*Ann. Anim. Sci., Vol. 24, No. 4 (2024) 1007–1024* *DOI: 10.2478/aoas-2024-0012*

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# PESTICIDES AND HEAVY METAL TOXICITY IN FISH AND POSSIBLE REMEDIATION – A REVIEW

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**Abstract**

**Pesticides and heavy metals are considered as potent contaminants in aquatic environment. Both contaminants are sourced into the aquatic ecosystems by various types of anthropogenic as well as natural practices. Such types of aquatic contamination drastically affect the normal activity of associated living organisms particularly fish. Both the pesticides and heavy metals toxicity cause several negative effects on fish growth, physiology, immune response, reproduction, embryonic and larval development as well as different histopathology of major organs including fish gill, kidney, liver, gonads, and intestine. Besides, the consumption of contaminated fish poses a serious health concern to associated consumers. Considering these serious issues, the current review is designed to investigate the toxic effects of pesticides and heavy metals on different aspects of fishes along with their possible sources, major types, and mode of action as well as role of medicinal herbs to mitigate their toxicity.**

**Key words: pesticide, heavy metal, contamination, fish, remediation**

Contamination of aquatic ecosystem is a matter of serious concern throughout the world. Both the natural and anthropogenic activities adversely affect the aquatic environment as well as associated living organisms. Various types of contaminants including pesticides (Santana et al., 2021, Ghafarifarsani et al., 2023 a; Rohani, 2023), heavy metals (Mirghaed et al., 2018; Mahmuda et al., 2020; Suchana et al., 2021; Taslima et al., 2022) etc. have resulted in a wide range of complexities in aquatic communities (fauna and flora) and posed a serious threat. Rapid industrial establishment resulted in discharge of a number of toxicants which either directly or indirectly affects both the aquatic ecology as well as organisms (Jan et al., 2022). Among them, heavy metals and pesticides are considered as the most potent contaminants in aquatic environment (Alam et al., 2023; Emon et al., 2023; Ramesh et al., 2023). Generally, pesticides have beneficial effects that are important, including controlling pests, weeds, and rodents, high productivity, and better quality of crops which also results in additional economic revenue (Popp et al., 2013). Yield protection and food affordability, thereby provide economic benefits to farmers and the consumers (Mesnage et al., 2019). The increases in outputs and production, and the decline of losses caused by diseases, insect pests, and weeds can reduce the quality, market value, and the number of harvestable crops has been related to some factors comprising the use of pesticides (Aktar et al., 2009).

Certain ingredients of pesticides including azadirachtin and/or glufosinate are compounds that happen naturally and are created using processes of synthetic chemistry (Fernandes et al., 2019; Mesnage et al., 2019). These naturally occurring pesticides are commonly established to have profitable well-being influences in humans because they evoke cellular stress adaption response pathways (Martel et al., 2019; Mesnage et al., 2019).

Since 1945, the utilization of pesticides has contained roughly 7 million people from death as a result of killing pests, which extend diseases, including yellow fever, typhoid fever, bubonic plague, and encephalitis. Preventing the outbreaks of diseases was one of the advantageous uses of pesticides to improve human health. For example, malaria is reported to be responsible for the death of over 5000 a day worldwide (Ross, 2005).

Heavy metals and pesticides toxicity negatively affect the physiology and growth of fish (Yang et al., 2021; Zulfahmi et al., 2021). Heavy metals toxicity significantly altered the hemato-biochemical profile of fish (Islam et al., 2020 a; Balali-Mood et al., 2021; Ahmed et al., 2022). Besides, heavy metal pollution exhibited genotoxicity in several fish species (Tlenshieva et al.,

2022; Choudhury et al., 2023). On the other hand, pesticides contamination also negatively affects the larval development and growth (Nataraj et al., 2023); hematobiochemical profiles (Rohani, 2023); cellular and nuclear structure of erythrocytes (Akter et al. 2020; Khatib et al., 2022); functions of important organs such as gill, liver, kidney and gonad (Khabbazi et al., 2014; Farag et al., 2021; Shah and Parveen, 2022) of different fish species. Finally, aquatic organisms especially fish have become the unvoiced victims of these contamination as it is believed that aquatic systems act as final destination of all these contaminants. And these types of alarming aquatic contamination has attracted the concentration of the concerned researchers throughout the world. Though heavy metals and pesticides severely affect the growth, physiology, reproduction of fishes, very little comprehensive information regarding their responses is available. Therefore, the current review summarizes the toxicity of heavy metals and pesticides in fish as well as highlights possible way to ameliorate their toxicity.

**Pesticides**

Pesticides are chemical (natural or synthetic) compounds which are toxic in nature and widely used to control different pests, insects, weeds and pathogens to enhance the yield quality as well as quantity (Kim et al., 2017) that act as a potent contaminant in aquatic waterbodies and hence exert negative impacts in aquatic organisms (Helfrich et al., 2009). Based on the harmfulness of pesticides, the World Health Organization (WHO) grouped them into four categories, including extremely hazardous, highly hazardous, moderately hazardous and slightly hazardous (Al-Mamun, 2017). Numerous groups of pesticides (insecticides, herbicides, bactericides, larvicides and fungicides) are extensively used all over the world (Abdel Khalek et al., 2018). Pesticides in aquatic ecosystems are mainly sourced from agricultural runoff and exert serious concern to not only aquatic species but also human health as they have the ability to accumulate to a different extent in fish and hence destroy the food chain (Bodnar et al., 2022). In review article of Kumar Sinha et al. (2022), toxicity of most pesticides has resulted in anemia and leukocytosis in fish. Altered hematological parameters in turn detrimentally change vital physiology of fish, e.g. respiration, feeding, reproduction etc. Any change in the physiology of fish could have catastrophic consequences like decrease in productivity of fish. So, Kumari (2012) reviewed pesticides toxicity in fishes and it can be assumed that the long-term exposure of fish to pesticides (including insecticides) is an ongoing danger to the population's health. The rationalization of the use of pesticides has been considered a crucial factor in reducing the degradation of the marine ecosystem by pesticides and other pollutants. Panda et al. (2023) have found that the strongest positive associations were discovered between Cu–Zn ($r = 0.74$, $P<0.05$) and Cr–Zn ($r = 0.57$, $P<0.05$). Spatial distribution maps depicting the consumption of fish as food and its corresponding Pb and Cr intake revealed a higher incidence of both carcinogenic and non-carcinogenic health concerns attributed to Pb and Cr in the region with populations consuming the fish. Beketov et al. (2013) reported that the pesticides are responsible for reducing regional biodiversity of aquatic insects and other fresh water invertebrates. A review study by Lakhani (2015) indicated that disadvantages of pesticides include their toxicity to some humans, animals and useful plants, and the persistence of some of these chemicals in the environment, which causes serious hazard to both the public health and the environment.

