



Microplastic Toxicity: Unveiling the Physiological and Histopathological Impact on *Cyprinus carpio*

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A B S T R A C T

Microplastic pollution has arisen as environmental concern related to their distribution and adverse effect on aquatic organisms. The aim of this study was to evaluate the effects of polyethylene microplastics (PE-MPs) on *Cyprinus carpio* through physiological function tests and histopathological assessment. Six groups (one control and five treatment groups) were prepared with various microplastics concentrations (0.0, 5, 10, 15, 20, and 25 mg/kg) for four weeks. Ten fish per tank with two replicates per group were used. Treated fish were fed twice a day. Hematological tests showed significant changes ($P < 0.05$) in WBC, Hb, RBC, and PCV levels in treated fish group compared with control group. WBC level increased ($26.00 \text{ cell} \times 10^3 \text{ mm}^3$) in group five, while it was recorded $7.96 \text{ cell} \times 10^3 \text{ mm}^3$ in control group. Whereas, Hb, RBC, and PCV levels revealed a significant reduction, recording 5.47 g/dL, $0.96 \text{ cell} \times 10^6 \text{ mm}^3$, and 16.43%, respectively, for group five, in contrast to the control group, which reached 11.1 g/dL, $2.00 \text{ cell} \times 10^6 \text{ mm}^3$ and 33.30%. Liver enzyme values increased significantly, with AST reaching 156.88 IU/L and ALT 89.00 IU/L, in group five, compared with 38.67 IU/L and 19.60 IU/L in the control group. Renal function analysis demonstrated significant elevated levels of blood urea nitrogen (46.07 mg/dL) and creatinine (1.70 mg/dL), compared with 14.43 mg/dL and 0.50 mg/dL in the control group. Histopathological lesions observed in treated groups' fish gills included blood congestion of the central vein, dilatation, epithelial hyperplasia, increased mucous cells, and inflammatory cell infiltration. The anterior intestine exhibited villi shortening and hyperplasia, with the lamina propria showing moderate infiltration of mononuclear cells and goblet cell depletion. Liver tissue exhibited cytoplasmic vacuolation, necrosis, aggregation of macrophages, blood congestion, dilatation of sinusoid, and mononuclear cell infiltration. In conclusion, this study found that PE-MPs impact on liver, renal function test, hematological profile and causing histopathological changes. Chronic exposure led to fish health deterioration and mortality risk related to increasing concentration directly.

Keywords: microplastic, *Cyprinus carpio*, toxicity, histopathology alterations, physiological parameters

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INTRODUCTION

Freshwater systems act as important storage compartments for water supply and biodiversity, and, as such, they are especially prone to collecting various kinds of contaminants deriving from stream urbanization,

industry pollutants, agrochemical runoff, and waste mismanagement (1). Modern research posits pollution as a multi-disciplinary risk, and primary assessment methodologies are needed to address pollution's various sources and long-term impacts (2). The most recent plastic

debris assessments from the scientific community show that plastic waste is highly poly-faceted, comprising multiple types and classes of pollutants, and is almost impossible to remediate (3).

Recent studies highlight plastic pollution as one of the most critical environmental issues of the 21st century due to contamination of food webs and freshwater systems, and the proliferation of plastic waste in rivers and oceans (1,4). The accumulation of plastic waste ensures prolonged ecological exposure, while the plastic's active and persistent chemical additives, such as phthalates, and the pollutants to which plastics are exposed, add even greater toxicity to the environment, affecting organisms up to the level of humans (4,5).

In Iraq, researches on the Tigris River, has shown microplastic particles in different locations of the river with a variation in their abundance and characteristics among sites within the river, and highlights wide range of microplastic pollution and confirming the need for further studies to monitor its distribution and assess its potential environmental impacts (6).

Most microplastics (MPs) enter the aquatic food web at the level of plankton, Zooplankton and filter feeders tend to ingest suspended MPs since they are similar in size and appearance to natural food particles (7). Contaminated plankton is then eaten by small fish and invertebrates and MPs are then able to continue their upward movement in the food web, In Juveniles and adult fish, frequent microplastic ingestion has been documented in many freshwater systems such as the Tigris River and Gelingüllü Reservoir, reflecting exposure ubiquity across all feeder groups (8).

Microplastics are also present in the gut, liver, and, in some cases, the muscle tissue of predatory fish, which have accumulated higher loads from trophic transfer (9,10). The trophic transfer of MPs from fish to birds and mammals, including humans, who eat the contaminated fish, is a significant environmental and public health concern (4,5).

When MPs lodge in tissues, the immune system detects them as foreign entities and an inflammation response begins, gastrointestinal inflammation is among the most prevalent and entails immune cell infiltration, thickening of the tissues, and disruption of the epithelial layer, edema, and hyperplasia of the tissues, alongside immune system response, characterize the inflammation of the gills (11). When MPs and/or their chemicals enter the bloodstream, they trigger a systemic inflammatory response through the stimulation of cytokines and the activation of inflammatory response systems (12). Damage to organs, immune system dysregulation, and increased susceptibility to diseases result from prolonged inflammation (13).

Hematological parameters include Hemoglobin (Hb) and packed cell volume (PCV), white blood cells (WBCs) and red blood cells (RBCs) represent important physiological indicators. These parameters indicate fish response as a result of ecological pollutants and environmental stressors, for example Hb, RBCs and WBCs changes reflect failure oxygen transport and anemia, while WBCs alterations usually revealed to stress states and

immunity response (14). Alanine aminotransferase (ALT) is known as enzyme exists in hepatocytes and other tissues in normal condition, which is dependent on transformation of proteins into energy in hepatic cells, while the enzyme aspartate aminotransferase (AST) helps with the amino acid's metabolism (15). It usually accumulates in blood circulation as a result of cellular membranes damage that is caused by exposure to environmental pollutants such as pesticides, xenobiotics, MPs, heavy metals and other environmental stressors, which is leading to High values of AST and ALT in fish. This increase can be associated with exposure to environmental pollutants, which contributed to reactive oxygen species (ROS), also reflected in destabilization of cell membrane (16). Renal function biomarkers, especially Urea and Creatinine usually utilized as a bioindicator to evaluate fish physiological states, exposure to environmental pollutants such as nanoplastic and microplastic produced histological and functional kidney damage, besides oxidative stress, which leads to urea and creatinine being abnormal levels in fish blood (15).

