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Pathophysiological Toxicity Effects of Volatile Organic Compounds (VOCs) in Freshwater Fishes: A Short Review

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Abstract

The rapid expansion of various industrial sectors due to the industrial revolution has been a global concern in the current scenario. The indiscriminate discharges of various industrial xenobiotics without proper treatment into the aquatic ecosystem create a severe threat to the functioning status of non-target bioindicators like fish. Volatile organic compounds (VOCs) are large group of organic chemicals originated from various sources of natural and anthropogenic activities. Natural sources of VOCs are emissions from trees and vegetation, forest fires and anaerobic marshy bog process with the aid of some microorganisms while anthropogenic sources such as metal surface degreasing, textile cleaning, formulation of various agricultural practices, fumigation, petroleum storage, building materials etc. The health status of aquatic ecosystem can be evaluated precisely by employing various biomarkers. The assessment of fish health through hemato-biochemical biomarkers considered as an effective diagnostic tool in toxicological research. The variations of different blood parameters serve as indicators of physiological changes due to the presence of xenobiotics.

Keywords: Volatile Organic Compounds; Bioindicators; Biomarker; Hematotoxicity Studies; Biochemical Toxicity Studies

Abbreviations

VOC: Volatile Organic Compounds; VMS: Volatile Methyl Siloxanes; PAHs: Polycyclic Aromatic Hydrocarbons; MCH: Mean Corpuscular Haemoglobin; DLC: Differential Leukocyte Counts; ALT: Alanine Aminotransferase.

Introduction

Volatile organic compounds (VOCs) are a diverse class of chemicals characterized by their ability to evaporate at ambient temperatures, typically exhibiting a vapor pressure of ≥ 0.01 kPa at 20°C. These compounds are ubiquitous in the environment and originate from a multitude of natural and anthropogenic sources. Structurally, VOCs are characterized by low molecular weights (50–200 Da), high vapor pressures under ambient conditions, and varying levels of hydrophilicity [1]. They encompass a wide array of chemical classes, including terpenoids, sulphur compounds, hydrocarbons, alcohols, aldehydes, esters, amines, furans and ketones, among others. This broad chemical diversity is reflected in their wide-ranging biosynthetic origins and functional roles in both terrestrial and aquatic ecosystems. Generally volatile organic compounds are of two types; aromatic hydrocarbons and halogenated hydrocarbons. The aromatic hydrocarbons including benzene, toluene, ethyl benzene, xylene and halogenated hydrocarbons such as chloroethylene and trichloroethylene are most frequently found in environment. Cancerous volatile organic compounds (cVOCs) are a subset of VOCs that can cause cancer in human beings. The most important exposure pathways for VOCs contaminated water for both non-cancer and cancer risks are identified as drinking, swimming, bathing, food, showering and laundries [2,3]. Natural sources of VOCs include emissions from plants, fungi, bacteria, and protists such as microalgae, while anthropogenic sources span household and industrial products such as paints, wood preservatives, aerosols, disinfectants, pesticides, and building materials [4]. VOCs are also released during the combustion of fuels like gasoline, coal, and natural gas. Their environmental prevalence underscores their potential as pollutants, with many VOCs contributing to the formation of ground-level ozone, or smog, when they react with nitrogen oxides.

Aquatic ecosystems are especially vulnerable to VOC contamination, as these compounds can diffuse through water and air, often traveling far from their original sources. Biogenic VOCs in aquatic systems are predominantly emitted by algae, cyanobacteria, and other microorganisms, contributing compounds like terpenoids, furans, sulphur-containing molecules, halogenated compounds, and polyphenols. These natural emissions play vital roles in ecological processes but may also interact with anthropogenic pollutants, amplifying their environmental impact. Anthropogenic VOCs in aquatic ecosystems arise from diverse sources, including wastewater discharge, industrial effluents and atmospheric deposition. Wastewater originating from industrial, domestic, urban, and agricultural activities, is a major contributor to aquatic VOCs contamination. Untreated or inadequately treated wastewater effluents can introduce nitrogen and phosphorus excess into water bodies, causing eutrophication and associated phenomena like algal blooms and odor production [5].

Additionally, industrial sectors, such as cosmetics, construction, and maritime transport contribute significant VOCs loads to aquatic environments. For instance, cyclic volatile methyl siloxanes (cVMS) from industrial applications have been detected in Arctic waters due to their volatility and long-range transport potential [6]. Similarly, maritime transport emits semi-volatile polycyclic aromatic hydrocarbons (PAHs), which are deposited into surface oceans after atmospheric transport. Fish species are considered as a significant bioindicators for toxicological studies due to their sensitivity to any kind of environmental alterations occurred in the aquatic ecosystem. In addition to that, they are the good source of protein and fatty acids for human and as the accumulation of any xenobiotics within the fish body, they can transmitted to the human body system leads to noxious effects at various extent [7].

