Full Length Research Article

The effect of deltamethrin insecticide on oxidative stress and liver function in albino male rats and the protective role of citrus peel extraction

https://doi.org/10.62940/als.v13i1.2448

Issue: Volume 13, Issue 1

Received: 14-12-2024

Revised: 01-12-2025

Accepted: 14-01-2026

Published online: 31-03-2026

Keywords: Deltamethrin toxicity, Oxidative stress, Citrus peel extracts, Liver and testicular protection, Biochemical markers

Hind Bahjat Mohammed Aldik[1,2,*], **Adel H. Talib**[1]

1. Department of Biology, College of Science for Women, University of Baghdad, Baghdad, Iraq
2. General Directorate of Education Baghdad Rusafa, Baghdad, Iraq

* Hind.Bahjat1102a@csw.uobaghdad.edu.iq

ABSTRACT

Background: The study investigates the protective effects of citrus peel extracts (mandarin and lemon) against deltamethrin- induced liver and testicular toxicity in male rats.

Methods: Forty-two male rats were divided into 7 groups: Group I (control), Group II (deltamethrin 6 mg/kg), Group III (deltamethrin + mandarin extract), Group IV (deltamethrin + mandarin oil), Group V (deltamethrin + lemon extract), Group VI (deltamethrin + lemon oil) and Group VII (deltamethrin + mandarin + lemon extract). The liver functions and oxidative stress were evaluated by testing biochemical markers (AST, ALT, ALP, SOD and MDA). Evaluation of tissue injury included histopathology of liver and testis.

Result: In Group II, Deltamethrin treatment alone increased AST (198.36 U/L), ALT (123.02 U/L), ALP (97.35 U/L), and MDA (83.92 nmol/mL) and decreased SOD (4.72 U/mg) indicating oxidative stress and subsequent tissue damage due to Deltamethrin. In Groups III-VII, the use of citrus peel extracts improved all measured biochemical markers compared to Deltamethrin alone. Group III decreased AST levels to 180.55 U/L, ALT to 114.75 U/L, ALP to 95.49 U/L, and MDA to 75.97 nmol/mL, with SOD levels increasing to 5.95 U/mg. Other treatment groups also showed similar biochemical improvements. The greatest improvement was observed in Group VII (mandarin + lemon extract), showing a decreased AST (162.50 U/L), ALT (85.04 U/L), ALP (90.36 U/L), and MDA (54.98 nmol/mL) as well as an increase in SOD recovery (7.39 U/mg).

Conclusion: The extracts of citrus peel reduced liver and testicular toxicity from deltamethrin exposure. The mixture of mandarin and lemon extract produced the most protective ability, due to restoring antioxidant imbalance and reducing biochemical and histological damage. These findings indicate that citrus peel extracts could be a potential natural agent against oxidative stress elicited by pesticide exposure.

