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Research Article

Dietary Protective Influence of *Petroselinum crispum* Nanoparticles on Some Biochemical, Reproductive Hormones, and Physiological Biomarkers of Female *Clarias gariepinus* (Burchell, 1822) Exposed to Bisphenol A Toxicity

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The current study is a pioneer trial to verify the effectiveness of *Petroselinum crispum* (parsley) nanoparticles (PNPs) for fortifying physiological and biochemical biomarkers in female African catfish postexposure to bisphenol A (BPA) toxicity. The aim of this experiment is to verify the influence of PNPs for mitigating serum hemato-biochemical alterations as well as antioxidant enzyme, and hormonal changes induced by BPA toxicity in the hepatic and ovarian tissues. Fish were equally allocated into four groups: group I as a control without any treatments, group II received a commercial diet + PNPs (4 g/kg diet). In group III, fish were subjected to 1/10 LC50 (BPA) (1.43 μg/L), while in group IV, fish got 1/10 LC50 BPA (1.43 μg/L) + PNPs (4 g/kg diet) for 60 consecutive days. Exposure to BPA showed macrocytic hypochromic anemia and leukopenia, and a noticeable elevation in glucose, alanine amino-transferase (ALT), aspartate aminotransferase (AST), ALP, urea, creatinine, cortisol, cholesterol, and testosterone (T) hormone. Furthermore, serum AchE, estradiol (E2), follicle-stimulating hormone (FSH), luteinizing hormone (LH), globulin,

albumin, and total proteins were significantly decreased in a BPA-exposed group. Alternatively, activities of superoxide dismutase (SOD), lipid peroxidation (LPO), and catalase (CAT) were notably augmented in the hepatic tissue and ovaries of the BPA-supplemented fish. While total antioxidant capacity (TAC) and reduced glutathione (GSH) levels decreased in the equal tissues of exposed fish. PNPs-supplemented diets in combination with BPA alleviated its destructive effects on the tested parameters. In conclusion, the results proved that BPA is an endocrine hormonal disruptor that induces imbalances in blood profile, hepato–renal indicators, and stress parameters, besides the occurrence of oxidative damage and reproductive dysfunction. Interestingly, PNPs have a protective role in attenuating BPA toxicity and modulating all the measured biomarkers, as well as improving the fertility of female *Clarias gariepinus*.

Keywords: African catfish; biochemical parameters; bisphenol A; *Petroselinum crispum* nanoparticles; reproductive hormones

1. Introduction

Aquaculture faces the risk of microplastic pollution. Among them, bisphenol A (BPA) is broadly utilized and enters various chemical industries, including the manufacturing of containers, pipes, lenses, electronics, and kids' toys [1–3]. BPA finds its way to the aquatic environment through numerous sources, such as factory effluents, landfill locations, and plastic wastes [4–6]. BPA is considered a threat to aquatic animals' population sustainability and food safety due to its harmful effects on living organisms. Such effects include genotoxicity and endocrine disruption. It has been recently reported that BPA exerts antiandrogen action and estrogen-like effects, which negatively influence the immune system, reproductive mechanism, and neuroendocrine process [7]. Recent reports assume the gradual substitution of BPA with safer analogs in plastics industry [6, 8–10].

Herbal remedies are currently used as safe natural compounds in aquaculture owing to their beneficial properties, including ameliorating toxicity, promoting growth, enhancing immune-antioxidant response in fishes [11–14]. Among herbals, *Petroselinum crispum* (parsley), belonging to the Umbelliferae family, has a Mediterranean origin and has been spread throughout the world [15]. Parsley leaves are a source of essential oils and a combination of active antioxidant ingredients as flavonoids, oleic acid, α-pinene, D-limonene, and myristicin [16]. In aquaculture practice, they have a potential role in regulating gastrointestinal health and alleviating toxicity, plus they have anticoagulant and anti-inflammatory activities [17, 18]. Recently, nano herbal preparations have become well known in aquaculture for their amelioration of toxicity, growth enhancement, and immunostimulation [19, 20]. Dietary supplementation of *P. crispum* has been reported either as a plant or in the form of NPs to alleviate ZnO-NPs and Bifenthrin toxicological impacts in the Nile tilapia [18, 20]. Furthermore, dietary parsley can modulate the antioxidant system in rainbow trout exposed to ammonia toxicity [21], and has a hepato–renal protective function in the Nile tilapia exposed to bacterial infection [17].

Hence, we place an emphasis in the present work on the potential role of *P. crispum* nanoparticles (PNPs)-enriched diets on mitigating BPA toxicity in female African catfish (*Clarias gariepinus*). Hematological picture, hepato–renal function, stress condition, biochemical analysis, hepatic and ovarian antioxidants activities responses, and reproductive hormones are assessed.

2. Materials and Methods

2.1. Ethics Statement. All experimental procedures with live fish were approved by the animal welfare and ethical review committee of the Faculty of Veterinary Medicine, Sadat City University, Egypt, VUSC 030-1-23. All experimental procedures were conducted in compliance with the ARRIVE ethical guidelines and following the National Institutes of Health for Use and Treatment of Laboratory Animals.

2.2. Chemicals. BPA (98% purity) was bought from Sigma Aldrich Trade Co., Egypt. Parsley leaves were obtained from Mashreq Company for Business Development-Smouha-Alexandria, Egypt. Then, PNPs powder (4 g/kg diet) was prepared according to Goda et al. [20]. Antioxidant kits (lipid peroxidation [LPO], glutathione [GSH], superoxide dismutase [SOD], total antioxidant capacity [TAC], and catalase [CAT]) were purchased from Biodiagnostic Trade Co., Dokki, Egypt. Reproductive hormones (luteinizing hormone [LH], T, follicle-stimulating hormone [FSH], and 17-β E2) were purchased from (Gamma Trade Co., Dokki, Cairo, Egypt).

2.3. Synthesis and Characterization of PNPs. PNPs were synthesized by a top–down approach adopting the ball milling method [22]. Briefly, 5 g of *P. crispum* powder were put in the ball mill (Photon ball mill model of 210s) and milling was performed under vacuum for 3 h at 12,000 rpm. The synthesized PNPs were characterized in a previous article published by our group [20].

2.4. Diet Preparation. Dried parsley leaves were obtained from Mashreq Company for Business Development-Smouha-Alexandria, Egypt. Then, the PNPs powder (4 g/kg diet) was prepared. This used concentration of PNPs was previously tested and applied in vitro [20]. PNPs were included in the control diet (30% crude protein; CP) as depicted in Table 1. The ingredients of the diet, including PNPs, were carefully mixed into 100 mL of water for each 1 kg of diet to create dough. Then, the dough was passed to a meat grinder, and the resulting strings were kept to dry for a day prior to being crushed to get 1 mm diameter pellets. The experimental diets were maintained at 4°C until further use.

