

The repellent and attractant effect of nano-extractors of clove, star anise, and garlic on the *Khapra granarium* (Everts) *Trogoderma* (Order: Coleoptera) beetle in laboratory

Hussein T M Al-Sharees and Mohammed Sh. Mansor

Mesopotamia General Seed Company, Ministry of Agriculture, Baghdad, Iraq
Plant Protection, Faculty of Agriculture, University of Tikrit, Tikrit, Iraq
hm23168pag@st.tu.edu.iq; <https://orcid.org/0009-0003-3250-633X>
mshmansor@tu.edu.iq; <https://orcid.org/0000-0002-8013-8725>

Department of
E-mail:
E-mail:

Abstract

Attractant and repellent effects of nano-extracts of carnation flowers, star anise fruits, and garlic seeds were tested on the fourth larval stage and adults of the Khapra beetle at the Mesopotamia General Company for Seed Production / Ministry of Agriculture. The repellent and attractant effects of nano-extracts of clove, star anise, and garlic at different concentrations (1%, 0.50%, and 0.25 ml) on fourth-instar larvae and adults of Khapra beetle *Trogoderma granarium* were studied under laboratory conditions. The results showed that star anise at concentrations of 1% and 0.5 ml Add % with the number 0.5 was the best repellent for larvae and adults (83.33%, 76.66%, 86.66%, and 90.00%, respectively), while garlic at a concentration of 0.50 ml exhibited the lowest repellent effect among the nano-extracts used in the experiment. Conversely, garlic at a concentration of 0.50 ml was the best attractant for fourth-instar larvae and adults (66.66% and 50.00%, respectively), while star anise at concentrations of 1% and 0.50 ml was the weakest attractant for both larvae and adults. At rates of 10% and 16.66% respectively, The nano-sized clove extract showed a repellent effect on fourth-stage larvae and adults of *T. granarium* at a concentration of 0.50%, where it reached 76.66% and 83.33% respectively, and at a concentration of 1%, where it reached 63.33% and 76.66% respectively. The effect of a concentration of 0.25% was attractive to fourth-stage larvae, where it reached 56.66%. the use of star anise nano-extracts as a repellent and garlic as an attractant is effective in controlling Khapra beetle within integrated pest management programs for wheat seed stores.

Introduction:

Grain crops are among the most vital and strategic agricultural crops globally, with wheat (*Triticum aestivum*), belonging to the Poaceae family, topping the list. Given wheat's pivotal role in enhancing food security, global demand is steadily increasing. The area cultivated with wheat in Iraq for the 2024 agricultural season was estimated at approximately 8,177 million dunams, with an estimated production of 5,234 million tons [1]. Producing these large quantities of wheat requires healthy seeds free from storage infestations. These losses are not limited to quantity alone, but also extend to a decrease in grain quality due to the deterioration of its

chemical composition, such as proteins, carbohydrates, and fats, in addition to the emergence of molds. Some undesirable physical characteristics include discoloration and the emission of unpleasant odors [24] and [12]. Globally, the annual infestation rate of stored crops is estimated to be between 20–30% in developing countries, compared to much lower rates in developed countries, which is attributed to the effectiveness of modern storage techniques [20] and [11]. The hairy grain beetle, *T. granarium*, is one of the most serious stored-product pests worldwide, classified as a highly dangerous quarantine pest due to its ability to cause significant losses in stored grains and the diversity of its

host range [7]. This insect is characterized by its high ability to survive for long periods through diapause, in addition to its tolerance to extreme temperatures, both low and high, which enhances its ability to survive and spread in different environments and climatic conditions [14]. Plant extracts and volatile oils taken from plants such as garlic, cloves (*Syzygium aromaticum*), and star anise play a role in controlling it. Grain extracts hold a promising role as biological alternatives to chemical pesticides. They contain active compounds such as sulfur compounds in garlic, eugenol in cloves, and anethole and phenolic compounds in star anise, which exhibit attractant or repellent activity against grain-feeding insects. Recent studies have demonstrated the potential and commercial value of these extracts against stored grain pests, with increasing application possibilities [13] and [22]. However, significant technical challenges hinder the practical use of these extracts, including rapid volatilization and degradation due to light, oxidation, and heat; limited solubility; and rapid release, which reduces the duration of activity of the active compounds. To overcome these obstacles, recent research has developed nano-encapsulation/nanocapsule/nanoemulsion technologies. These technologies maintain the stability of the active compounds, allow for graded control of their release rate, and improve compatibility with application media (such as coating grains or spraying). In experiments, these technologies have led to increased insect efficacy and prolonged active ingredient activity. Laboratory and field studies [19] and [15] [The strategy of combining garlic, clove, and star anise extracts with nano-coating techniques represents an integrated approach to managing the Khapra beetle in stored grains. This study aims to reduce reliance on harmful chemical-based pesticides, increase the effectiveness of natural compounds, extend the protection window for stored grains, and introduce nano-plant extracts into integrated pest management programs.