INTRODUCTION

Deltamethrin is a widely used synthetic pyrethroid insecticide with various applications in agriculture, pest control, food protection, and disease vector management in both public and animal health programs [1-5]. Deltamethrin is metabolized in rats and its metabolites eliminated over a few days. Prior studies have demonstrated that deltamethrin produces dose-dependent biochemical effects on male Wistar rat testis, liver, and kidney tissues, indicating both systemic toxicity and organ-specific effects [6]. The study found that deltamethrin exposure significantly increased lipid peroxidation (LPO) level in the liver and caused histological alterations in the liver. The study concluded that the system toxicity induced by deltamethrin was dose dependent. Another study investigated the toxicokinetics and tissue distribution of deltamethrin in adult Sprague-Dawley rats [7]. The study found that deltamethrin is rapidly absorbed and eliminated from the body, primarily through urine and feces, after oral administration in rats. A study investigated the metabolism of deltamethrin in rats. The study found that deltamethrin is metabolized into 3-phenoxybenzoic acid (PBacid) in vivo, and PBacid is also the major metabolite when 14C-alcohol-labeled deltamethrin is incubated with rat liver microsomes [7]. Deltamethrin's metabolism necessitates the oxidation of the alcohol moiety at position 4 of the phenoxy ring. Further conversion into conjugated metabolites occurs with the acid and alcohol moieties produced. Deltamethrin's considerable stability during metabolism is reflected in the fact that it is largely eliminated in the feces in its original form [4, 8]. It has been known that cytochrome P450 (CYP) enzymes are activated in the rat brain and liver to metabolize it on exposure to deltamethrin, implying that ROS production during deltamethrin metabolism may be contributing to oxidative stress. However, data shows that exposure to deltamethrin may have adverse effects on fertility. Since mammalian sperm plasma membranes are rich in polyunsaturated fatty acids and have limited antioxidant defenses, they are susceptible to damage by reactive oxygen species (ROS). Sperm cells may be damaged and rendered sterile by lipid peroxidation of sperm cells. To determine the dose dependent toxicity of deltamethrin to the testis, liver and kidney of male Wistar rats, a study was conducted [9]. The study also showed that deltamethrin is important and it induced sperm abnormalities and lipid peroxidation (LPO) in the testis besides inducing histological changes in the testis, liver and kidney. Based on the results of the study, the system toxicity of deltamethrin was depicted as a function of dose. Another study was designed to investigate the impact of deltamethrin on oxidative stress and meiotic maturation in mouse oocytes [10]. It was concluded from the results of the study that deltamethrin exposure caused oxidative stress and affected meiotic maturation of mouse oocytes. Similarly, an alternative study was conducted to investigate the oxidative stress and biochemical changes in tissues and blood of catfish (Clarias gariepinus) exposed to deltamethrin [11]. The study established that deltamethrin led to an increase in the level of Malondialdehyde (MDA), a lipid peroxidation product, in the liver, kidney and gills and decreased the activity of catalase in the same tissues. Moreover, the present study demonstrates that deltamethrin exposure caused increased activities of serum ALT and AST, urea and creatinine and decreased levels of serum albumin and total proteins; thus, deltamethrin induces hepatic dysfunction.

This research was conducted to establish the differences between the effects of deltamethrin administration with and without citrus peel extracts (mandarin oil, lemon oil, lemon extract, and mandarin extract) with emphasis being given to the liver. Mandarin oil and lemon oil are some of the citrus oils which are derived from the peel and are rich in bioactive compounds such as antioxidants, flavonoids, and polyphenols. These compounds are very good antioxidants and can scavenge and neutralize free radicals and reactive oxygen species (ROS). We had earlier suggested that the oxidative stress resulting from the ROS generated during the metabolism of deltamethrin may have adverse effects on the liver function and other biochemical markers in rats. This study was conducted to establish if it was possible to minimize the toxicity of deltamethrin to the liver and other biochemical indicators by administering it with extracts from citrus peels, which are known to have beneficial components. In order to preserve the liver and make it function normally, it is thought that the antioxidants present in the citrus peel extracts can chelate the oxidative stress that is being caused by the deltamethrin. The general aim of the study was to explain how the product of deltamethrin and the bioactive compounds present in the citrus peel extracts affect liver function and other biochemical parameters in the rat model. These results may be helpful in understanding the role of antioxidant rich natural products in the management of risk associated with exposure to specific pesticides and overall health. However, for a better understanding of the specific mechanisms involved and to be sure of the safety and optimal usage of both deltamethrin and citrus peel extracts, further investigation and more detailed studies are clearly required.

METHODS

Experimental animals

Forty-two normal male rats were used for the study; their ages were between 8-10 weeks and weighed between 120–180 g. The rats were randomly placed into groups of six rats each for a total of seven treatment groups (n = 6).

Housing and environmental conditions

The rats were kept in plastic cages, one rat per cage, with 12 h light / 12 h dark cycle. The room temperature was maintained, and the relative humidity was between 40 and 60%. Standard pellets and water were available ad libitum to the rats throughout the study.