The previous studies on the river studied have focused primarily on the distribution of MPs in abiotic compartments such as water and sediments. However, comparatively little attention has been given to the bioaccumulation and fate of MPs within the biotic components of the river ecosystem. This gap limits our understanding of ecological and health risks, as the biotic part represents a critical link in the transfer of contaminants through food webs or/research has largely overlooked MPs accumulation in biota, focusing instead on water and sediments. The objective of this study is to simulate and evaluate the impact of selected pollutants (polyethylene-microplastic) on aquatic organisms (*Cyprinus carpio*) under controlled experimental conditions, with the aim of elucidating their physiological and biochemical responses. By mimicking real-world contamination scenarios, the study seeks to provide insights into pollutant-induced stress mechanisms, bioaccumulation patterns, and potential risks to aquatic ecosystem health.

MATERIALS AND METHODS

Ethical Approval

All procedures of the current study, including those involving animals, were carried out in accordance with the standards and regulations for the care and use of laboratory animals, and ethical approval was obtained from the Scientific Committee of the College of Science for Women, University of Baghdad (CSW-REC 1035, 20/4/2026).

Diet Preparation

Polyethylene- microplastic (PE-MPs) it is particularly a low density polyethylene (LDPE), (Polymerverve, China origin) have been purchased from local scientific supplier in Baghdad, Iraq and based on specifications of product MPs particles were spherical powdered material with a density 917 to 930 kg/m³, particle size were about 74 µm,

molecular weight 1700-1800 and CAS number 9002-88-4, thus the product was utilized as received for exposure. Experiment PE-MPs, then PE-MPs were mixed well with powdered fish feed at various concentrations (0, 5, 10, 15, 20, and 25 mg/kg). The levels were selected based on (18). The diet of experimental was formulated by utilizing local feed ingredients and the diet composition contained yellow corn 15%, animal protein 12%, barley 20%, wheat 20%, soyabean meal 32%, beside to mineral and vitamin 1%, which total protein crude in diet was modified to about 26% for satisfying the fish nutritional requirements and all of them were obtained from local commercial feed suppliers in Baghdad, Iraq. For ensuring homogenous distributions PE-MPs required concentrations that were measuring by analytical balance, produced mixture was repelled and added a little deionized water for enhancing the binding, followed by air drying over 48h. at room temperature, finally the new pellets stored in clean and sterile containers (19). Treated fish were fed twice a day every morning and evening, which is approximately 3.5 g per fish, with daily feed.

Experimental Design

The current study included six groups, one control group and five groups of treatment, each group consisting of two replicate tanks containing 10 fish per tank, for a total of 120 fish used in the experiment. Two replicate tanks were used per group for maintaining appropriate densities, avoid overcrowding, ensure consistent and uniform breeding conditions during the experimental period, minimize variability due to tank variations, in addition to increase the reliability of results, this protocol followed in many previous studies. After the four-week exposure period, three fish were randomly selected from both tanks in each group. These fish underwent physiological and biochemical testing, and then the same fish were used for tissue collection and histopathological examination. Statistical analysis was performed using data from individual fish ($n=3$ per group). Fish were fed a fish food pellet diet, and the water was changed (50%) every three days. The physicochemical properties of the water were monitored in the tanks (70×60×40 cm), including: pH (7-8.5), Dissolved oxygen (DO) (5-7.6 mg/L), and water temperature (25-30°C).

Hematobiochemical Parameters

For hematological analysis, blood samples (1-2 mL) were collected from three fish per tank, using sterile syringes and heparin sodium anticoagulant and it was manufactured by Pines Co., Ltd., Chungcheongbuk-do/ Republic of Korea. Prior to sampling, fish were anesthetized with a 50 mg/L tricaine methanesulfonate solution (MS-222, Syndel, Canada) by a typical immersion bath method, the solution of anesthesia was formed in tank of water, that was previously aerated, then sodium bicarbonate was included for maintaining the pH balance, for the treated fish wouldn't stressed due to acidity, and the typical dose ranging between 25 to 100 mg/L and its requires 3.7-4.9 minutes to being work, fish being completely anesthetized

when the movement of opercula reduced, beside to fish balance reduction before collection, during anesthesia technique constant aeration was carried out for ensuring efficient O₂ supply and reducing physiological stress (20), and blood was drawn from the caudal vein. WBCs and RBCs counts were performed using a hemocytometer and Hb concentrations and PCV were also measured. Colorimetric determinations of the following important biochemical biomarkers: ALT, AST, creatinine, and blood urea nitrogen (BUN) were conducted according to Hamed et al. (21).

Histological Examination

Three fish from each group were collection their gill, anterior intestine, and liver tissue samples were obtained for determining histopathological changes, formalin 10% (supplied by Darmstadt, Germany) was used for preserving samples, dehydration by utilizing ethanol, then methyl benzoate (supplied by Himedia (Mumbai, India) was used for clearing, then embedded into paraffin wax and cutting to a thin slice (5 microns) by microtome (MRS 3500/ITALY, SN: 3500.131.660.) (22) essential stains such as hematoxylin and eosin were used to stain the tissue samples (23). Finally, it was examined under a light microscope in addition to being photographed and a histopathological lesion.

Contamination Control

For reducing contamination risks, all utilizing equipment was well-cleaned and sterilized with ethanol and distilled water, and cotton lab coats and gloves were worn to avoid air clothing contamination (24).

Determination of Median Lethal Concentration (LC₅₀) of MPs

LC₅₀ value was estimated by utilizing probit method (25), and according to the calculated procedure that described by Al-Rekabi (26), and confident interval 95% at the 0.05 level was calculated to assess precision estimation. LC₅₀ was determined after fourteen days of *C. carpio* exposure to PE-MPs with various concentrations (0.0, 5, 10, 15, 20, and 25 mg/kg) through food and totally of sixty fish were randomized divided into experimental groups. Mortality of fish was recorded every day during the period of experiment, then value of LC₅₀ was calculated according to percentage of cumulative mortality.

Statistical Analysis

The results of the current study were reported as means $\pm$ standard error, and a one-way analysis of variance (ANOVA) was performed all the data by utilizing SPSS software. Statistically significant probability was set at ($P \leq 0.05$).