Materials and Methods

Insect Rearing

Approximately 300 larvae and adults (males and females) infested with Khapra beetle (*T. granarium*) were collected from a wheat seed storage facility. They were reared in 10 x 10 x 15 cm plastic containers, open at the top. A quantity of wheat was placed with the larvae and adults, and the containers were sealed with cotton wool, secured with rubber bands, and placed in an incubator at $27^{\circ}\text{C} \pm 2^{\circ}\text{C}$ and $70\% \pm 2\%$ humidity.

[Note: The last sentence appears to be incomplete and possibly contains errors. It has been omitted from the translation.] Preparation of Plant Extract. The nano-extract was prepared at three concentrations (1%, 0.50%, and 0.25% for each plant extract) in the laboratories of the Ministry of Higher Education and Scientific Research/Scientific Research Authority. Two hundred grams of dry powder of clove flowers, star anise fruit, and garlic seeds were taken and naturally dried at room temperature without exposure to sunlight to prevent oxidation. The powder was placed in a 1-liter flask, and 600 ml of hexane was added to each sample. The mixture was mixed several times and left to stand for 72 hours. Afterward, it was filtered using a Buchner funnel and filter paper (NO1). The hexane was then removed using a rotary evaporator (Soxholet apparatus). The resulting solution was a thick, viscous liquid. The sample was placed in the refrigerator until use. Preparation of Chitosan Nanocapsules Loaded with Extract

The extract-loaded nanocapsules were prepared according to the methods of [21], [17], and [23] with some modifications. A 0.3% chitosan solution was prepared in 500 ml by dissolving 0.4 g of chitosan in (1.5 g per 500 ml of 1% dilute acetic acid). After dissolving the chitosan for 24 hours using a rotating magnetic device, the plant extracts (star anise 12 ml at 50% concentration, clove 15 ml at 50% concentration, garlic 20 ml at

50% concentration) were added separately to bring the volume up to 500 ml of chitosan solution. The solution was added drop wise via burette. After obtaining a homogeneous solution, drops of STPP solution (a binding agent that reacts with the positive group of chitosan to form a network) were added. Add 100 ml of deionized water at a concentration of 0.15% until the solution becomes slightly turbid. Then add 1-2 ml of TWEEN 80 (a dispersing, emulsifying, and anti-caking agent). Adjust the pH to 5.5 using 0.01 N NaOH solution and continue mixing for 5 hours to obtain a homogeneous suspension of the chitosan nanocapsules loaded with the extracts mentioned above.

Testing the Attractive and Repellent Effect of the Nano-Extracted Plant Extracts of Clove, Star Anise, and Garlic on the Fourth Larval Stage and Adults of Khapra beetle (*T. granarium*): The attractant and repellent effect of the above nano-extracts was tested using a chemotropometer with ten adults per replicate (three replicates) at the previously prepared concentrations. The box was closed to prevent light from reaching the adults and larvae. The fourth round and the adults were left to move around for 30 minutes, then the box was opened and the results were calculated by applying the following equations [2].

$$\text{Percentage of attraction} = \frac{\text{Number of insects towards the extract}}{\text{Total number of insects}} \times 100\%$$

$$\text{Percentage of repulsion} = \frac{\text{Number of insects opposite the extract}}{\text{Total number of insects}} \times 100\%$$

$$\text{Attraction strength} = \frac{\text{Sum of distances of insects towards the extract}}{\text{Number of insects}} \times 100\%$$

$$\text{Repulsion strength} = \frac{\text{Sum of distances of insects opposite the extract}}{\text{Number of insects}} \times 100\%$$

Statistical Analysis

The experiments were conducted according to a Randomized Design Complete Factorial (CRD) design, where the experiments were single-factor. The Least Significant Difference (LSD) and Duncan's test were used at a probability level of 0.05 to test the significance of the results [3].