Group allocation and treatment

After a one-week acclimatization period, rats were randomly assigned to one of seven treatment groups (six rats per group): 1. Group I (Control): Rats in this group were orally treated with normal saline for five weeks. 2. Group II (Deltamethrin): Rats in this group were orally treated with deltamethrin at a dose of 6 mg/ kg body weight (BW) for five weeks. 3. Group III (Deltamethrin + Mandarin extract): Rats in this group were orally treated with deltamethrin (6 mg/kg BW) with mandarin extract for five weeks. 4. Group IV (Deltamethrin + Mandarin oil): Rats in this group were orally treated with deltamethrin (6 mg/ kg BW) with mandarin oil for five weeks. 5. Group V (Deltamethrin + Lemon extract): Rats in this group were orally treated with deltamethrin (6 mg/ kg BW) with lemon extract for five weeks. 6. Group VI (Deltamethrin + Lemon oil): Rats in this group were orally treated with deltamethrin (6 mg/kg BW) with lemon oil for five weeks. 7. Group VII (Deltamethrin + Mandarin + Lemon extracts): Rats in this group were orally treated with deltamethrin (6 mg/ kg BW) with a mix of mandarin and lemon extracts for five weeks.

Sampling and data collection

The rats were fasted overnight at the end of the five-week treatment period and euthanized by decapitation. Blood samples were collected from the abdominal aorta with no anticoagulant for biochemical analysis. Serum was analysed for AST, ALT, ALP, SOD, and MDA. Liver samples were collected for tissue histopathology and enzyme analyses.

Statistical analysis

Quantification of serum aspartate aminotransferase (AST), alanine aminotransferase (ALT), alkaline phosphatase (ALP), superoxide dismutase (SOD), and malondialdehyde (MDA) was performed using commercial ELISA kits. AGAPPE, India, supplied the ALT and ALP ELISA kits used in this study, and SUNLONG, China, supplied the rat SOD and MDA ELISA kits. The kits gave accurate, precise, reliable biomarker measurements, providing vital information on deltamethrin and mixed citrus peel extract effects on male rat liver health. Data were expressed as mean ± standard deviation (SD) for each group (n = 6). Statistical comparisons among groups were performed using one- way analysis of variance (ANOVA), and differences were considered statistically significant at $p < 0.05$.

RESULTS

Deltamethrin and combined Citrus peel extract effect on the levels of serum AST, ALT and ALP

This study sought to assess the effects of citrus peel extract on deltamethrin-exposed male rat livers. AST, a liver injury marker, was measured. Table 1 shows deltamethrin significantly increased AST levels. The control group AST was 146.66 U/L. The deltamethrin alone group had the highest AST, 198.36 U/ L. Citrus peel extracts, including mandarin oil and lemon, in combination with deltamethrin, altered AST levels. The deltamethrin- mandarin extract group AST was 180.55 U/L, while the deltamethrin-mandarin oil group had 179.65 U/L. The AST of the deltamethrin- lemon extract group was 174.46 U/ L, whereas the deltamethrin- lemon oil group had an AST level of 170.3 U/ L. The deltamethrin, mandarin, and lemon extracts group had the lowest AST, 162.5 U/L.

The impact of deltamethrin and citrus peel extracts on rat serum alanine aminotransferase (ALT) levels was studied; the outcomes of which are stated in Table 1. The control group that received no treatment had a baseline ALT level of 69.91 U/ L. However, the group that only received deltamethrin had the highest ALT level of 123.02 U/ L. Upon administration of deltamethrin in combination with mandarin extract, the ALT level decreased to 114.75 U/L, while the group treated with deltamethrin and mandarin oil showed an ALT level of 112.96 U/ L. Interestingly, the co-administration of deltamethrin with lemon extract led to a further decrease in ALT levels, measuring 99.22 U/ L, while the group treated with deltamethrin and lemon oil exhibited an ALT level of 98.18 U/ L. Lastly, the group treated with deltamethrin, mandarin, and lemon extracts altogether showed the minimum amount of ALT, which was 85.04 U/L.