RESULTS

Based on the linear regression analysis, the logarithmic concentration of PE-MPs that caused 50% mortality on *C. carpio* fish is determined to be 4.50. By taking the antilogarithm (base10), the LC₅₀ value was calculated as: LC₅₀ = 31.62 mg/kg (Table 1, Figure1) and the standard

error (SE) of log LC₅₀ estimated is 0.05, while confident interval (CI) 95% ranged between (Lower bound is $31.62 \times 10^{-1.96 \times 0.05} \approx 28.5$ mg/kg) and (Upper bound is $31.62 \times 10^{+1.96 \times 0.05} \approx 34.7$ mg/kg).

The results showed hepatic enzyme activity increased, as evidenced by the elevated levels of AST and ALT after exposure to PE-MPs and a dose dependent response was reported in this study, which exhibiting a strong positive

correlation between hepatic enzyme activity and PE-MPs concentration. Statistical analysis verified that there was a highly significant increase ($P < 0.05$) in comparison between experimental groups and control group. Additionally, all groups were revealed to have a significant increasing based on least significant differences (L.S.D) as mentioned in (Table 2).

Table1. Probit values and percentage of mortality

Group	Concentration mg/kg	Log Concentration	Number of Fish	Number of Dead Fish	% of Death	Probit Number
G1	5	0.69	10	0	0	0
G2	10	1	10	0	0	0
G3	15	1.17	10	2	20	4.16
G4	20	1.30	10	4	40	4.75
G5	25	1.39	10	5	50	5.00

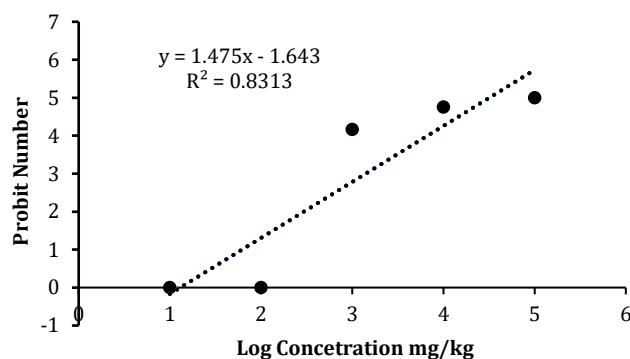


Figure 1. Regression curve of LC₅₀ probit analysis. Log concentration respons of polyethelen-microplastics (PE-MPs) after acute exposure (24 h) on *Cyprinus carpio*

Table 2. Values of AST and ALT liver enzymes' function

Group	ALT (IU/L)	AST (IU/L)
Control (0)	19.60 ± 0.71 ^f	38.67 ± 1.67 ^e
G1	25.73 ± 0.69 ^e	44.07 ± 1.41 ^e
G2	35.13 ± 1.47 ^d	54.90 ± 1.91 ^d
G3	52.37 ± 2.14 ^c	75.07 ± 2.46 ^c
G4	71.93 ± 3.04 ^b	114.4 ± 2.61 ^b
G5	89.00 ± 2.05 ^a	156.9 ± 1.08 ^a
L.S.D.	5.791 [*]	5.967 [*]
P-value	0.05	0.05

The values refer to mean±SE, different letters (a-f) within the same row indicate significant differences between groups according to LSD test at $P \leq 0.05$, while identical letters indicate no significant differences, and asterisk (*) indicates a statistically significant differences at $P \leq 0.05$

Table 3. Mean (±SE) values of Creatinine and BUN

Group	Creatinine (mg/dL)	Urea (mg/dL)
Control (0)	0.500 ± 0.02 ^e	14.43 ± 0.47 ^f
G1	0.600 ± 0.02 ^e	17.63 ± 0.78 ^e
G2	0.780 ± 0.03 ^d	24.17 ± 1.42 ^d
G3	0.983 ± 0.04 ^c	31.27 ± 0.64 ^c
G4	1.350 ± 0.06 ^b	35.03 ± 1.07 ^b
G5	1.700 ± 0.08 ^a	46.07 ± 0.89 ^a
L.S.D.	0.1471 [*]	2.870 [*]
P-value	0.05	0.05

The values refer to mean±SE, different letters (a-f) within the same row indicate significant differences between groups according to LSD test at $P \leq 0.05$, while identical letters indicate no significant differences, and asterisk (*) indicates a statistically significant differences at $P \leq 0.05$

The main findings of this study presented increasing levels of renal function biomarkers. Fish that fed with PE-MPs recorded a significant increase in BUN and creatinine concentrations, which indicates metabolic changes that cause a renal function failure. fish treated with MPs show increasing levels of BUN and creatinine in G5, compared to

control as shown in (Table 3). Statistical analysis showed a highly significant increasing based on least significant differences ($P < 0.01$) in all used groups compared to the control group. The progressive elevation in values, due to increasing of MPs concentrations incorporated into fish diet.

Hematological analysis found that the values of RBCs ranged from $0.96 \text{ cell} \times 10^6 \text{ mm}^3$ in group 5 to $2.00 \text{ cell} \times 10^6 \text{ mm}^3$ in control group, while Hb ranged between 5.47 to 11.1 g/dL, with the lowest values recorded in group 5 and the highest in the control group. The values of PCV decreased gradually with increasing PE-MPs, while WBCs counts showed opposite trend, gradually increasing to reach their

highest value in group 5 and their lowest value in the control group. Statistical analysis confirmed significant difference between the groups ($P < 0.05$), with RBCs count, Hb and PCV values decreasing, while WBCs counts increased with increasing PE-MPs concentration, indicating a dose- dependent response, as shown in **Table 4**.