TABLE 1: Ingredients and proximate analysis (%; on dry matter basis) of diets containing parsley.

Ingredients	Parsley level (%)	
	0.0 (control)	1.0
Fish meal (72% crude protein)	8.5	8.5
Soybean meal (45% crude protein)	46.5	46.5
Wheat bran	18.3	18.3
Ground corn	10.0	10.0
Corn oil	2.0	2.0
Cod liver oil	2.0	2.0
Mineral mixture[a]	3.0	3.0
Vitamin mixture[b]	3.0	3.0
Starch	6.7	6.2
PNP powder	0	10
Total	100	100
Chemical composition (%)		
Dry matter	91.5	91.3
Crude protein	30.7	30.3
Total lipids	7.1	6.9
Crude fiber	4.8	4.9
Total ash	6.1	5.9
NFE	951.3	952
DE (kcal/kg)	167.33825	164.32

Note: NFE "nitrogen free extract" = 1000 − (g/kg crude protein + fat + ash + crude fiber). Digestible energy (DE) was calculated based on values of protein 3.5 Kcal g^{-1}, fat 8.1 Kcal g^{-1}, and NFE 2.5 Kcal g^{-1} according to Santiago et al. [23].

[a]Vitamin premix (per kg of premix): thiamine, 2.5 g; riboflavin, 2.5 g; pyridoxine, 2.0 g; inositol, 100.0 g; biotin, 0.3 g; pantothenic acid, 100.0 g; folic acid, 0.75 g; paraaminobenzoic acid, 2.5 g; choline, 200.0 g; nicotinic acid, 10.0 g; cyanocobalamine, 0.005 g; a-tocopherol acetate, 20.1 g; menadione, 2.0 g; retinol palmitate, 100,000 IU; cholecalciferol, 500,000 IU.

[b]Mineral premix (g/kg of premix): $CaHPO_4.2H_2O$, 727.2; $MgCO_4.7H_2O$, 127.5; KCl 50.0; NaCl, 60.0; $FeC_6H_5O_7.3H_2O$, 25.0; $ZnCO_3$, 5.5; $MnCl_2.4H_2O$, 2.5; Cu (OAc)2·H_2O, 0.785; $CoCl_3$. $6H_2O$, 0.477; $CaIO_3.6H_2O$, 0.295; $CrCl_3.6H_2O$, 0.128; $AlCl_3.6H_2O$, 0.54; Na_2SeO_3, 0.03.

2.5. Fish Acclimatization. A total of 200 female African catfish, *C. gariepinus* (body weight of 200 ± 50 g and body length of 30.5 ± 2.0 cm), were collected from Abbassa fish farm, Egypt, in plastic bags. Fish groups were allocated randomly to glass aquaria carrying 100 L of dechlorinated tap water, and were inspected morphologically to guarantee that all samples were females. Fish were kept for 2 weeks for acclimatization under laboratory conditions. Analysis of water was performed to identify the physicochemical features of the water samples following the protocol of the Hack assay (Sigma Laboratory) based on the World Health Organization, 2001, pH 7.4 ± 0.5, dissolved oxygen 7.2 ± 0.4 mg/L, temperature 25 ± 1°C, total hardness 150 mg/L CaCO3, and alkalinity 123 mg/L. Water was constantly renewed daily to lessen contamination from fish metabolic excreta, and fish were received on a commercial diet with 30% protein.

2.6. Assessment of the Lethal Concentration of BPA. The half lethal concentration of BPA that induced 50% mortality (LC50) in African catfish after 96 h. of exposure was assessed (14.30 μg/L), and it was performed based on Litchfield and Wilcoxon [24]. 1/10 LC50 of (BPA 1.43 μg/L) was calculated and applied following Hussein et al. [25].

2.7. BPA Toxicity and Experimental Protocol. Four groups of female *C. gariepinus* ($n = 144$) (body weight of 200 ± 50 g and body length of 30.5 ± 2.0 cm) were randomly picked and equally allocated to 12 fish for each aquarium (3 replicates/group). Fish were fed the diet for 60 days, twice per day, which had 30% protein and was offered to the fish until satisfaction. Considering the aquarium ventilation, it was provided by compressed air using air pumps.

The groups included: group I was a control group and given free commercial diet; group II: fish supplied by free basal diet + PNPs (4 g/kg diet); group III: fish were subjected to 1/10 LC50 (BPA) (1.43 μg/L); and group IV: fish were supplied with 1/10 LC50 BPA (1.43 μg/L) + PNPs (4 g/kg diet). Throughout this experimental period (60 days), water was continuously changed every 48 h. The parameters of water quality were maintained during the experiment, as illustrated for fish acclimation.

2.8. Sampling. Toward the end of the experiment (60 days), fish were randomly chosen (12 fish per group) for the collection of samples. Depending on the [26] protocol, fish received benzocaine solution (100 mg/L) as an anesthetic agent by direct immersion, then blood was withdrawn from the caudal blood vessels for assessment of the blood picture using tubes with anticoagulant. Another set of hematological samples was drained in tubes without anticoagulant, then centrifugation of the samples was carried out at 1750 × *g* for 10 min after incubation at 22 ± 3°C for 5 h. Clear serum was then maintained at 20°C for biochemical assays. For the collection of hepatic and ovarian tissues, female *C. gariepinus* (12 fish/group) were euthanized using an anesthetic overdose of 2-phenoxyethanol (0.8 mL/L) [26], followed by the subsequent severing of the spinal cord. After that, samples were collected and maintained in liquid nitrogen to assess the antioxidant capacity.

2.9. Assessment of Blood Picture. Hematological indices, including hemoglobin (Hb), red blood cell (RBC) count, and packed cell volume (PCV), were evaluated using an automatic blood count analyzer (Mindray BC 3000 plus, China). The analyzer automatically computes the above-mentioned biomarkers. It is an advanced automated hematology system, which is also utilized and validated for mammals, depending on fluorescence flow cytometry and an impedance analysis system (multispecies software 3.05). The total number of white blood cells (WBCs) was calculated in smears of blood using the indirect assay [27]. Such an indirect protocol requires computing WBC using RBC value and the ratio of leukocytes to erythrocytes in the blood smear [28].

2.10. Biochemical Parameters. Values of alanine aminotransferase (ALT; Catalog No. MBS038444), (MyBioSource Co., California, USA), serum aspartate aminotransferase (AST; Catalog No. EK12276) (Biotrend Co., Maryland,

TABLE 2: Changes in the haematological parameters (means ± SD) in female African catfish, *Clarias gariepinus*, exposed to 1/10 LC_{50} BPA (1.43 μg/L) and treated with *Petroselinum crispum* NPs, respectively, for 60 days.

