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(Original Article)

Toxicity and Combined Impact of Certain Insecticides and Jojoba Oil Against German Cockroach, *Blattella germanica* L.

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Abstract

The German cockroach, *Blattella germanica*, is a prominent housing urban pest that poses significant public health concerns due to its capacity to transmit various pathogens. This study investigated the toxicity of several insecticides emamectin benzoate, spinetoram, indoxacarb, thiocyclam hydrogen oxalate, and metaflumizone alone and in combination with jojoba oil at concentrations of 250, 500, and 1000 ppm. Based on the LC_{50s} values of the tested insecticides for the adult of *B. germanica,* the most toxic insecticide was emamectin benzoate (0.414, 0.012 and 0.002 ppm), followed by spinetoram (2.96, 0.093 and 0.056 ppm), indoxacarb (4.88, 0.602 and 0.090 ppm), thiocyclam hydrogen oxalate (17.04, 0.769 and 0.182 ppm), metaflumizone (96.67, 21.22 and 2.042 ppm) and jojoba oil (350.64, 258.97 and 197.61 ppm) after 24, 48 and 72 hrs. post exposure, respectively. The incorporation of jojoba oil as a synergist significantly enhanced the toxicity, with pronounced effects observed at higher concentrations and extended exposure durations. Emamectin benzoate, spinetoram and indoxacarb showed marked improvements in efficacy when combined with jojoba oil. In contrast, thiocyclam hydrogen oxalate and metaflumizone remained the least effective compound, although slight enhancements were observed with jojoba supplementation. These findings suggest that jojoba oil may function as a valuable synergist, amplifying the insecticidal potency of conventional chemical agents. Its integration into pest management programs could improve control outcomes for *B. germanica* while potentially reducing the reliance on higher pesticide doses. Future research should focus on practical, application-oriented strategies to establish jojoba as a bioinsecticide and explore its combinations with other insecticides.

Keywords: *Blattella germanica, Insecticides, Jojoba oil, Toxicity.*

Introduction

The German cockroach, *Blattella germanica* L. (Dictyoptera: Blattellidae) is a pervasive urban pest known for its rapid reproduction, adaptability, and role in transmitting pathogens (Shiff, 1998; Kawther *et al*., 2013; Memona *et al*., 2017). Traditional chemical insecticides have been widely used to control its populations; however, the emergence of resistance and concerns over environmental and human health have necessitated the exploration of alternative control methods. Recent studies have focused on evaluating the efficacy of both novel synthetic insecticides and plant-derived compounds in laboratory settings to determine their potential in integrated pest

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management strategies (Wang *et al.,* 2013). Hence, various control strategies should be implemented to suppress German cockroach populations. The household agents for cockroach control (mostly aerosol sprays) usually contain chemical insecticides, e.g., pyrethroids (permethrin, tetramethrin, cypermethrin, prallethrin), carbamates (propoxur) and organophosphates (dichlorvos, chlorpyrifos). However, insecticide resistance, especially against pyrethroids, has already become common among German cockroach (Atkinson *et al*., 1991; Hemingway *et al*., 1993). In addition, the use of insecticides has been hindered by a growing concern about possible effects on the environment and non-target organisms. Control strategies should therefore be redirected to emphasize the knowledge of the biology and ecology of the target German cockroach in addition to insecticide use, if any, and should be more selective and less environmentally polluting (WHO, 1996).

Spinosad is a naturally derived insecticide obtained from the fermentation of *Saccharopolyspora spinosa*. It acts on the insect nervous system by targeting nicotinic acetylcholine receptors, leading to paralysis and death. Laboratory studies have demonstrated its effectiveness against various insect pests, including the German cockroach, with minimal impact on non-target organisms (Habbachi *et al.,* 2009). Emamectin benzoate, a derivative of avermectin, exhibits its insecticidal activity by enhancing the release of gamma-aminobutyric acid (GABA), leading to increased chloride ion influx and subsequent paralysis. While primarily used against lepidopteran pests, their potential against cockroaches is being explored due to its unique mode of action and reduced risk of resistance development (Lasota and Dybas, 1991). Indoxacarb is an oxadiazine insecticide that blocks voltage-dependent sodium channels in insect neurons, leading to cessation of feeding and death. Studies have shown its efficacy against German cockroaches, including strains resistant to other insecticides. Notably, indoxacarb exhibits horizontal transfer, where exposed individuals can transmit lethal doses to conspecifics through contact or ingestion of excretions (Buczkowski *et al.,* 2008).

Metaflumizone, belonging to the semicarbazone class, also targets sodium channels but with a different binding site than indoxacarb. Its mode of action results in feeding cessation and eventual death. Laboratory evaluations have indicated its potential as an effective control agent against German cockroaches, with a favourable safety profile for non-target species (Nauen and Bretschneider, 2002). Natural bioinsecticides containing essential oils, such as jojoba oil, have garnered significant interest due to numerous reports highlighting their effectiveness (Oladipupo *et al*., 2022). The unique properties of essential oils disrupt fundamental metabolic, biochemical, and physiological processes in insect pests (Campolo *et al*., 2018). Research has also shown that essential oils exert neurotoxic effects, ultimately causing paralysis and death in insects (Jankowska *et al*., 2017).