Table 4. Hematological values of experimental fish

Group	RBC cell $\times 10^6 \text{ mm}^3$	Hb (g/dL)	PCV (%)	WBC cell $\times 10^3 \text{ mm}^3$
Control (0)	2.00 ± 0.06^a	11.1 ± 0.14^a	33.30 ± 0.95^a	7.96 ± 0.43^e
G1	1.83 ± 0.14^a	11.0 ± 0.20^b	33.10 ± 0.72^a	9.03 ± 0.41^{de}
G2	1.50 ± 0.06^b	10.1 ± 0.23^c	30.43 ± 0.95^b	11.1 ± 0.38^d
G3	1.30 ± 0.06^{bc}	8.06 ± 0.28^d	24.20 ± 0.61^c	13.6 ± 0.49^c
G4	1.10 ± 0.15^{cd}	6.92 ± 0.26^e	20.76 ± 0.92^d	19.8 ± 0.40^b
G5	0.96 ± 0.04^d	5.47 ± 0.23^f	16.43 ± 0.32^e	26.0 ± 1.64^a
L.S.D.	0.2968^*	0.7134^*	2.409^*	2.387^*
P-value	0.01	0.01	0.01	0.01

The values refer to mean $\pm$ SE, different letters (a-f) within the same row indicate significant differences between groups according to LSD test at $P \leq 0.05$, while identical letters indicate no significant differences, and asterisk (*) indicates a statistically significant differences at $P \leq 0.05$

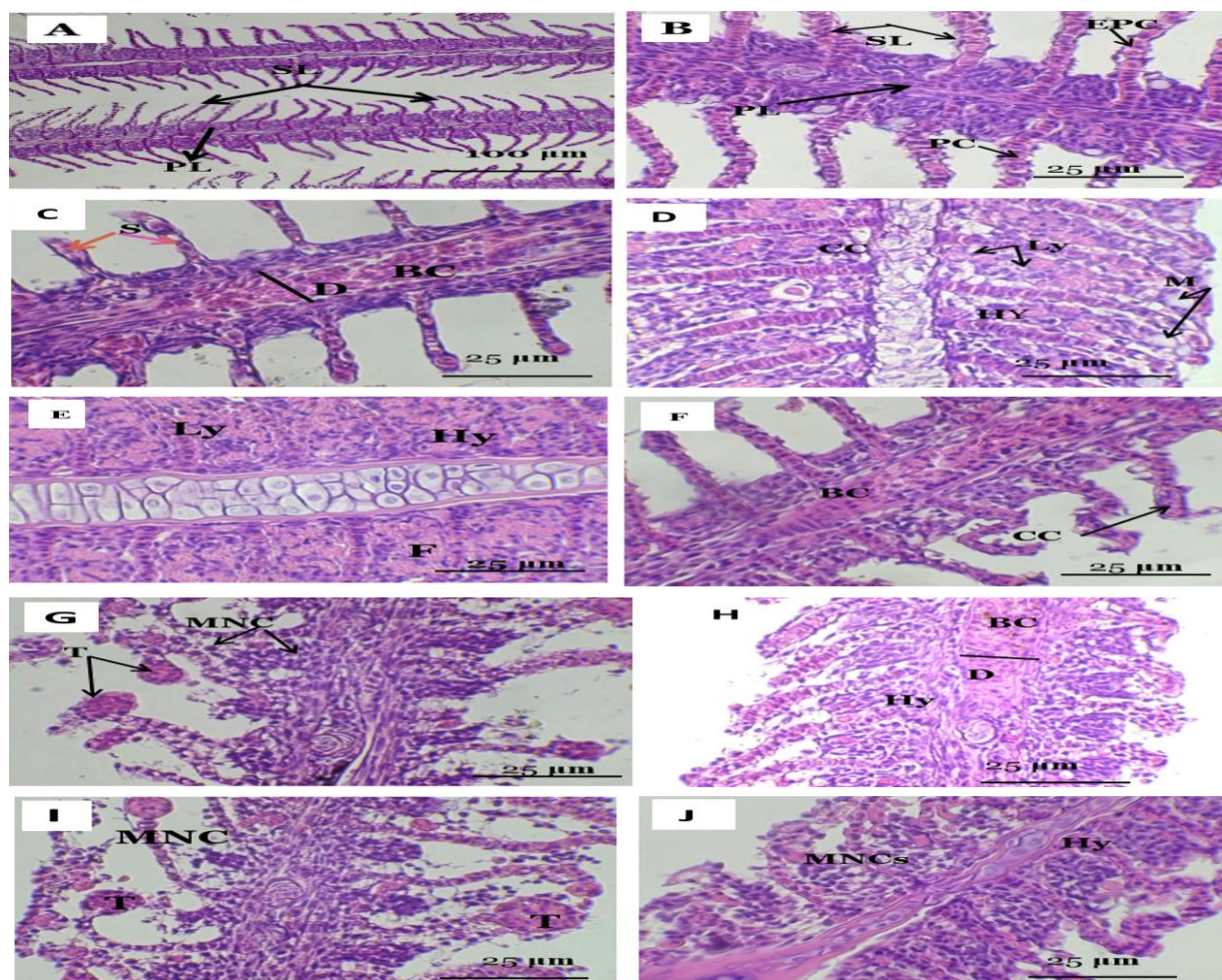


Figure 2. Histopathological sections of gill of *C. carpio* (A,B): control group, showing normal architecture of secondary lamellae B: showing secondary lamellae (SL), epithelial cells (EPC) and pillar cells; (C): G1(5 mg/kg) showing dilatation (D) and blood congestion (BC) of the central venous sinus, with shorting (S) of the secondary lamellae; (D): G2 (10 mg/kg) showing increased inflammatory cells especially lymphocytes (Ly), increased in mucous cells (M) and hyperplasia of epithelial cells with hyperemia of the secondary lamellae (Hy) and prominent of chloride cells (CC); (E,F): G3 (15 mg/kg) exposed to 15mg/kg showing increased inflammatory cells especially lymphocytes (Ly), and moderate chloride cells hyperplasia (Hy) and fusion of the epithelial cells (F). B: blood congestion of the central venous sinus; (G,H): G4 (20 mg/kg) showing mononuclear cells infiltration (MNS), telangiectasis (T), and sloughing of the secondary lamellae . B: showing dilatation (D), blood congestion (BC) of the central venous sinus, and severe hyperemia of the secondary lamellae (Hy); (I,J): G5 (25 mg/kg) showing mononuclear cells infiltration (MNCs), telangiectasis (T), and sloughing of the secondary lamellae B: $\times 40$ showing hyperemia of the secondary lamellae (Hy). H&E stain, $\times 40$ magnification

Gills of control group histological examination exhibited normal architecture and no obvious pathological alterations, involving primary and secondary lamellae with a layer of epithelial tissue and typical vessels under normal conditions as illustrated in (Figure 2A,B), while gills in treated fish that exposed to MPs showed several abnormal histopathological changes and these detected changes such as blood congestion of the central vein and dilatation observed in G1 and G4, epithelial cells hyperplasia was reported in G2, G3, G4, and G5, mucous cells observed in G2, and inflammatory cells was increasing in G2 and G3, secondary lamellae shortness were observed in G1, fusion of the epithelial cells was observed in G3, elevate of inflammatory cells was observed in G2 and G3 and hyperplasia were noticed in G2, G3, G4, and G5, while mononuclear cells infiltration and telangiectasises were observed in G4 and G5, as presented in (Figure 2A-J).

liver tissue exhibited abnormalities alterations in treated groups such as cytoplasmic vacuolation and necrosis of hepatocytes, aggregation of melanomacrophage, blood congestion in portal vein, dilatation of sinusoids,

mononuclear cells infiltration, while no significant lesions found in control fish group as shown in (Figure 3A-F).

