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Efficacy of Abamectin and Thiamethoxam Mixture Against *Bemisia Tabaci* in Tomato and Toxicity on Male Albino Rats

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Abstract

There are many benefits to mixing pesticides including controlling a broad spectrum of pest species and overcoming the phenomenon of insect resistance to the action of pesticides. Two field experiments were conducted during the 2019 and 2020 seasons, at Alwakeel village, El-Beheira Governorate, Egypt to investigate the efficacy of abamectin and thiamethoxam mixture (AB+THIA) against the whitefly, *Bemisia tabaci*. The mixture gave a high reduction of whiteflies, where the general means of initial and residual reduction percentage of adult stages were 83.3, 87.1% and 84.1%, 86.1% during 2019 and 2020, respectively. It recorded 85.4, 86.4% and 89.8, 87.8% of immature stages during 2019 and 2020, respectively. Recognized method, Quick, Easy, Cheap, Effective, Rugged and Safe (QuEChERS) was conducted to extract and clean up tomato fruits and liquid chromatography-tandem mass spectrometry (LC-MS/MS) was used to quantify AB and THIA residue levels. They were below the maximum residue level (MRL). For toxicological studies, AB+THIA at MRL was administered on male Sprague Dewaly rats twice a week orally treated with the mixture for 4 weeks. The results obtained that activities of serum aspartate aminotransferases (AST), alanine aminotransferases (ALT), alkaline phosphatase (ALP), lactate dehydrogenase (LDH), gamma-glutamylamyl transferase (γGT) and levels of uric acid, creatinine and urea significantly increased in the treated rats, respect to their controls. The mixture of AB and THIA triggered histopathological defects in liver and kidney sections of male rats. The present findings suggest that the mixture of AB and THIA could be used as an effective formulation for whitefly management by following the safety guidelines of pesticides usage and choosing the appropriate time for plant harvest to avoid as possible the harmful effects of pesticides.

Keywords: Abmectin+Thiamethoxam (AB+THIA); *Bemisia tabaci*; Tomato; biochemical quantities; histopathological defects; albino Rats

1. Introduction

Tomato *Lycopersicon esculentum* (Miller) represents the record vital vegetal crop in Egypt. It is a respectable basis of income for many farmers in both local and export trade. The Nutritive value of tomato plants represents a rich source of minerals, vitamins (A and C) and antioxidant lycopene that contribute to a healthy and well-balanced diet [1]. It is susceptible to many pest infections. Whitefly, *Bemisia tabaci* (Gennadius) (Hemiptera: Aleyrodidae) is the top critical pest. It causes direct damage through the sucking of leaves, and transmission of numerous plant viruses ending in large economic losses in the crops [2,3]. Such this infestation results in carbohydrate-rich honeydew secretion, which create the leaves gummy, weaken photosynthesis and support the growth of sooty mold fungi on the leaves and fruits [4]. Abamectin (AB) consists of two molecules, avermectin B1a (≥80%) and avermectin B1b (20%) [5]. It is isolated from eight molecules that are created by an original soil microorganism. It has broad-spectrum rum insecticidal potency with contact and translaminar action against arthropods e.g. spider mites, leaf miners, thrips, psylla and also the diamond back moth and selected lepidopteran pest species [6].

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Thiamethoxam (THIA) is one of the 2nd neonicotinoid groups, which developed in the last decade. It is applied as a foliar spray and seed dressing against sucking pests and some chewing and soil living insects in a wide range of vegetable crops [7]. Neonicotinoids have been the kindest upward class of insecticides, owing to their probable moderate toxicity to mammals and their benefit in fighting insects that are resistant to other pesticides [8]. Their activity is principally the action on nicotinic acetylcholine receptors (nAChRs) [9,10]. The toxicity induced by these substances is considered to be centrally mediated because the symptoms of poisoning are similar to those of nicotine [10].

Insecticides are a key component of adult and immature whitefly and virus management. Today, AB and THIA are used individually in great amounts in Egypt, but this can rise a problem when the possible risks of occupational and environmental contamination are taken into account. Since AB and THIA are being reflected to substitute other current insecticides, therefore the relative risk and profits of these insecticides must be considered. Although the data about AB action on GABA receptors and THIA on nAChRs in insects are clear, there are few investigations that demonstrated possible in vivo effects of them on the biological system of the mammalians.