The intoxication of VOCs for a wide range of fish species have been performed by evaluating the sub-lethal toxicity effects of VOCs under different concentration and duration of exposure. The toxicity effects due to the exposure of VOCs are highly variable in fish species and these fluctuations can be reflected in the biological component like blood and considered as hence considered an effective biomarkers in aquatic ecosystem. Both the hematological and biochemical evaluation is a widely used method to evaluate the physiological status and health of fish, offering valuable insights into their overall condition. Routine hematological analyses encompass the assessment of blood cell counts, cell-related parameters, the concentrations or activities of plasma compounds etc [8]. The red blood cell parameters include erythrocyte count (RBC), hemoglobin concentration (Hb), hematocrit value (Ht), mean corpuscular volume (MCV), mean corpuscular hemoglobin (MCH), mean corpuscular hemoglobin concentration (MCHC). The white blood cell parameters include leukocyte count (WBC) and in some cases, differential leukocyte counts (DLC) to determine the percentage or number of various leukocyte types such as lymphocytes, neutrophils or heterophils , monocytes, eosinophils and basophils . Although thrombocyte count and blood cell morphology are less frequently evaluated as they can also provide important information. Blood analysis often extends to biochemical parameters in full blood, plasma or serum, measuring levels of glucose (GLU), proteins (P), cholesterol (Cho) and enzymes like alanine aminotransferase (ALT), aspartate aminotransferase (AST) etc. also indicates toxicity effect [9]. The toxicity analysis based on the measurement of aforementioned blood parameters helps to monitor the physical health status as well as well-being condition of fish species in response to variable diets, disease states and environmental settings [10]. This paper aims to review and summarize data of various hemato- biochemical toxicity studies in response to different source of VOCs in different fish species. The noxious effect of different VOCs in the fish physiological parameters helps to understand the process of distribution and bioaccumulation of various compounds in the water ecosystem. This review compiled the information regarding the impacts of VOCs based on fish physiological biomarkers.

Chronic Toxicity Effect of VOCs on Hematological Parameters of Fish

Fish blood is an important diagnostic tool to detect any stressful or pathological condition in any place within the body to various biotic and abiotic stresses [11]. The chronic intoxication due to the presence of VOCs in fish species causes various changes in the values of different hematological parameters such as red blood cells (RBC), white blood cells (WBC), hemoglobin (Hb), hematocrit (PCV), mean corpuscular volume (MCV), mean cellular hemoglobin

(MCH), mean cellular hemoglobin concentration (MCHC) etc. The changes in hematological values may be attributed by increased or decreased values of different blood parameters due to the exposure of VOCs. Several hematological alterations due to VOCs toxicity have been summarized in Table 1.

Fish Species	Source of VOCs/ Duration (Hrs.)	Hematological Alterations	References
Sarotherodon mossambicus	Formalin/ 524	↓RBC, ↑MCV, MCH, MCHC	Beevi, et al. [12]
Oreocbromis niloticus	Formalin/1416	↓RBC	Omoregie, et al. [13]
Pleuronectes flesus	Crude oil Industrial Effluent/ 144	↓RBC, PCV	Alkindi, et al. [14]
Clarias gariepinus	Industrial Effluent / 450	↓RBC, Hb, PCV, MCHC, WBC : ↑MCV, MCH	Mekkawy, et al. [15]
Etroplus maculatus	Pesticide Industrial Effluent/ 720	↓RBC, Hb, PCV, MCV, MCH, MCHC: ↑WBC	Nandan, et al. [16]
Cyprinus carpio	Industrial Effluent/ 1440	↓RBC,MCHC: ↑Hb, MCV	Witeska, et al. [17]
Labeo rohita	Textile Industry/ 900	↓RBC, Hb: ↑WBC	Bhanu, et al. [18]
Oncorhynchus mykiss	Paper mill Effluent/ 336	↑RBC, WBC, PCV	Miandare, et al. [19]
Clarias gariepinus	Industrial Effluent/ 360	↓RBC, PCV: ↑WBC	Adeboyejo, et al. [20]
Heteropneustes fossilis	Industrial Waste water/ 480	↓RBC:↑WBC	Maurya, et al. [21]
Clarias gariepinus	Herbicide Industry/ 300	↓RBC, Hb, PCV: ↑MCV	Abd El-Rahman, et al. [22]
Clarias batrachus	Textile Industry/ 216	↓RBC, Hb, Hct, MCV, MCH, MCHC: ↑WBC	Makwana, et al. [23]
Oreochromis niloticus	Formalin/ 300	↓RBC, Hb, Hct, MCV, MCH, MCHC: ↑WBC	Arun, et al. [24]
Heteropneustes fossilis	Fertilizer Industrial Effluent/ 315	↓RBC, Hb, PCV, MCV, MCH, MCHC	Singh, et al. [25]
Oreochromis niloticus	Petroleum Industry/ 280	↓RBC, Hb: ↑WBC	Hassan, et al. [26]
Oreocbromis niloticus	Industrial Effluent/ 672	↓RBC, Hb: ↑WBC, MCV	Muzaffar, et al. [27] 2023
Oreochromis niloticus	Benzene Toluene Xylene (BTX)/ 360	↓RBC, Hb, Hct, WBC: ↑MCV, MCH, MCHC	Sayed, et al. [28]

Table 1: Hematological alterations due to VOCs toxicity.