Current investigations revealed that there were histopathological lesions in *C. carpio* anterior intestine tissues exposed to PE-MPs compared to fish of control group. PE-MPs in treated groups produced goblet cells depletion and distortion in intestine mucosa layer, besides to intestinal tract damage at higher dose (Figure 4A-F).

The present study reported that histological changes caused by exposure to microplastic such as villi shortage, thickening of mucosa due to hyperplasia presence of vacuolation or edema in mucosa or submucosa, increased cellularity in lamina propria, Muscularis mucosa separating mucosa from submucosa, detachment or erosion of the epithelial cells (De), inflammatory cells infiltration (Lymphocyte) in lamina propria, lamina propria exhibiting moderate infiltration of mononuclear cells (MNCs) and goblet cells depletion, lamina propria exhibiting infiltration of mononuclear cells (MNCs) mainly neutrophils and lymphocyte.

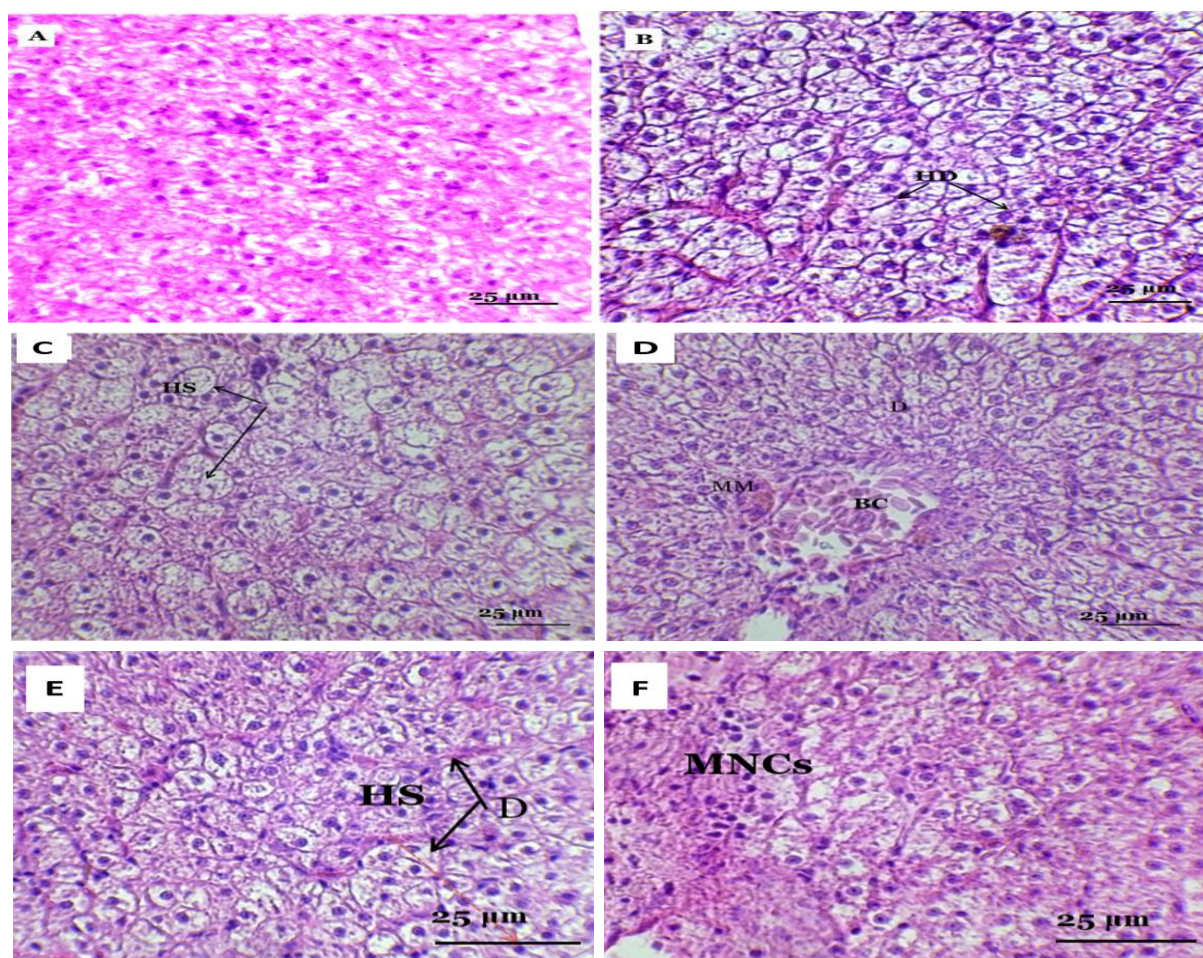


Figure 3. Histopathological sections of liver of *C. carpio* (A): control showing normal hepatocytes and sinusoids (S); (B): G1 (5 mg/kg) showing slight hyperemia of sinusoids (D); (C) G2 (10 mg/kg) showing obvious hydropic swelling of hepatocytes (V); (D): G3 (15 mg/kg) showing melanomacrophage aggregation (MM) and portal vein congestion (C) with degeneration of hepatocytes; (E): G4 (20 mg/kg) showing cytoplasmic vacuolation of hepatocytes (V), dilatation and congestion of sinusoids (D) necrosis in hepatocytes (N); (F): G5 (25 mg/kg) showing necrosis (N) in some hepatocyte, vacuolation (V) and obvious mononuclear cells infiltration (MNCs). H&E stain, ×40 magnification