In multi-residue pesticide analysis, the QuEChERS method has exchanged less effective outdated methods attributing to its many advantages. This method has been commonly employed to detect and analyze pesticides in food, biological, and environmental matrices.

High-performance (HPLC) joined with a Mass spectrometer (MS) is the greatest extensive technique to separate and identify the widespread range of pesticides, following the QuEChERS method. Coupling of LC with MS has been efficiently engaged in the analysis of several foods and environmental samples, in association with its high selectivity, sensitivity and specificity [11, 12]. Gas chromatography (GC) separation is imperfect for volatile analytes, while LC separation permits the analysis of numerous compounds, including thermally unstable and ionic. So, LC is preferred for the analysis of multiclass pesticides. Actually, the development of QuEChERS technique increased the use of LC–MS/MS [13].

Many adverse effects of AB or THIA have been stated on haematological, biochemical, behavioural and histopathological defects in laboratory animals following oral and/or intraperitoneal administration [14-16].

For these reasons, the present study has been directed to assess the mixture of AB and THIA efficacy on whiteflies, determine the residue levels in tomato fruits and their impact at MRL levels on male rats after oral administration for 4 weeks.

2. Experimental

2.1. Tested insecticides and Chemicals

Abamectin 2% + Thiamethoxam 10% (Gat fast-Extra® 12% SC) was produced by Nihon Nohyaku company, Ltd., Japan and applied at the rate of 500 cm^3/hectare. Abamectin (technical 95%) was obtained from Herbal Veyong Biochemical Company. Thiamethoxam (technical 98%) was obtained from Jiangsu Subin Agrochemical Company. All solvents and other chemicals used in the experiments were HPLC grade and the highest purified grades were purchased from -Sigma-Aldrich and Merck Chemical Companies.

2.2. Field experiments

Two field experiments were conducted during the 2019 and 2020 seasons, at Alwakeel village, El-Beheira Governorate, Egypt. Tomato plants were cultivated on the 1^{st} of May, 2019 and the 15^{th} of May, 2020. Experimental designs were in a complete randomized block pattern. Each treatment was simulated in three replicates (each, 42 m^2). The treatments were sprayed by Knapsack sprayer equipment (CP3) at water solutions (500 L/ha). Control plants were sprayed with water-free insecticides.

The efficiency of AB+THIA against adult stages of whitefly was determined by counting insects on ten leaves designed for treatment. The population of insects was done just earlier and after application at 1^{st} d (initial effect), 3, 7 and 10 d (residual effect). Count of whitefly adults was completed in an earlier time before sunshiny, when flight activity is minimal [17]. Regarding immature stages, ten leaves for each replicate were taken to examine the lower surfaces by using a stereoscopic binocular microscope. Reduction percentages were calculated according to equation of Henderson and Tilton [18]. Cultivated processes were done next to the profitable production package of tomato. Tomato fruits (5 kg) were randomly collected from each replicate including the control after 29 d of the last insecticide spray. Fruits were homogenized and a sample of 0.5 kg of each one was placed in polyethylene bags and stored at -20 °C until used.

2.3. Residue quantifications

Residue levels of AB+THIA were analyzed following the QuEChERS extraction method according to the British-Adopted European Standard (BS EN) 15662 [19]. Ten g of homogeneous sample was extracted with 10 ml of acetonitrile in a centrifuge tube of 50 ml. Then, magnesium sulfate (4±0.2 g), sodium chloride (1±0.05 g) and buffering citrate salts [1±0.05 g trisodium citrate dehydrate and 0.5±0.03 g disodium hydrogen citrate sesquihydrate] were added. The mixture was shaken intensively for 1 min until well blended and centrifuged at 4000 rpm for 5 min. The cleaned extract was transferred into a screw cap vial and purified by using dispersive solid phase extraction (D-SPE). The samples were acidified (a few drops of formic acid) to advance the packing stability of confident base-sensitive compounds and achieved to LC-MS/MS instrument.