Results and Discussion

Attractive and Repellent Effects of Nanoparticles of Carnation (*Syzygium aromaticum*), Star Anise (*Pimpinella anisum*), and Garlic (*Allium sativum*) Seeds on Fourth Larval Instars and Adults of Khapra beetle (*T. granarium*) Using a Chemotropism Apparatus

1- Repellent Effects of Nanoparticles of Carnation (*Syzygium aromaticum*), Star Anise (*Pimpinella anisum*), and Garlic (*Allium sativum*) Seeds on Fourth Larval Instars of Khapra beetle (*T. granarium*) Using a Chemotropism Apparatus . The results showed that the highest overall percentage of Khapra beetle larvae repelled by the nanoparticles was star anise (77.77%), significantly higher than the effect of carnation extract (50%) and no significant difference from the effect of garlic extract (61.10%). The highest repellent strength was also observed. The highest ejection strength (19.0 cm) was achieved with star anise, followed by garlic extract (11.99 cm) and clove extract (7.15 cm), respectively, with a significant difference (Table 1). The highest overall ejection strength (70.0%) was observed with the 1% concentration, followed by 0.50% and 0.25% concentrations (64.44% and 54.44%, respectively), with no significant difference. The 1% concentration, which recorded the highest ejection strength (14.79 cm), showed no significant difference compared to the 0.50% concentration (14.6 cm) and a significant difference compared to the 0.25% concentration (8.75 cm), as shown in Table 1. The highest ejection strength was recorded with star anise (19.0 cm), followed by garlic extract (11.99 cm) and clove extract (7.15 cm), respectively. The results of the

interaction between extracts and concentrations on the larval expulsion rate showed that the interaction of star anise extract at a concentration of 0.50% was superior, achieving the highest larval expulsion rate of 83.33%, significantly higher than the lowest expulsion rate achieved by the interaction of garlic extract at a concentration of 0.50%,

which reached 33.33%. Meanwhile, the highest interaction effect between extracts and concentrations on larval strength was recorded between star anise extract at a concentration of 1%, reaching 22.10 cm, significantly higher than the lowest larval strength of 4.56 cm, achieved by the interaction of clove extract at a concentration of 0.25% (Table 1).

Table 1: Effect of Plant Nanoparticle Extracts on the Rate and Strength of Expulsion of Fourth Instar Larvae of Khapra Beetle

The overall rate is affected by	Expulsion force of fourth-stage larvae of Khapra beetle/cm			The overall rate is affected by	Fourth-stage larvae expulsion rate (Khapra beetle%)			Extracts
concentration	Garlic	Star anise	Cloves	concentration	Garlic	Star anise	Cloves	concentration
8.75	7.24	14.47	4.56	54.44	46.66	73.33	43.33	%0.25
14.60	6.76	20.44	16.61	64.44	33.33	83.33	76.66	%.050
14.79	7.47	22.10	14.81	70.00	70.00	76.66	63.33	%1
	11.99	19.00	7.15		61.10	77.77	50.00	The overall rate is affected by the extract.
Extracts 6.3249				Extracts 16.78				LSD(0.05)
Concentration 6.3249				Concentration 16.78				
For extract × concentration 10.955				Extracts × Concentration 29.064				

The results showed that the nano-extract of star anise was superior to both garlic and clove extracts in inducing repellent behavior in fourth-instar larvae of Khapra beetle, with an overall repellent rate of 77.77% and a repellent strength of 19.0 cm. This repellent effect may be attributed to the active ingredient trans-anethole in star anise. This result is consistent with [8], which indicated that the main active ingredient with insect-repellent properties is

trans-anethole, an aromatic phenolic compound belonging to the phenylpropanoids group, with the molecular formula $C_{10}H_{12}O$. It is the main component of star anise (*Illicium verum*) oil. The strong irritation of olfactory and gustatory receptors resulting from the larvae's exposure to vapors or surfaces saturated with the compound may be due to this irritation of the olfactory receptors, which then generates a repellent effect.

Furthermore, a study [9] showed that the compound trans-anethole can alter the activity of acetylcholinesterase (AChE), a key enzyme in neurotransmission, and concluded that trans-anethole combined with limonene affects acetylcholinesterase activity and causes irritation and aversion in the armyworm *Spodoptera frugiperda*.

2- The effect of nano-extracts of clove flower (*Syzygium aromaticum*), star anise fruit (*Pimpinella anisum*), and garlic seed (*Allium sativum*) on adult Khapra beetle (*T. granarium*) using a chemoprevention device.

