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Botanical insecticides and mineral oils synergize toxicity of imidacloprid against Bemisia tabaci (Hemiptera: Aleyrodidae)

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ABSTRACT

Management of *Bemisia tabaci* requires the use of multiple control techniques in addition to pesticides, and plant-derived essential oils and mineral oils are one of the control options. The evaluation of new chemistry synthetic insecticide (imidacloprid) mix with jojoba oil or KZ oil, to enhance its synergistic efficacy against whitefly (*B. tabaci*) in laboratory trails as well as evaluated in experimental field plots at Menia El-Kameh, El-Sharkia Governorate, Egypt. The influence of these compounds and their mixtures on natural predators and crop yield were simultaneously investigated. Based on laboratory tests, synergistic action was observed in the whitefly by a combination of imidacloprid with jojoba oil or KZ oil approximately 12 and 40 times more respectively than the imidacloprid alone, interestingly, the combination of the insecticide with the mineral oil was more toxic than the essential oil. Similar trend was also recorded for these mixtures at sublethal dose against biological aspects of whitefly, it has significantly reduced development and fecundity. Infield application, all tested compounds, and mixtures caused a significant decrease in the whitefly populations; the mixtures gave more than 75% control over the whitefly, and there were differences in treatment over the abundance of predators as more predators were recorded within the mixtures with significantly higher yields than those compounds alone or the untreated control. Mixtures treatment also resulted in the longest residual effect under field conditions.

HIGHLIGHTS

- This study shows evidence for synergistic between botanical insecticides or mineral oils with neonicotinoid insecticides as these mixtures resulted in ineffective management for *Bemisia tabaci*.
- The results demonstrate that it is possible to lower the doses of insecticide and get improved efficacy against the development and fecundity of whitefly; with this botanical insecticide or mineral oils.
- Mixtures are compatible with predators while not compatible with *B. tabaci* populations, resulting in increased yield.

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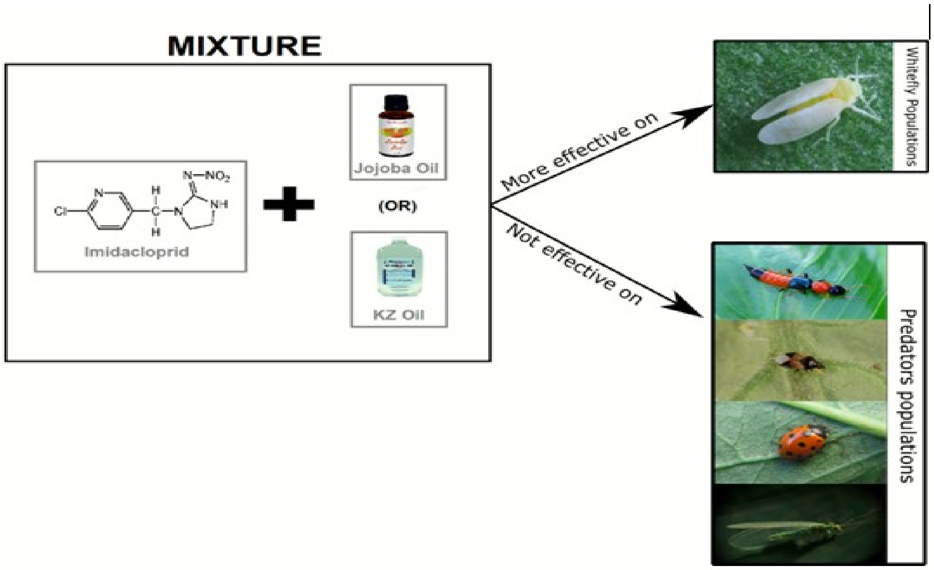
GRAPHICAL ABSTRACT