Thiocyclam hydrogen oxalate (Evisect) is a broad-spectrum synthetic insecticide used to control sucking and chewing pets on a variety of crops. It contains thiocyclam hydrogen oxalate, and its chemical name is N, N-dimethyl- 1,2,3-trithian-5-amine hydrogen oxalate. It was initially prepared by Sandoz Laboratories, Basle, Switzerland. It has been usually supplied as a soluble powder or as granules. As it is degraded rapidly, residues do not persist in the environment (Celikler *et al*., 2010). Thiocyclam hydrogen oxalate belongs to Nereistoxin analogue group which is used to control major sucking pests such as aphid and whitefly, is similar to neonicotinoids that act on the nicotinic acetylcholine (nACh) receptor as a partial agonist at low concentrations with little difference at high concentrates as channel blocker (Eldefrawi *et al*., 1980; Suganthan *et al*., 2020). It is an effective insecticide that can be used to control cockroaches. It acts by blocking the nicotinic acetylcholine receptors in the cockroach's nervous system, causing paralysis and death.

Among bioinsecticides, natural products containing essential oils such as jojoba oil have enjoyed the most attention, owing to widespread reports of activity (Oladipupo *et al*., 2022). The intrinsic properties of essential oils interfere with the basic metabolic, biochemical, and physiological functions of insect pests (Campolo *et al*., 2018). Several studies have demonstrated that essential oils induce neurotoxic effects, leading to the paralysis and subsequent death of insects (Jankowska *et al*., 2017). Jojoba oil, while primarily used as a carrier, may enhance the efficacy of other active compounds (Nerio *et al.,* 2010).

For the control of cockroaches, boric acid and chemical insecticides have been studied extensively (Appel and Benson, 1995; Appel and Stanley, 2000; Appel, 2003; Wang and Bennett, 2006). However, Cockroach resistance has been reported to some insecticides such as bendiocarb, cypermethrin, permethrin, propoxur, and chlorpyrifos (Valles, 1996; Wei *et al*., 2001; Pridgeon *et al*., 2022). Till now this study considered one of the few studies to test German cockroaches' toxicity against insecticides and jojoba oil mixture in Egypt. The integration of novel synthetic insecticides like spinosad, emamectin benzoate, indoxacarb, and metaflumizone, along with jojoba oil, presents a multifaceted approach to managing German cockroach infestations. Therefore, this study aimed to assess the toxicity of five insecticides from different new groups: avermectin (emamechtin benzoate), spinosyn (spinotram), oxadiazine (indoxacarb), nereistoxin (thiocyclam hydrogen oxalate), semicarbazone (metaflumizone) and jojoba oil alone and combined against the adults of the German cockroaches, *B. germanica* under laboratory conditions.

Materials and Methods

1. Insect rearing

This study was conducted at the Laboratory of the Department of Plant Protection, Faculty of Agriculture, Assiut University. The German cockroaches *(Blattella germanica)* used in this study were collected from dairy and food industry laboratories during January and February 2024 and subsequently reared under controlled laboratory conditions. The insects were housed in plastic boxes (60 × 30 × 30 cm) maintained at 28 ± 3°C, 50 ± 5% relative humidity (RH), with a photo period of 12:12 (light: dark). The cockroaches were provided with a diet of bread, powdered milk, and cotton soaked in water. Paper egg cartons were added as shelters, and the cages were sealed using fabric sleeves.

2. Insecticides and Jojoba oil

Five commercial insecticides from different chemical groups were tested emamectin benzoate (Excellent 1.9% EC) – avermectin group, indoxacarb (Sorento 15% SC) – oxadiazine group, metaflumizone (Krbalent 24% SC) – semicarbazone group, thiocyclam hydrogen oxalate (Kemclam 50% WP) – Nereistoxin group and spinetoram (Radiant 12% SC) – spinosyn group. Jojoba oil (Top Healthy 60% EC) was tested as a representative essential oil alone and combined with other insecticides. Three concentrations were prepared 250, 500 and 1000 ppm Jojoba oil. Cockroaches were dipped in each solution for 10 seconds and observed for mortality at the same intervals. Stock solutions were prepared by mixing each insecticide with water, and serial dilutions were made to achieve the following concentrations: 1000, 100, 10, 1, 0.1, and 0.01 ppm. For each concentration, three replicates were prepared.

3. Toxicity bioassay

Toxicity tests were conducted using a dip bioassay method adapted from Chandrasena *et al.* (2011). Fifteen adult cockroaches were placed in a metal mesh tea strainer and immersed in 20 ml of insecticide solution for 10 seconds. After treatment, insects were transferred to individual jars (5 insects per jar), supplied with food and water, and sealed with gauze. Mortality was assessed after 24, 48, and 72 hours after exposer. The toxicity experiment for each tested insecticide and jojoba oil were performed twice, and the results were adjusted using Abbott's formula (1925).