Matrix-matched adjustment is regularly engaged in pesticide residue requests because it is moderately relaxed to apply and cheap [20]. Matrix properties are known to undesirable influence on the target analytes quantify [21]. Matrix matched standards were used in order to compensate the matrix effects either enhancement or suppression on the results by stimulating 450 µl of blank sample with 50 µl of certified reference solutions (0.1, 0.5 and 1 µg/ml) to acquire 0.01, 0.05 and 0.1 µg/ml levels. The concentration of pesticide in sample C_s (mg/kg) was planned as follows:

$$\mathbf{C_s} = \frac{V_e}{W} \times \frac{A_{sam}}{A_{st}} \times Y$$

Where, V_e= extraction volume (ml), A_{sam}= peak area of the sample, A_{st}= peak area of standard, Y= standard concentration (µg/ml), W= sample weight (g) used for extraction.

2.4. Quality assurance

The limits of detection (LOD_s) of measured pesticides were planned as twofold of the standard deviation of a series of quantities of a solution against the blank absorbance [22]. Quality assurance procedures and precautions were followed to ensure the reliability of the data.

2.5. Toxicological studies

2.5.1. Tested animals and treatment

Male of Sprague-Dawley rats, *Rattus norvegicus*, weighting 170-180 g and 2-3 months' age were reserved from the breeding culture of Medical Technology Center, Medical Research Institute, Alexandria University, Egypt. The animals were randomly housed in special healthy standard cages and maintained on *ad libitum* for water and a standard rat chew diet. Guideline of animal care was surveyed permitting the National Institutes of Health Guide for the care and use of laboratory animals (NIH Publications No. 8023, revised 1987). They were kept in air-conditioned rooms at a temperature of 25±2 °C with a relative humidity of 50-60% and a normal light/dark cycle and divided into two main groups (5 individuals for each). The experiment was approved by ARC-IACUC Committee of Animal Health Research Institute, Agricultural Research Center (ARC) [IACUC protocol Number (ARC-AH-22-15)]. As stated by the Codex MRLs of pesticides, the proposed MRLs for AB and THIA in tomato fruits are 0.01 and 1 mg/kg [23]. The Control group was orally given (corn oil), while the rats in AB and THIA group received oral doses equal to the MRL of each one weekly for 28 d. Weights of animals were weekly recorded and signs of morbidity and mortality were daily stated. At the finish of the experiments, the animals were given up deep anesthesia with inhalation of isoflurane. Blood samples were reserved from the animals from the posterior vena cava into free-heparin tubes, allowed until clotting occur and centrifuged at 4000 rpm for 10 min. The sera were kept at -20 °C until used for biochemical quantifications. Liver and kidney were dissected, rinsed in saline solution (0.9% NaCl), and weighted, as follows: body and the relative organ weights were intended and fixed closely in 10% buffered formalin for histopathological investigation.

2.5.2. Biochemical quantifications

Liver enzyme functions of AST and ALT were determined following the directions of Bio diagnostics kits [24]. Activities of ALP and LDH were assayed by using Diamond Diagnostics kits [25]. Determination of γGT activity was completed by using Linear Substances kits [26]. For kidney biochemical parameters, serum creatinine, urea and uric acid levels were measured using commercial kits from Bio diagnostics kits [27,28].

2.6. Histopathological investigation

Dehydrated by standard procedures, embedding in paraffin wax, sections approximately 5 µm thick preparing, staining with haematoxylin and eosin (H&E) stains, and then examination on the light microscope was conducted for the fixed samples [29].

2.7. Statistical analysis

The data were stated as mean ± SE, where it was subjected to analysis of variance (ANOVA) and analysed using the student-Newman Keuls test. Computer software Costate program, Version 6.311, 2005 was used. Comparison between means was completed at $P \leq 0.05$.

3. Results

3.1. Efficacy of AB+THIA against adult stages of whitefly

In 2019, the data show that whitefly adults were affected by 1st spray of AB+THIA which gave an initial reduction percentage 85.4% on 1st day after application and the mean residual reduction percentage was 85.4% at 3, 7 and 10 d after application. In the 2nd spray, AB+THIA achieved a high reduction percentage against whitefly adults giving an initial reduction percentage of 81.3% and a residual reduction percentage of 88.9%. In 2020, AB+THIA gave high initial and residual reduction percentages of 82.0, 88.0% in 1st spray and 86.3, 84.3% in 2nd spray. The general means of an initial and residual reduction percentage of 1st and 2nd sprays as a result of AB+THIA applications were 83.3, 87.1% and 84.1, 86.1% during 2019 and 2020, respectively (Table 1).