According to Sud and Kaur (2012) unutilized soluble pesticides of plants are converted into less soluble ones and then released into the waterbodies through run-off. Being an essential part of aquatic system, fish are sensitive to several environmental contamination and therefore widely used as bio-indicator of several toxicity parameters (Okwuosa et al., 2019) (Figure 1).

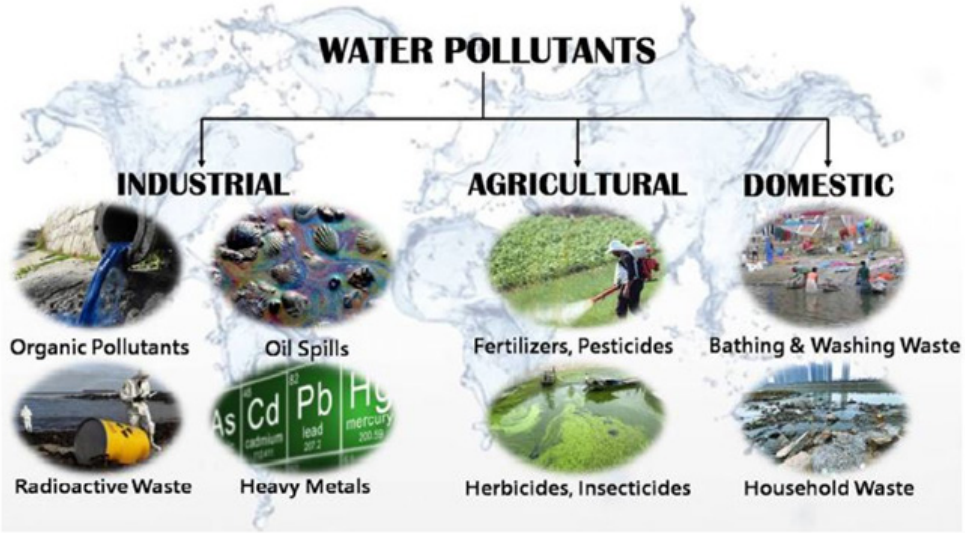



Figure 1. Various kinds and sources of water pollutants (Yadav et al., 2019)

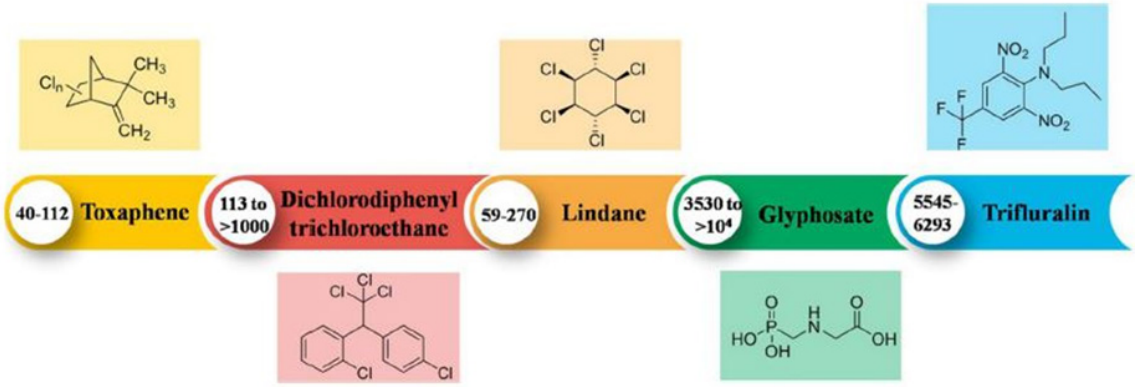



Figure 2. Structures of some of the major pesticides (values in the circles denote median lethal doses [LD50] in mg/kg in mammals) (Yadav et al., 2019)

Primarily, pesticides are accumulated into the body of aquatic organisms including fish by three possible routes: skin, gills and mouth. Firstly, pesticides are directly absorbed through fish skin when fish swim into the contaminated waters. Secondly, gills play an important role in pesticides uptake through respiration process and finally, pesticides absorption occurs by mouth through consumption of pesticides contaminated water as well as prey known as "secondary poisoning" (Helfrich et al., 2009; Poopak et al., 2023). Pesticides toxicity adversely affects the normal physiology of gills, liver, kidney and digestive tract of fish and hence disturbs their functions (Khatib et al., 2022). Pourgholam et al. (2013) demonstrated that pesticides toxicity caused severe histopathology (hyperemia, hyperplasia, necrosis, separation of membrane, and fusion of lamellae) in fish gills and affected the osmoregulation as well as respiration in fish.

Median lethal dose ($LD_{50}$) is a toxic unit which is generally used to measure the toxicity of different toxins including pesticides in aquatic systems. Generally, lower value of $LD_{50}$ indicates the more toxicity of the toxicants and range between 0 and 10 regarded as extreme toxicity. However, severity of pesticides contamination in aquatic ecosystems depends on various factors (toxicity, degradation and persistence) (Figure 2). Major groups of pesticides are described below:

*Fungicides*

Fungicides are important pesticides which are considered less toxic to fish and other aquatic organisms in comparison to insecticides. However, some of them caused destructive impacts on the ecosystem and have been banned. Application of mercury bearing fungicides has been stopped in the USA since 1976 as accumulation and transmission of mercury in the food cycle resulted in huge fish deaths. Some of the currently used fungicides are found very toxic to fish as well as other aquatic invertebrates. So, proper care and management should be taken during their application adjacent to the aquatic waterbodies.

*Herbicides*

Herbicides are frequently used in different crops lands, gardens, and lawns. Besides, they are applied in various aquatic systems to restrict the growth of different unwanted aquatic weeds including submerged (coontail, milfoil, naiad); floating (duckweed, spatterdock), and emergent (cattails, rushes, reeds). Moreover, the production of different nuisance algal species such as colonial, filamentous and single cells is controlled by their application. Herbicides significantly affect the reproductive performance of fish. Some of the aquatic weeds act as shelter and food source for fish. Destruction of these weeds by herbicides negatively affects their protection as well as food source. Moreover, aquatic plants play an important role in maintaining dissolved oxygen levels in aquatic systems and their destruction results in adverse impacts on aquatic environment.