	Parameters			
Groups	**RBCs (10^6/mm^3)**	**WBCs (10^6/mm^3)**	**Hb (g/dL)**	**Ht (%)**
Group I	3.66 ± 0.08^a	0.82 ± 0.24^a	9.30 ± 0.41^a	37.21 ± 1.07^a
Group II	3.59 ± 0.05^a	0.83 ± 0.27^a	9.64 ± 0.45^a	39.13 ± 1.34^a
Group III	2.47 ± 0.16^c	0.51 ± 0.32^b	5.31 ± 0.08^c	28.12 ± 1.10^b
Group IV	3.39 ± 0.27^b	0.80 ± 0.20^a	8.96 ± 0.33^b	38.12 ± 1.31^a

Note: Means with different superscript letters in the same row for each parameter are significantly different ($p < 0.05$).

USA), urea (Catalog No. MBS9374784) (MyBioSource Co., California, USA), albumin (Catalog No. MBS019), globulin (Catalog No. MB 500–0001), and total protein (Catalog No. MBS9917835) levels were measured spectrophotometrically based on the standard method of their pamphlets using spectrophotometer (Lambda EZ201; Perkin Elmer) via using commercial kits (Biodiag nostic Co., Giza, Egypt). The creatinine level was computed using a spectrophotometric protocol as described by [29] following the use of the Centromic GmbH kit manual (German) and estimated at a wavelength of 340 nm. Level of serum cholesterol (Catalog No. EK12283) was assayed using kits purchased from Biotrend Co. (Maryland, USA), Cusabio Co. (Texas, USA). The level of blood cortisol and glucose was estimated using the peroxidase assay using the BioSystem BTS- 350 Spectrophotometer and an accustomed wavelength of 500 nm [27, 30] using commercial kits (Biodiagnostic Co., Giza, Egypt). Serum 17-β estradiol (E2), AchE, LH, and FSH levels were computed using ELISA according to [31] using a commercial kit (Gamma Trade Co., Cairo, Egypt).

2.11. Antioxidant Assays. The liver and ovarian levels of GSH (Catalog No. TA2511), CAT (Catalog No. CA2517), and SOD (Catalog No. SD2521), TAC (Catalog No. AB65329), and LPO (Catalog No. AB118970) were estimated spectrophotometrically following the shown assay of Hacker et al. [32], Hadwan [33], Nishikimi et al. [34], Benzie and Strain [35], and Gasparovic et al. [36]. The antioxidant biomarkers were monitored spectrophotometrically in the liver and ovaries using the kits (Bio-Diagnostic, Cairo, Egypt). SOD was evaluated depending on the power of the enzyme at 560 nm wavelength to avert the phenazine methosulphate-mediated reduction of nitroblue tetrazolium dye. The mixture of an enzymatic reaction, which carried samples, hydrogen peroxide (H_2O_2), and potassium phosphate (pH 7.0) was utilized to compute CAT. The molar attenuation coefficient of H_2O_2 was assessed at 240 nm with the aid of a UV–VIS spectrophotometer set. The basis for estimating GSH was the reduction of 5,5′dithiobis (2-nitrobenzoic acid, DTNB), dissolved in 25 mM PBS (pH 7.0) by the GSH to yield a yellow product calculated at 405 nm [37].

2.12. Data Analysis. The Shapiro–Wilk test was primarily carried out to assess if all the data were ordinary. One-way analysis of variance (ANOVA) was achieved to investigate if there is a significant statistical difference between treatments with Tukey's post hoc analysis (SPSS version 18; IBM Corp., Armonk, NY, USA. A p-value of less than 0.05 symbolizes statistical difference, involving all tests.

3. Results

3.1. Hematological Assay. BPA caused a clear decline in RBC and WBC counts, Hb, and hematocrit concentrations (Table 2). PNPs supplementation significantly ($p < 0.05$) raised those decreased levels of RBCs and WBCs, Hb, and hematocrit in comparison to the control positive group to a degree returning them to the control negative group, as shown for hematocrit values (Table 2). Meanwhile, PNPs incorporation didnot reveal a significant difference before exposure to 1/10 LC50 BPA (1.43 μg/L) (Table 2).

3.2. Biochemical Assay. Supplementation with 4 g/kg PNPs exhibited a significant ($p < 0.05$) reduction in AST, ALP, ALT, uric Acid, creatinine, urea, glucose, cortisol, and cholesterol levels that were elevated in response to BPA toxicity (Tables 3 and 4). However, no significant ($p < 0.05$) differences were recorded before exposure to BPA toxicity, except for AST and uric acid levels (Table 3).

PNPs revealed significantly ($p < 0.05$) reduced levels of total proteins, albumin, and globulin levels before exposure to BPA toxicity (Table 3). BPA exposure significantly ($p < 0.05$) increased total proteins, albumin, and globulin levels, and PNPs incorporation markedly reduced those elevated levels (Table 3). Exposure to BPA toxicity has a significant ($p < 0.05$) reduction in AchE and PNPs showed a significant elevation to this decreased level (Table 4). Reproductive hormones LH and T significantly ($p < 0.05$) increased in response to BPA exposure, and PNPs supplementation significantly ($p < 0.05$) reduced those levels (Table 5). While FSH, 17-β E2 hormones were significantly ($p < 0.05$) decreased after BPA toxicity, and the PNPs diets significantly ($p < 0.05$) elevated those values (Table 5).

3.3. Oxidative Stress Biomarkers. BPA toxicity exposure significantly ($p < 0.05$) increased both hepatic and ovarian LPO, SOD, and CAT activities; and the group that received PNPs demonstrated a clear decline in those levels (Figures 1 and 2). However, PNPs-enriched diets significantly ($p < 0.05$) elevated hepatic and ovarian GSH and TAC levels that were decreased after exposure to BPA toxicity (Figures 1 and 2). Before exposure to BPA, both hepatic LPO and GSH were increased in the PNPs-supplemented group (Figure 1).

Table 3: Changes in the biochemical parameters (means ± SD) in female African catfish, *Clarias gariepinus*, exposed to 1/10 LC_{50} BPA (1.43 μg/L) and treated with *Petroselinum crispum* NPs, respectively, for 60 days.