3.2. Efficacy of AB+THIA against immature stages of whitefly

In 2019, the data show that AB+THIA gave high reduction percentages of immature stages (79.5 and 85.0%) for initial and residual reduction, respectively, in 1st spray. At the 2nd spray, the values were 91.4 and 87.9%. In 2020**,** the data assured that AB+THIA was still effective against immature stages, giving 91.2 and 91.4% for initial and residual reduction percentage, respectively, in 1st spray, while the values were 88.5 and 84.3% in 2nd spray. The general means of an initial and residual reduction percentage of 1st and 2nd sprays were 85.4, 86.4% and 89.8, 87.8% during 2019 and 2020, respectively (Table 2).

3.3. Residue levels in tomato fruits

Residue levels of AB+THIA in tomato fruits are showed in Table 3. In 2019, AB residue was below the detection limit, while THIA residue was 0.02 mg/kg. However, during 2020 the mean values of residue levels of AB and THIA were 0.02 and 0.09 mg/kg, respectively. It was remarked that the residue levels of AB and THIA during both seasons were below the MRL of each one.

3.4. Toxicological studies

3.4.1. Signs of toxicity

The results showed that no symptoms of toxicity, behavioural alterations, or mortality in the treatments during the experimental period were recorded.

3.4.2. Body weight alterations

The evaluated whole-body weights and relative liver and kidney weights of male rats administered AB+THIA mixture are shown in Tables 4 and 5. Table 4 shows that the weekly body weight of rats was significantly increased during the experimental period either in control or AB+THIA groups. An insignificant decline in body weight of AB+THIA treatment was recorded after 28 d, compared to the control group. Significant alterations in relative liver and kidney weights of rats exposed to AB+THIA were noticed (Table 5).

3.4.3. Biochemical responses

The obtained data showed that activities of serum γGT, LDH, ALT, AST and ALP significantly increased ($P \leq 0.05$) after AB+THIA treatment, with respect to untreated rats (control group) (Fig. 1). Regarding kidney functions, the treatment caused significant increases ($P \leq 0.05$) in creatinine, uric acid and urea levels, respect to control group (Fig. 2).

Table 1: Efficacy of AB+ THIA against adult stages of whitefly infesting tomato plants, (*Lycopersicon esculentum*) during season of 2019 and 2020

2019

Treatment	% Reduction at days after application (Mean ± SE)				mean of residual reduction	% Reduction at days after application (Mean ± SE)				mean of residual reduction	General mean of initial reduction	General mean of residual reduction
	First spray					Second spray						
	Initial (1day)	Residual 3	7	10		Initial (1day)	Residual 3	7	10			
Control	-	-	-	-	-	-	-	-	-	-	-	-
AB+THIA	85.4 ±3.1	85.2 ±4.2	85.9 ±4.4	85.2 ±5.0	85.4 ±0.2	81.3 ±6.3	93.4 ±1.2	92.2 ±1.0	81.2 ±1.3	88.9 ±3.9	83.3 ±4.6	87.1 ±2.7

2020

Treatment	% Reduction at days after application (Mean ± SE)				mean of residual reduction	% Reduction at days after application (Mean ± SE)				mean of residual reduction	General mean of initial reduction	General mean of residual reduction
	First spray					Second spray						
	Initial (1day)	Residual 3	7	10		Initial (1day)	Residual 3	7	10			
Control	-	-	-	-	-	-	-	-	-	-	-	-
AB+THIA	82 ±2.9	92.5 ±2.5	93.8 ±1.3	77.7 ±2.8	88 ±5.2	86.3 ±2.3	87.2 ±4.4	86.2 ±1.8	79.7 ±4.4	84.3 ±2.4	84.1 ±2.7	86.1 ±3.8

Table 2: Efficacy of AB+ THIA against immature stages of whitefly infesting tomato plants, (*Lycopersicon esculentum*) during season of 2019 and 2020