Alkaline phosphatase (ALP) in rats was also examined to determine deltamethrin and citrus peel extract impacts. The results are shown in Table 1. When rats were treated only with deltamethrin, the ALP levels were found to be higher (97.35 U/L) compared to the control group (88.83 U/ L) that received no treatment. This indicates that deltamethrin alone had an effect on increasing ALP levels. However, when deltamethrin was administered in combination with citrus peel extracts, particularly mandarin and lemon extracts, the ALP levels showed a decrease. For instance, the group treated with deltamethrin and mandarin oil exhibited an ALP level of 93.55 U/ L, which is lower than the ALP level in the group treated with deltamethrin alone. Similarly, when deltamethrin was given to rats along with mandarin extract or lemon extract, ALP level dropped even further to 95.49 U/ L and 92.16 U/ L, respectively. Furthermore, the group treated with a combination of deltamethrin, mandarin, and lemon extracts simultaneously demonstrated the most significant reduction in ALP levels, measuring 90.36 U/L.

This study measured the levels of superoxide dismutase (SOD) in male rats to see how deltamethrin and citrus peel extracts influenced them. Table 1 displays the major and engaging findings from the study. To begin, when compared to the untreated control group, SOD levels were significantly lower in the rats that received just deltamethrin (4.72 U/mg protein vs. 7.353 U/mg protein). As a result, it appears that deltamethrin may be able to inhibit SOD activity when used alone. Deltamethrin was shown to have the opposite effect when combined with citrus peel extracts, especially those of the mandarin and lemon varieties. The SOD levels were significantly elevated by the combination of deltamethrin, mandarin, and lemon extracts, measuring 7.398 U/mg. The SOD levels of those given deltamethrin and mandarin extract were 5.952 U/mg, whereas those given deltamethrin and mandarin oil showed a level of 6.793 U/mg. The SOD levels of the group treated with deltamethrin and lemon extract were 6.691 U/ mg, whereas the SOD levels of the group treated with deltamethrin and lemon oil were 7.509 U/mg. As supported by the data, the SOD restoring effect of citrus peel extracts is enhanced when combined with mandarin and lemon extracts or oils in male rats. These outcomes are helpful in understanding the potential of citrus peel extracts in protecting against oxidative stress induced by deltamethrin.

An experiment was carried out to establish the effects of deltamethrin and citrus peel extracts on rats' serum malondialdehyde (MDA) levels as shown in (Table 1). Malondialdehyde is a marker of oxidative stress and may be used to signal the potential for harm to the body's cells. The MDA level was measured at 50.55 nmol/mL in the control group that received no treatment. When rats were exposed to deltamethrin alone, their MDA levels were found to be significantly higher at 83.92 nmol/ mL than in the untreated control group. This means that deltamethrin on its own increased MDA levels (oxidative stress). However, the study also included the use of deltamethrin which, when used with citrus peel extracts, especially mandarin and lemon extracts, lowered MDA levels as compared to the group that only received Deltamethrin. For instance, the rats that were fed deltamethrin and mandarin extract had a lower MDA level of 75.97 nmol/ mL than the deltamethrin alone group. Likewise, the other groups that received deltamethrin with mandarin oil or lemon extract had still lower MDA levels of 73.66 and 64.61 nmol/ mL respectively. The highest MDA level drop was observed in the group that received deltamethrin, mandarin and lemon extracts, where MDA levels were 54.98 nmol/mL.

Histological study

The results of the histological study of the liver and testes of male rats treated with (6 mg/ kg BW) deltamethrin over a period of five weeks revealed as follows:

Histological change of the rat's liver

The histological changes in male rats' liver after five weeks of daily administration of deltamethrin (6 mg/kg BW) revealed a marked necrosis in the liver cells, destroyed hepatocytes, a dilated sinusoidal network, and bleeding. In addition, the section showed the existence of obvious inflammatory leucocyte infiltration composed mainly of lymphocytes (rounded cells), as shown in Figure 1, in comparison with the control liver section, which showed normal histological characteristics of hepatocytes, sinusoidal networks, and the central vein, as shown in Figure 1a. However, when plant extracts were used (Mandarin extract, Lemon Extract, Mandarin oil, Lemon oil and Mandarin-Lemon Extract combination), they showed a protective effect and normal histological structure of the central vein and sinusoidal networks (Figure 1.b-g).