	Groups			
Parameters	**Group I**	**Group II**	**Group III**	**Group IV**
AST (μ/L)	50.15 ± 0.26^{c}	48.51 ± 0.36^{b}	65.84 ± 0.31^{a}	48.20 ± 0.16^{b}
ALT (μ/L)	16.53 ± 0.13^{c}	17.24 ± 0.18^{c}	26.82 ± 0.30^{a}	20.03 ± 0.05^{b}
ALP (μ/L)	26.34 ± 0.41^{c}	28.91 ± 0.52^{b}	35.69 ± 0.17^{a}	29.15 ± 0.06^{b}
Urea (mg/dL)	10.63 ± 0.24^{c}	10.68 ± 0.33^{c}	19.52 ± 0.40^{a}	12.81 ± 0.24^{b}
Creatinine (mg/dL)	0.32 ± 0.04^{c}	0.31 ± 0.02^{c}	0.95 ± 0.03^{a}	0.29 ± 0.01^{b}
Uric acid (mg/dL)	8.21 ± 0.44^{d}	9.60 ± 0.13^{bc}	14.53 ± 0.24^{a}	10.80 ± 0.53^{b}
Cholesterol (mg/dL)	55.30 ± 0.23^{c}	57.41 ± 0.31^{c}	78.05 ± 2.34^{a}	60.03 ± 0.17^{b}
Total proteins (g/dL)	7.60 ± 0.12^{a}	6.94 ± 0.30^{ab}	4.03 ± 0.22^{d}	6.18 ± 0.15^{c}
Albumin (g/dL)	3.57 ± 0.13^{a}	3.63 ± 0.20^{a}	2.34 ± 0.21^{c}	3.15 ± 0.31^{b}
Globulin (g/dL)	4.03 ± 0.08^{a}	3.31 ± 0.11^{b}	1.69 ± 0.01^{d}	3.03 ± 0.15^{c}

Note: Means with different superscript letters in the same row for each parameter are significantly different ($p < 0.05$).

Table 4: Changes in stress indicators (means ± SD) in female African catfish, *Clarias gariepinus*, exposed to 1/10 LC_{50} BPA (1.43 μg/L) and treated with *Petroselinum crispum* NPs, respectively, for 60 days.

	Groups			
Parameters	**Group I**	**Group II**	**Group III**	**Group IV**
Glucose (mg/dL)	74.60 ± 0.14^{d}	77.52 ± 0.21^{bc}	98.25 ± 2.10^{a}	79.07 ± 0.15^{b}
Cortisol (μg/dL)	8.38 ± 0.28^{c}	9.02 ± 0.19^{c}	15.31 ± 0.20^{a}	10.45 ± 0.09^{b}
AchE (μ/L)	540.40 ± 2.41^{a}	537.07 ± 2.17^{ab}	374.09 ± 2.19^{c}	530.24 ± 1.05^{b}

Note: Means with different superscript letters in the same row for each parameter are significantly different ($p < 0.05$).

Table 5: Changes in serum reproductive hormones (Means ± SD.) in female African catfish, *Clarias gariepinus*, exposed to 1/10 LC_{50} BPA (1.43 μg/L.) and treated with *Petroselinum crispum* NPs (4 g/kg diet), respectively, for 60 days.

	Parameters			
Groups	**FSH (μ/L)**	**LH (μ/L)**	**T (g/mL)**	**17-β E2 (g/mL)**
Group I	0.72 ± 0.05^{a}	0.33 ± 0.01^{b}	58.15 ± 0.36^{c}	248.04 ± 0.11^{b}
Group II	0.73 ± 0.04^{a}	0.31 ± 0.02^{b}	59.33 ± 0.54^{c}	251.02 ± 0.21^{a}
Group III	0.31 ± 0.05^{c}	0.81 ± 0.07^{a}	82.30 ± 0.20^{a}	165.29 ± 0.37^{c}
Group IV	0.69 ± 0.03^{b}	0.34 ± 0.05^{b}	63.21 ± 0.01^{b}	245.60 ± 0.31^{b}

Note: Means with different superscript letters in the same row for each parameter are significantly different ($p < 0.05$).

4. Discussion

Contamination by BPA represents a potential hazard not only for the fish populations, but also poses a significant risk to human health via consuming contaminated fish [38]. Herbal remedies are being extensively utilized in aqua feeds for a variety of reasons, such as growth stimulation, immune boosting, enhancing fertility, relieving oxidative stress conditions, and antagonizing toxicity [14, 39, 40]. Currently, utilizing natural plants and their nanoformulations have achieved great success in aquaculture practices for mitigating toxicity because of the unique characteristics of nanoparticles [19, 20, 41]. However, the present perspective aims to assess the mitigating impacts of PNPs-supplemented diets against BPA toxicity in female African catfish via monitoring hematological picture, biochemical profile, hepatic and ovarian antioxidant activities, as well as reproductive hormones.

The current study clarified that the addition of PNPs into female African catfish diets markedly ameliorated BPA endocrine hormonal disruption and improved female *C. gariepinus* fertility with relevance to enhanced hemato-biochemical, antioxidative responses. Concerning the hemato-biochemical picture, which represents key indicators of the fish's health condition [19, 42]. At this point, BPA toxicity caused a notable reduction in RBC and WBC counts, Hb, and hematocrit concentrations. In line with [38], toxicity caused by BPA resulted in a notable reduction in the hematological profile in common carp. PNPs supplementation clearly augmented levels of blood parameters, returning them to the control. Similar results we described in aquaculture following nanoherbal supplementations in aqua feed [19, 42]. On the same instance, the erythrogram of the Nile tilapia (*Oreochromis niloticus*) exposed to methomyl (MET) showed remarkably minor values for RBCs, PCV, MCHC,

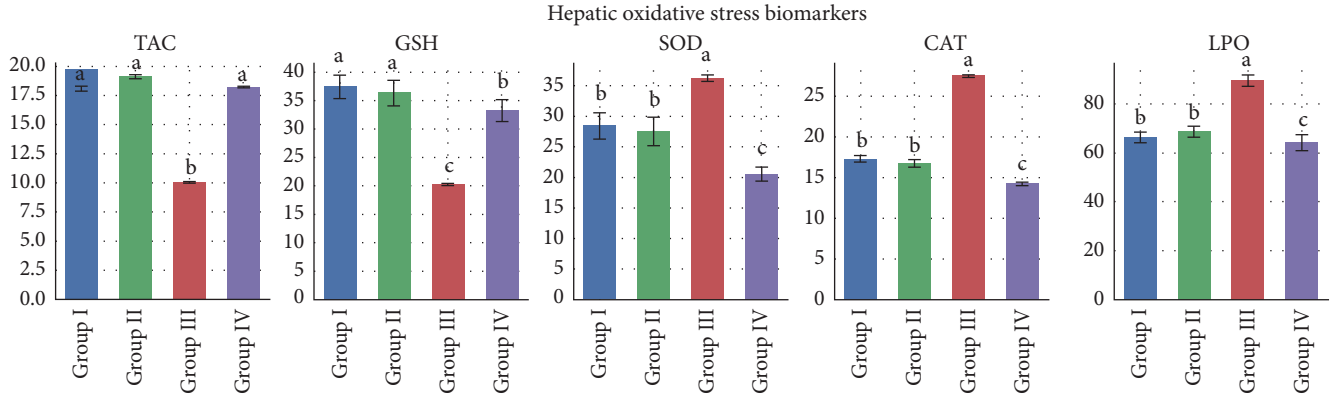

FIGURE 1: Changes in hepatic oxidative stress biomarkers (means ± SD) in female African catfish, *Clarias gariepinus*, exposed to 1/10 LC_{50} BPA (1.43 μg/L) and treated with *Petroselinum crispum* NPs, respectively, for 60 days. Bar chart for hepatic oxidative stress biomarkers, showing all parameters across groups (mean ± SD). Different letters (a, b, c) in each parameter mean a significant difference between means ($p < 0.05$).