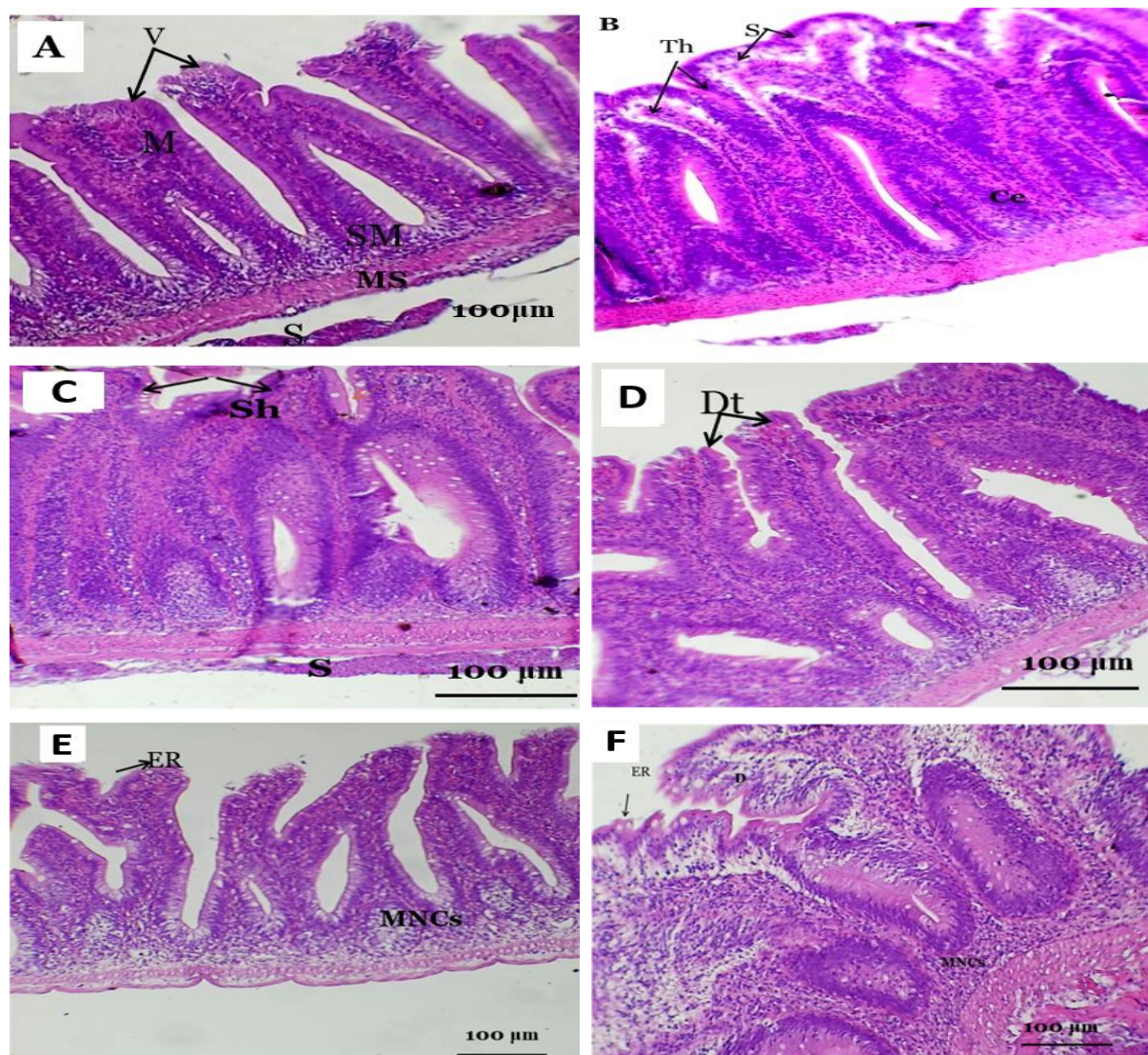


Figure 4. Histopathological sections of anterior intestine of *C. carpio* (A): control showing villi (V), mucosal folds (M), submucosa (SM), muscularis layer (MS) and serosa (S); (B): G1 (5 mg/kg) showing shortened villi (S), thickening (Th) of mucosa due to hyperplasia presence of vacuolation or edema in mucosa or submucosa, increased cellularity (Ce) in lamina propria; (C): G2 (10 mg/kg) showing muscularis mucosa separating mucosa from submucosa, (S) the villi appear shortened, thickened, and fused rather than long and slender (Sh); (D): G3 (15 mg/kg) showing inflammatory cells infiltration in lamina propria; (E): G4 (20 mg/kg) showing and lamina propria exhibiting moderate infiltration of mononuclear cells (MNCs); (F): G5 (25mg/kg) showing goblet cells depletion (D), lamina propria and submucosal layers inflammatory cells infiltration. H&E stain, $\times 40$ magnification

DISCUSSION

The result of LC50 revealed that PE-MPs produce toxic impacts on *C. carpio* under acute exposure concentration, the detected toxicity effect in current study could be related to physiological disruption, metabolic activities, tissue accumulation and oxidative stress, which caused by PE-MPs particles, on the other hand, previous studies recorded adversely impact of PE-MPs such as inflammatory responses trigger, antioxidant defense mechanisms in addition to histopathological abnormalities in common *C. carpio*, beside to toxicity effect levels may various based on polymer physicochemical characteristics, environmental condition and exposure duration(27-30).

The notable increase of ALT and AST enzymes levels significantly indicates cellular damage and hepatic dysfunction in *C. carpio* due to exposure to PE-MPs in this study, usually these hepatic enzymes are utilized as a particular liver integrity biomarker and their elevation in the bloodstream of group reveals a leakage from hepatocytes caused by disruption of the membrane, in addition to damage of hepatocellular (31).

The dose-dependent an increasing in liver enzymes demonstrates a direct relationship between liver injury severity and PE-MPs, which this relationship could be associated with MPs accumulation within liver tissue of fish and lead to an inflammatory response and oxidative stress, MPs commonly produced ROS (reactive oxygen species),

which is causing peroxidation of lipids, DNA impair, and denaturation of proteins, then leading to induce normal liver function inhibition (32). Furthermore, PE-MPs transport toxic chemicals and environmental pollutants, such as heavy metals and phthalates, that increasing hepatotoxicity, the combination impact of chemical toxicity and physical irritation may cause impairing of regulation of enzymes and metabolic activity in hepatocellular (33). This explains liver enzyme levels (ALT and AST) progressive increasing with PE-MPs increase concentrations reported in current study.