Figures

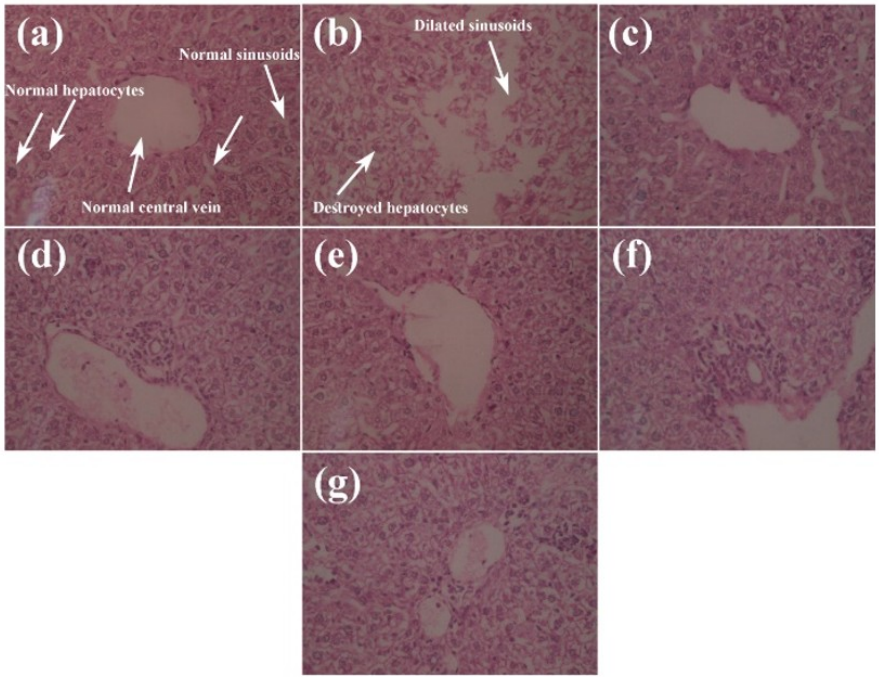

Figure 1: Histopathological section of (a) control group, (b) deltamethrin group, (c) deltamethrin treated with mandarin extract group, (d) deltamethrin treated with Lemon extract group, (e) deltamethrin treated with mandarin oil group, (f) deltamethrin treated with lemon oil group and (g) deltamethrin treated with mandarin and lemon extract group.

Tables

Samples	AST U/L	ALT U/L	ALP U/L	SOD (U/mg protein)	MDA nmol/mL
Group I	146.66±6.86	69.91±5.8	88.83±5.98	0.457±7.353	50.55±3.49
Group II	198.36±21.29	123.02±9.3	97.35±9.64	4.72±0.518	83.92±3.53
Group III	180.55±11.78	114.75±7.26	95.49±7.4	5.952±0.491	75.97±4.7
Group IV	179.65±11.94	112.96±8.73	93.55±8.64	6.793±0.547	73.66±4.93
Group V	174.46±12.51	99.22±7.21	92.16±10.13	6.691±0.519	64.61±5.04
Group VI	170.3±13.03	98.18±7.22	91.12±7.4	7.509±0.571	58.92±5.67
Group VII	162.5±10.5	85.04±7.84	90.36±10.92	7.398±0.549	54.98±5.36

Table 1: Deltamethrin exposure and citrus peel extract effects on serum enzymes (ALT, AST, ALP) and antioxidant enzymes (SOD, MDA) were assessed in rats. Group I was control; Group II was treated with deltamethrin alone; Groups III-VII were treated with various combinations of deltamethrin and citrus peel extract.

DISCUSSION

These findings suggest that citrus peel extracts, particularly lemon and mandarin, may possess

hepatoprotective properties, as evidenced by the potential mitigation of deltamethrin-induced liver dysfunction. AST level change reflects the potential advantages of these extracts in liver health maintenance under deltamethrin exposure. The AST levels in male rats were measured after deltamethrin treatment; the impacts of citrus peel extracts were further explored. Mandarin and lemon extracts have hepatoprotective effects, possibly inducing the reduction in AST level. Antioxidants in mandarin and lemon extracts eliminate deltamethrin-induced ROS, alleviating oxidative stress in liver cells. The anti-inflammatory action of these extracts alleviates liver inflammation, reducing AST production. In addition, active compounds in the extracts promoted liver repair and detoxification, alleviating deltamethrin-induced liver injury severity. Combined use potentially synergizes liver-protecting components of mandarin and lemon extracts. The current study provides evidence for therapeutic value of citrus peel extracts, which have been shown to alleviate deltamethrin-related liver injury [12-15].