Treatment	% Reduction at days after application (Mean ± SE) First spray				mean of residual reduction	% Reduction at days after application (Mean ± SE) Second spray				mean of residual reduction	General mean of initial reduction	General mean of residual reduction
2019												
	Initial (1day)	Residual 3	7	10		Initial (1day)	Residual 3	7	10			
Control	-	-	-	-	-	-	-	-	-	-	-	-
AB+THIA	79.5 ±4.8	80.4 ±1.9	90.5 ±1.9	84.1 ±1.7	85.0 ±2.9	91.4 ±1.0	92.6 ±1.7	89.4 ±2.0	81.5 ±3.8	87.9 ±3.3	85.4 ±4.9	86.4 ±2.9
2020												
	Initial (1day)	Residual 3	7	10		Initial (1day)	Residual 3	7	10			
Control	-	-	-	-	-	-	-	-	-	-	-	-
AB+THIA	91.2 ±1.1	91.1 ±1.0	92.8 ±1.4	90.2 ±0.5	91.4 ±0.7	88.5 ±3.1	90.7 ±1.9	87.2 ±1.6	74.9 ±3.3	84.3 ±4.8	89.8 ±2.3	87.8 ±3.8

Values are expressed as means ± standard Error (SE).

Table 3: Residue levels of AB and THIA in tomato fruits after 29 days of the last application in the two seasons.

Season	Compound	Residue (mg/kg)	Remark
2019	AB	ND	-
	THIA	0.02	Below MRL
2020	AB	0.02	Below MRL
	THIA	0.09	Below MRL

ND=Not detected

Table 4: Effects of orally administration with AB+THIA mixture at MRL level for 1, 2, 3 and 4 weeks on body weight pattern in male rats.

Weeks after treatment	Control (g)	AB+THIA(g)	% Change*
0	175 ± 1.73^{c}	171 ± 5.57^{c}	2.34
1st	198.67 ± 9.33^{bc}	180.67 ± 7.88^{c}	9.06
2nd	216 ± 10.69^{ab}	201.67 ± 7.53^{b}	6.63
3rd	227 ± 13.51^{ab}	203.33 ± 3.33^{ab}	10.43
4th	243 ± 18.51^{a}	220.67 ± 1.77^{a}	9.19

- Each value represents the 5 replicates ± (SE), Values in column with different letters are significantly different at (P < 0.05),* % Change = (mean control groups – treatment / mean control groups) ×100.

Table 5: Body weight gain and relative weights of male rats after 4 weeks of exposure to AB + THIA mixture.

Treatments	Organ	Body weight gain (%)	Weight (g)	Relative weight (%)	% Change
Control	Liver	-38.86 ± 9.51	8.93 ± 0.97	3.68	-
AB+THIA		-29.05 ± 3.49	8.75 ± 0.37	3.97	-7.88
Control	Kidney	-38.86 ± 9.51	1.81 ± 0.18	0.75	-
AB+THIA		-29.05 ± 3.49	1.57 ± 0.06	0.72	4.00

Values are expressed as means (5 rats) ± standard Error (SE).
Percentage of increase (-) or decrease (+) in treatment weights compared to control

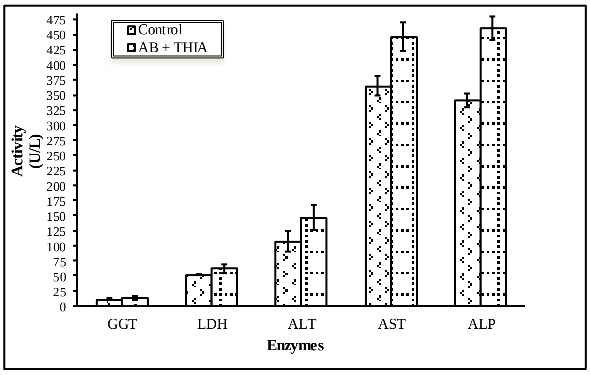

Fig.1. Effects of AB+ THIA mixture exposure for 28 d in liver function enzymes in male rats.