4. Statistical analysis

Data were subjected to the Probit analysis using the SPSS program version26 to obtain the LC_{50}, LC_{90}, 95% confidence limits (CL) and slopes values for thesepesticides and jojoba oil according to Finney (1971). A significant level of mean separation ($P< 0.05$) was based on non-overlap between the 95% confidence intervals of two LC_{50}values and expressed in ppm. As a result, LC_{50} values were utilized to calculate the toxicity index and relative potency (Sun, 1950), which served to compare the relative effectiveness of the insecticides tested. All figures and statistical analyses were performed using GraphPad Prism 5 software (San Diego, CA).

Results

1. Toxicity of certain insecticides and jojoba oil on the adults of German cockroach, *Blattella germanica*

The toxic effects of various insecticides and jojoba oil on adult *B. germanica* were assessed at 24, 48, and 72 hours post-treatment. The results indicated clear differences in potency among the tested substances. There are direct correlations between insecticide and period of exposure (24, 48 and 72 hrs), as the toxicity increases with an increasing period of exposure. As shown in Table (1), emamectin benzoate exhibited the highest toxicity, with an LC_{50} of 0.414 ppm and a toxicity index of 100, serving as the reference compound. In contrast, Jojoba oil was the least toxic (LC_{50} = 350.64 ppm), with a toxicity index of 0.12 and the highest relative potency value (846.96). The remaining compounds ranked in toxicity (from highest to lowest) as follows: spinetoram, indoxacarb, thiocyclam hydrogen oxalate and metaflumizone. The LC_{90}

values further supported these trends, with emamectin benzoate requiring the lowest concentration (21.19 ppm) to kill 90% of the tested cockroach population. Based on the relative potency, emamectin benzoate was more toxic for the adults of *B. germanica* than spinetoram, indoxacarb, thiocyclam hydrogen oxalate, metaflumizone and jojoba by (7.15, 11.78, 41.23, 233.50 and 846.96) fold, respectively. These results indicated that emamectin benzoate, spinetoram and indoxacarb were the most toxic insecticides against the adults of *B. germanica*, followed by thiocyclam hydrogen oxalate, metaflumizone and jojoba (Table 1).

Results as shown in Table (2) indicate that, after 48 hours, the toxicity increased across all treatments. Emamectin benzoate remained the most effective with LC_{50} values (0.012 ppm), followed by spinetoram (0.093 ppm). Notably, the LC_{50} values of both indoxacarb and thiocyclam hydrogen oxalate dropped significantly 0.602 and 0.769 ppm, respectively. Whereas jojoba oil remained the least toxic, showing only a marginal increase in efficacy with LC_{50} value 258.97 ppm. Comparison between the LC_{90s} of the tested compounds for the adults of *B. germanica* showed that the highest effective one is emamectin benzoate (3.85 ppm), followed by spinetoram (3.98 ppm), indoxacarb (358.26 ppm), thiocyclam hydrogen oxalate (418.73 ppm) metaflumizone (1066.38 ppm) and jojoba (2077.02 ppm) after 48 hrs exposure, respectively. Based on the relative potency, emamectin benzoate was more toxic for the adults of *B. germanica* than spinetoram, indoxacarb, thiocyclam hydrogen oxalate, metaflumizone and jojoba by (7.75, 50.17, 64.08, 1768.33 and 21580.83) fold, respectively.

Toxicity continued to rise at 72 hours of expouser (Table 3), with emamectin benzoate exhibiting the highest toxicity for the adults of *B. germanica* with LC_{50} (0.002 ppm), reinforcing its exceptional potency. Spinetoram, indoxacarb and thiocyclam hydrogen oxalate followed (0.056, 0.090 and 0.182 ppm, respectively. Metaflumizone and Jojoba oil remained the least effective, with LC_{50} values of 2.042 and 197.61 ppm, respectively. Comparison between the LC_{90s} of the tested compounds for the adults of *B. germanica* showed that the highest effective one is emamectin benzoate (0.376 ppm), followed by spinetoram (0.986 ppm), indoxacarb (48.53 ppm), thiocyclam hydrogen oxalate (74.19 ppm), metaflumizone (10.9.40 ppm) and jojoba (736.51 ppm) after 72 hrs exposure, respectively. Based on the relative potency, emamectin benzoate was more toxic for the adults of *B. germanica* than spinetoram, indoxacarb, thiocyclam hydrogen oxalate, metaflumizone and jojoba by (28.0, 45.0, 91.0, 1021.0 and 98805) fold, respectively. Across all time points, emamectin benzoate consistently demonstrated superior toxicity against B. germanica, while Jojoba oil was persistently the least toxic. Spinetoram and indoxacarb showed moderate efficacy, with improved effects over time. The LC_{50} and LC_{90} values for all compounds decreased with prolonged exposure, indicating time-dependent toxicity enhancement. Statistical comparisons based on non-overlapping 95% CLs confirmed significant differences among treatments.