1. INTRODUCTION

The whitefly, *Bemisia tabaci* (Gennadiüs), ranks among the most serious insects affecting economically important crops in fields and greenhouse, it is widely distributed in Egypt and many countries. It causes severe economic damage to more than 60 crop plants as bark that absorbs sap or as a vector for more than 30 viral diseases of food crops and other fibers. So, it is considered one of the world's top 100 most invasive and dangerous species of insect pests. Besides, its adults directly damage plant leaves by removing them and injecting their saliva into them. The honeydew secreted by its numerous larvae is also provocative to the importance of crystalline rot on the leaves [1]. Due to the negative impact produced by *B. tabaci* population control is needed, to reduce their risk. Although effectively to control this pest managed mainly with synthetic insecticides particularly neonicotinoids but, the long-term and intensive use of synthetic insecticides, with the addition that it has tremendous potential for developing resistance, rendered the management of this pest extremely difficult as it has become resistant to more than 40 pesticides [2, 3, 4]. Moreover, negative effects are associated with synthetic insecticides, such as misapplication, deleterious side effects on natural enemies and ecosystems. These problems lead to a greater need to develop alternative or additional techniques, which would allow rational use of pesticides to reduce their risks while at the same time not affecting the natural enemies and providing adequate protection to the crops [5].

Essential oils show a wide range of actions against insects: they can act as repellents, attractants, or antifeedants; They may also inhibit respiration, impede identification of host plants, inhibit oviposition and reduce adult emergence by ovicidal and larvicidal effects [6,7]. In addition to essential oils, mineral oils are also used to combat insect pests [8]. Perhaps the main cause of death of arthropods with mineral oil is obstruction of the trachea or respiratory openings, and lack of oxygen causes the death of insects [9]. However, mineral oils also affect integration, with cell membranes rupturing and turning brown. Insect behavior is influenced by these oils, which have typical repellant effects on oviposition and feeding, as well as influence on the nervous system [10,11]. Despite several practical, environmental, and biochemical characteristics of both essential oils and mineral oils make them a potential alternative for insect pest management, they have seen limited use in crop protection due to these limitations are inconsistencies in efficacy and composition, lower potency against target pests relative to many synthetic insecticides, and relatively lower persistence and residual activity. The latter three in particular may restrict the use of these oils as stand-alone products for crop protection in many situations [9]. An alternative strategy for the use of oils in crop protection could be to use them in mixtures with synthetic insecticides. Early applications of synergism, revealed that a mixture of chemicals with a different mode of action can result more potent and could theoretically inhibit or delay the emergence of resistant strains to the wide array of insect pests [5]. In the same context, it has been found that both mineral and essential oils when mixed with synthetic insecticides lead to a synergistic effect against insects [12,13,14]. At present, some essential oils, mineral oils, and new chemistry insecticides are available in the market that is cheap, eco-friendly (safe for natural predators and parasitoids), and also have no adverse effects on human health. In the present study, the new synthetic insecticide (imidacloprid) mixture with essential oil (jojoba oil), or mineral oil (KZ oil) by sublethal effects on biological aspects for whitefly were evaluated also determined the residual effect under field condition. The study also included the mixtures effect on populations of *B. tabaci* in tomato fields, the possible adverse effects of these mixtures on populations of natural predators, such as lacewings, lady beetles, rove beetles, and pirate bug, as well on tomato yield.

2. EXPERIMENTAL

2.1. Laboratory trials

2.1.1. Bioassays tests

Bioassays were carried out on the first, third instar larvae and adults of whitefly. Leaflets of tomato seedlings, 22 days old (15-20 cm height) were dipped for 5 minutes in each concentration of the commercial grades imidacloprid 20% SC, jojoba oil 96% EC, and KZ oil 95% EC. Control plants were dipped in distilled water containing .5% Triton X-100. Treated and control plants were air-dried for 5 min. Twenty of each instar of *B. tabaci* were introduced onto treated and control plants covered with glass cages with muslin in the upper opened and then kept under controlled room conditions at 25 ± 2°C, 65 ± 5% RH, and natural light conditions. Each treatment was repeated three times, mortality was recorded after 48h and subjected to probit analysis of Finney [15].