The lower ALT levels observed in the citrus peel extract-treated groups indicate that these may have protective effects from deltamethrin induced hepatocellular injury. The protective effect of the citrus peel extracts may be due to the bioactive constituents of the lemon and mandarin peels (flavonoids, phenolic compounds, vitamin C), which are known antioxidants with anti-inflammatory effects. These bioactive constituents may decrease oxidative stress and inflammatory response due to deltamethrin thus stabilizing hepatocyte membranes and preventing release of these enzymes into serum.

The combination extract (mandarin + lemon) exhibited the largest decrease in ALT levels, this may indicate a synergistic effect of phytochemicals present in the lemon and mandarin fruit interacting with one another. Synergistic effects have been documented in a polyphenol rich plant extract mixture, which exhibited a combined antioxidant capacity with stronger free radical stopping and lipid peroxidation effects than any individual extract. This may also account for the hepatoprotective effects observed in Group VII [15]. Secondly, the lowest levels of ALT were noted when the rats were administered deltamethrin with mandarin and lemon extracts at the same time. The reasons for this are most probably the capability of the extracts to complement one another well to offer liver protection from deltamethrin toxicity. Although more study should be done to discern the precise mechanisms by which the citrus peel extracts complement and enhance liver functionality despite deltamethrin treatment, the result holds great promise for the use of such extracts [12, 16, 17].

The decrease in ALP levels following the treatment of rats with a combination of deltamethrin, mandarin, and lemon extracts can be attributed to the potential synergistic effect of these compounds on the enzymatic processes and metabolic pathways of the liver, a number of reasons can be responsible for this effect: Deltamethrin is a synthetic pyrethroid insecticide that is metabolized and detoxified in the liver. Mandarin and lemon extract mixtures can induce liver detoxification, enabling more efficient deltamethrin and metabolite breakdown and elimination. This would minimize deltamethrin's toxic impact on ALP release and production [18]. Mandarin and lemon extracts include various hepatoprotective bioactive compounds. These compounds can defend liver cells from deltamethrin-like chemical toxicity. By maintaining liver integrity, citrus extracts can minimize ALP release into the blood [16, 19]. In addition, citrus peel extracts are well known for anti-inflammatory and antioxidant activities, counteracting deltamethrin-induced inflammation and oxidative stress. This may account for overall liver function recovery, leading to decreased ALP levels [20, 21].

Deltamethrin alone caused the superoxide dismutase level to reduce in rats, indicating that the chemical induces oxidative stress [22]. Deltamethrin, a synthetic pyrethroid insecticide, is also said to generate reactive oxygen species (ROS) upon application in controlling insects [23]. Destruction of cells and tissue by reactive oxygen species (ROS) may be responsible for the lowering of the enzyme SOD activity [6]. Superoxide radicals are the most widespread and most toxic of the types of ROS and are opposed by the enzyme SOD. Deltamethrin alone did not enhance SOD levels, but it did so when combined with citrus peel extracts, especially those from mandarin and lemon. Flavonoids, phenolic acids, and vitamin C are just a few of the many bioactive chemicals found in citrus peel extracts that give it its antioxidant capabilities [24, 25]. These substances can scavenge ROS and prevent oxidative stress in cells. Therefore, the antioxidant qualities of mandarin and lemon extracts, when mixed with deltamethrin, presumably counteracted the detrimental effects of deltamethrin-induced ROS, resulting in an increase in SOD levels. In addition, increased SOD levels were seen when deltamethrin was combined with citrus peel extracts. The significant increase in SOD activity seen here shows that the synergistic antioxidant effects of the citrus peel extracts were even more effective than

each alone in reducing the oxidative stress brought on by deltamethrin.

