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Transfer of toxic substances through aquatic food chains

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Aquatic ecosystems are highly sensitive to anthropogenic pollution caused by agricultural, industrial, and domestic activities. Toxic substances such as heavy metals, herbicides, and mycotoxins can accumulate in water bodies and circulate through trophic chains, affecting aquatic organisms at different biological levels. Algae play an important role in these processes because they absorb contaminants directly from the aquatic environment and serve as food sources for herbivorous fish (Mekhed & Yakovenko, 2010). Herbivorous fish, including silver carp and grass carp, are widely used in aquaculture and may accumulate toxic compounds in their tissues through continuous feeding on aquatic vegetation and phytoplankton. The migration of pollutants through the "water – algae – fish" system may lead to bioaccumulation, oxidative stress, and metabolic disturbances in aquatic organisms (Yakovenko et al., 2017). Previous studies demonstrated that xenobiotics and phosphorus-containing pollutants negatively affect the physiological state of aquatic biota and ecosystem stability. Therefore, investigation of toxic substance transfer in aquatic food chains is important for environmental monitoring and the assessment of ecological safety.

The study was conducted using samples collected from freshwater aquatic ecosystems within Chernihiv region. Water samples, algae, and tissues of herbivorous fish species, including silver carp and grass carp, were analyzed for the presence of heavy metals, herbicide residues, and mycotoxins. The selection of aquatic plants and algae was based on their role as primary accumulators of pollutants in trophic chains (Mekhed & Kyrienko, 2023). Fish samples were examined to evaluate the transfer of toxic substances from lower trophic levels into higher organisms. The concentration of pollutants was determined using standard hydroecological and biochemical methods commonly applied in environmental toxicology studies. Comparative analysis was performed to identify differences in contaminant accumulation among water, algae, and fish tissues. The obtained data were interpreted according to ecological monitoring approaches described in previous studies of aquatic ecosystems and pollutant bioaccumulation (Daineko et al., 2013; Lukash et al., 2012). Statistical and multivariate approaches such as MANOVA were previously applied to ensure reliability and integrity of ecological and biomedical data (Lukash et al., 2026).

The obtained results demonstrated that algae accumulated considerable concentrations of toxic substances from the aquatic environment and acted as the first trophic level in the transfer of pollutants through aquatic ecosystems. Heavy metals detected in water samples were also identified in algal biomass, confirming the active absorption of contaminants by aquatic vegetation and phytoplankton (Daineko et al., 2013). Among the analyzed pollutants, compounds of lead, cadmium, and zinc showed the highest tendency toward accumulation in algal tissues. The accumulation capacity of algae is associated with their large absorption surface and constant contact with the surrounding aquatic environment. Herbicide residues were detected both in water and in biological samples, indicating the penetration of agricultural chemicals into aquatic food chains (Mekhed & Yakovenko, 2010). The study revealed that the concentration of toxic substances in fish tissues depended on feeding intensity and the contamination level of aquatic vegetation. Silver carp and grass carp consumed polluted algae and macrophytes, which promoted the transfer of xenobiotics into muscle and liver tissues. Liver tissues demonstrated higher concentrations of pollutants than muscles because the liver is the main organ responsible for detoxification processes in fish organisms. Similar tendencies of xenobiotic accumulation were observed in previous investigations focused on aquatic organisms exposed to chemical pollutants (Yakovenko et al., 2017).

Biochemical analysis indicated that exposure to toxic compounds caused disturbances in metabolic activity and antioxidant defense systems. Elevated activity of antioxidant enzymes suggested the development of oxidative stress in fish tissues under the influence of herbicides and heavy metals. Oxidative stress may lead to cellular damage, lipid peroxidation, and impairment of physiological functions. Previous studies also reported that phosphorus-containing pollutants negatively affect the stability of aquatic ecosystems and physiological condition of hydrobionts. The detected biochemical changes indicate adaptive responses of organisms to long-term toxic exposure. The results confirmed the important role of aquatic vegetation as a bioindicator of environmental contamination. Aquatic and coastal plants are capable of reflecting the ecological condition of water bodies through the accumulation of pollutants in their tissues (Mekhed & Kyrienko, 2023). Such properties make algae and macrophytes valuable objects for ecological monitoring and hydroecological assessment. In addition, changes in plant community composition may indicate chronic anthropogenic pressure on aquatic ecosystems (Lukash et al., 2016). Long-term contamination of freshwater ecosystems may negatively influence trophic interactions, biodiversity, and fish productivity. The transfer of toxic substances through food chains creates risks not only for aquatic organisms but also for human health due to the consumption of contaminated fish products. Continuous accumulation of pollutants may contribute to ecosystem destabilization and reduction of ecological resilience. Therefore, regular monitoring of toxic substances in the "water – algae – fish" system is essential for environmental protection and sustainable management of aquatic biological resources.

The study confirmed that toxic substances actively migrate through aquatic trophic chains. Algae function as primary accumulators of heavy metals, herbicides, and mycotoxins in freshwater ecosystems. Pollutants absorbed by algae are subsequently transferred to herbivorous fish during feeding processes. Silver carp and grass carp demonstrated the ability to accumulate toxic compounds in their tissues. The presence of xenobiotics in fish organisms may cause metabolic disturbances and oxidative stress reactions. Heavy metals and herbicides were identified as significant environmental contaminants affecting aquatic biota. Aquatic vegetation can be effectively used as a bioindicator for ecological monitoring of polluted water bodies. Continuous contamination of freshwater ecosystems may negatively influence biodiversity and fish productivity. Monitoring of pollutant migration within the "water – algae – fish" system is important for assessing ecological risks and food safety. Further studies should focus on long-term bioaccumulation processes and the development of strategies for reducing toxic contamination in aquatic ecosystems.

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