*Rodenticides*

Rodenticides are also termed as rat poison. Some commonly used rodenticides are warfarin, red squill, sodium fluoroacetate, and zinc phosphide. They kill the rodents by inhibiting the vitamin K and make them unavailable to the rodents. Different forms of vitamin D ($D_3$ and $D_2$) result in hypercalcemia in rodents. Strychnine, a rodenticide generally found in semen nut tree (*Strychnos nux-vomica*) kills the rats by causing asphyxia. Chloralose derived from glucose and Paris green rodenticide (arsenic trioxide + copper acetate) act as important rodenticides.

*Insecticides*

Insecticides harm the insects by three main ways such as upon ingestion, direct contact and finally play the role as fumigants. In general, insecticides are of two types namely natural insecticides and synthetic insecticides. Commonly used natural insecticides are *Azadirachta indica*, *Peganum harmala* and *Chrysanthemum*. Among them *A. indica* specifically infect the larval stage of insects hence known as larvicides. On the other hand, organochlorines, organo-

phosphates, carbamates, and pyrethroids (ethylene dibromide, EDB) are commonly used as synthetic insecticides. Sporeine, the first commercially available bioinsecticide was introduced in Germany. Various types of insect growth regulatory ingredients (azadirachtin, hydroprene etc.) are used in insecticides that restrict the formation of chitin and ecdysone of different insects such as mosquitoes, cockroaches etc. Depending on the chemical formation, pesticides are mainly categorized into (a) organochlorines; (b) organophosphates; (c) carbamates; (d) pyrethroids and (e) triazines (Figure 3).

**Heavy metals**

Different types of organic and inorganic substances are responsible for aquatic contamination and among them heavy metals caused severe contamination (Raeeszadeh et al., 2022; Vijayaram et al., 2023). Metals and metalloids that have high molecular density and exert toxicity in even very low concentrations are known as heavy metals (Koller and Saleh, 2018). Commonly occurring heavy metals are arsenic, As; lead, Pb; mercury, Hg; cadmium, Cd; chromium, Cr; thallium, Tl; etc. Among them, Pb, Hg, and Cd are considered as most potent toxic metals in the environment (Raeeszadeh et al., 2022). On the basis of their positive as well as negative roles, heavy metals can be classified into two broad types such as essential and non-essential metals (Kim et al., 2017). Essential heavy metals are those which are generally harmless or less harmful at low concentrations. Metals including Zn, Cu, Fe and Co are categorized as essential heavy metals. These metals can influence several biological processes by playing the role of coenzyme. For instance, Fe plays an important role in the formation of hemoglobin (Hb) and myoglobin while Co is essential for the production of vitamin $B_{12}$. On the contrary, the metals which exert toxicity even at very small concentrations, result in severe negative impacts on living organisms and are generally non-biodegradable are known as non-essential heavy metals. Metals such as Pb, Cr, As, Hg and Cd are grouped as non-essential metals. In addition, heavy metals can also be classified as: i. macro-nutrient elements (Co, Fe etc.); ii. micro-nutrient elements (Cu, Ni, Cr etc.); iii. highly toxic metals (Hg, Cd, Pb, As etc.); iv. precious elements (platinum, Pt; gold, Au; silver, Ag etc.) and v. radionuclides (uranium, U; radium, Ra etc.). On the other hand, trace elements including copper, Cu; selenium, Se; and zinc, Zn are also recognized as heavy metals. Though some of the metals are essential for fish growth and feed utilization (Akter et al., 2021; Rohani et al., 2022), all are toxic in excess levels (Suchana et al., 2021; Sarkar et al., 2022). Sources of heavy metals in the environment are broadly divided into two types: natural or anthropogenic activities. Heavy metals in aquatic environment are mainly sourced from several types of anthropogenic practices such as agricultural, docking and embarkation activities, effluents from industrial and household practices and natural sources including outbreaks of volcanos, soil and rock formation etc. (Roozbahani et al., 2015). Most of the metals are non-biodegradable and carcinogenic in nature. Bioaccumulation of heavy metals occurs in different tissues of aquatic organisms that possess severe chronic health impacts (Ghafarifarsani et al., 2023 b). Therefore, it is utmost necessary to find out appropriate methods for removal from the environment. Guideline values for some of the heavy metals are listed in Table 1.

Heavy metals toxicity in fish varies with various factors such as ecological condition, metabolic rate, salinity concentration, state of water contamination, feed and sediment. Basically, types and concentration of heavy metals determine the metal toxicity on human as well as other aquatic species (Ghaedi et al., 2007). Gill is the main site by which different contaminants including heavy metals accumulate into fish (Hansen et al., 2002). Bioaccumulation and biotransformation of metals has become a great concern for human health (Smith, 1993). Results of a research (Begum et al., 2009) showed that the highest concentration of heavy metals is in kidney and liver of ten different fish species. Contaminated sediments can threaten creatures in the benthic environment, exposing worms, crustaceans and insects to hazardous concentrations of toxic chemicals. Also, Vinodhini et al. (2009) in common carp (*Cyprinus carpio*) exposed to heavy metals showed that the concentrations of red blood cells, blood glucose and total cholesterol were significantly elevated.

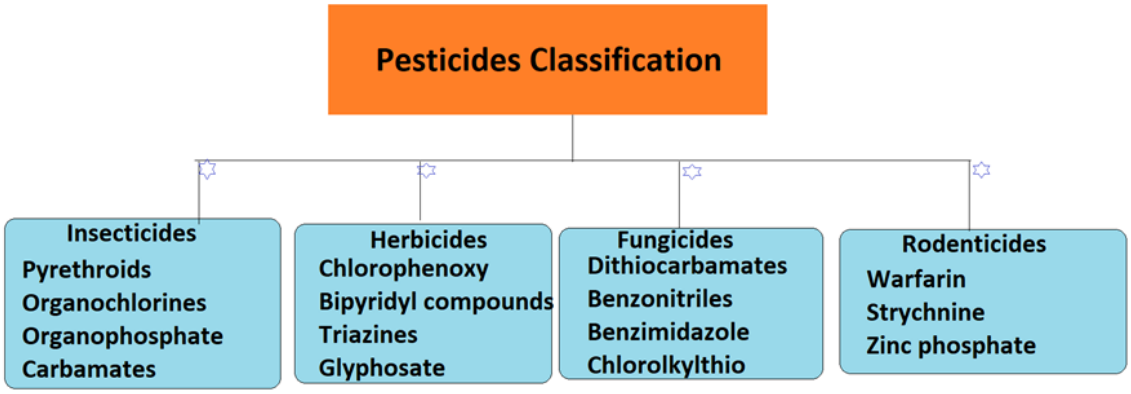



Figure 3. Classification and the chemical composition of pesticides (Fishel and Ferrell, 2010; modified after Yadav and Devi, 2017)