Previous studies have revealed similar results, where fish exposure to MPs induces significant enzyme liver change, which verifying metabolic dysfunction and hepatocellular impairing (34,35), consequently, the present study findings are align with exciting studies and highlight MPs pollution risk on health of fish.

One study revealed that liver enzymes such as ALT and AST are secreted in abnormal range when fish exposure to MPs then, causes a hepatotoxicity (36). According to another study, it reported that the activity of liver enzymes ALT and AST in fish is significantly increased to enhance the role of proteins in energy creation under stress caused by toxicants (37). Additionally, pomatoschistus microps (common goby) revealed a significant biochemical change during the exposure to pyrene and/or MPs, and the same impact was observed after exposure to nickel and/or MPs (38).

When *C. carpio* was exposed to MPs with paraquat noticed significantly increased liver function activity (ALT and AST enzymes), which indicates damage to cellular and organ membranes, that enzymatic rises reflect to oxidative stress, in addition to liver tissues injury, which commonly recognized as a hepatocellular stress and permeability of membrane in exposed fish to MPs with other pollutants (39).

The increasing blood urea values in current study indicating to altered in metabolism of nitrogen and impairing renal function. Production of urea in the fish body usually occur as a result of proteins digestion, which requires to discharge by urine and glomerular filtration (40). As a consequence, urea level in fish blood is utilized as an indicator to measure glomerular filtration rate in addition to renal nephron function (41), according to studies that conducting on fish exposed to MPs have found a significant association between increasing urea concentration and renal dysfunction (28). Other studies reported the direct impact of MPs on the pathways of metabolism of the fish urea cycle (42), a similar observation reported the effect of MPs on urea in blood (43).

Creatinine is considered a waste product, which is formed through creatinine breakdown in fish muscles during metabolism activity, which filtered by fish kidney from the blood then discharge in urine, thus there is a relationship between renal damage and increasing creatinine levels in blood (44). The current study noticed a marked increase of creatinine contents in blood, as a result of MPs toxicity. several studies on MPs toxicity conducted

on some species of fish reported an increase in creatinine values (45,46).

MPs reaching circulation system of fish through gills and lead to abnormal blood changes. This study revealed lower values of RBCs, Hb and PCV, which considered as blood indicators for MPs toxicity (45). The studies demonstrated a response to inflammation and tissues hypersensitivity induced by exposure fish to MPs, which cause problems with hemopoiesis process and raising anemia risk (18). MPs toxicity impact on RBCs trigger hemolysis in addition to reducing tissue's ability of receiving oxygen, also, physical and chemical stress, that causing by MPs, usually leading to erythrocyte membranes damage (47). Plasma components and parameters of fish blood regarded essential indicators of stress and health problems (48). The noticed changes in endocrine system and blood profiles in fish associated with exposure to MPs (49).

The *C. carpio* gills consist of primary and secondary lamellae structures and stabilized by a framework of cartilage, which linked with epithelial tissue and provided by network of vascular to facilitating change of gas (50).

Blood congestion was noticeable change in secondary lamellae of treated fish groups gills, in addition to lamellar capillaries dilation, these alterations detect decreasing hemodynamic regulation, beside to integrity of endothelial, which resulted by MPs accumulation and related oxidative stress. Congestion elevates blood pressure within vessels and cause reduction of blood flow through microcirculation, hence affecting by consumption of oxygen and ionoregulation. identical histopathological alterations reported in juvenile Nile tilapia because of exposure to MPs (51). Exposure to MPs induced branchial epithelial cells hyperplasia, that surrounding primary as well as secondary lamellae, MPs responses enhanced formation of cells for improving the epithelial barrier tissue. Interlamellar space becomes narrow and extends diffusion gases path, due to increase of epithelial layer thickness, which leading to secondary lamellae functioning decline, in addition to reduction in surface area of respiratory (51).

This histopathological shortness was noticed in gills of tilapia after MPs exposure, there was indication of epithelial lift beside to fusion, in addition to shortness of secondary lamellae, due to raised exposure. MPs impact on permeability of epithelial tissue and reduce ability for gases exchange reported in killifish, as well as aligned with this lamellar shortness (52).

Another observation reported was adjacent secondary lamellae fusion, as a result of development of epithelial cells proliferating. Interlamellar channels of water have been removed by fusion, that results in decreases efficient respiration on surface spaces, leading to gas change inefficiency, Lamellar fusion observed in *C. carpio* and Goldfish, that exposed to MPs, which structurally fusion in close borders of secondary lamellae usually exhibit (53).

Capillaries focal dilation inside lamellae, which known as Telangiectasia was observed in treated fish groups, telangiectatic vessels represent an indication of chronic hypertension of circulatory within lamellar core in addition to specific weakness of capillary walls (53).

Most treated fish groups revealed significantly increasing inflammatory cells infiltration like mononuclear leukocyte into interlamellar connective tissues. These recruitment of immunity cells seems to be an indication of inflammation signals pathways activity during MPs exposure and its common tissue reaction against chronic toxicity, based on investigations performed *C. carpio* gills, MPs induced molecular and structural inflammation response through stimulating inflammatory processes such as hyperplasia and structural damage, all reported lesions demonstrated lead to various aspects of gill function beside to physiological stress and fish decline fitness (54).

Liver is one of the fundamental metabolic organs, which is responsible for metabolism of lipids, protein and carbohydrates, xenobiotic transformation, detoxification, also supporting immunity defenses, in addition to its representation an environmental pollutants organ, due to extensive blood circulation and playing a key role in blood purity (55). Current study revealed dysfunctional metabolic of liver activities (liver damage), due to after being exposed to PE-MPs. These findings agree with previous studies, which demonstrate MPs exposure potentially impact on liver (tissue structure, vacuoles formation and necrosis of hepatocytes, blood congestion in portal vein, dilation of sinusoids, melanomacrophages aggregation and (MNC) (30,56-59).