The results of the study showed that the highest overall percentage of adult Khapra beetle repelled by the nano-extracts was 84.44% for star anise, followed by clove extract at 78.88% (no statistically significant difference), and then garlic extract at 55.55% (no statistically significant difference). The average repelling strength was 7.88, 7.17, and 7.04 cm for clove, star anise, and garlic extracts, respectively, with no statistically significant difference (Table 2). The results of the study showed that the highest overall percentage of adult Khapra beetle repelled by the nano-extracts was 84.44% for star anise, followed by clove extract at 78.88% (no statistically significant difference), and then garlic extract at 55.55% (no statistically significant difference). The average repelling strength was 7.88, 7.17, and 7.04 cm for clove, star anise, and garlic extracts, respectively, with no statistically significant difference (Table 2). The results of the study showed that

the highest overall percentage of adult Khapra beetle repelled by the nano-extracts was 7.17% for star anise, and then 7.04 cm for garlic extract, respectively. The highest overall concentration-induced expulsion rates for adult insects were 76.66%, 73.33%, and 68.88% for concentrations of 1%, 0.50%, and 0.25%, respectively, with no statistically significant difference between the concentrations. Meanwhile, the overall average expulsion strength was 8.22, 7.8, and 6.08 cm for concentrations of 0.50%, 0.25%, and 1%, respectively, also with no statistically significant difference (Table 2). The highest overall concentration-induced expulsion rates for adult insects were 76.66%, 73.33%, and 68.88% for concentrations of 1%, 0.50%, 0.25%, and 1%, respectively, with no statistically significant difference between the concentrations.

Table 2 The results of the interaction between extracts and concentrations for the expulsion rate of adult beetles showed that star anise extract at a concentration of 1% had the highest expulsion rate of 90.0%, significantly exceeding the lowest expulsion rate of 50.0% resulting from the interaction of garlic extract at a concentration of 0.50%. Meanwhile, the results of the interaction between extracts and concentrations for expulsion strength showed the highest expulsion strength of 9.64 cm, resulting from the interaction of clove extract at a concentration of 0.25%, which was not statistically significant compared to the lowest expulsion strength of 5.23 cm resulting from the interaction of garlic extract at a concentration of 1%. (Table 2)

Table 2: Effect of plant nano-extracts on the rate and expulsion strength of adult Khapra beetles

The overall rate is affected by concentration	Adult repellent force of the khapra beetle			The overall rate is affected by concentration	Adult expulsion rate of Khapra beetle%)			Extracts
	Garlic	Star anise	Cloves		Garlic	Star anise	Cloves	concentration
7.80	8.11	5.66	9.64	68.88	53.33	76.66	76.66	%0.25
8.22	7.8	8.99	7.87	73.33	50.00	86.66	83.33	%.050
6.08	5.23	6.88	6.15	76.66	63.33	90.00	76.66	%1
	7.04	7.17	7.88		55.55	84.44	78.88	The overall rate is affected by the extract.
Extracts 4.516				Extracts 10.643				LSD(0.05)
Concentration 4.516				Concentration 10.643				
For extract × concentration 7.8219				Extracts × Concentration 18.434				

The results showed that the nano extract of star anise gave the highest expulsion rate for adults at 84.44%, followed by cloves at 78.88% with no significant difference between them, while the garlic extract had the least effect at an expulsion rate of 55.55%. Also, the values of expulsion strength differed between the extracts (highest value for cloves 7.88 cm, then anise 7.17 cm, then garlic 7.04 cm). The apparent repellent effect may be attributed to the chemical and physical properties of the extracts. The two main chemical compounds The nanocapsules had an inhibitory effect on acetylcholinesterase or on sensory receptors, and their effect played a role in the slow and continuous release of these volatile compounds, depending on the cohesive strength of the nanocapsule and the

experimental conditions. and in clove, eugenol, possess a repellent effect. This aligns with [4], who observed that eugenol was the most active inhibitor of acetylcholinesterase and that essential oils like eugenol bind to the acetylcholinesterase protein model. Furthermore, the physical properties of trans-anethole and eugenol allow them to volatilize and disrupt odor sensing or feeding behavior in insects, thus providing a superior effect in repellent tests. This finding is consistent with [5], who demonstrated a variation in the repellent effect depending on the concentration of trans-anethole applied to the wheat weevil, *Sitophilus granarius* (L.). This result also agrees with [16], whose electrophysiological experiments on the The American cockroach exhibits a similar effect to the components of

essential oils and octopamine, an organic compound that influences insect behaviors such as movement, flight, and jumping. This suggests that essential oils are capable of modulating the activity of nerve cells, including sensory cells, via octopamine receptors. Significant interactions between extract type and concentration were observed, such as the superior interaction of 1% anise (90% expulsion) compared to 0.5% garlic (50%). This indicates that expulsion effectiveness is not always linear with increasing concentration, and that there is an optimal concentration threshold for each extract that depends on the balance of volatility, stimulation, and behavioral effect. This aligns with [5], which demonstrated that some oils vary in their effect with different concentrations due to increased sensory variability. It was found that concentration-response curves should be examined for each nano-extract individually.