Table 1. Toxicity of certain insecticides and jojoba oil on the adults of German cockroach, *B. germanica* after 24 hrs. exposure

Treatments	Slope± SE	LC_{50}(1) (ppm)	95% Confidence Limits (CL)		Toxicity Index (2)	Relative Potency (3)	LC_{90} (ppm)	95% Confidence Limits (CL)		χ^2(df)
			Lower	Upper				Lower	Upper	
E. Benzoate	0.75 ± 0.05	0.41a	0.339	0.456	100	1.00	21.19a	16.26	27.38	11.33 (4)
Spinetoram	0.41 ± 0.03	2.96b	1.18	4.01	13.98	7.15	225.14b	210.17	268.17	32.28 (4)
Indoxacarb	0.36 ± 0.03	4.88b	3.76	5.67	8.48	11.78	764.13c	681.25	901.14	12.80 (4)
T.h. oxalate	0.43 ± 0.04	17.04c	12.66	24.67	2.43	41.23	1785.38d	1726.82	1986.74	0.066 (4)
Metaflumizon	0.29 ± 0.03	96.67d	77.49	104.17	0.43	233.50	2903.10e	2235.11	3461.51	0.878 (4)
Jojoba oil	1.81 ± 0.31	350.64e	266.84	425.19	0.12	846.96	6506.44f	6141.23	7156.20	18.53 (4)

(1) LC_{50} and LC_{90} values having different letters are significantly different (95% CL did not overlap). (2) Toxicity index = [(LC_{50} of the most toxic tested compound/LC_{50} of the tested compound) × 100]. (2): (3) Relative Potency = LC_{50} for least toxic tested compound/ LC_{50} of the most toxic tested compound.

Table 2. Toxicity of certain insecticides and jojoba oil on the adults of German cockroach, *B. germanica* after 48 hrs. exposure

Treatments	Slope± SE	LC_{50} (PPM)	95% Confidence limits (CL)		Toxicity Index (1)	Relative Potency (2)	LC_{90} (PPM)	95% Confidence limits		χ^2(df)
			Lower	Upper				Lower	Upper	
E. Benzoate	0.51 ± 0.05	0.012a	0.004	0.019	100	1.00	3.85a	3.47	4.93	5.84 (4)
Spinetoram	0.83± 0.06	0.093b	0.007	0.114	12.90	7.75	3.98a	3.26	4.86	29.15 (4)
Indoxacarb	0.35 ± 0.03	0.602c	0.469	0.878	1.99	50.17	358.26b	323.14	373.25	3.87 (4)
T.h. oxalate	0.47 ± 0.04	0.769c	0.508	0.976	1.56	64.08	418.73c	388.15	476.31	15.51 (4)
Metaflumizon	0.34 ± 0.03	21.22d	17.22	27.33	0.06	1768.33	1066.38d	819.15	1201.38	0.475 (4)
Jojoba oil	2.08 ± 0.34	258.97e	186.86	317.36	0.004	21580.83	2077.02e	2027.17	3412.31	1.48 (4)

(1) LC_{50} and LC_{90} values having different letters are significantly different (95% CL did not overlap). (2) Toxicity index = [(LC_{50} of the most toxic tested compound/LC_{50} of the tested compound) × 100]. (2): (3) Relative Potency = LC_{50} for least toxic tested compound/ LC_{50} of the most toxic tested compound.

Table 3. Toxicity of certain insecticides and jojoba oil on the adults of German cockroach, *B. germanica* after 72 hrs. exposure

Treatments	Slope± SE	LC_{50} (PPM)	95% Confidence limits (CL)		Toxicity Index (1)	Relative Potency (2)	LC_{90} (PPM)	95% Confidence limits		χ^2(df)
			Lower	Upper				Lower	Upper	
E. Benzoate	0.56 ± 0.07	0.002a	0.0007	0.008	100	1.0	0.376a	0.351	0.411	6.05 (4)
Spinetoram	1.03 ± 0.09	0.056b	0.031	0.091	3.57	28.0	0.986b	0.966	1.01	40.22 (4)
Indoxacarb	0.44 ± 0.04	0.090b	0.061	0.123	2.22	45.0	48.53c	39.72	57.01	6.07 (4)
T.h. oxalate	0.46 ± 0.05	0.182c	0.126	0.298	1.10	91.0	74.19d	64.11	89.26	6.68 (4)
Metaflumizon	0.42 ± 0.04	2.042d	1.810	3.101	0.09	1021.0	109.40e	98.21	126.33	10.75 (4)
Jojoba oil	2.24 ± 0.38	197.61e	179.46	223.98	0.001	98805	736.51f	694.69	857.43	0.326 (4)

(1) LC_{50} and LC_{90} values having different letters are significantly different (95% CL did not overlap). (2) Toxicity index = [(LC_{50} of the most toxic tested compound/LC_{50} of the tested compound) × 100]. (2): (3) Relative Potency = LC_{50} for least toxic tested compound/ LC_{50} of the most toxic tested compound.

