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Commentary

Triclosan-induced hematological perturbations in freshwater Teleosts: Implications for ecotoxicological risk and biomarker development

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Abstract

Significant dose and time-dependent changes in important blood parameters, such as hemoglobin concentration, hematocrit value, erythrocyte count, and leukocyte profile, have been found in recent studies on the hematological consequences of triclosan (TCS) exposure in *Oreochromis niloticus*. These changes, which are visible even at amounts that are relevant to the environment, point to anemia and immunological activation that are probably caused by oxidative stress and erythrocyte membrane damage. The relationship between TCS exposure and haematotoxin outcomes is strengthened by the study's robust design, which includes graded TCS concentrations and temporal sampling. From an ecotoxicological perspective, these results highlight the usefulness of *O. niloticus* as a bioindicator species for tracking aquatic contamination, with consequences for food safety, environmental health, and regulatory policy. To clarify the mechanistic routes of TCS toxicity and improve biomonitoring instruments for newly developing aquatic contaminants, future research combining molecular, histopathological, and field-based techniques is crucial.

Keywords: Hematology, Triclosan, *Oreochromis niloticus*, Biomarker, Toxicology

Introduction

Global population increase and fast industrial development, which creates new contaminants, pose a severe danger to access to clean, high-quality water. Over the past 25 years, there has been a growing awareness of the presence of persistent and dangerous pollutants known as endocrine-disrupting chemicals (EDCs) in terrestrial and aquatic ecosystems [1]. Due to their possible risks to both human health and the environment, EDCs have drawn increased attention from researchers in recent years [2]. Blood biomarkers are highly relevant for environmental risk assessment studies because of their sensitivity to environmental pollution and their connection to fish health status [3]. Environmental pollutants are currently a major danger to aquatic biodiversity, especially in freshwater systems. EDCs like triclosan (TCS), a popular antimicrobial component in personal care items, have drawn increasing scientific attention because of their trophic-level toxicological effects, bioaccumulation potential, and persistence [4]. The increasing convergence of environmental science and hematology suggests that hematological indices can serve as early warning indicators of toxicant exposure in sentinel aquatic creatures [5]. Tilapia is the common name for a group of species in the family Cichlidae, of which the genus *Oreochromis* is the primary source of income and is therefore classified as fish of greater commercial relevance in aquaculture; as a result, they appear to be the third most important group globally, after salmon and carp, and their cultivation represents one of the fastest growing activities worldwide [6].

Fish hematology is a sensitive indication of both acute and chronic stress, according to ecotoxicology [7]. Blood indicators such as hemoglobin (Hb), hematocrit (Hct), total erythrocyte and leukocyte counts, and erythrocytic morphological abnormalities reflect both underlying cellular problems and systemic physiological responses. In this regard, our recently published study, “Alterations in hematological indices of a freshwater fish, *Oreochromis niloticus* (Linnaeus, 1758) on exposure of Triclosan,” significantly advances our knowledge of the hematotoxic potential of triclosan in *O. niloticus*, an economically and ecologically significant species [8].

The purpose of this commentary is to expand on the scientific discourse that our research initiated, situate it within the broader framework of aquatic toxicity, include fresh findings, and recommend future research directions. This article focuses on the relevance of hematological measures as biomarkers of xenobiotic stress and how exposure to triclosan fits with global ecotoxicological issues.

Study Commentary

The recently published study on the hematological effects of exposure to Triclosan (TCS) in *O. niloticus* provides important information about the ecotoxicological importance of this widely used antibacterial drug. Even at ecologically relevant doses, research unequivocally demonstrates that exposure to TCS produces significant and gradual alterations in critical hematological parameters, such as leukocyte profiles, hemoglobin concentration, hematocrit value, and red blood cell (RBC) count [8]. These findings are consistent with our understanding that blood-based markers are reliable early biomarkers of toxicant exposure due to their high sensitivity to chemical insult and physiological stress [9]. The observed decline in erythrocytic indices indicates the onset of anemia, which may be brought on by oxidative damage, hemolysis, or erythropoiesis suppression, all of which are common responses in fish exposed to pro-oxidant pollutants [10]. The increase in the total leukocyte count, particularly in lymphocytes and neutrophils, concurrently reflects an immune response that may involve inflammation or increased cellular stress.

By using graded TCS concentrations (T1, T2, and T3) and sequential sampling at 15, 30, and 45 days, the scientists were able to produce a unique dose- and time-dependent profile of hematological disruption. Because it makes patterns of acute and sub-chronic toxicity clearer, this temporal resolution is very helpful. The design additionally divides the control and vehicle control groups to account for any potential confounding effects from the solvents used in dosing. This methodological rigor supports the conclusion that TCS alone is responsible for the hematotoxic changes observed. When taken into consideration in the context of current studies on fish physiology and pollutant stress, the results corroborate broader conclusions that triclosan, even at low doses, can impair hematological function and immunological competence. The results reported here are corroborated by other studies that have shown leukocyte activation, hemoglobin denaturation, and erythrocyte membrane damage as following effects of xenobiotic exposure [11].