3- The effect of nano-extracts of carnation (*Syzygium aromaticum*) flowers, star anise (*Pimpinella anisum*) fruits, and garlic (*Allium sativum*) seeds on fourth-instar larvae of *Khaphra* beetle (*T. granarium*) using a chemotaxis device.

The results showed that the highest overall attraction rate of fourth-instar larvae of *Khaphra* beetle was 49.97% for the garlic nano-extracts, significantly exceeding the effect of star anise (22.22%) and not significantly exceeding the effect of carnation (38.88%). The average attraction strength of the extracts was 12.94, 10.36, and 10.0 cm for garlic, star anise, and carnation extracts, respectively, with no statistically significant difference (Table

3). The results of the study showed that the highest overall attraction rate of fourth-instar larvae of *Khaphra* beetle was 49.97% for the garlic nano-extracts, significantly exceeding the effect of star anise (22.22%) and not significantly exceeding the effect of carnation (38.88%). The average attraction strength of the extracts was 12.94, 10.36, and 10.0 cm for garlic, star anise, and carnation extracts, respectively, with no statistically significant difference (Table 3). [Note: The table appears to be incomplete and lacks context.] ... The overall average larval attraction percentage influenced by concentrations was 45.55%, 35.53%, and 30.00% for concentrations of 0.25%, 0.50%, and 1%, respectively, with no significant difference between them. Meanwhile, the effect of concentrations on the attraction strength was 14.19, 10.52, and 8.6 cm for concentrations of 0.25%, 0.50%, and 1%, respectively, also with no significant difference between them (Table 3). The results of the interaction between extracts and concentrations for attraction percentage showed that the interaction effect of garlic extract at a concentration of 0.50% resulted in the highest attraction percentage, recording 66.6%. This significantly exceeded the lowest interaction effect resulting from the interaction of star anise extract at a concentration of 0.50%, which recorded 16.66%. Meanwhile, the results of the interaction between extracts and concentrations for the highest attraction strength were obtained from the interaction of garlic extract at a concentration of 0.25%, recording 16.02 cm. This was not significantly different from the lowest attraction strength resulting from the interaction of star anise extract at a concentration of 1%, which recorded 6.25 cm. (Table 3)

Table 3: Effect of plant nano-extracts on the rate and strength of attraction of fourth-instar larvae of Khapra beetle

The overall rate is affected by concentration	Attractive force of fourth-stage larvae of the khapra beetle			The overall rate is affected by concentration	Attraction rate of fourth-stage larvae of the Khapra beetle %			Extracts concentration
	Garlic	Star anise	Cloves		Garlic	Star anise	Cloves	
14.19	16.02	13.83	12.73	45.55	53.33	26.66	56.66	%0.25
10.52	12.88	11.01	7.67	35.53	66.60	16.66	23.33	%0.50
8.60	9.94	6.25	9.62	30.00	30.00	23.33	36.66	%1
	12.94	10.36	10.00		49.97	22.22	38.88	The overall rate is affected by the extract.
Extracts 7.7801				Extracts 16.78				LSD(0.05)
Concentration 7.7801				Concentration 16.78				
For extract × concentration 13.476				Extracts × Concentration 29.064				

The overall rate of attraction due to the effect of the extracts is relatively low. This is attributed to the fact that these extracts have a more repellent than attractive effect on Khapra beetle larvae. However, the effect of the medium-attractive garlic extract is noted at concentrations of 0.25% and 0.50%, which recorded an attraction rate of 53.33% and 66.60%, coupled with an attraction strength of 16.02 and 12.88 respectively. This effect is attributed to the slow release and volatilization of the sulfur compounds that have a repellent effect in their nature from the nanocapsules, as these odors at the beginning of their simple release are interpreted by the olfactory receptors of adults as an indicator of the presence of food or an organic medium such as diallyl disulfide, which is an organic sulfur