2.1.2. Synergistic action

Synergistic action new synthetic insecticide (imidacloprid) with the essential oil (jojoba oil) and mineral oil (KZ oil) against 1st instar larvae of *B. tabaci* was investigated. Larvae were treated with these mixtures at LC_{25} values by dipping technique as described above.

2.1.3. Sublethal effects on biological parameters

Tomato leaflets were dipped in the sublethal concentration (LC_{25}) of each mixture (imidacloprid/KZ oil and imidacloprid/jojoba oil) and imidacloprid alone as a control for 5 min. After air drying, the plants were transferred to the glass cages and twenty new emerged adults (24 hours old) were randomly captured from the stock colony and released into cages. After 24 h, all adults were removed from the cages and released into new ones. The numbers of eggs laid for 48 h by each female were recorded by binocular microscope and the number of eggs was divided by the number of females to determine the overall effects on oviposition. Egg hatchability was recorded 8-10 d after treatment and pupation rate was determined 3 weeks after treatment.

2.2. Field trials

2.2.1. Study area and experimental design

The field experiments were conducted at Menia El-Kameh, El-Sharkia Governorate, Egypt. The experimental area of 2400 m^2 was sown with tomato seeds 22 days old, ('Miller', *Lycopersicon esculentum*, variety Beto 86). All the standard agricultural practices were followed as recommended for the growth of tomatoes. Treatments were tested in this area under a randomized complete block design with four replications (plots), each 42 m^2. The plots were treated with imidacloprid alone (0.6 g (a.i.)/feddan), 1% KZ oil or jojoba oil, and a mixture of imidacloprid/KZ oil or imidacloprid/jojoba oil. The plots were sprayed on August 15, 2020, with a single nozzle knapsack sprayer at a rate of 200 liters/feddan. Also, residual effects on whitefly at various periods (7, 13, 20, 27 d) after application of treatments for 48 h were evaluated.

2.2.2. Predators and yield

From each plot,3 inner rows were selected for sampling. To record the data of several insect pests and predators, a total of 5 plants from the selected rows were examined after 3, 7, and 10 days of treatment applications. The main target insect pest was *B. tabaci*. The target predators were the lacewings *Chrysoperla carnea* (Chrysopidae), lady beetles *Coccinella undecimpunctata* (Coccinellidae), pirate bug *Orius*spp (Anthocoridae), and rove beetles, *Paederusalfierii* (Staphylinidae), these predators consider biological control agents against *B. tabaci*. In the case of *B. tabaci,* both immature (3rd larva and pupa) populations were considered, while only adults were recorded in the case of predators. Tomato yield/plot from the check and treated plots were also calculated and recorded.

2.3. Data analysis

The data mentioned were subjected to analysis of variance using One-way ANOVA followed by Tukey's test.

3. RESULTS

3.1. Laboratory trials

3.1.1. Toxicity study

Three compounds (imidacloprid, jojoba oil, and KZ oil) evaluated against *Bemisia tabaci* stages, observed the toxicity is decreased by the increase in the insect instars (Table 1). The first instar is more susceptible than the third instar and adult stage with LC_{50} values of 0.016, 0.19, and 0.62 mg (a.i.)/ L^{-1} for imidacloprid, KZ oil, and jojoba oil respectively. The LC_{50} values of the adults' stage are greater than the first and third instars larvae with LC_{50} values of 1.58, 2.73, and 4.45 mg (a.i.)/ L^{-1} for imidacloprid, KZ oil, and jojoba oil respectively.

3.1.2. Toxicity of binary mixtures

Bioassays using binary mixtures evaluated against first instar larvae of *B. tabaci* (Table 2). Results revealed that a combination of imidacloprid with jojoba oil or KZ oil synergized the toxicity against *B. tabaci* approximately 12 and 40 times more respectively than the imidacloprid alone, in the same context as imidacloprid/KZ oil combination was the most toxic.