2. Toxicity combined of tested insecticides and jojoba oil against adults of German cockroach, *Blattella germanica*

Table (4) shows the toxicity of emamectin benzoate, spinetoram, indoxacarb, thiocyclam hydrogen oxalate, metaflumizone mixtures with different concentration of jojoba oil (250, 500 and 1000 ppm) after 24 hrs. exposure. Emamectin benzoate remained the most effective with LC_{50} values (0.273, 0.046 and 0.001 ppm), followed by spinetoram (1.810, 0.123 and 0.003 ppm), indoxacarb (2.047, 0.319 and 0.006 ppm), thiocyclam hydrogen oxalate (4.023, 0.414 and 0.170 ppm), and metaflumizone (11.81, 0.804 and 0.240 ppm) with different concentration of jojoba oil 250, 500 and 1000 ppm, respectively. Based on the relative potency, emamectin benzoate was more toxic for the adults of *B. germanica* than spinetoram, indoxacarb, thiocyclam hydrogen oxalate, and metaflumizone by (6.63, 7.50, 14.74 and 43.26) fold, (2.67, 6.93, 9.0 and 17.48) fold, and (3.0, 6.0, 170.0 and 240.0) fold, with 250, 500 and 1000 ppm of jojoba oil, respectively.

Based on Table (5) the combined toxicity of various insecticides with jojoba oil at concentrations of 250, 500, and 1000 ppm against the adults of *B. germanica* after 48 hours of exposure. Emamectin benzoate was consistently the most potent insecticide, exhibiting the lowest LC_{50} values (0.01, 0.009 and 0.002 ppm), followed by spinetoram (0.083, 0.011 and 0.003 ppm), indoxacarb (0.117, 0.015 and 0.0072 ppm), thiocyclam hydrogen oxalate (0.212, 0.0320 and 0.010ppm), and metaflumizone (1.223, 0.184 and 0.100 ppm) at concentrations of 250, 500, and 1000 ppm jojoba oil, respectively. Acoreding to the relative potency, emamectin benzoate was more toxic for the adults of *B. germanica* than spinetoram, indoxacarb, thiocyclam hydrogen oxalate, and metaflumizone by (8.3, 11.7, 21.2 and 122.3) fold, (1.22, 1.67, 3.56 and 20.44) fold, and (1.55, 3.6, 5.0 and 50.0) fold, with 250, 500 and 1000 ppm of jojoba oil, respectively.

Initially, the combined effect of different concentration of jojoba oil significantly potentiated the toxicity of tested insecticides against the adults of *B. germanica* after 72 hours of exposure (Table 6). All three concentration of jojoba oil (250, 500 and 1000 ppm) decreased significantly the LC_{50} values of emamectin benzoate, spinetoram, indoxacarb, thiocyclam hydrogen oxalate and metaflumizone. Comparison between the LC_{50s} of the tested insecticides for the adults of *B. germanica* showed that the most toxic insecticide was emamectin benzoate (0.001, 0.0006 and 0.0001 ppm), followed by spinetoram (0.045, 0.0080 and 0.0010 ppm), indoxacarb (0.110, 0.0120 and 0.0021 ppm), thiocyclam hydrogen oxalate (0.165, 0.0151 and 0.0095ppm), and metaflumizone (1.108, 0.136 and 0.090 ppm) at concentrations of 250, 500, and 1000 ppm jojoba oil, respectively. In addition, based on the relative potency, emamectin benzoate was more toxic for the adults of *B. germanica* than spinetoram, indoxacarb, thiocyclam hydrogen oxalate, and metaflumizone by (45.0, 110.0, 165.0 and 1108) fold, (13.33, 20.0, 25.17 and 226.67) fold, and (10.0, 21.0, 95.0 and 900.0) fold, with 250, 500 and 1000 ppm of jojoba oil, respectively.

Table 4. Toxicity combined of tested insecticides and jojoba oil (250, 500 and 1000ppm) against adults of German cockroach, *B. germanica* after 24 hrs. exposure

Jojoba oil con.	250 ppm				500 ppm				1000 ppm			
Insecticides	Slope ± SE	LC_{50} (ppm) (95%FL) *	T.I. (1)	R.P.(2)	Slope ± SE	LC_{50} (ppm) (95%FL) *	T. I. (1)	R.P. (2)	Slope ± SE	LC_{50} (ppm) (95%FL) *	T. I.(1)	R.P.(2)
E. Benzoate	0.34± 0.03	0.273a (0.256-0.283)	100	1.00	0.51± 0.05	0.046a (0.037-0.056)	100	1.00	0.49± 0.05	0.0010a (0.008-0.0015)	100	1
Spinetoram	0.46± 0.04	1.810b (1.789-1.840)	15.08	6.63	0.53± 0.04	0.123b (0.118-0.131)	37.39	2.67	0.76± 0.08	0.0030b (0.0027-0.0033)	33.33	3
Indoxacarb	0.47± 0.05	2.047c (2.023-2.068)	13.33	7.50	0.56± 0.05	0.319c (0.309-0.328)	14.42	6.93	0.37± 0.05	0.0060c (0.0055-0.0067)	16.67	6
T.h. oxalate	0.38± 0.04	4.023d (4.017-4.037)	6.79	14.74	0.50± 0.05	0.414d (0.401-0.418)	11.11	9.00	0.57± 0.06	0.170d (0.165-0.177)	0.59	170
Metaflumizon	0.43± 0.04	11.810e (11.742-11.876)	2.31	43.26	0.42± 0.03	0.804e (0.798-0.826)	5.72	17.48	0.46± 0.04	0.240e (0.233-0.247)	0.42	240

T.I. (1) Toxicity index = [(LC_{50} of the most toxic tested compound/LC_{50} of the tested compound) × 100]. R.P. (2): Relative Potency = LC_{50} for least toxic tested compound/ LC_{50} of the most toxic tested compound. * LC_{50} values having different letters are significantly different (95% CL did not overlap).