compound and is one of the main components of garlic oil. This compound is a liquid with a strong garlic odor, but the release of a larger quantity of the active ingredient led to a decrease in this attractant effect at a concentration of 1%, which recorded an attraction percentage and attraction strength of 30.00% and 9.94 cm respectively. This result is consistent with [6], which showed that essential oils can exert both attractant and repellent activity depending on their chemical composition and concentration. [10] indicated that the toxic and repellent effect of essential oils against harmful insects may act as attractants for harmful insects. The nano-clove extract also contains the active ingredient eugenol, a natural phenolic compound that repels insects. Its effect varies with

concentration. A concentration of 0.25% was observed to have an attraction rate of 56.66%, coupled with an attraction strength of 12.73 cm. This effect is attributed to the slow release and evaporation of eugenol, which has a naturally repellent effect, from the nanocapsules. These initial, simple scents are interpreted by the olfactory receptors of adult insects as an indicator of the presence of food or organic matter. However, the effect of concentrations 0.50% and 1% decreased, with attraction rates of 23.33% and 36.66%, and attraction strengths of 7.67 cm and 9.62 cm, respectively, after the 0.25% concentration had achieved an attraction rate of 56.66% and an attraction strength of 12.73 cm. The attraction of fourth-instar larvae of Khapra beetle to clove and garlic extracts, with attraction rates of 56.66% and 53.33% respectively at the same concentration, is in principle consistent with [18], which showed that using an LC25 concentration of clove and garlic extracts gave an attraction effect on Khapra beetle larvae of 73.33% and 53.33% respectively. The attraction of fourth-instar larvae of the Khapra beetle to clove and garlic extracts, with attraction rates of 56.66% and 53.33% respectively at the same 0.25% concentration, is in principle consistent with [18], which showed that using an LC25 concentration of clove and garlic extracts gave an attractant effect on Khapra beetle larvae of 73.33% and 53.33% respectively. This effect is attributed to the slow release and volatilization of eugenol and sulfur compounds, which are inherently repellent, from the nanocapsules, depending on the cohesive strength of the nanocapsule and the experimental conditions. These aromas, in their initial, simple release, are interpreted by the olfactory receptors of the adults as an indicator of the presence of food or an organic medium.

4- Attractive Effect of Nanoparticles of Carnation (*Syzygium aromaticum*) Flowers, Star Anise (*Pimpinella anisum*) Fruits, and Garlic (*Allium sativum*) Seeds on Adult Khapra beetles (*T. granarium*) Using a Chemotropism Apparatus

The results showed that the highest overall attraction percentage of adult Khapra beetles was for the garlic nanoparticle extract (44.44%), significantly exceeding the effects of carnation and star anise (21.11%) and (15.55%), respectively. The highest attraction strength (7.19 cm) was achieved with the garlic extract, significantly exceeding the attraction strengths of the carnation and star anise extracts (2.91 cm and 2.42 cm, respectively). (Table 4) The results showed that the highest overall concentration effect on the percentage of attraction was due to the effect of a 0.25% concentration, which recorded 31.11%. This was not significantly higher than the effects of 0.50% and 1% concentrations, which recorded 26.66% and 23.33%, respectively. For the strength of attraction, the highest overall effect was 5.61 cm, resulting from the effect of a 0.50% concentration. This significantly exceeded the effects of 0.25% and 1% concentrations, which recorded 3.49 and 3.42 cm, respectively (Table 4). The results of the interaction between extracts and concentrations on the percentage of adult attractants showed that the interaction of garlic extract at a concentration of 0.50% resulted in the highest percentage of attraction (50.0%), significantly exceeding the interaction of star anise extract at a concentration of 1%, which recorded 10.0%. The results of the interaction between extracts and concentrations on the strength of attraction showed that the highest strength (9.44 cm) was observed with the interaction of garlic extract at a concentration of 0.50%, significantly exceeding the lowest strength (1.72 cm) with the interaction of clove extract at a concentration of 0.25%. (Table 4)

Table 4: Effect of Plant Nanoparticle Extracts on the Rate and Strength of Attraction of Adult Khapra Beetles

The overall rate is affected by concentration	Khapra beetle's attractiveness			The overall rate is affected by concentration	Khapra beetle adult attraction rate %			Extracts concentration
	Garlic	Star anise	Cloves		Garlic	Star anise	Cloves	
3.49	6.00	2.75	1.72	31.11	46.66	23.33	23.33	%0.25
5.61	9.44	3.66	3.75	26.66	50.00	13.33	16.66	%0.50
3.42	6.15	2.33	1.80	23.33	36.66	10.00	23.33	%1
	7.19	2.91	2.42		44.44	15.55	21.11	The overall rate is affected by the extract.
Extracts 1.8978 Concentration 1.8978 For extract × Concentration 3.2872				Extracts 10.643 Concentration 10.643 Extracts × Concentration 18.434				LSD(0.05)