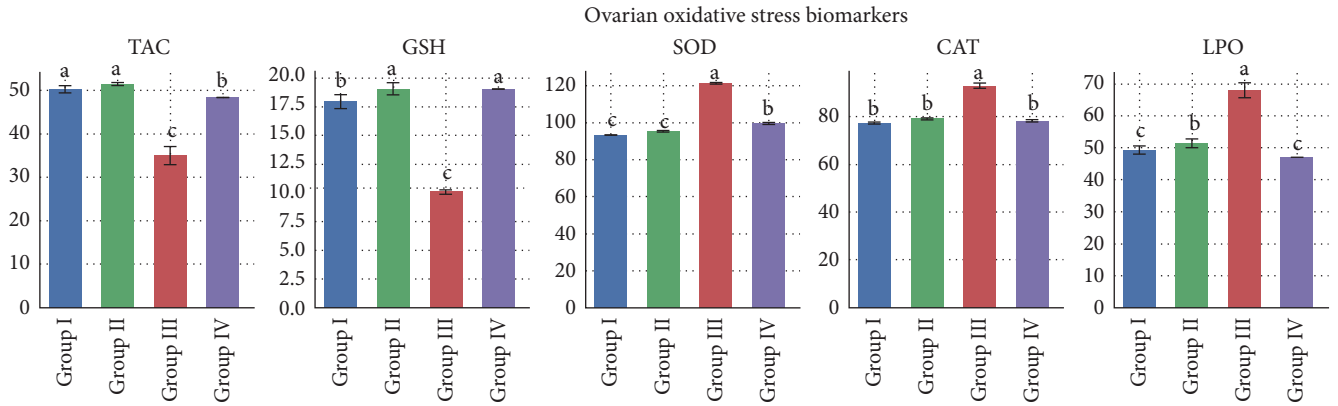

FIGURE 2: Changes in ovarian oxidative stress biomarkers (means ± SD) in female African catfish, *Clarias gariepinus*, exposed to 1/10 LC_{50} BPA (1.43 μg/L) and treated with *Petroselinum crispum* NPs, respectively, for 60 days. Bar chart for ovarian oxidative stress biomarkers, showing all parameters across groups (mean ± SD). Different letters (a, b, c) in each parameter mean a significant difference between means ($p < 0.05$).

and Hb% compared to groups supplemented with different levels of parsley seed meal (PSM) [17]. In addition, parsley extract effectively ameliorated the decrease in the Hb level in *O. niloticus* exposed to aflatoxin toxicity [43]. The decline in tested blood indices could be owed to the ability of BPA, as a part of microplastics aquaculture pollution, to initiate oxidative stress through emission of oxidizing molecules and reactive oxygen species (ROS), producing inflammatory conditions, despair of leukopoiesis, erythropoiesis, blood cells damage, and immune suppression [5, 20]. The ameliorating properties of *P. crispum* may be due to its ability to protect the erythrocyte membrane, sustain erythropoiesis, and thus prevent cellular damage, oxidative damage, and ROS generation [20, 43].

Coming to the biochemical parameters as indicators for hepatorenal function, stress, and cellular damage, results for ALP, AST, ALT, creatinine, urea, uric acid, cortisol, glucose, and cholesterol were significantly ($p < 0.05$) lowered in response to BPA toxicity. A recent study by Guo et al. [44] supported our findings and described the mechanism of BPA in inducing hepatic toxicity through different mechanisms, involving disturbance of the cell signaling pathways, epigenetic modifications, gene expression, metabolome, and microbiome. Furthermore, Smorodinskaya et al. [45] verified that BPA can induce acute nephrotoxic impact on zebrafish, as the head part of the kidney combines both hematopoietic and excretory functions. Birceanu et al. [46] described the adverse influence of BPA on the alteration of cortisol response in rainbow trout. Additionally, Faheem and Bhandari [47] monitored that excessive exposure to BPA altered levels of cortisol and glucose, which negatively influence metabolic regulation and fish health. Shedding light on the potential role of PNPs, the current study exhibits an antidotal role against BPA toxicity via modulating the elevated hepatic and renal parameters, as well as stress indicators. This could be returned to the potent antioxidant and phenolic constituents of PNPs as recently enumerated by Malkawi et al. [48]. For the same instance, a preceding study described ameliorating effects of *P. crispum* essential oil against Bifenthrin toxicity via obviously modulating the elevated activities of AST, ALT, and ALP in the Nile tilapia, owing to toxicant-produced hepatic damage with enzyme release in the blood

[18]. The antitoxic effects of parsley could be owed to its hepatoprotective, antioxidant, and cellular sustaining actions Goda et al. [20]. The effectiveness of PNPs on minimizing oxidative stress, enhancing metabolic indicators, and hepatorenal function could be attributed to parsley's biochemical characteristics, such as terpenoids, flavonoids, phenolic acids, and essential oils, which share in anti-inflammatory, antioxidant, and nephroprotective impacts as depicted by Alobaidi [49]. Concurrently, Hajirezaee et al. [21] explained that dietary parsley minimized the levels of stress indicators (glucose and cortisol) and hepatic enzymes in rainbow trout upon exposure to ammonia toxicity. Concurrent with El-Houseiny et al. [17], dietary parsley seeds had an effective hepatorenal protective function in the Nile tilapia exposed to bacterial infection. Likewise, Goda et al. [20] recorded elevated glucose and cholesterol in *O. niloticus* groups exposed to zinc oxide nanoparticle toxicity, which was overwhelmed with parsley and nanoparsley supplementations.

Considering the impact of BPA on fish fertility, the current perspective clarified that BPA induced a notable disruption to LH, T, FSH, and 17-β E2 hormones. The disruption caused by BPA may be because of their ability to initiate oxidative conditions and release of ROS particles, cellular destructive actions, and reproductive toxicity as documented by Del Piano et al. [8], Ghosh et al. [9], Porcino et al. [10], and Štampar et al. [6]. Also, it could be attributed to the BPA effect on alterating the expression of chef genes of the hypothalamic–pituitary–gonadal (HPG) axis, involving estrogen receptor α (ER_α), aromatase (CYP19), and androgen receptor genes as represented by Letcher et al. [50]. Such molecular implications have profound consequences on the reproductive health of fish, as stated by Iswaran et al. [38]. In addition, Rochester and Bolden [51] described that BPA can stimulate ER_α and estrogen receptor beta (ER_β) in vitro, reflecting their importance in disturbing hormonal signaling. Focusing on the efficacy of PNPs, we reveal that PNPs have a protective effect against the toxic effects of BPA via improving female *C. gariepinus* fertility and modulating the measured reproductive indicators. It is suggested that the protective properties of PNPs, including flavonoids, carotenoids, terpenoids, coumarins, myristicin, and ascorbic acid, have the power to boost and enhance organ activity, resulting in better absorption of nutrients as previously mentioned by Wong and Kitts [52] and Fejes et al. [53].