Table 1. Guideline values of heavy metals (according to World Health Organization, WHO, 2004)

| Heavy metals | Guideline value (mg/l) |
|---|---|
| Antimony (Sb) | 0.02 |
| Arsenic (As) | 0.01 |
| Barium (Ba) | 0.7 |
| Cadmium (Cd) | 0.003 |
| Chromium (Cr) | 0.05 |
| Copper (Cu) | 2 |
| Lead (Pb) | 0.01 |
| Manganese (Mn) | 0.4 |
| Mercury (Hg) | 0.006 |
| Molybdenum (Mo) | 0.07 |
| Nickel (Ni) | 0.07 |
| Selenium (Se) | 0.01 |
| Uranium (U) | 0.015 |

**Effects of pesticides on fish**

Pesticides are regarded as one of the most toxic contaminants in aquatic system which can be sourced from three main ways including water column, organic compounds (several algae, aquatic vegetation, leaf litter) and inorganic sediment (Golshani et al., 2020). Several biological methods are established to assess the toxic effects of these pesticides on living aquatic species including fish (Pandey et al., 2011; Kushwaha et al., 2012). Effects of different pesticides on various fish species are demonstrated in Table 2. Pesticides can affect fish either directly or indirectly (Ullah et al., 2014). Pesticides indirectly affect fish by reducing natural food availability of the aquatic systems (Helfrich et al., 2009). In addition, pesticides make fish more prone to the predators by altering their normal behavior as well as by degrading their habitat (Gill and Raine, 2014). A number of studies reported that pesticides induced several alterations in fish behavior (Rani and Kumaraguru, 2014; Tang et al., 2017). Kinds of effects of various pesticides can be variable to a greater extent on fish population. Survival, growth, and reproduction of fish are badly affected either by direct death due to starvation or by the destruction of food organisms (Prashanth, 2011; Murthy et al., 2013). Now, it has been a fact that all pesticides are potentially lethal to the fishes even at relatively low concentrations (Ullah and Zorriehzahra, 2015). Moreover, fish mortality due to pesticides like malathion (organophosphorus pesticide) and aldrin (organochlorine pesticide) groups of chemicals is on the record (Sabra and Mehana, 2015; Jayaraj et al., 2016).

Table 2. Effects of different pesticides on various fish species

| Species | Pesticides | Doses | Exposure time (days) | Effects | References |
|---|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 | 6 |
| *Trichogaster fasciata* | Thiamethoxam | 9.37, 18.75, 37.5, 75 and 150 mg/l | 90 | Pathologies such as necrosis, autolysis, vacuolation, cell swelling observed in liver. Deformed cell and irregular renal corpuscle in kidney. | Hasan et al., 2023 |
| *T. fasciata* | Thiamethoxam | 0, 9.37, 18.75, 37.5, 75 and 150 mg/l | 60 | Telangiectasia, hemorrhage, clubbed and damaged gill rakers and filaments were noticed. Water dissolved oxygen level significantly lowered. | Hasan et al., 2021 |
| *Danio rerio* | Sumithion | 0.235 and 0.341 mg/l | 3 | Edema, notochord deformity, yolk sac damage, body arcuation, lordosis, black pigmentation on the yolk sac. | Rahman et al., 2020 |
| *C. carpio* | Imidacloprid | 0, 10, 30, 100, 300 and 1000 µg/l | 4 | Hatching rate of fertilized eggs and number of dead embryos and larvae significantly decreased. Several malformations were observed in embryos and larvae. | Islam et al., 2019 |
| *O. niloticus* | Sumithion | 0.025, 0.050 and 100 mg/l | 180 | Vacuolation, ruptured and degenerated hepatopancreas, necrotic and hemorrhagic hepatocytes. Deformed renal cells, unusual blood vessel, vacuolation and necrosis were seen in kidney. | Kabir et al., 2019 |
| *Pangasianodon hypophthalmus* | Sumithion | 5.886 mg/l | 4 | WBCs, blood glucose level increased while Hb, RBCs decreased significantly Increased micronucleus formation. | Islam et al., 2019 |
| *M. cavasius* | Cypermethrin | 0, 2, 4, 8, 16 and 32 µg/l | 3 | Hatching success decreased and mortality of larvae increased significantly. Malformations in embryos and larvae were noticed. | Ali et al., 2018 |
| *Barbonymus gonionitus* | Sumithion | 0.00, 0.025, 0.05 and 0.1 mg/l | 30 | Hypertrophic, pyknotic, necrotic, hemorrhagic cells were found in liver and kidney tissues. | Al-Emran et al., 2018 |

Table 2 – contd.

| 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|
| *T. fasciata* | Chlorpyrifos | 0, 0.01, 0.10, 1.0, 10 and 100 µg/l | 4 | Hatching success decreased and mortality of larvae significantly increased. Hampered the development of larvae. | Sumon et al., 2017 |
| *H. fossilis* | Sumithion | 150 and 250 µg/l | 2 | Irregular head shape, lordosis, yolk sac edema, body arcuation, tissue ulceration were noticed in larvae. | Shahjahan et al., 2017 |
| *Clarias batrachus* | Sumithion | 5.25 mg/l | 1 | Hb, RBC and HCT significantly reduced. | Naqvi et al., 2017 |
| *D. rerio* | Sumithion | 0.5, 1.0 and 2.0 mg/l | 7 | Blood glucose increased but Hb decreased. Abnormal mucosal lumen, disrupted villi, sluggish epidermal cells were noticed in intestine. | Ahmed et al., 2016 |
| *H. fossilis* | Sumithion | 0.5, 1.0, 2.0, 4.0 and 8.0 mg/l | 120 | Very poor reproductive performances. Decreased fertilized eggs, egg malformation increase. | Das et al., 2016 |
| *C. carpio* | Sumithion | 0.85 and 1.7 mg/l | 21 | Vacuoles, hemorrhage, degenerated hepatic cells. | Hossain et al., 2016 |
| *C. carpio* | Sumithion | 0.85 and 1.7 mg/l | 4 | Glu, MCV and MCH increased while Hb, RBC and Hct decreased. | Hossain et al., 2015 |
| *C. carpio* | Sumithion | 4.25 mg/l | 4 | Significantly changed physiological functions. | Salam et al., 2015 |
| *O. niloticus* | Fenitrothion | 0–7.0 mg/l | 4 | Several histopathological disorders observed in gills, liver and kidney tissues. | Abu Zeid and Khalil, 2014 |
| *Ctenopharyngodon idella* | Sumithion | Fed contaminated grass | 4 | Cholinesterase in blood serum decreased while blood glucose level increased. | Pucher et al., 2014 |
| *H. fossilis* | Sumithion | 0.24 mg/L | 240 | Glucose increased; RBC, WBC and Hb decreased. | Ali et al., 2014 |
| *O. niloticus* | Sumithion | 1.89 mg/l | 4 | Bioconcentration factor of the muscle tissue increased. | Sherif et al., 2013 |
| *Channa punctatus* | Fenitrothion | 0.01, 0.02, 0.03, 0.04 and 0.05 mg/l | 21 | Fibrostic, necrotic, vacuoles found in hepatic cells. Hemorrhagic, edematic Bowman's capsule, atrophic glomeruli in kidney. | Akhter and Saha, 2013 |
| *H. fossilis* | Sumithion | 0.64 mg/l | 4 | Glycogen and cholesterol content significantly altered in ovary. | Kumari, 2012 |
| *O. niloticus* | Fenitrothion | 0.005, 0.05, 0.1 and 0.5 mg/l | 4 | Hyperaemia, haemorrhage in kidney. Cloudy swelling, hydropic degenerations, lipid infiltration in liver. Hyperplasia, fusion, telangiectasia in gills. | Benli and Ozkul, 2010 |
| *Poecilia reticulata* | Fenitrothion | 3.28 mg/l | 4 | Sluggish movement at high concentration. | Sarikaya et al., 2007 |
| *C. carpio* | Fenitrothion | 10 mg/l | 2 | Several histopathological disorders observed. | Sepici-Dincel et al., 2007 |