The overall attraction rate of the extracts is relatively low. This is attributed to the fact that these extracts have a more repellent than attractive effect on adult Khapra beetles. However, the moderate attraction effect of garlic extract was observed at concentrations of 0.25% and 0.50%, registering an attraction rate of 46.66% and 50.00%, respectively, with attraction strengths of 6.00 cm and 9.44 cm. The effect of the 1% nano-garlic extract was less pronounced, registering an attraction rate of 36.66%, with a lower attraction strength of 6.15 cm. This varying effect of the garlic extract is attributed to the slow release and volatilization of the naturally repellent sulfur compounds from the nanocapsules. These simple odors, initially released, are interpreted by the olfactory receptors of the adult beetles

as an indicator of the presence of food or an organic medium. For example, Diallyl disulfide has an organic sulfurous odor similar to that produced by food sources such as pest-infested grains. Insect and fungal activity. This result is consistent with [6], which showed that essential oils can exert both attractant and repellent activity depending on their chemical composition and concentration.

Conclusions:

1- The nano-extracts of clove, star anise, and garlic differed in their effect on various aspects of the life cycle of *T. granarium* insect according to the concentration and insect stages.

2- The nano-extract of clove showed a repellent effect on fourth-instar larvae and adults of *T. granarium* at all concentrations determined in the experiments, except for the low concentration, which had an attractant effect on fourth-instar larvae.

3- The nano-extract of star anise showed a repellent effect on fourth-instar larvae and adults of *T. granarium* at all concentrations determined in the experiments.

4- The nano-extract of garlic differed in its effect according to the concentrations used and the studied stages of *T. granarium* insect. Its effect on fourth-instar larvae was attractant at low and medium concentrations and repellent at higher concentrations. The high concentration used in the experiments showed a repellent effect on adults at all concentrations used.

-5 The results, when comparing the repellent and attractant effects of the nano-extracts and concentrations used, showed that star anise at medium and high concentrations was the best repellent for larvae and adults, respectively, while garlic was the best attractant for fourth-instar larvae and adults at medium concentration.

Recommendations:

-1 Use star anise nano-extract in integrated pest management programs against the hairy grain beetle, *T. granarium*, due to its repellent effect.

-2 Use garlic nano-extract in integrated pest management programs against the hairy grain beetle, *T. granarium*, due to its attractant effect.

References

1. Statistics and Geographic Information Systems Authority (ASGIS) (2024). Wheat and Barley Production for 2024. https://cosit.gov.iq/documents/agriculture/agre_plan

2. Shaaban, Awad, and Al-Mallah, Nizar Mustafa. (1993). Pesticides. Ministry of Higher Education and Scientific Research. Dar Al-Kutub for Printing and Publishing; University of Mosul. 250 pages.
3. Al-Rawi, Khashaa Mahmoud, and Abdul Aziz Muhammad Khalaf Allah. (2000). Design and Analysis of Agricultural Experiments. Mosul: Dar Al-Kutub for Printing and Publishing, University of Mosul.
4. Alimi, D., Hajri, A., Jallouli, S., & Sebai, H. (2023). Toxicity, repellency, and anti-cholinesterase activities of bioactive molecules from clove buds *Syzygium aromaticum* L. as an ecological alternative in the search for control *Hyalomma scupense* (Acari: Ixodidae). *Heliyon*, 9(8).
5. Alkan, M., & Ertürk, S. (2020). Insecticidal efficacy and repellency of trans-anethole against four stored-product insect pests. *Journal of Agricultural Sciences*, 26(1), 64-70.
6. Bedini, S., Djebbi, T., Ascrizzi, R., Farina, P., Pieracci, Y., Echeverría, M. C., ...& Conti, B. (2024). Repellence and attractiveness: The hormetic effect of aromatic plant essential oils on insect behavior. *Industrial Crops and Products*, 210, 118122.
7. Bukhari, M., & Khan, H. A. A. (2025). Susceptibility and resistance profiles of field and laboratory strains of *Trogoderma granarium* Everts to pirimiphos-methyl, alpha-cypermethrin and spinetoram. *PeerJ*, 13, e19423.
8. Choi, I., Kim, S., Lee, J. S., Chang, Y., Na, J. H., & Han, J. (2022). Analysis of the insect-repelling mechanism of star anise extract and its major active compounds against *Plodia interpunctella*. *Food Science and Biotechnology*, 31(4), 451-462.
9. Cruz, G. S., Wanderley-Teixeira, V., Oliveira, J. V., D'assunção, C. G., Cunha, F. M., Teixeira, Á. A.,