3.1.3. Biological parameters

The adult mortality, fecundity, egg hatchability, and pupation of *B. tabaci* insects were negatively impacted after treatment by mixtures compared to the insecticide alone (Table 3). Mixtures were the most effective, as they caused a significant reduction in the fertility of the surviving *B. tabaci* females as well development. Imidacloprid/KZ oil combination was the most effective, reducing fertility by (38.1), followed by the imidacloprid/jojoba oil combination giving (60.4%) as compared to imidacloprid alone, which had the lowest decrease (79.5%). Likewise, adult mortality, egg hatchability, and pupation of *B. tabaci* were decreased after treatment with mixtures (Table 3).

Table 1. LC_{50} values of treatments against different stages of *B. tabaci.*

Stage	Treatment	LC_{50} mg (a.i.)/L^{-1} (95 % CL)	LC_{25} mg (a.i.)/L^{-1} (95 % CL)	Slope ± SE
1st instar	Imidacloprid	0.016 (0.03-0.08)	0.012 (0.010-0.014)	0.44 ± 0.23
	Jojoba oil	0.62 (0.96-0.35)	0.33 (0.17-0.79)	2.47 ± 1.23
	KZ oil	0.19 (0.12-0.26)	0.032 (0.33-0.89)	2.96 ± 0.31
3rd instar	Imidacloprid	0.11 (0.16-0.08)	0.053 (0.015-0.054)	2.03 ± 0.19
	Jojoba oil	1.67 (2.07-1.18)	0.51 (0.17-0.82)	1.32 ± 0.23
	KZ oil	1.54 (1.92-1.07)	0.49 (0.17-0.79)	1.36 ± 0.21
Adult	Imidacloprid	1.58 (1.20-1.85)	0.63 (0.33-0.89)	1.73 ± 0.19
	Jojoba oil	4.45 (2.51-6.42)	1.63 (1.32-1.88)	1.67 ± 0.22
	KZ oil	2.73 (3.12-2.48)	1.35 (0.15-0.59)	1.86 ± 0.28

Table 2. LC_{25} values of treatments against 1st instar of *B. tabaci*

Treatment	LC_{50} mg (a.i.)/L^{1-} (95 % CL)	LC_{25} mg (a.i.)/L^{-1} (95 % CL)	Slope ± SE
Imidacloprid	0.016 (0.03-0.08)	0.012 (0.010-0.014)	0.44 ± 0.23
Imidacloprid+Jojoba oil	0.008 (0.016-0.004)	0.001 (0.002-0.071)	0.46 ± 0.16
Imidacloprid+KZ oil	0.003 (0.001-0.006)	0.0003 (0.0001-0.0008)	0.53 ± 0.18

Table 3. Effect treatments at LC_{25} values on biological aspects of *B.tabaci*.

Treatment	% Adult mortality	% Fecundity	**%**Eggs hatchability	% pupation
Imidacloprid	54 ± 2.11a	79.5 ± 2.93c	67 ± 2.60c	81 ± 1.63c
Imidacloprid+Jojoba oil	69 ± 1.70b	60.4 ± 3.55b	58 ± 4.23b	58 ± 1.40b
Imidacloprid+KZ oil	88 ± 2.32c	38.1 ± 1.84a	52 ± 1.52a	47 ± 2.62a

Means within the same column followed by a common letter do not differ significantly at P = 0.05. Data are averages of 3 replicates of 20 females each, mean± SE.

3.2. Field trials

3.2.1. Residual effects of treatments on B. tabaci population

There were no significant post-treatment differences in density of *B. tabaci* during both 7, 13, and 20 days of observation (Table 4). However, 27 days' post-treatment, the density of *B. tabaci* in control plots was significantly higher compared to all treated plots. The lowest whitefly density was recorded post-treatment in the mixture of imidacloprid/KZ oil-treated plots (4.5 larvae per leaf), followed by imidacloprid/jojoba oil-treated plots (5.7 larvae per leaf), while each of the imidacloprid, KZ oil, and jojoba oil caused, 11.1, 14.5 and 16.2 larvae per leaf, respectively. Results showed that the combination of these oils with the insecticide treatment decreased the pest abundance significantly compared to all other treatments and the control situation.