Blood is an important tool for investigating the effects of pesticides on fish. In fact, hematological parameters provide a signal of a change in the physiological state of fish due to stress, pollution, exposure to pesticides or infection. By studying changes in important blood parameters of fish including total red blood cell count (TEC), Hb content, packed cell volume (PCV), red blood cell sedimentation rate (ESR), absolute values, total leukocyte count (TLC), coagulation time and the number of thrombocytes, changes in the quality of the water environment can be easily evaluated.

Pesticides resulted in sluggish movement and abnormal swimming (Nagaraju et al., 2011); interrupted their nature to maintain fish schooling (Gill and Raine, 2014) that enhanced the chance of different preys attack. Pesticides resulted in stressful situations for fish and caused several infections and diseases by lowering their immune responses (Satyavardhan, 2013). Methyl parathion exhibited irregular movement, alteration in body color, and enhanced mucus secretion in katla, *Catla catla* (Ilavazhahan et al., 2010). Marigoudar et al. (2009) revealed that cypermethrin caused erratic swimming, loss of balance, hyperactivity in rohu, *Labeo rohita*. Histopathological changes in different fish tissues due to pesticides toxicity were also documented by several studies (Mohammed et al., 2019; Ghafarifarsani et al., 2023 a). Thiamethoxam and chlorpyrifos caused several liver pathologies including necrosis, vacuolation, hemorrhages etc.; kidney pathologies such as degenerated glomerulus, congested and damaged renal tubules, infiltrated lymphocytes; gill pathologies including telangiectasia, fused gill lamellae, damaged and clubbed gill rakers and arches etc. in

striped gourami, *Trichogaster fasciata* (Hasan et al., 2021). Moreover, numerous studies revealed toxicities of different pesticides in various tissues of fish including sumithion to Nile tilapia, *Oreochromis niloticus* (Kabir et al., 2019), Thai sharputi, *Barbonymus gonionitus* (Al-Emran et al., 2018), common carp (Hossain et al., 2016); fenitrothion to spotted snakehead, *Channa punctatus* (Akhter and Saha, 2013); cypermethrin to amazon bluespotted corydora *Corydoras melanistius* (Santos et al., 2012). Pesticides also altered the hemato-biochemical profiles of fish (Sivanatarajan and Sivaramakrishnan, 2013). Several pesticides such as fenitrothion, profenofos, sumithion were reported to cause significant changes in red blood cells (RBCs), white blood cells (WBCs), Hb, blood glucose level, packed cell volume (PCV) etc. in different fish species (Islam et al., 2019). Besides, enzymes secretion inhibited by pesticide contamination especially acetylcholinesterase (AChE) is very much sensitive to pesticides of organophosphate and carbamate groups (Bibi et al., 2014), and, AChE inhibition resulted in overall poor performance of fish including reduced swimming capacity (Rao et al., 2007). Cypermethrin induced alterations in several enzymes (AChE, succinic dehydrogenase, lactic dehydrogenase) and resulted in hyperactivity in *L. rohita* (Marigoudar et al., 2010); complexities in nervous system in *C. fasciatus* (Singh et al., 2010). Moreover, pesticides induced several biochemical changes and caused stress in fish (Muthukumaravel et al., 2013). Thenmozhi et al. (2011) reported that malathion toxicity restricts the functions of catalase (CAT) and glutathione-S-transferase (GST) in several organs (muscle, gill, liver) of *L. rohita*. Similar results were also exhibited due to the sodium cyanide exposure (Dube et al., 2013). Another study reported reduced catalase activity by sodium cyanide in *C. carpio* (David et al., 2008). Moreover, pesticides lowered the immune response and endocrine disorders in different fishes (Dey and Saha, 2014). Furthermore, genetic damages (genotoxicity) as a result of pesticides contamination have been reported by several studies (Devi et al., 2011; Kushwaha et al., 2012; Poorbagher et al., 2018). Oxygen consumption rate also changed due to pesticides toxicity (Shereena et al., 2009). Heavy contamination resulted in fish mortality by damaging their metabolic activity (Shanker et al., 2013). Moreover, pesticides negatively change the nutritional composition of several fish species (Bibi et al., 2014).

**Effects of heavy metals on fishes**

Heavy metals are the most hazardous contaminants in ecological systems (Radkhah et al., 2020, 2022) that negatively influence the physiology of fish. Heavy metals result in different types of complexities (Jadhav et al., 2010). Bioaccumulation and toxicity of heavy metals in different fish tissues not only varies with metals concentration and exposure duration but also chemical properties (temperature, salinity, pH, and hardness) of water (Has-Schön et al., 2007). Generally, heavy metals are absorbed into the fish by gills or intestine, then transported with blood and finally deposited in different fish organs (Javed and Usmani, 2014; Al-Taee et al., 2020). Extent of metals bioaccumulation in fish body depends on metals absorption as well as elimination rates (Ahmed et al., 2016). Effects of heavy metals on different aspects of fish are summarized in Table 3.