Deltamethrin's ability to generate oxidative stress in the body explains why the substance alone raised malondialdehyde (MDA) levels in treated rats. Deltamethrin, a synthetic pyrethroid pesticide, can cause oxidative stress by producing free radicals and reactive oxygen species, which in turn can harm cells and raise levels of malondialdehyde (MDA) [9, 11, 26, 27]. Deltamethrin alone has been shown to cause oxidative damage, however, when combined with mandarin and lemon extracts, this damage is mitigated. Antioxidants and polyphenols, two types of bioactive substances found in citrus peel extracts, can neutralize free radicals and alleviate oxidative stress in the body. These extracts, when given alongside deltamethrin, may mitigate the insecticide's deleterious effects, resulting in lower levels of malondialdehyde (MDA). Deltamethrin and the antioxidant capabilities of mandarin and lemon extracts work together synergistically to reduce oxidative stress and lipid peroxidation in the rats [28, 29].

Severe necrotic, inflammatory and degenerative changes in liver and testis tissues were induced by Deltamethrin as revealed by histopathology. These results indicate that citrus extracts can enhance the recovery of tissue structure and mandarin and lemon extracts are promising natural shields against chemical toxicity and thus can be used in the treatment of oxidative stress and tissue damage.

CONFLICT OF INTEREST

There is no conflict of interest in the authors' decision to publish this work.

AUTHOR CONTRIBUTIONS

Hind Bahjat Mohammed Aldik: (Conceptualization, review & editing, supervision, project administration, data curation, methodology, and formal analysis). Adel H. Talib: (Writing original draft, resources, and investigation).

ACKNOWLEDGMENT

The authors would like to express sincere gratitude to the Department of Biology, College of Science for Women, University of Baghdad, Baghdad, Iraq, for providing the necessary facilities and support throughout the course of this research. Additionally, heartfelt thanks are extended to the General Directorate of Education Baghdad Rusafa, Baghdad, Iraq, for their ongoing support.

REFERENCES

1. Abd Al-Zahra S, Najim NH. Determination of insecticide Deltamethrin residues in local and imported raw milk samples collected from different animal species and the effect of processing heat treatment on its content in milk. The Iraqi Journal of Veterinary Medicine, (2017); 41(1): 49-54.
2. Jawad BM, Musa TN, Ali AJ. Determination of Deltamethrin residues in mandarin orange and studying its physiological effects on male mice blood profile. Iraqi Journal of Agricultural Sciences, (2018); 49(6): 1160-1167.
3. Abass EH, Zair SK, Mohammud TK, Nagem SA. Recovery of pure hesperidin from Iraqi sweet orange peel and study of its effect on some bacteria. Baghdad Science Journal, (2014); 11(2): 455-460.
4. Najim NH, Ali AH. Deltamethrin residues in imported and locally produced butter, cream, and soft cheese in the south of Baghdad city. The Iraqi Journal of Veterinary Medicine, (2017); 41(1): 86-91.
5. Faraj AA, Al-Amery AM. Microscopic and molecular diagnosis of Ascaridia spp. in domestic pigeons (Columba livia domestica) in Baghdad city, Iraq. The Iraqi Journal of Agricultural Science, (2020); 51(4): 1220-1225.
6. Sharma P, Singh R, Jan M. Dose-dependent effect of deltamethrin in testis, liver, and kidney of Wistar rats. Toxicology International, (2014); 21(2): 131.
7. Kim KB, Anand SS, Kim HJ, White CA, Bruckner JV. Toxicokinetics and tissue distribution of deltamethrin in adult Sprague–Dawley rats. Toxicological Sciences, (2008); 101(2): 197-205.
8. Anand SS, Bruckner JV, Haines WT, Muralidhara S, Fisher JW,
9. Lu Q, Sun Y, Ares I, Anadón A, Martínez M,
10. Jia ZZ, Zhang JW, Zhou D, Xu DQ, Feng XZ. Deltamethrin exposure induces oxidative stress and affects meiotic maturation in mouse oocyte. Chemosphere, (2019); 223(2019): 704-713.
11. Amin KA, Hashem KS. Deltamethrin-induced oxidative stress and biochemical changes in tissues and blood of catfish (Clarias gariepinus): antioxidant defense and role of alpha-tocopherol. BMC veterinary research, (2012); 8(2012): 1-8.
12. Pantsulaia I, Iobadze M, Pantsulaia N, Chikovani T. The effect of citrus peel extracts on cytokines levels and T regulatory cells in acute liver injury. BioMed research international, (2014); 2014(1): 127879.
13. Huang CH, Hsiao SY, Lin YH, Tsai GJ. Effects of fermented citrus peel on ameliorating obesity in rats fed with high-fat diet. Molecules, (2022); 27(24): 8966.
14. Putri H, Nagadi S, Larasati YA, Wulandari N, Hermawan A. Cardioprotective and hepatoprotective effects of Citrus hystrix peels extract on rats model. Asian Pacific Journal of Tropical Biomedicine,