Table 5. Toxicity combined of tested insecticides and jojoba oil (250, 500 and 1000 ppm) against adults of German cockroach, *B. germanica* after 48 hrs. exposure.

Jojoba oil con.	250 ppm				500 ppm				1000 ppm			
Insecticides	Slope ± SE	LC_{50} (ppm) (95%FL) *	T.I.(1)	R.P.(2)	Slope ± SE	LC_{50} (ppm) (95%FL)*	T. I.(1)	R.P.(2)	Slope ± SE	LC_{50} (ppm) (95%FL) *	T. I.(1)	R.P.(2)
E. Benzoate	0.29 ± 0.04	0.010a (0.007-0.014)	100	1.0	0.56 ± 0.04	0.0090a (0.0086-0.0098)	100	1.00	0.56 ± 0.04	0.0020a (0.0015-0.0025)	100	1.00
Spinetoram	0.38 ± 0.03	0.083b (0.074-0.089)	12.05	8.3	0.62 ± 0.05	0.0110b (0.0091-0.0115)	81.82	1.22	0.94 ± 0.03	0.0031b (0.0026-0.0037)	64.52	1.55
Indoxacarb	0.64 ± 0.06	0.117c (0.103-0.133)	8.55	11.7	0.55 ± 0.06	0.0150c (0.0143-0.0157)	60.00	1.67	0.76 ± 0.06	0.0072c (0.0063-0.0079)	27.78	3.60
T.h. oxalate	0.51 ± 0.05	0.212d (0.208-0.218)	4.72	21.2	0.52 ± 0.07	0.0320d (0.0309-0.0327)	28.13	3.56	0.45 ± 0.05	0.010d (0.008-0.015)	20.00	5.00
Metaflumizon	0.40 ± 0.04	1.223e (1.201-1.245)	0.82	122.3	0.42 ± 0.04	0.184e (0.171-0.193)	4.89	20.44	0.38 ± 0.04	0.100e (0.088-0.114)	2.00	50.00

T.I. (1) Toxicity index = [(LC_{50} of the most toxic tested compound/LC_{50} of the tested compound) × 100]. R.P. (2) Relative Potency = LC_{50} for least toxic tested compound/ LC_{50} of the most toxic tested compound. * LC_{50} values having different letters are significantly different (95% CL did not overlap).

Table 6. Toxicity combined of tested insecticides and jojoba oil (250, 500 and 1000 ppm) against adults of German cockroach, *B. germanica* after 72 hrs. exposure.

Jojoba oil con.	250 ppm				500 ppm				1000 ppm			
Insecticides	**Slope ± SE**	**LC_{50} (ppm) (95%FL)***	**T.I.(1)**	**R.P.(2)**	**Slope ± SE**	**LC_{50} (ppm) (95%FL)***	**T. I.(1)**	**R.P.(2)**	**Slope ± SE**	**LC_{50} (ppm) (95%FL)***	**T. I.(1)**	**R.P.(2)**
E. Benzoate	0.37± 0.04	0.0010a (0.0007-0.0013)	100	1	0.61± 0.06	0.00060a (0.00053-0.0076)	100	1.00	0.53± 0.09	0.00010a (0.0007-0.0014)	100	1
Spinetoram	0.43± 0.03	0.045b (0.034-0.056)	2.22	45	0.75± 0.08	0.0080b (0.0071-0.0087)	7.5	13.33	1.16± 0.17	0.0010b (0.0007-0.0015)	10.0	10
Indoxacarb	0.59± 0.06	0.110c (0.107-0.115)	0.91	110	0.56± 0.07	0.0120c (0.0117-0.0126)	5.0	20.00	0.80± 0.19	0.0021c (0.0017-0.0027)	4.76	21
T.h. oxalate	0.65± 0.07	0.165d (0.157-0.174)	0.61	165	0.56± 0.08	0.0151d (0.0147-0.0158)	3.97	25.17	0.53± 0.09	0.0095d (0.0081-0.0099)	1.05	95
Metaflumizon	0.41± 0.04	1.108e (1.096-1.125)	0.09	1108	0.46± 0.04	0.136e (0.128-0.145)	0.44	226.67	0.45± 0.06	0.090e (0.085-0.096)	0.11	900

T.I. (1) Toxicity index = [(LC_{50} of the most toxic tested compound/LC_{50} of the tested compound) × 100]. R.P.(2): Relative Potency = LC_{50} for least toxic tested compound/ LC_{50} of the most toxic tested compound. * LC_{50} values having different letters are significantly different (95% CL did not overlap).