Evaluating the oxidative/antioxidative responses is a key marker for stress and toxicity conditions [8, 54]. Herein, we report that BPA produces oxidative damage, indicated by alterations in antioxidant biomarkers. Previous reports by Gassman [55] found that BPs induced oxidative stress, and such oxidative damage is associated with a range of hazardous health impacts, including cell dysfunction, inflammation, and tissue damage. The alteration in antioxidant readings could be related to the ability of BPA to release ROS species, as mentioned by Alberghini et al. [5]. Presently, PNPs caused a significant ($p < 0.05$) elevation in GSH and TAC levels that were decreased after exposure to BPA toxicity. It is assumed that the antioxidant activity of PNPs is returned to the higher contents of analyzed phenolic compounds, as noted by Ullah et al. [56]. Similarly, El-Houseiny et al. [17] reported that GPx, CAT, and SOD activities were decreased after exposure to MET in *O. niloticus*, and parsley efficiently boosted those levels through alleviation of oxidative damage and cellular protection. Additionally, Hajirezaee et al. [21] clarified that dietary parsley supplementation modulated antioxidant parameters in rainbow trout exposed to ammonia toxicity.

5. Conclusion

The study outcomes confirm the toxic impacts of BPA on the biochemical biomarkers and as an endocrine hormonal disruptor. Interestingly, PNPs-enriched diets in combination with BPA palliate the damaging influence of BPA via ameliorating all the tested biochemical parameters and enhancing the blood profile. In addition, dietary PNPs exert potent antioxidant activity and have a potential role in improving fertility via promoting reproductive hormones. In conclusion, PNPs have a shielding role in attenuating BPA toxicity and enhancing the fertility of female *C. gariepinus*. Further work is required to investigate other effects of PNPs on other fish species.

Data Availability Statement

The data of the current study are available upon request.

Ethics Statement

All experimental procedures with live fish were approved by the animal welfare and ethical review committee of the Faculty of Veterinary Medicine, Sadat City University, Egypt, VUSC 030–1–23. All experimental procedures were conducted in compliance with the ARRIVE ethical guidelines and following the National Institutes of Health for Use and Treatment of Laboratory Animals.

Consent

Permission from Abbasa Farm was obtained for using their fish for research purposes.

Conflicts of Interest

The authors declare no conflicts of interest.

Author Contributions

Conceptualization, methodology, software, data curation: Zeinab Hassan, Rehab M. Amen, Hiam Elabd, Abdelwahab A. Abdelwarith, Elsayed M. Younis, Gehad E. Elshopakey, Mohamed Shaalan, Asmaa W. Basher, Azza H. Elelemi, Heba H. Mahboub, Heba S. Hamed, Sherif M. Shawky, Sahar H. Orabi, Ferdaus Mohd Altaf Hossain, Simon J. Davies, and Hassnaa Mahmoud Elsheshtawy. Writing – original draft preparation: Hiam Elabd, Heba H. Mahboub, Heba S. Hamed, Rehab M. Amen, and Asmaa W. Basher. Writing – review and editing: Hiam Elabd, Heba H. Mahboub, Mohamed Shaalan, and Heba S. Hamed.

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References

[1] F. Liu, G. Liu, Z. Zhu, S. Wang, and F. Zhao, "Interactions Between Microplastics and Phthalate Esters as Affected by Microplastics Characteristics and Solution Chemistry," *Chemosphere* 214 (2019): 688–694.

[2] P. Wu, Z. Cai, H. Jin, and Y. Tang, "Adsorption Mechanisms of Five Bisphenol Analogues on PVC Microplastics," *Science of the Total Environment* 650 (2019): 671–678.

[3] A. Timilsina, K. Adhikari, A. K. Yadav, P. Joshi, G. Ramena, and K. Bohara, "Effects of Microplastics and Nanoplastics in Shrimp: Mechanisms of Plastic Particle and Contaminant Distribution and Subsequent Effects After Uptake," *Science of the Total Environment* 894 (2023): 164999.

[4] T. S. Galloway, B. P. Lee, I. Burić, et al., "Plastics Additives and Human Health: A Case Study of Bisphenol A (BPA)," *Environmental Science & Technology* 16, no. 47 (2018): 131–155.

[5] L. Alberghini, A. Truant, S. Santonicola, G. Colavita, and V. Giaccone, "Microplastics in Fish and Fishery Products and Risks for Human Health: A Review," *International Journal of Environmental Research and Public Health* 20, no. 1 (2023): 789.

[6] M. Štampar, T. Ravnjak, A.-M. Domijan, and B. Žegura, "Combined Toxic Effects of BPA and Its Two Analogues BPAP and BPC in a 3D HepG2 Cell Model," *Molecules* 28, no. 7 (2023): 3085.

[7] M. F. Manzoor, T. Tariq, B. Fatima, et al., "An Insight Into Bisphenol A, Food Exposure and Its Adverse Effects on Health: A Review," *Frontiers in Nutrition* 9 (2022): 1047827.

[8] F. Del Piano, A. Lama, G. Piccolo, et al., "Impact of Polystyrene Microplastic Exposure on Gilthead Seabream (*Sparus aurata* Linnaeus, 1758): Differential Inflammatory and Immune Response Between Anterior and Posterior Intestine," *Science of the Total Environment* 879 (2023): 163201.

[9] S. Ghosh, J. K. Sinha, S. Ghosh, K. Vashisth, S. Han, and R. Bhaskar, "Microplastics as an Emerging Threat to the Global Environment and Human Health," *Sustainability* 15, no. 14 (2023): 10821.

[10] N. Porcino, T. Bottari, and M. Mancuso, "Is Wild Marine Biota Affected by Microplastics?" *Animals* 13, no. 1 (2023): 147.

[11] S. H. Hoseinifar, Y.-Z. Sun, Z. Zhou, H. Van Doan, S. J. Davies, and R. Harikrishnan, "Boosting Immune Function and Disease Bio-Control Through Environment-Friendly and Sustainable Approaches in Finfish Aquaculture: Herbal Therapy Scenarios," *Reviews in Fisheries Science & Aquaculture* 28, no. 3 (2020): 303–321.