Recent work has also highlighted potential pathways that support the findings of this study. For instance, it has been shown that TCS generates reactive oxygen species (ROS) that damage cellular membranes, proteins, and nucleic acids, indicating that oxidative stress is a major mediator of hematotoxic effects [12]. The integrity of the erythrocyte membrane may be directly compromised by this oxidative assault, leading to hemolysis and anemia [13]. Additionally, there is mounting evidence that triclosan may hinder heme production, disrupt mitochondrial function in hematopoietic cells, and interfere with immune signaling pathway-related gene expression [14]. The hematological findings of current study are consistent with these mechanistic understandings, indicating a systemic toxicity profile caused by TCS, despite the fact that it did not investigate molecular endpoints.

The ecological implications of such findings are significant. As a species that is widely cultivated and has substantial ecological and economic value, *O. niloticus* is a useful bio indicator in aquatic toxicology. Particularly in areas where domestic and industrial water pollution is not adequately controlled, hematological evaluation in such species can provide quick, non-lethal insights into water quality and contaminant exposure. TCS is commonly found in lakes and rivers close to cities, frequently at levels high enough to cause biological effects in aquatic life [15]. Therefore, the use of hematological indices in environmental bio monitoring systems may be very advantageous for conservation and regulatory objectives.

The findings have implications for public health beyond ecological monitoring, especially considering that *O. niloticus* is a fish that is commonly eaten worldwide [16]. Chronic TCS exposure, bioaccumulation, and trophic transfer raise serious questions about the safety of fisheries products and the potential for indirect human exposure. Although they cannot be directly applied to humans, hematological changes in fish may serve as sentinel indications of broader environmental deterioration with consequences for food safety. This also highlights the need for harmonized regulations and improved effluent treatment methods to lower the environmental loading of non-essential antibacterial chemicals like Triclosan. Blood parameters of Nile tilapia (*O. niloticus*) and other fish species have shown negative effects from a variety of herbicides, insecticides, and heavy metals [17]. In the tissues of *Cyprinus carpio*, bispyribac-sodium demonstrated oxidative stress [18]. Acetachlor caused thyroid endocrine disruption in fish and amphibians, including *Rana catesbeiana* tadpoles [19], larvae of zebrafish *Danio rerio* at concentrations of ≤0.3 mg/L [20], and *Gobiocypris rarus* at doses of 0.02–2 μg/L [21].

Future research on Triclosan-induced hemotoxicity in aquatic creatures should concentrate on a multidisciplinary approach that links molecular biology, toxicology, and environmental monitoring. Advanced omics technologies, such as transcriptomics, proteomics, and metabolomics, can identify early exposure and effect biomarkers and offer comprehensive insights into the molecular pathways affected by Triclosan. Combining these techniques with traditional hematological evaluations might increase the sensitivity and specificity of biomonitoring devices.

In-depth histopathological and ultrastructural examinations of hematopoietic organs, such as the kidney and spleen, may also show tissue-level effects that complement blood-derived findings. Chronic toxicity studies that mimic long-term, low-level environmental exposure situations are crucial to understanding the practical implications of triclosan pollution. These should be expanded to include a range of species and developmental stages in order to capture differences in sensitivity across taxa and life history. It is essential to investigate the combined effects of triclosan with other contaminants, such as heavy metals, medicines, or pesticides, in order to evaluate combination toxicity, which more closely reflects environmental conditions. Furthermore, field-based research is crucial for verifying laboratory findings and figuring out whether biomarkers are appropriate in natural settings. Encouraging interdisciplinary collaboration among ecotoxicologists, chemists, environmental engineers, and policymakers will be the final stage in transforming scientific data into practical policies, effective wastewater treatment methods, and improved environmental risk assessments for novel contaminants like Triclosan.

Conclusion

Our study significantly advances aquatic toxicology by characterizing the hematological abnormalities in *Oreochromis niloticus* following exposure to triclosan. The data supports the use of blood-based biomarkers in ecotoxicological assessments and highlights the potential health and ecological risks associated with persistent organic pollutants like TCS. Because environmental toxins continue to threaten aquatic ecosystems, it is imperative to use integrative, biomarker-based methodologies for monitoring, regulatory review, and public health protection. Further studies that incorporate mechanistic insights, molecular diagnostics, and practical validations will support the scientific and societal value of such hematotoxicity research.

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