Heavy metals toxicity greatly affect the growth and feed utilization of fish. Some of the metals showed positive impacts in fish growth up to certain levels (Akter et al., 2020; Rohani et al., 2022). While excess levels of Cr negatively affect the growth of fish (El-Sayed et al., 2010). Toxic effects of Zn resulted in poor growth and feed utilization in *O. niloticus* (Tan et al., 2011) and juvenile yellow catfish, *Pelteobagrus fulvidraco* (Luo et al., 2011). Reproductive performances of fish are severely affected by heavy metals contamination, which hampered the sperm and ovum production of fish as well as lowered their quality, hatching, and fertilization rate (Celino et al., 2009). Cr toxicity resulted in shrunken sperm lobules, fibrosis in the testis, reduced sperm movement as well as fertilization rates (Dietrich et al., 2012; Hayati et al., 2017; Raeeszadeh and Fallah, 2018). Moreover, negative effects of heavy metals on embryonic and larval development including lower hatchability, poor survival, improper skeletal structure, incomplete pigmentation, abnormal eyes etc. have been demonstrated in several studies (Gárriz and Miranda, 2020; Taslima et al., 2022).

Heavy metals significantly altered the blood profiles of fish (Islam et al., 2020 a; Suchana et al., 2021). RBCs, Hb, and leukocytes decreased significantly WBCs, and blood glucose levels increased in different heavy metals contaminated fish (Fazio, 2019). Cr toxicity significantly enhanced the WBCs content of striped catfish, *Pangasianodon hypophthalmus* (Islam et al., 2020 a) which could result from increased lymphocytes production to boost up immunity in stressed condition. On the other hand, Al-Ghanim (2011) reported significant reduction in WBCs level in Ni exposed *C. carpio* which could be caused by the inhibition of lymphopoiesis by heavy metals. Heavy metals toxicity significantly decreased the packed cell volume, PCV (Soundararajan and Veeraiyan, 2014) while decreasing and increasing trends observed in terms of mean corpuscular volume, MCV; mean corpuscular Hb, MCH (Banday et al., 2019). Several studies reported that exposure to Cd, Cu and Fe significantly enhanced blood glucose level in *C. catla;* African catfish, *Clarias gariepinus; C. punctatus* (Javed and Usmani, 2014; Banday et al., 2019). Besides, exposure to heavy metals caused a significant increase in blood cholesterol and low density lipid (LDL) level in *C. punctatus* (Javed et al., 2017). Moreover, different cellular and nuclear anomalies were reported for heavy metals toxicity in fish erythrocytes (Islam et al., 2020 a).

Table 3. Effects of heavy metals on different aspects of fish

| Species | Doses | Exposure period | Effects | References |
|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 |
| **Cd** | | | | |
| *Catla catla* | 4.5 mg/l | 30 days | Atrophy, telangiectasia, and necrosis in gill. Degenerated, congested and hemorrhagic hepatocytes. Atrophic glomerulus, degenerated and necrotic renal tubes, melanomacrophages center in kidney. | Naz et al., 2021 |
| *Mystus seenghala* | 1/3 of LC50 | 112 days | Poor growth as well as feed utility. | Fazio et al., 2021 |
| *Ictalurus punctatus* | 0.5 and 2.6 µg/l | 180 days | Negatively affected the growth performances of fish. | Paul and Small, 2021 |
| *Odontesthes bonariensis* | 0.25 and 2.5 µg/l | 10 days | Poor survival of larvae and embryo. | Gárriz and Miranda, 2020 |
| *Pelteobagrus fulvidraco* | 0, 50 and 200 µg/L | 56 days | Significantly lowered the weight gain and specific growth rate. | Xie et al., 2019 |
| *C. gariepinus* | 0.316 mg/l | – | AST, ALP, ALT, Cort, Glu, MCH increased while CK, TLC, MCV decreased. | Banday et al., 2019 |
| *Oncorhynchus mykiss* | 2 µg/l | 4 days | Micronucleus, nuclear bud and bi-nucleated erythroblasts in larvae . | Jurgelėnė et al., 2019 |
| *Channa striata* | 0.001 mg/l | – | HDL, LDL, TP, AST and ALT increased while Glu level decreased. | Phoonaploy et al., 2019 |
| *D. rerio* | 30 µg/l | 35 days | Growth and survival rate significantly declined. | Yuan et al., 2017 |
| *C. carpio* | 0.10 mg/l | 30 days | Spiked and fused lamellae, club-shaped epithelial filaments in lamellae. Hepatic cells with ruptured vein and vacuoles. | Rajeshkumar et al., 2017 |
| *D. rerio* | 60 ppb | 7 days post--fertilization | Otolith diameter decreased, various fiber observed between otoliths. | Green et al., 2017 |
| *C. carpio* | 8.4 mg/l | 15 days | Fused gill lamellae, widen vessel, hyperemia, and hyperplasia in epithelial cells of gill. | Khalesi et al., 2017 |
| *Sparus aurata* | 0.5 mg/kg | 15 days | Expression of cytochrome P450 increased while heat shock protein (HSP90) decreased. | Benhamed et al., 2016 |
| *C. carpio* | 0.3 and 0.06 mg/l | 60 days | Poor survival and growth, deformed yolk sac, cardiac edema, bent vertebral column. | El-Greisy and El-Gamal, 2015 |
| *O. niloticus* | 0.5 mg/l | 56 days | Reduced growth and feed intake. | Abdel-Tawwab and Wafeek, 2014 |
| *Leuciscus idus* | 0.1 mg/l | 21 days | Body length and perimeter small, survival rate declined. | Witeska et al., 2014 |
| *L. rohita* | 0.826 mg/l | – | WBC level increased significantly while RBC, Hct decreased significantly. | Chandanshive et al., 2012 |
| *Oryzias latipes* | 0.18–19.8 µg/l | 10 days | Kyphosis, lordosis observed in larval spine. | Barjhoux et al., 2012 |
| *Colisa fasciatus* | 1.86 mg/l | - | Protein, gly, nucleic acid decreased. | Tripathi et al., 2012 |
| *O. mykiss* | 35.9 µg/kg | 28 days | Level of hepatic transferrin, metallothionein (MTs) and heat shock protein (HSP70) increased. | Kwong et al., 2011 |
| *O. niloticus* | 1.0 mg/l | 7–14 days | ALT, Cort., Glu and TP level increased while cholesterol level decreased. | Firat and Kargin, 2010 |
| **Cr** | | | | |
| *P. hypophthalmus* | 2, 4 and 8 mg/kg | 60 days | Growth and feed utilization significantly decreased in fish fed 8 mg/kg with micronucleus formation. | Akter et al., 2021 |
| *P. hypophthalmus* | 0.8, 1.6 and 3.2 mg/l | 30 days | Erythrocytic cellular and nuclear complexities resulted in histopathologies observed in gills, liver and kidney. WBCs, blood glucose level increased. | Suchana et al., 2021 |
| *Oryzias melastigma* | 10.44 and 20.88 mg/l | 4 days | Vacuoles, pyknotic cells, abnormal nucleus observed in hepatic cells. | Ni and Shen, 2021 |
| *O. niloticus* | 4.57 mg/l | 60 days | Weight gain, specific growth rate reduced. | Mohamed et al., 2020 |
| *P. hypophthalmus* | 10, 20, 30, 40, 50 and 60 mg/l | 4 days | Different anomalies observed in erythrocytes. RBC, Hb, PCV decreased significantly. | Islam et al., 2020 |
| *Platichthys stellatus* | 0, 50, 100, 200 and 400 ppb | 28 days | Daily weight and length gain declined. Hepatosomatic index (HSI) reduced. | Ko et al., 2019 |