[12] M. Yousefi, H. Adineh, M. Reverter, et al., "Protective Effects of Black Seed (*Nigella sativa*) Diet Supplementation in Common Carp (*Cyprinus carpio*) Against Immune Depression, Oxidative Stress and Metabolism Dysfunction Induced by Glyphosate," *Fish & Shellfish Immunology* 109 (2021): 12–19.

[13] H. M. R. Abdel-Latif, M. M. Abdel-Daim, M. Shukry, J. Nowosad, and D. Kucharczyk, "Benefits and Applications of *Moringa oleifera* as a Plant Protein Source in Aquafeed: A Review," *Aquaculture* 547 (2022): 737369.

[14] H. S. Hamed, S. M. Ismal, and M. Abdel-Tawwab, "Modulatory Effects of Dietary Cinnamon (*Cinnamomum zeylanicum*) Against Waterborne Lead Toxicity in Nile Tilapia Fingerlings: Growth Performance, Haemato-Biochemical, Innate Immunity, and Hepatic Antioxidant Indices," *Aquaculture Reports* 25 (2022): 101190.

[15] H. Singh, P. Karmakar, B. Kumar, et al., "Parsley Genetic Resources," in *Vegetable Crops. Handbooks of Crop Diversity: Conservation and Use of Plant Genetic Resources*, ed. P. Kalia, (Springer, 2025).

[16] L. M. Casanova, L. B. dos Santos Nascimento, and S. S. Costa, "What Is New About Parsley, a Potential Source of Cardioprotective Therapeutic Substances?" *Nutraceuticals* 4, no. 1 (2024): 104–126.

[17] W. El-Houseiny, S. A. Algharib, E. A. A. Mohamed, et al., "Dietary Parsley Seed Mitigates Methomyl-Induced Impaired Growth Performance, Hemato-Immune Suppression, Oxidative Stress, Hepato-Renal Damage, and *Pseudomonas aeruginosa* Susceptibility in *Oreochromis niloticus*," *Antioxidants* 11, no. 6 (2022): 1185.

[18] M. R. Farag, M. Alagawany, S. R. Khalil, et al., "Effect of Parsley Essential Oil on Digestive Enzymes, Intestinal Morphometry, Blood Chemistry and Stress-Related Genes in Liver of Nile Tilapia Fish Exposed to Bifenthrin," *Aquaculture* 546 (2022): 737322.

[19] H. Elabd, H. H. Mahboub, S. M. R. Salem, et al., "Nano-Curcumin/Chitosan Modulates Growth, Biochemical, Immune, and Antioxidative Profiles, and the Expression of Related Genes in Nile Tilapia, *Oreochromis niloticus*," *Fishes* 8, no. 7 (2023): 333.

[20] M. N. Goda, A. A. M. Shaheen, and H. S. Hamed, "Potential Role of Dietary Parsley and/or Parsley Nanoparticles Against Zinc Oxide Nanoparticles Toxicity Induced Physiological, and Histological Alterations in Nile Tilapia, *Oreochromis niloticus*," *Aquaculture Reports* 28 (2023): 101425.

[21] S. Hajirezaee, S. Sharifi, A. Momeninejad, S. Ahani, M. P. Anzabi, and S. Taheri, "Ameliorating Effects of Dietary Parsley (*Petroselinum crispum*) on Ammonia Toxicity in the Rainbow Trout, *Oncorhynchus mykiss*: Growth, Digestive Enzymes, Immunity, and Stress Resistance," *Annals of Animal Science* 24, no. 2 (2024): 563–574.

[22] S. Karthik, R. Suriyaprabha, K. S. Balu, P. Manivasakan, and V. Rajendran, "Influence of Ball Milling on the Particle Size and Antimicrobial Properties of *Tridax procumbens* Leaf Nanoparticles," *IET Nanobiotechnology* 11, no. 1 (2017): 12–17.

[23] C. B. Santiago, M. Bañes-Aldaba, and M. A. Laron, "Dietary Crude Protein Requirement of Tilapia Nilotica Fry," *Kalikasan, the Philippine Journal of Biology* 11 (1982): 255–265.

[24] J. T. Litchfield and F. Wilcoxon, "A Simplified Method of Evaluating Dose – Effect Experiments," *Journal of Pharmacology and Experimental Therapeutics* 96, no. 2 (1949): 99–133.

[25] N. M. Hussein, R. M. A. Saeed, A. A. Shaheen, and H. S. Hamed, "Ameliorative Role of Chitosan Nanoparticles Against Bisphenol-A Induced Behavioral, Biochemical Changes and Nephrotoxicity in the African Catfish, *Clarias gariepinus*," *Egyptian Journal of Aquatic Biology and Fisheries* 25, no. 1 (2021): 493–510.