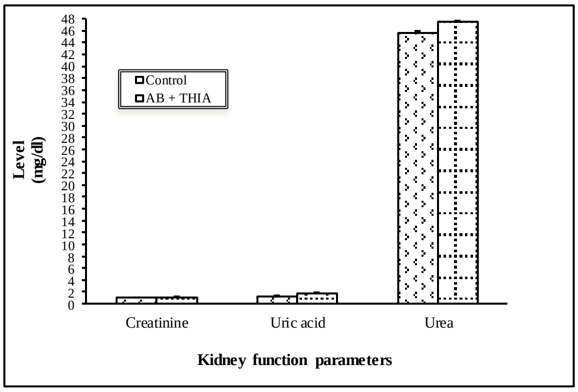

Fig.2. Effects of AB +THIA mixture exposure for 28 d in kidney function parameters in male rats

3.4.4. Histopathological defects

Treatmentof this mixture induced histopathological changes in the liver as observed in Lobular inflammation, focal lytic necrosis and Kuepfer cell hyperplasia (Fig. 3B) compared to control which has no histopathological alteration in hepato-section (Fig. 3A). On the other hand, band sections of treated rats showed atypical proliferation (ON) and tubular necrosis (Fig. 4B) compared with the control group (Fig. 4A).

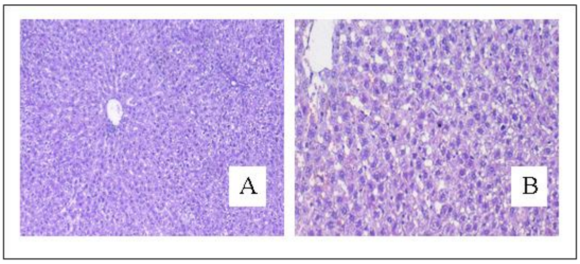

Fig. 3. Liver section photomicrographs of male rats treated with AB+THIA for 4 weeks (H &E, 100 and 200X: (A) Control and (B) AB+THIA groups

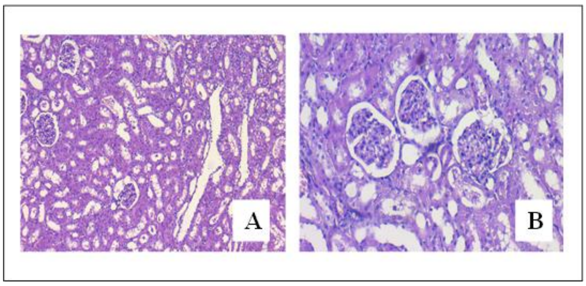

Fig. 4. Kidney section photomicrographs of male rats treated with AB+THIA for 4 weeks (H &E, 100 and 200X: (A) Control and (B) AB+THIA groups

4. Discussion

The mixture of AB+THIA is being applied extensively on many vegetables and fruits in order to control many pests in Egypt and worldwide. The present findings showed that the AB+THIA mixture gave high reduction percentages of adult and immature stages of *B. tabaci*. These data are in contrast with that obtained by Horowitz *et al*. [30], where the mixture of 18 g a.i/ha abamectin with 1% mineral oil decreased larval population levels of *B. tabaci* on cotton plants to a greater extent than the insecticide applied alone, resulting in 2.9 larvae per leaf at 27th d in the abamectin-oil mixture, respect to 9.6 and 14.6 larvae per leaf in the abamectin or mineral oil alone. Several researchers reported that OPs combined with pyrethroids had a synergistic effect against a number of pests [31,32]. For example, the combination of chlorpyrifos with either emamectin benzoate, indoxacarb or, spinosad showed a synergistic influence besides *Phenacoccus solenopsis* Tinsley (Hemiptera: Pseudococcidae) [33]. Abdel-Hamid *et al*. [34] reported that the combination of acetamiprid or thiamethoxam with chlorpyrifos at half recommended rate exhibited a great decline percentage of *Aphis gossypii* and *B. tabaci* in cotton plants ending to 100% at the same exposure time during seasons 2014 and 2015. Similar to the present results, Actara® binary mixtures with mineral oil had a highly significant effect on decreasing pests' population infesting eggplant growth and yield [35]. Ali and Zedan [36] reported that the mixture of emamectin benzoate+lambda-cyhalothrin proved to be superior achieving a reduction level 80.6% of the tomato leaf miner, *Tuta absoluta*. El-Sherbeni *et al*. [37] evaluated the efficiency of three insecticides mixed with salicylic acid (SA) on *A. gossypii*, and *B. tabaci* on a cotton field. They found that, the greatest actual mixture was profenofos at 75% of recommended dosage + SA at a concentration of 1 mM intended for aphids (reduction of 95.68%), and cyhalothrin at 75% of recommended dosage + SA (0.5 mM) intended for whiteflies (reduction of 88.00%). Mohsen *et al*. [38] assessed the potency of emamectin benzoate alone and combined with acetamiprid, (thiamethoxam+lambda-cyhalothrin) and hexaflumuron against 2nd instar larvae of *T. absoluta* (Meyrick). A Combination of emamectin benzoate with acetamiprid at the LC50 level gave synergistic action, but the others showed additive possessions. Kary *et al*. [39] recorded synergistic effects of the entomopathogenic nematode *Steinernema feltiae* when combine with low rates of abamectin against the potato tuber moth (PTM) *Phthorimaea opercullella*. In the case of *Heterorhabditis bacteriophora*, low concentrations of both the insecticide and the nematode showed synergistic effects.