The Table 1 illustrated that various fish species exhibited differential responses of hematological parameters at different exposure periods. Some blood parameters increased significantly while others decreased under different exposure periods have been noticed. RBCs are very sensitive blood component, which respond immediately to the alterations of environmental parameters and causes morphological aberrations also [7]. The decreased value of hematological parameters due to the membrane damage of red blood cells by hemolysis leads to anemic like conditions in fish species. The increased value of hematological parameters was attributed by increased production of red blood cells to facilitate oxygen transport system effectively under stress condition. The reduction in the level of leucocytes in fish species expressed the disability to fight against infections because of the immunosuppressive effects of VOCs in aquatic ecosystem. An elevation in the count of white blood cells in different fish species indicated the compensatory responses against the damage of hematopoietic tissues induced due to the presence of VOCs in aquatic medium.

Chronic Toxicity Effect of VOCs on Biochemical Parameters of Fish

The potential adverse effect of VOCs has been detected by evaluating various biochemical parameters as a sensitive biomarker in aquatic ecosystem. It is one of the excellent pathophysiological reflectors of the health status of aquatic organisms, in particular fishes. The table 2 illustrated that various fish species exhibited differential responses of biochemical parameters at different exposure periods. The exposed fish species exhibited variations in the values of biochemical parameters were depending on concentration of exposure as well as duration of chemical treatment. Glucose and total protein play a vital role in the physiology and metabolism are commonly used stress indicators induced by environmental pollutants [29]. The fish converts the body protein into energy to facilitate the energy transport during stress condition [30]. The aggregation of xenobiotics sometimes leads to cell damage and induced the production of enzymes such as GOT and GPT found in the cell membrane, cytoplasm and mitochondria into the blood circulation and it gradually leads to significant elevation of blood serum transaminases [31]. The stress induced reduction in the value of triglyceride and cholesterol in exposed fishes may be due to higher energy demand to get the positive survival values while the increased trend of the aforementioned parameters related with the glycogen storage deficiency and hepatic dysfunction during the prolonged duration [32]. Several biochemical alterations due to VOCs toxicity have been summarized in Table 2.

Fish Species	Source of VOCs/ Duration (Hrs.)	Biochemical Alterations	References
Oreochromis niloticus	Benzene/360 Toluene/360 Xylene/360	↑Glu, TP, AST, ALT, ALP ↑Glu, TP, ALP: ↓AST, ALT ↑Glu, TP, AST, ALT, ALP	Sayed, et al. [33]
Oreochromis mossambicus	Industrial water/2160	↑ ALP, ACP, LDH, SOD, CAT, GST, GSH, GOT, GPT	Chinnadurai. et al. [34]
Oreochromis niloticus	Formalin/300	↑Glu: ↓TP, Alb, Glb	Arun, et al. [24]
Cyprinus carpio	Formalin/150	↑Glu	Şahan [35]
Cyprinus carpio	Formalin/240	↑Glu: ↓ALT	Chmelova, et al. [36]
Carassius auratus	Formalin/24	↑Glu, Alb, TP	Hoseini, et al. [37]
Oreochromis niloticus	Formalin/240	↑Glu, ALT: ↓TP, Alb	Nouh, et al. [38]
Clarias gariepinus	Toluene/504	↑ALT, ALP: ↓AST	Ujagwung, et al. [39]
Paralichthys olivaceus	Formalin/3	↓TP, ALP, LDH	Jung, et al. [40]
Clarias lazera	Toluene/96	↑Glu: ↓Chol, TP	Ghazaly [41]

Table 2: Biochemical alterations due to VOCs toxicity.

Mitigation Measures of Volatile Organic Compounds

The presence of volatile organic compounds in freshwater ecosystem is a significant concern due to their potential noxious effects on aquatic fauna, in particular non-target organisms like fish. Proper monitoring and taking beneficial mitigation strategies including source reduction, proper wastewater treatment techniques like activated carbon adsorption and advanced oxidation process, public awareness by educating people as well as various industrial sectors regarding the impact of exposure of volatiles in ecosystem etc. should be consider for effective and sustainable management of aquatic ecosystem.

Conclusion

The piscine physiology and the stress induced responses due to the presence of xenobiotics in aquatic ecosystem can be detected with the aid of various hemato-biochemical parameters as effective biomarkers. It provides a comprehensive toxicity data and functional status of fish under different exposure conditions. This short review focuses the occurrence, point of origin and hemato-biochemical toxicity effects of various volatile organic compounds in various freshwater fishes. Finally this review illustrates the proper mitigation measures for reducing the emission of different volatiles in aquatic ecosystem.

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