Table 4. Residual effects of treatments against *B. tabaci* population.

	Days after application			
Treatment	7	13	20	27
	Large scales per tomato leaf (mean ±SE)			
Imidacloprid	15.4 ± 2.31b	9.2 ± 4.62b	5.8 ± 0.29b	11.1 ± 3.64a
Jojoba oil	21.6 ± 1.73a	10.9 ± 2.32b	6.2 ± 1.70b	16.2 ± 1.15a
KZ oil	19.3 ± 3.64ab	9.8 ± 1.55b	5.4 ± 2.31b	14.5 ± 1.52a
Imidacloprid+Jojoba oil	13.7 ± 2.88b	8.9 ± 4.04b	6.4 ± 2.23b	5.7 ± 1.66b
Imidacloprid+KZ oil	11.8 ± 4.04b	7.0 ± 2.11b	5.2 ± 4.70b	4.5 ± 0.57b
Check	26.5 ± 0.26a	20.4 ± 1.66a	11.5 ± 0.22a	10.9 ± 1.30a

The initial 3rd larva and pupa level was 26 ± 2 per leaf. Means within the same column, followed by a common letter do not differ significantly at P = 0.05.

3.2.2. Effect of treatments on Bemisia tabaci and its natural predator in tomato crop

Mixtures positively affected populations of predators (lacewings, lady beetles, pirate bug, and rove beetles) more than the plots treated with insecticide, essential oil and mineral oil alone (Table 5). Overall, there was a significant difference between densities of tested predators, between treated and untreated plots. The population density of *B. tabaci* was found to be strongly negatively correlated with the predators/plot, on the contrary, it was observed that yield/plot was positively correlated with predators (Table 5). Tomato yield was significantly higher in the plots treated with mixtures as well as tested compounds alone compared to control. Imidacloprid/KZ oil combination was the highest yield, giving 64.2%, followed by the imidacloprid/jojoba oil combination giving 55.7% (Table 5).

4. DISCUSSION

The bioassay results of imidacloprid, KZ oil and jojoba oil showed that these compounds have toxicity against *Bemisia tabaci*, the toxicity of compounds depended on the insect instars used, the LC_{50} values of the adult stage are greater than first and third instars larvae respectively. Single compounds were lower toxicity than the mixtures, but insecticide mixture with essential oil was also toxic, but not as efficient as the mixture with mineral oil, so a synergetic effect between insecticide and these oils could explain these results.

Table 5. Effects of treatments on the abundance of *B. tabaci*, associated predators, and percentage tomato yields simultaneously.

Treatment	Means ± SE		Yield increase %
	Pest abundance	*Predator abundance*	
Imidacloprid	2.44 ± 0.121c	1.03 ± 0.133b	33.4
Jojoba oil	3.23 ± 0.169de	5.11 ± 0.134d	25.6
KZ oil	2.91 ± 0.158d	5.47 ± 0.129de	28.3
Imidacloprid+Jojoba oil	1.03 ± 0.175b	4.44 ± 0.116c	55.7
Imidacloprid+KZ oil	0.47 ± 0.179a	5.00 ± 0.118d	64.2
Check	4.91 ± 0.086f	0.70 ± 0.091a	-------

Abundance values are the average number of pests and predators per plant recorded at 3, 7, and 10 days after application. Key pest is*. B. tabaci* while key predators are *Chrysoperla carnea*, *Coccinella undecimpunctata*, *Orius* spp, and *Paederus alfierii*. Means sharing similar letters within columns are not significantly different at P > 0.05.