- ...&Breda, M. O. (2017). Effect of trans-anethole, limonene and your combination in nutritional components and their reflection on reproductive parameters and testicular apoptosis in *Spodoptera frugiperda* (Lepidoptera: Noctuidae). *Chemico-Biological Interactions*, 263, 74-80.
10. Faly, L., Brygadyrenko, V., & Paulauskas, A. (2024). Repellent and Attractant Activities of Organic Compounds on Female and Male *Philonthus decorus* (Coleoptera, Staphylinidae). *Biology*, 13(5), 294.
 11. FAO. (2021) *Post-harvest management of grain losses: Insect pests and control strategies*. Food and Agriculture Organization of the United Nations. Rome, Italy. Retrieved from <https://www.fao.org/3/cb6712en/cb6712en.pdf>
 12. Geremew, M., Molla, A., Gabbiye, N., Harvey, J., Mahroof, R., & Abay, F. (2023). Effects of threshing and storage conditions on post-harvest insect infestation and physical characteristics of maize grain. *Journal of Stored Products Research*, 103, 102131.
 13. Giuliano, G., Campolo, O., Forte, G., Urbaneja, A., Pérez-Hedo, M., Latella, I., ... & Giunti, G. (2024). Insecticidal activity of *Allium sativum* essential oil-based nanoemulsion against *Spodoptera littoralis*. *Insects*, 15(7), 476.
 14. Harman, R. R., Morrison III, W. R., Altunç, Y. E., Athanassiou, C. G., & Gerken, A. R. (2025). Increasing global risk of khapra beetle invasion forecasted under projected environmental conditions. *Scientific Reports*, 15(1), 26064.
 15. Ibrahim, S. S., El-Kholly, M. Y., & Shalaby, S. E. S. M. (2025). Insecticidal effects of nano-encapsulated lemongrass essential oil on the population parameters of *Spodoptera frugiperda* using two-sex life table. *Scientific Reports*, 15(1), 11138.
 16. Jankowska, M., Rogalska, J., Wyszowska, J., & Stankiewicz, M. (2017). Molecular targets for components of essential oils in the insect nervous system—a review. *Molecules*, 23(1), 34
 17. Kain, D., & Kumar, S. (2020). Synthesis and characterization of chitosan nanoparticles of *Achillea millefolium* L. and their activities. *F1000Research*, 9, 1297
 18. Karso, B. A. (2022). Bio Effect of Seven Aqueous Plant Extracts Against Khapra Beetle *Trogoderma Granarium* Everts. *NTU Journal of Agriculture and Veterinary Science*, 2(1), 9-13..
 19. Luneja, R. L., & Mkindi, A. G. (2025). Advances in botanical-based nanoformulations for sustainable cotton insect pest management in developing countries. *Frontiers in Agronomy*, 7, 1558395.
 20. Mlambo, C. (2024). Financial development and economic growth: Evidence from low-income nations in the SADC region. *International Journal of Financial Studies*, 12(3), 62.
 21. Salama, R. M., Osman, H., & Ibrahim, H. M. (2022). Preparation of biocompatible chitosan nanoparticles loaded with Aloe vera extract for use as a novel drug delivery mechanism to improve the antibacterial characteristics of cellulose-based fabrics. *Egyptian Journal of Chemistry*, 65(3), 589-604.
 22. Sanga, A. G., Mazigo, H. D., Manjurano, A., Morona, D., Thomas, A., & Kweka, E. J. (2023). Measuring repellence and mortality effects of clove and cinnamon essential oils impregnated nets against *Anopheles gambiae* *senso stricto* using tunnel test. *Journal of Natural Pesticide Research*, 5, 100046.
 23. Sharma, A., Sood, K., Kaur, J., Khatri, M., Agrochemical loaded

biocompatible chitosan nanoparticles for insect pest management, Biocatalysis and Agricultural Biotechnology (2019), doi: <https://doi.org/10.1016/j.bcab.2019.101079>.

24. **Stathas, I. G., Sakellaridis, A. C., Papadelli, M., Kapolos, J., Papadimitriou, K., & Stathas, G. J. (2023).** The effects of insect infestation on stored agricultural products and the quality of food. *Foods*, 12(10), 2046.