Discussion

Recently, essential oils have demonstrated insecticidal properties against a variety of insects, including cockroaches, as observed in several studies (Alali, *et al*., 1998; Phillips and Appel, 2010; Alzogaray *et al*., 2013; Isman, 2017;2020; Boné *et al*., 2022; Azmy, 2024; Manzanares-Sierra *et al*., 2025). These oils are concentrated liquids extracted from plants through processes such as distillation or solvent extraction. They contain numerous secondary metabolites, such as terpenoids, phenols, alkaloids, and other phytochemicals, which play a vital role in protecting plants against herbivores. The chemical components of essential oils can act as direct insect toxins, function as repellents, or enhance the toxicity of other insecticidal constituents (Isman, 2000; 2006). Due to their minimal toxicity to mammals and limited environmental impact, plant essential oils are considered a promising alternative to traditional insecticides. While they have been developed and commercially used as pesticides and repellents for household and garden pests over the years, their application as cockroach biopesticides remains limited (Alzogaray *et al*., 2013; Isman, 2017, 2020; Boné *et al*., 2022; Azmy, 2024; Manzanares-Sierra *et al*., 2025).

The present study provides valuable insights into the toxicological effects of several insecticides alone and in combination with jojoba oil against the adult German cockroach, *B. germanica*. Across all time points (24, 48, and 72 hours), emamectin benzoate demonstrated the highest efficacy, showing the lowest LC_{50} values and serving as a consistent reference for toxicity index and relative potency calculations. This confirms previous findings that emamectin benzoate is a potent insecticide effective at low concentrations against cockroach populations. Along with Lee *et al.* (2022), the results from the present study suggest that emamectin benzoate could be an excellent active ingredient for the control of otherwise-resistant German cockroach populations regardless of population size, cross-resistance profiles, or prior insecticide exposure history.

Spinetoram can be effective against German cockroaches, especially when used in bait formulations or applied as a residual treatment (Kritikou, 2011; Küçüksari and Tunaz, 2021). It is a biopesticide derived from bacterium and works by overexciting the nervous system of insects. Küçüksari and Tunaz, (2021) reported that spinetoram can cause high mortality in German cockroaches when applied at certain concentrations. According to the study, this insecticide possessed acute toxicity alone and combination with different concentrations of jojoba oil (250, 500 and 1000 ppm) against the adult German cockroach, *B. germanica* after 24, 48 and 72 hrs. exposure. Other insecticides showed varying degrees of synergism when combined with jojoba oil where spinetoram showed moderate toxicity enhancement, with LC_{50} values significantly decreasing at higher jojoba oil concentrations (1000 ppm). After 72 hrs at 1000 ppm jojoba oil, the LC_{50} dropped to 0.0021 ppm. Habbachi *et al*. (2009) reported that a non-lethal dose of spinosad causes adult male and female German cockroach, Blattella germanica, to exhibit altered responses to their aggregation pheromone as well as to have a changed cuticular hydrocarbon profile.

Indoxacarb works effectively through both contact and ingestion. With its ability to target various insect pests while maintaining relatively low toxicity to mammals (U.S.

Environmental Protection Agency, 2000), it stands out as an ideal pesticide choice for combating cockroaches. Indoxacarb showed improved toxicity over time, with substantial reduction in LC_{50}, especially at 1000 ppm jojoba oil (LC_{50} = 0.0010 ppm at 72 hrs.). All three concentration of jojoba oil (250, 500 and 1000 ppm) decreased significantly the LC_{50} values of indoxacarb. The result of this finding agrees with that of various authors (Appel, 2003, Liang, 2005, Agrawal and Tilak, 2006; Chuks *et al*., 2014) on the toxicity of indoxacarb gel bait to different cockroach species.

Thiocyclam hydrogen oxalate is an insecticide that can be used against German cockroaches, but it is not specifically labeled for cockroach control and may not be as effective as other cockroach-specific insecticides. It primarily acts by disrupting insect feeding and digestive processes, as well as interfering with growth and development. Thiocyclam hydrogen oxalate demonstrated lower efficacy compared to other insecticides but did exhibit enhanced toxicity with increasing jojoba oil concentrations, especially notable after 72 hrs exposure. While thiocyclam hydrogen oxalate and Metaflumizon were less effective individually, their toxicity also improved with jojoba oil addition, though to a lesser extent compared to the other insecticides. Metaflumizon, in particular, showed the highest LC_{50} values even in combination treatments, indicating limited practical use against B. germanica under these conditions. Metaflumizone demonstrates a very high level of toxicity against German cockroaches, particularly effective when used in baits or other contact methods (Hempel *et al*., 2007). Its mechanism of action involves blocking sodium channels in the cockroach nervous system, leading to paralysis and death. metaflumizone, although the least effective in general (LC_{50} = 11.81 ppm at 250 ppm jojoba oil after 24 hrs), showed improved performance with time and higher jojoba oil levels, albeit still significantly less potent than other insecticides. Plant extracts, such as jojoba oil, exhibit a wide range of activities against various pests, making them appealing alternatives to synthetic chemical pesticides for pest management. They are favored due to their minimal environmental impact and low risk to human health (Abdel-Razik & Mahmoud, 2017). The harmful effects of plant extracts or natural/synthetic compounds on insects are evident in several ways, including their toxic properties, induction of mortality, antifeedant effects, growth inhibition, suppression of reproductive behaviors, and reduction in fecundity or fertility. Plants are well-known producers of diverse chemical compounds, many of which play a critical role in defending against different types of pests (Isman and Akhtar, 2007). Plant extracts and isolated metabolites have been the focus of extensive research, driven by concerns over the detrimental effects of conventional insecticides on both human health and the environment.