Present study showed that there were histopathological changes in *C. carpio* anterior intestine tissues exposed to PE-MPs and Mucosal system in fish provides a diffusion barrier and protects the epithelial tissue from pathogens by antimicrobial substances (60). Goblet cells are considered essential biological elements, by playing a crucial role in the innate immune system of fish, which is responsible for secreting materials of mucosal barrier (61), and histopathological changes exhibited that PE-MPs led to mechanical injury, chronic inflammatory responses, disrupting intestinal absorption and mucosal protecting (58).

The histopathological assessment in this study relied on the diagnostic description of tissue lesions based on established morphological criteria in histopathology. that's allowed for accurate characterization of pathological changes resulting from PE-MPs exposure. Descriptive histopathological assessment is fundamental to diagnosis and interpretation of tissue lesions, while lesion severity scoring systems and quantitative morphometric analysis contribute to enhancing the objectivity of the assessment and enabling quantitative comparisons between studies (62,63). Therefore, they can be adopted as complementary tools to descriptive assessment in future studies.

The present study showed that PE-MPs had a notable effect on hematological profile, liver and renal function besides to histological changes. Main findings suggested that long-term period of MPs exposure may adversely impact fish health, also, maybe leading to mortality, PE-MPs toxicity impact increased progressively according to increasing concentration, which is reflected to dose-dependent association.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

FMH and A.JAR conceptualization; resources; project advisors; editing the final draft. ZJK curation; methodology; statistical analysis; writing the draft. All the authors have approved the final draft of the manuscript.

ARTIFICIAL INTELLIGENT DECLARATION

The authors declare that they are responsible for the accuracy and integrity of all content of the manuscript, including part generated by AI, and it is not used as a co-author.

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دراسة التأثيرات السامة للجسيمات البلاستيكية الدقيقة في المؤشرات الفسلجية والتغيرات النسيجية في أسماك الكارب الشائع

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الخلاصة

يعتبر تلوث المياه بالجسيمات البلاستيكية الدقيقة أحد المشاكل البيئية نظراً لتوزيعها وتأثيرها السلبي على الكائنات المائية. تهدف هذه الدراسة إلى تقييم تأثير الجسيمات البلاستيكية الدقيقة على سمكة الكارب الشائع طريق اختبارات الوظائف الفسلجية والتأثيرات النسيجية المرضية. تم إجراء تجربة تضمنت خمس مجاميع تجريبية بالإضافة إلى مجموعة السيطرة وبتراكيز مختلفة من جسيمات البلاستيك الدقيقة (البولي إيثيلين) وكانت: (٠,٠٠, ١٠, ٢٠, ٣٠ ملغ/كغم) واستغرقت التجربة أربعة أسابيع. تم وضع عشرة أسماك لكل حوض (مع تكرارين لكل مجموعة تجريبية). تم تغذية الأسماك مرتين يومياً (صباحاً ومساءً). أظهرت نتائج الفحوصات الفسلجية تغيرات معنوية ملحوظة ($P \leq 0.01$) في مستويات كريات الدم البيضاء والهيموغلوبين وخلايا الدم الحمراء وحجم خلايا الدم المرصوصة في مجاميع الأسماك المعالجة مقارنة بمجموعة السيطرة. ارتفع مستوى كريات الدم البيضاء (٢٦,٠٠٠ خلايا/ملم^٣) في المجموعة الخامسة بينما سجل ٧,٩٦ خلايا/ملم^٣ في مجموعة السيطرة، وأظهرت مستويات الهيموغلوبين وكريات الدم الحمراء وحجم خلايا الدم المرصوصة انخفاضاً ملحوظاً حيث بلغت ٥,٤٧ غم/دل و ٠,٩٦ خلايا/ملم^٣ و ١٦,٤٣٪ على التوالي في المجموعة الخامسة مقارنة بمجموعة السيطرة التي بلغت فيها ١١,١ غم/دل و ٢,٠٠ خلايا/ملم^٣ و ٣٣,٣٠٪ على التوالي. وارتفعت مستويات انزيمات الكبد حيث بلغ مستوى انزيم ناقلة الاسبارتات ١٥٦,٨٨ وحدة دولية/لتر، وناقلة امين الالانين ٨٩,٠٠ وحدة دولية/لتر مقارنة بمجموعة السيطرة ٣٨,٦٧ وحدة دولية/لتر و ١٩,٦٠ وحدة دولية/لتر على التوالي. أظهر اختبار وظائف الكلى ارتفاعاً في مستوى نيتروجين يوريا الدم حيث بلغ ٤٦,٠٧ ملغم/ديسيلتر و مستوى الكرياتينين ١,٧٠ ملغم/ديسيلتر، مقارنة بمجموعة السيطرة ٤٣,٤٣ ملغم/ديسيلتر و ٠,٥٠ ملغم/ديسيلتر على التوالي. كانت معظم التغيرات النسيجية المرضية التي لوحظت في غلاصم الأسماك المعرضة للجسيمات البلاستيكية الدقيقة هي احتقان الدم في الوريد المركزي وتوسعه، تضخم الخلايا الظهارية، زيادة الخلايا الالتهابية والمخاطية، بينما أظهرت الانسجة المرضية في الجزء الأمامي من القناة الهضمية تقصير بالزغابات وتضخمها وأظهرت الصفحية المخصوصة ارتشاحاً متوسطاً للخلايا احادية النواة وتآكل الخلايا الظهارية ونقص بالخلايا الكاسية، وأظهر الكبد وجود فجوات ساينوبلازمية وتخر في الخلايا الكبدية، تجمع الخلايا البليمية بالإضافة إلى احتقان دموي، وتوسع الجيوب الكبدية وارتشاحاً للخلايا احادية لنواة. وقد أشارت النتائج إلى أن التعرض للجسيمات البلاستيكية الدقيقة (البولي إيثيلين) تؤثر على وظائف الكبد والكلى وعلى مكونات صورة الدم، وتسبب تغيرات نسيجية مرضية. ويؤدي التعرض لهذه الجسيمات إلى تدهور صحة الأسماك وزيادة خطر النفوق المرتبط بزيادة تركيزها بشكل مباشر.

الكلمات المفاحية: الجسيمات البلاستيكية الدقيقة، السمية، أسماك الكارب، التغيرات النسيجية، المعايير الفسلجية