Whole-body and organ weights of experimental animals are recognized as important criteria to evaluate pesticide toxicity [40]. Declines in body weight of AB+THIA-treated rats may be due to the decrease in food consumption (anorexia or food escaping), unfortunate food delectableness, or amplified degradation of lipids and protein due to treatment-related toxicity of pesticides [41]. The present data are in accordance with Abd-Elhady and Abou-Elghar [42] and El-Gendy *et al*. [43], where AB and THIA encouraged shifts in liver dysfunction parameters e.g. AST, ALT, and γGT. Histopathological defects in the liver tissues of male and female rats were noticed [44].

The present findings suggest that both pesticides significantly disrupt normal hepatic and renal functions in the treated rats, which are used as biomarkers for pesticides in association with liver or kidney damage. There is a link between the increased activity of these measurements and reduced antioxidant ability in the rats. The increased serum enzyme activities may be attributed to the significant tissue injury proved by pesticides, even at low doses. When the liver or kidney cell plasma membrane is damaged, a variety of enzymes normally located in the cytosol are released into bloodstream.

Regarding histopathological investigations, Mohssen [45] reported that the histopathological examinations in animal tissues are a delicate and express process, frequently conducted to identify and approve the effects of pesticides on various tissues and organs. Hepatic-impact of xenobiotics such as pesticides is recognized via the portal vein in the liver as the first organ exposed to substances greatest others. It contains highly active metabolic tissue which is reliable as a detoxication structure. The kidney seems to be mainly delicate to a diversity of toxins independent on great renal blood flow, the capability to uptake substances and the biotransformation of the parent compound to water-soluble metabolites. The present data of histopathological alterations in hepatic and renal tissues after AB+THIA treatments are in parallel with that obtained by Mahmoud and Mahmoud [14], Khaldoun-Qularbi, *et al* [44] and El-Gendy *et al* [43]. These alterations are completely reliable with the variations in numerous measurements that were achieved in the liver or kidney. Several mechanisms have been identified for cell injury in three different ways: inhibition of fatty acid beta-oxidation, inhibition of respiratory enzymes or by a direct effect on mitochondrial DNA [46].

5. Conclusion

From the present study, it can be concluded that the AB+THIA mixture was effective against immature and adult stages of *B. tabaci* under field conditions. This mixture which has a different mode of action is unique to the actual conduct to decline the progress of insecticide resistance toward whitefly populations. In a toxicological study, the sub-acute repeated dose of AB+THIA mixture for 28 d at MRL of each pesticide caused significant harmful effects in the different biochemical parameters (liver and kidney functions) besides the histological changes of male rats. Such this mixture may provide an alternative method to increase efficacy and low residue limits after harvesting tomato fruits.

6. Funding information

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

7. Compliance with ethical standards

The experiments have been carried out in accordance with the European Ethical Guidelines [47].

8. Declaration of Conflicting of Interest

The authors declare that no potential conflicts of interest with respect to the research, authorship and/or publication of this article.

9. Supplementary data

No supplementary data are provided.

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