
0.4	45	11.5	5	0.1 7	0.6	59.0	0.1	-0.03	0.9 6	0.0017	- 0.90	—	≈ 0.6	≈ 0.17
0.6	46	10.0	0	0.0	0.0	56.0	0.0	- ∞	0.0	0.00	- 1.00	—	≈ 0.0	≈ 0.0

From the above table it is clear that

the treating different stages of the insect with the pesticide Insegar 25 WP containing Fenoxycarb, which is similar to the juvenile hormone (JH), caused a significant prolongation in the duration of the larval and pupal stages (Ld, Pd) compared to the control, as the average duration of the larva increased from 28 days in the control to 40–46 days at the treated concentrations, and the duration of the pupa increased from 7 days in the control to 9–11.5 days at 0.2–0.4 g/l , This is consistent with Wigglesworth's suggestion that juvenile hormone analogues keep larvae in an 'immature' state and result in delayed moulting or the appearance of abnormal instars [15]. As shown by Slama and Darvas et al. that these substances disrupt metamorphosis and delay sexual maturity in the insect [16], [17]. As for the survival rate to maturity (l_x), it decreased sharply from 0.85 in the control to 0.25 at 0.2 g/L, and reached zero at 0.6, meaning that most individuals were not able to reach adulthood. This pattern of decreased survival has been documented in similar studies on Fenoxycarb in warehouse insects where it caused very low survival rates [18]. As for fertility (m_x), it decreased from 18.9 eggs in the control to 1.0 and 0.6 in 0.2 and 0.4, respectively, and reached zero at 0.6, this indicates that the effect of the pesticide was not limited to prolonging the incomplete stages, but also extended to reducing reproductive capacity and disrupting egg production, this is consistent with the results of Biddinger et

al. who confirmed that Fenoxycarb reduces egg fertilization and hatching rate via a dose-dependent mechanism [19]. The lifespan of adults (Al) also decreased from 18 days in the control to 5–7 days at different concentrations, and reached zero at 0.6, indicating that the resulting adults are biologically weak and short-lived. Oberlander & Silhacek have shown that JHAs result in the production of weak adults that are unable to survive long or reproduce [20]. As for the level of population dynamics, this was reflected in the net reproduction rate (R_0), which decreased from 16.17 in the control to 0.25 and 0.1 and then zero at 0.6. Intrinsic rate of increase (r) also shifted from a positive value (0.063) in the control to negative (−0.02 and −0.03), which means that the population moved from a state of growth to a state of decrease, and reached complete collapse at the highest concentration. These indicators show that the pesticide was able to tip the population balance from positive growth to decline and extinction, which is consistent with the explanatory framework developed by Birch and later developed in the work of Carey [6], [21]. R_0/T for the control was 0.37 female/female/day, while it decreased to 0.0047, then 0.0017 at 0.2 and 0.4, and zero at 0.6. This reflects an extreme slowdown in the rate of replacement, consistent with the analysis of Birch [21]. ΔN was very positive in the control (+15.17) and indicative of growth, but it became negative (−0.75 and −0.9) and then zero at 0.6, indicating a collapse in replacement capacity [7]. Doubling Time (DT): for the control it was 11 days, while it became undefined for the negative r , this indicator translates growth or decline into a practical time scale [13]. Gap between GRR and R_0 : As expected theoretically, $GRR \geq R_0$ because R_0 incorporates survival l_x while GRR ignores it [6], [21]. In control: $GRR=18.9$ versus $R_0=16.17$; The gap (≈ 2.73) is due to survival losses before/during reproduction, at 0.2 and 0.4, GRR is still higher (1.0, 0.6) than R_0 (0.25, 0.10), showing that population constraints are driven by losses in survival rather than theoretical reproductive potential alone [10]. Collapse of GNR ($\Sigma l_x/n$) with dose: decrease from ≈ 0.85 (control) to 0.25 and then 0.17 reaching zero at 0.6 reflects that the hormonal antagonist first affected survival across the pre-adulthood phases (prolonged Ld/Pd and disrupted metamorphosis), thereby pulling R_0 below 1 and turning r to negative values [15], [18]. This is consistent with the role of juvenile hormone analogues (JHAs) that maintain individuals in an immature state and impair their reaching reproductive age [16], [20]. Comparing GRR (theoretical reproductive capacity) with GNR ($\Sigma l_x/n$) (average survival over the life cycle) reveals that the most influential factor in the collapse of the Khapra population is not only poor fertility, but reduced survival to adulthood. Even if females have a latent reproductive capacity (GRR), most individuals do not survive to reproductive age, effectively reducing the net reproductive rate (R_0) and making the latent rate of increase (r) negative. This means that Insegar essentially breaks the life cycle by reducing survival chances, and is therefore more effective in warehouse environments where it can be combined with Integrated Pest Management (IPM) such as cleaning, humidity and temperature reduction, and physical treatments, such consolidation increases pressure on different insect instars, accelerates population collapse and reduces the likelihood of long-term resistance emerging [6], [7].

Conclusions

1- The use of Insegar 25 WP significantly prolonged the larval and pupal stages, reflecting its direct effect on disrupting the moulting and metamorphosis process.

2- Both survival (l_x) and fecundity (m_x) decreased with increasing concentration, as no reproduction was recorded at 0.6 g/L.

3-Population dynamics indicators (R_0 , r , λ) showed the transformation of the khapra from a state of positive growth in the control to a state of decrease and extinction at the treated concentrations, starting from 0.2 g/L.

4-Comparison between GRR and R_0 showed that loss of survival is the most influential factor in population collapse compared to inherent reproductive capacity.

5- This demonstrates that Fenoxycarb not only acts as a direct pesticide, but also directs its mechanism primarily to breaking the life cycle, which opens the way for its combination with physical and management control methods within the framework of Integrated Pest Management (IPM).

6- The study recommends the need to benefit from these results in developing sustainable strategies to combat warehouse pests, taking into account environmental aspects to reduce potential risks to non-target organisms.

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