Table 3 – contd.

| 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|
| *C. punctatus* | 0.08 mg/l | – | Albumin, triglyceride, HDL and VLDL level in serum decreased. | Javed et al., 2017 |
| *O. latipes* | 4 mg/l | 90 days | GSI and fecundity significantly lowered.<br>Frequencies of immature oocytes and spermatozoa increased in gonad. | Chen et al., 2016 |
| *Sebastes schlegelii* | 0, 30, 60, 120 and 240 mg/kg | 28 days | Growth performance reduced.<br>Poor feed utilization. | Kim and Kang, 2016 |
| *Acipenser ruthenus* | 0.1 and 5.0 mg/l | 2 h | Higher Cr concentration inhibited the sperm motility and velocity. | Li et al., 2010 |
| *C. punctatus* | 4 mg/l | 30 days | Oocytes with incomplete vitellogenesis. | Mishra and Mohanty, 2008 |
| **Cu** | | | | |
| *C. carpio* | 0.05 and 0.1 mg/l | 90 days | Significantly reduced the growth and feed utilization indices. | Ghosh et al., 2020 |
| *Channa gachua* | 1.4202 mg/l | 4 days | Vacuoles in the cytoplasm and stroma, degenerated nuclei observed in liver. | Kawade, 2020 |
| *P. reticulata* | 0, 5 and 10 mg/l | 56 days | Poor reproductive performances, increased parturition period, highest mortality of larvae. | Forouhar Vajargah et al., 2020 |
| *Oryzias melastigma* | 0.32 mg/l | 7 days | Improper skeletal structures, anomalies in vascular system, lower pigmentation of embryo. | Wang et al., 2020 |
| *O. niloticus* | 25, 50 and 75 µg/l | 90 days | Weight gain, specific growth rate declined. | Shokr, 2020 |
| *C. carpio* | 20, 30, 40 and 70 µg/l | 28 days | TL, WG and CF decreased; HSI increased . | Sevcikova et al., 2016 |
| *Carassius carassius* | 0.30 and 0.60 mg/l | 20 days | Hindered the growth performances. | Jiang et al., 2016 |
| *P. reticulata* | 0, 0.004, 0.013, 0.019 and 0.029 mg/l | 56 days | Higher feed conversion ratio.<br>Poor growth response. | Moosavi and Shamushaki, 2015 |
| *Leuciscus idus* | 0.1 mg/l | 21 days | Yolk sac malformation, lower body length and perimeter, curve vertebrae. | Witeska et al., 2014 |
| *Carassius auratu* | 0.1–1 mg/l | 1 day | Scoliosis and tail curvatures. | Kong et al., 2013 |
| **Pb** | | | | |
| *Myoxocephalus scorpius* | 4.01 µg/l | 28 days | Gill lamellae fused, hyperplastic epithelial cells, synechia and telangiectasia observed in gill tissue.<br>Hepatosis, necrosis, granuloma, and neoplasm in hepatocytes. | Jantawongsri et al., 2021 |
| *Mugil cephalus* | 0.0015 and 0.0025 mg/l | 4 days | Glucose, malondialdehyde level in blood increased. | Hajirezaee et al., 2021 |
| *Chanos chanos* | 0, 42.64, 63.97 and 85.2 mg/l | 40 days | WG, LG, SGR, FE, and FCR significantly reduced with the increase of Pb concentration. | Zulfahmi et al., 2021 |
| *C. carpio* | 0.25 mg/l | 30 days | Spiked and fused secondary lamellae, club-shaped filaments epithelium tissue of gill. | Rajeshkumar et al., 2017 |
| *Carassius gibelio* | 8, 13, 24 and 49 mg/kg | 365 days | Poor reproductive performance. | Łuszczek-Trojnar et al., 2014 |
| *L. rohita* | 0.756 mg/l | – | RBCs, Hct decreased while WBCs increased. | Chandanshive et al., 2012 |
| **As** | | | | |
| *Clarias batrachus* | 84 mg/l | 4 days | Total serum proteins level decreased. | Pichhode and Gaherwal, 2020 |
| *H. fossilis* | 7.0 and 20.0 mg/l | 60 days | Split muscle fibers, edema, atrophy found in muscle.<br>Loss of serosal intactness, irregular villi formation.<br>Necrosis, hemorrhage and hemolysis in liver. | Begum et al., 2014 |
| *Tilapia mossambica* | sublethal | 21 days | WBC, MCH, MCHC level increased while Hb, RBC, PCV level decreased significantly. | Soundararajan and Veeraiyan, 2014 |
| *Oreochromis mossambicus* | 3.0, 28.0 and 56.0 mg/l | 8 days | Joined lamellae, hyperplasia and necrosis noticed in epithelial cells of gill.<br>Infiltrated macrophages, shrunken and congested hepatic cells, hypertrophy and vacuolation found. | Ahmed et al., 2013 |

Table 3 – contd.