(2013); 3(5): 371-375.
15. Hu M, Zhang L, Ruan Z, Han P, Yu Y. The regulatory effects of citrus peel powder on liver metabolites and gut flora in mice with non-alcoholic fatty liver disease (NAFLD). Foods, (2021); 10(12): 3022.
16. Chen SY, Chyau CC, Chu CC, Chen YH, Chen TH,
17. Omar AA, Gad MF, Refaie AA, Abdelhafez HM, Mossa AT. Benchmark dose approach to DNA and liver damage by chlorpyrifos and imidacloprid in male rats: The protective effect of a clove-oil-based nanoemulsion loaded with pomegranate peel extract. Toxics, (2023); 11(7): 569.
18. Kong Y, Li M, Shan X, Wang G, Han G. Effects of deltamethrin subacute exposure in snakehead fish, Channa argus: Biochemicals, antioxidants, and immune responses. Ecotoxicology and Environmental Safety, (2021); 209(2021): 111821.
19. Jaiswal SK, Gupta VK, Siddiqi NJ, Pandey RS, Sharma B. Hepatoprotective effect of Citrus limon fruit extract against carbofuran-induced toxicity in Wistar rats. Chinese Journal of Biology, (2015); 2015(1): 686071.
20. Gosslau A, Chen KY, Ho CT, Li S. Anti-inflammatory effects of characterized orange peel extracts enriched with bioactive polymethoxyflavones. Food Science and Human Wellness, (2014); 3(1): 26-35.
21. Malik A, Najda A, Bains A, Nurzyńska-Wierdak R, Chawla P. Characterization of Citrus nobilis peel methanolic extract for antioxidant, antimicrobial, and anti-inflammatory activity. Molecules, (2021); 26(14): 4310.
22. Saoudi M, Badraoui R, Bouhajja H, Ncir M, Rahmouni F,
23. Küçükler S, Kandemir FM, Özdemir S, Çomaklı S, Caglayan C. Protective effects of rutin against deltamethrin-induced hepatotoxicity and nephrotoxicity in rats via regulation of oxidative stress, inflammation, and apoptosis. Environmental Science and Pollution Research, (2021); 28(2021): 62975-62990.
24. Saleem M, Durani AI, Asari A, Ahmed M, Ahmad M,
25. Li P, Yao X, Zhou Q, Meng X, Zhou T,
26. Arnberg M, Refseth GH, Allan IJ, Benedetti M, Regoli F,
27. Adaay MH, Mattar AG. Effect of aqueous and ethanolic extracts of Tribulus terrestris, Phoenix dactylifera, and Nasturtium officinale mixture on some reproductive parameters in male mice. Baghdad Science Journal, (2012); 9(4): 640-650.
28. Montero L, Schmitz OJ, Meckelmann SW. Chemical characterization of eight herbal liqueurs by means of liquid chromatography coupled with ion mobility quadrupole time-of-flight mass spectrometry. Journal of Chromatography A, (2020); 1631(2020): 461560.
29. Amiri Resketi M, Yeganeh S, Jani Khalili K. Dietary sour lemon (Citrus limon) peel essential oil supplementation for reduction of deltamethrin-induced stress in rainbow trout (Oncorhynchus mykiss). Journal of the World Aquaculture Society, (2021); 52(1): 105-123.