In many studies, the activity of the essential oil or mineral oil could be against insects by solubility, surface tension, actually involvement in cell penetration, lipophilic or hydrophilic attraction, and fixation on cell walls and membranes. Thus, improving the effectiveness of insecticides may result from changes in their properties as a result of mixing them with these oils [8]. Based on the results of toxicity, mixtures were tested as leads for control effective biological agents. The sublethal dose applied in mixtures showed a significant synergistic effect on reduction of *B. tabaci* egg hatchability, fertility, adult mortality, and pupation, all representing significant ways of efficiency leading to reduced population density and harmfulness of pests. These mixtures may be caused a disturbance in the physiological functions which was remarkably caused by a mineral oils, including oils of folic, kemesol, and national, combined with cyhalothrin, had a synergism effect against *Spodoptera littoralis* larvae. In addition, Ismail [13] showed the combination of essential oils with synthetic chemical insecticides synergized 2.81- to 9-fold; reduction in feeding activity of the insect reduces normal development and fertility. Ismail and Shaker [12] revealed that all the local mineral oils, including oils of folic, kemesol and national, combined with cyhalothrin, had synergism effect against *Spodoptera littoralis* larvae. In addition, Ismail [13] showed the combination of essential oils with synthetic chemical insecticides synergized 2.81- to 9-fold; 2.74- to 8.35-fold, compared to insecticide alone against *Spodoptera littoralis* larvae. The combination of essential oils or mineral oils with conventional synthetic insecticides enhancing synergistic efficacy for sucking-piercing insects like whitefly [10,14]. These natural compounds with insecticides had a toxic effect on *Bemisia tabaci* as well as negative effect on lifecycle [16,17,18].

Based on the field application, mixtures imidacloprid/KZ oil or imidacloprid/jojoba oil longest persistence residues under field conditions. Therefore, these mixtures could be used in the management of whitefly to lead of negatively affect the development and reproduction of exposed individuals of *B. tabaci*.

This effect likely disrupted group *B. tabaci* dynamics, slowed population growth, and reduced infection levels. The reason for this effect may be to the use of essential oil or mineral oil with insecticide extended its residual toxicity foliar under field conditions. These results are consistent with those of Togni et al. which recorded a gradual decrease in whitefly numbers in tomato fields from 1 to 7 days after application [19], also with Gao et al. they reported that the addition of natural compounds significantly improved the residual activity of abamectin on both laboratory and field strains of *Plutella xylostella* L. for at least 14 days [20]. Predators are among the most important natural enemies of several pests, it has immense importance in managing the population of insect pests in the field [21]. These mixtures represent distinct working patterns that were relatively innocuous to predators and at the same time were extremely harmful to the pests, resulting in a higher yield, so should contribute to future IPM for *B. tabaci* on fields [22]. The synergistic effects between essential oil or mineral oil and chemical agents may lie in their resistance mechanisms, namely the ability of natural derivatives or mineral oil to antagonize pesticide resistance or to enhance insecticide properties, or possibly in the mitigation of side effects on predators, it has been reported that new chemistry insecticides, botanicals and are mineral oil relatively safe for the natural predators, which is reflected in increased yield [23,24]. He et al. and Hu et al. found that the application of imidacloprid at recommended field rate is not toxic for a predator of *S. japonicum* [25,26]. Nascimento et al. it has been shown that imidacloprid has a relatively mild effect on beneficial organisms [27]. The population of natural enemies especially predators is being affected negatively through excessive use of synthetic insecticides but the use of these insecticides mixed with mineral oil or essential oil showed less effect [28,29].

CONCLUSIONS

The present study demonstrated that the two tested mixtures effective for *Bemicia tabaci* management where keep whitefly populations well below economic injury levels in field conditions as well as these mixtures seem to be compatible with the biological control exerted by their predators, which is reflected in the increase in the yield, thus mineral oils or botanical insecticides have been suggested to act as synergists for synthetic insecticides of application for effective whitefly control management that can contribute to minimizing the resistance problem to the main synthetic insecticides used for their control in the field.

Declarations

Ethics approval and consent to participate

The manuscript does not contain any studies involving human participants, human
data or human tissue.

Consent for publication

Not applicable.

Availability of data and materials

All data generated during this study are included in this published article.

Competing interests

The author declares that there are no competing interests.

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Author's contributions

The author contributed to the production and writing of the manuscript.

The author(s) read and approved the final manuscript. 275

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