[26] D. L. Neiffer and M. A. Stamper, "Fish Sedation, Analgesia, Anesthesia, and Euthanasia: Considerations, Methods, and Types of Drugs," *ILAR Journal* 50, no. 4 (2009): 343–360.
[27] V. E. Sarmiento-Ortega, S. Treviño, J. Á. Flores-Hernández, et al., "Changes on Serum and Hepatic Lipidome after a Chronic Cadmium Exposure in Wistar Rats," *Archives of Biochemistry and Biophysics* 635 (2017): 52–59.
[28] M. Tavares-Dias, M. I. Mataqueiro, and D. Perecin, "Total Leukocyte Counts in Fishes by Direct or Indirect Methods?" *The Boletim do Instituto de Pesca* 28, no. 2 (2002): 155–161.
[29] J. F. Moore and J. D. Sharer, "Methods for Quantitative Creatinine Determination," *Current Protocols in Human Genetics* 93, no. 1 (2017): A.3O.1–A.3O.7.
[30] C. Audet, G. J. FitzGerald, and H. Guderley, "Photoperiod Effects on Plasma Cortisol Levels in *Gasterosteus aculeatus*," *General and Comparative Endocrinology* 61, no. 1 (1986): 76–81.
[31] N. Esmaeili, "Blood Performance: A New Formula for Fish Growth and Health," *Biology* 10, no. 12 (2021): 1236.
[32] C. Hacker, N. A. Christ, E. Duchardt-Ferner, et al., "The Solution Structure of the Lantibiotic Immunity Protein NisI and Its Interactions With Nisin," *Journal of Biological Chemistry* 290, no. 48 (2015): 28869–28886.
[33] M. H. Hadwan, "Simple Spectrophotometric Assay for Measuring Catalase Activity in Biological Tissues," *BMC Biochemistry* 19, no. 1 (2018): 7.
[34] M. Nishikimi, N. Appaji Rao, and K. Yagi, "The Occurrence of Superoxide Anion in the Reaction of Reduced Phenazine Methosulfate and Molecular Oxygen," *Biochemical and Biophysical Research Communications* 46, no. 2 (1972): 849–854.
[35] I. F. F. Benzie and J. J. Strain, "The Ferric Reducing Ability of Plasma (FRAP) as a Measure of "Antioxidant Power": The FRAP Assay," *Analytical Biochemistry* 239, no. 1 (1996): 70–76.
[36] A. C. Gasparovic, M. Jaganjac, B. Mihaljevic, S. B. Sunjic, and N. Zarkovic, "Assays for the Measurement of Lipid Peroxidation," *Methods in Molecular Biology* 965 (2013): 283–296.
[37] R. E. Ibrahim, G. E. Elshopakey, M. Y. M. Aly, A. A. Abdelwarith, E. M. Younis, and Y. M. Abd-Elhakim, "Camel Whey Protein Hydrolysate Diet Mitigates Alkaline Stress–Induced Biochemical Disorders and Restores the Target of Rapamycin MAPK Pathway, and Autophagy-Related Gene Expression in Nile Tilapia," *Aquaculture International* 11 (2024).
[38] A. Iswaran, M. Poorani, and S. Raja, "Effects of Bisphenol A (BPA) in Commercially Important Fish Common Carp (Cyprinus carpio) in Kerala," *International Journal of Biological Reports* 3, no. 2 (2025): 55–66.
[39] A. T. Mansour, H. S. Hamed, H. S. El-Beltagi, and W. F. Mohamed, "Modulatory Effect of Papaya Extract against Chlorpyrifos-Induced Oxidative Stress, Immune Suppression, Endocrine Disruption, and DNA Damage in Female *Clarias gariepinus*," *International Journal of Environmental Research and Public Health* 19, no. 8 (2022): 4640.
[40] M. Yousefi, H. Adineh, B. S. A. Gholamalipour, et al., "The Potential of the Inclusion of Prosopis farcta Extract in the Diet on the Growth Performance, Immunity, Digestive Enzyme Activity, and Oxidative Status of the Common Carp, Cyprinus Carpio, in Response to AmmoniaStress," *Animals* 15 (2025): 895.
[41] A. A.-R. Mohamed, W. El-Houseiny, A. E. EL-Murr, L. L. M. Ebraheim, A. I. Ahmed, and Y. M. A. El-Hakim, "Effect of Hexavalent Chromium Exposure on the Liver and Kidney Tissues Related to the Expression of CYP450 and GST Genes of *Oreochromis niloticus* Fish: Role of Curcumin Supplemented Diet," *Ecotoxicology and Environmental Safety* 188 (2020): 109890.
[42] F. Fazio, S. Marafioti, F. Arfuso, G. Piccione, and C. Faggio, "Comparative Study of the Biochemical and Haematological Parameters of Four Wild Tyrrhenian Fish Species," *Veterinární medicína* 58, no. 11 (2013): 576–581.
[43] M. I. El-Barbary and A. I. Mehrim, "Protective Effect of Antioxidant Medicinal Herbs, Rosemary and Parsley, on Subacute Aflatoxicosis in *Oreochromis niloticus*," *Journal of Fisheries and Aquatic Science* 4, no. 4 (2009): 178–190.
[44] T. L. Guo, F. Eldefrawy, and K. M. Guo, "Liver Toxicity Induced by Exposure to Bisphenol Analogs at Environmentally Relevant Levels: Insights From a Literature Review on Multiple Species," *Livers* 5 (2025): 24.
[45] S. Smorodinskaya, N. Kochetkov, K. Gavrilin, et al., "The Effects of Acute Bisphenol A Toxicity on the Hematological Parameters, Hematopoiesis, and Kidney Histology of Zebrafish (*Danio rerio*)," *Animals* 13, no. 23 (2023): 3685.
[46] O. Birceanu, T. Mai, and M. M. Vijayan, "Maternal Transfer of Bisphenol A Impacts the Ontogeny of Cortisol Stress Response in Rainbow Trout," *Aquatic Toxicology* 168 (2015): 11–18.
[47] M. Faheem and R. K. Bhandari, "Detrimental Effects of Bisphenol Compounds on Physiology and Reproduction in Fish: A Literature Review," *Environmental Toxicology and Pharmacology* 81 (2021): 103497.
[48] R. Malkawi, K. Battah, and M. Alkhreisat, "Pharmaceutical Insights Into Ammi and Parsley: Evaluating Antioxidant Activity, Total Phenolic Content, and Kidney Stone Disintegration Properties," *Advances in Pharmacological and Pharmaceutical Sciences* 2025, no. 1 (2025): 5522905.
[49] S. Alobaidi, "Renal Health Benefits and Therapeutic Effects of Parsley (*Petroselinum crispum*): A Review," *Frontiers in Medicine* 11 (2024): 1494740.
[50] R. J. Letcher, J. T. Sanderson, A. Bokkers, J. P. Giesy, and M. van den Berg, "Effects of Bisphenol A-Related Compounds on in Vitro Estrogenic and Androgenic Activities," *Toxicological Sciences* 85, no. 2 (2005): 784–793.
[51] J. R. Rochester and A. L. Bolden, "Bisphenol S and F: A Systematic Review and Comparison of the Hormonal Activity of Bisphenol A Substitutes," *Environmental Health Perspectives* 123, no. 7 (2015): 643–650.
[52] P. Y. Y. Wong and D. D. Kitts, "Studies on the Dual Antioxidant and Antibacterial Properties of Parsley (*Petroselinum crispum*) and Cilantro (*Coriandrum sativum*) Extracts," *Food Chemistry* 97 (2006): 505–515.
[53] S. Fejes, A. Blazovics, E. Lemberkovics, G. Petri, E. Szöke, and A. Kery, "Free Radical Scavenging and Membrane Protective Effects of Methanol Extracts From *Anthriscus cerefolium* L. (Hoffm.) and *Petroselinum crispum* (Mill.) Nym," *Phytotherapy Research* 14, no. 5 (2000): 362–365.
[54] H. S. Hamed, R. M. Amen, A. H. Elelemi, et al., "Effect of Dietary *Moringa oleifera* Leaves Nanoparticles on Growth Performance, Physiological, Immunological Responses, and Liver Antioxidant Biomarkers in Nile Tilapia (*Oreochromis niloticus*) Against Zinc Oxide Nanoparticles Toxicity," *Fishes* 7, no. 6 (2022): 360.

[55] N. R. Gassman, "Induction of Oxidative Stress by Bisphenol A and Its Pleiotropic Effects," *Environmental and Molecular Mutagenesis* 58, no. 2 (2017): 60–71.
[56] A. Ullah, S. Munir, S. L. Badshah, et al., "Important Flavonoids and Their Role as a Therapeutic Agent," *Molecules* 25, no. 22 (2020): 5243.