The incorporation of jojoba oil significantly enhanced the toxicity of all tested insecticides, confirming its role as a synergist. This effect was more pronounced at higher jojoba oil concentrations (500 and 1000 ppm) and with extended exposure times. The most notable synergistic effects were observed with emamectin benzoate, spinetoram and indoxacarb, which exhibited substantial reductions in LC_{50} values when combined with jojoba oil. This suggests that jojoba oil may increase insecticide penetration, reduce detoxification mechanisms, or otherwise facilitate increased toxicity (Alzogaray *et al*., 2013; Huang *et al*., 2020; Manzanares-Sierra *et al*., 2025). Jojoba oil can act as an antifeedant, reducing insect feeding activity, and can also inhibit the growth and development of some insect pests. The decline in LC_{50} values over time for all compounds and combinations indicates the importance of exposure duration in toxicity assessment, with longer exposure providing more accurate estimates of insecticidal efficacy. These findings highlight that the combined use of insecticides with jojoba oil can potentially reduce the required doses of synthetic chemicals, minimize environmental impact and delay resistance development.

Conclusion

The synergistic effect of jojoba oil with multiple insecticides presents a promising avenue for enhancing pest control efficacy against B. germanica. These results indicated that, emamectin benzoate, spinetoram and indoxacarb have shown good efficacy against the adults of B. germanica alone and in combination with jojoba oil. The enhancement effect was more pronounced with increasing jojoba oil concentration and longer exposure durations. Future research should explore the mechanisms underlying this synergy and evaluate field applications to establish practical recommendations for integrated pest management programs.

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السـمية والتأثير المشـترك لبعض المبيدات الحشـرية وزيت الجوجوبا ضـد الصـرصـور الألماني *Blattella germanica* L.

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الملخص

يُعد الصـرصـور الألماني، *Blattella germanica*، آفة حضـرية بارزة تُشـكل خطرًا كبيرًا على الصـحة العامة نظرًا لقدرته على نقل مُسببات الأمراض المُختلفة. تهدف هذه الدراسـة الى دراسـة سـمية بعض المبيدات الحشـرية، وهي: إيمامكتين بنزوات، وسـبينتورام، وإندوكسـاكارب، وثيوسـيكلام أكسـالات هيدروجين، وميتافلوميزون، سـواءً بمفردها أو مع زيت الجوجوبا، بتركيزات 250، 500، 1000 جزء في المليون. وبناءً على قيم LC_{50s} للمبيدات الحشـرية المختبرة على حشـرة الكاملة للصـرصـور الألماني، كان المبيد الحشـري الأكثر سمية هو إيمامكتين بنزوات (0.414، 0.012، 0.002 جزء في المليون)، يليه سـبينتورام (2.96، 0.093، 0.056 جزء في المليون)، إندوكسـاكارب (4.88، 0.602، 0.090 جزء في المليون) ثيوسـيكلام هيدروجين أكسـالات (17.04، 0.769، 0.182 جزء في المليون)، ميتافلوميزون (96.67، 21.22، 2.042 جزء في المليون) وزيـت الجوجوبـا (350.64، 258.97، 197.61 جزء في المليون) بعد 24، 48، 72 سـاعة من التعرض، على التوالي. أدى خلط زيت الجوجوبا كعامل منشـط إلى تعزيز سـمية جميع المبيدات الحشـرية المُختبرة بشـكل ملحوظ، حيث لوحظت التأثيرات الأكثر وضـوحًا عند تركيزات أعلى من زيت الجوجوبا وفترات التعرض الاكبر. والجدير بالذكر أن إيمامكتين بنزوات، وسـبينيتورام، وإندوكسـاكارب أظهرت تحسـنًا ملحوظًا في الفعالية عند اضـافتها مع زيت الجوجوبا. في المقابل، ظل مركبا ثيوسـيكلام هيدروجين أكسـالات وميتافلوميزون أقل المركبات فعالية، على الرغم من ملاحظة تحسـنات طفيفة عند إضـافة الجوجوبا. تشـير هذه النتائج إلى أن زيت الجوجوبا قد يعمل كعامل منشط قوى، مما يُعزز فعالية المواد الكيميائية التقليدية في مكافحة الحشرات. ويمكن أن يُحسّن دمجه في برامج مكافحة الآفات من نتائج مكافحة الصـرصـور الألماني، مع إمكانية تقليل الاعتماد على جرعات أعلى من المبيدات. كما ينبغي أن تُركز الأبحاث المسـتقبلية على اسـتراتيجيات عملية وتطبيقية لترسـيخ استخدام الجوجوبا كمبيد حيوي للحشرات، واستكشاف تركيباته مع مبيدات حشرية أخرى.

الكلمات المفتاحية: *السمية، الصرصور الألماني، زيت الجوجوبا، مبيدات حشرية.*