| 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|
| *O. mykiss* | 26–77 µg/kg | 30 days | Growth and feed utility declined significantly. | Erickson et al., 2010 |
| **Hg** | | | | |
| *O. niloticus* | 0.025 mg/l | 30 days | ALT, AST, SOD levels in blood increased significantly. | Mahboub et al., 2021 |
| *O. niloticus* | 500, 750 and 1000 mg/kg | 60 days | Epithelial lifting and hypertrophy. Fusion of secondary lamellae in gill.<br>Necrosis of hepatocytes and portal veins in liver. | Al-Ghanim et al., 2019 |
| *Cirrhinus mrigala* | 0.0206 and 0.0402 mg/l | 30 days | Lamellar degeneration, epithelial lifting and necrosis in intercellular epithelial cells of gill.<br>Necrosis in hepatocytes, blood vessels dilated, hemolysis, inflammation of hepatic cells, congestion in blood sinusoids. | Chavan and Muley, 2014 |
| *Channa gachua* | 1.0625 mg/l | 4 days | Vacuolation in the cytoplasm and stoma, degeneration of nuclei in liver. | Deore and Wagh, 2012 |
| *Acipenser baerii* | 0–100 mg/l | 4 h | Motility of sperm reduced with the increase of Hg concentration. | Dietrich et al., 2012 |
| *Acanthopagrus lates* | 0.01, 0.02, 0.04 and 0.08 mg/l | 21 days | Hb, Hct, monocyte increased but WBCs, eosinophil declined. | Safahieh et al., 2010 |
| *O. mykiss* | 1, 10 and 100 mg/l | 4 h | Sperm motility lowered. | Dietrich et al., 2010 |
| **Zn** | | | | |
| *Clarias magur* | 50, 200 and 300 mg/kg | 60 days | GSI and fecundity decreased with the increased concentration of Zn. | Gupta et al., 2021 |
| *O. melastigma* | 100 µg/l | 30 days | Incomplete oocytes formation including empty follicle with no follicular lining and enhanced follicular atresia. | Yan et al., 2020 |
| *D. rerio* | 50 and 500 mg/l | 4 days | Poor hatching success, heart rate of embryo increased with the increase of concentration. | Gouva et al., 2020 |
| *O. niloticus* | 500 and 2000 µg/l | 15 days | Significantly increased GSH, SOD, CAT, GST level. | Saddick et al., 2017 |
| *S. aurata* | 0.4 µg/l | 15 days | Metallothionein decreased significantly. | Benhamed et al., 2016 |
| *C. punctatus* | 0.30 mg/l | – | WBC increased while opposites result observed in RBC and Hb. | Javed and Usmani, 2014 |
| *Pagrus major* | 0.1, 0.3, 0.5, 0.7, 1.0, 1.5, 2.0 and 2.5 mg/l | 10 days | Poor reproductive success.<br>Abnormal embryo and larvae with improper pigmentation, hooked tail, deformed spine, hemorrhagic viscera etc. | Huang et al., 2010 |
| **Ni** | | | | |
| *C. gariepinus* | 0.302 mg/l | – | Significantly altered hemato-biochemical profile of fish. | Banday et al., 2019 |
| *C. punctatus* | 0.12 mg/l | – | RBC, Hb decreased while WBC increased. | Javed and Usmani, 2014 |
| *C. carpio* | 6, 9, 12, 15 and 18 mg/l | 4 days | RBC, WBC, Hct and Hb, MCV remarkably decreased. | Al-Ghanim, 2011 |
| *C. gariepinus* | 4, 6, 8, 10 and 12 mg/l | 4 days | Significantly changed biochemical indices of blood. | Ololade and Oginni, 2010 |

Heavy metals induced severe histopathology in different important fish organs. Heavy metals contamination resulted in hyperplastic and hypertrophic epithelial, chloride and mucous cells in gills, congested capillary, jointed gill lamellae, clubbing, telangiectasia in fish gill and caused respiratory difficulties (Rajeshkumar et al., 2017; Al-Ghanim et al., 2019). Liver is very much sensitive to heavy metals in comparison to other organs and several histopathological changes (necrotic and degenerated hepatocytes, cirrhosis and lysis of hepatic cells, pyknosis, and vacuoles) observed in different extent in various fish (Kawade, 2020). Degenerated and necrotic renal tubes, shrunken renal corpuscle, atrophic glomerulus, hypertrophic epithelial cells, etc. have been exhibited due to different metals toxicities in fish kidney and disrupted their normal functions (Islam et al., 2020 a). Moreover, significant negative effects of heavy metals on fish intestine were stated by different studies and caused difficulties in fish digestion (Kaoud et al., 2015).

**Impact of pesticides and heavy metals on the immune system in fish**

Pesticides and heavy metals adversely affect the immune responses of several fish species. They reduced the disease resistance capacity of fish by declining the leukocytes, granulocytes as well as lymphocytes, restricting the production of B and T cells (Abdel-Latif et al., 2020; Raeeszadeh et al., 2022). Lysozyme activity drastically lowered due to the exposure of cypermethrin in Korean rockfish, *Sebastes schlegelii* (Jee et al., 2005). Cypermethrin and deltamethrin activity noticeably decreased the serum protein content in *S. schlegelii* (Jee et al., 2005) that may be resulted by lower WBCs content that act as a major source of serum protein formation.

Heavy metals restrict the formation of WBCs, lymphocytes and phagocytosis functions of macrophages and hence disrupt the immune activity of fish (Jiaxin et al., 2020; Choudhury et al., 2021). Moreover, heavy metals negatively affect the hemolymph integrity of fish and results in immunosuppressive impacts (Naz et al., 2021). Cd exposure significantly interfered with the functions of lymphocytes, lysozymes and neutrophils and reduced the disease resistance capacity of juvenile *P. fulvidraco* (Tan et al., 2010) and zebrafish, *Danio rerio* (Xu et al., 2018). However, deficiency of certain metals resulted in significant reduction in cellular as well as humoral immune activities of fish (Altarelli et al., 2019) (Figure 4).

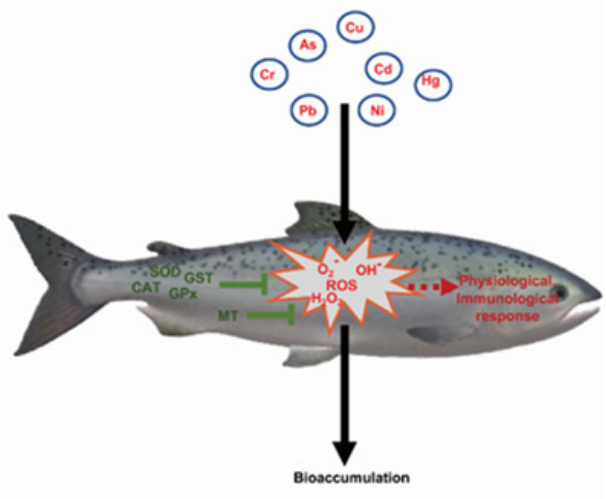



Figure 4. Heavy metals toxicity in fishes. Heavy metals induce oxidative stress by generating reactive oxygen species (ROS). The anti-oxidation defense mechanism (including different enzymes CAT, SOD, GST, GPx, and metal scavenging protein MT) involved in detoxification

**Oxidative stress is a prominent effect of environmental pollution**

Oxidative stress is very commonly induced by exposure of several contaminants that generates dangerous free radicals as reactive oxygen species (ROS) and produces some neutralizing nutritional substances termed antioxidants that favors ROS (Sharifi-Rad et al., 2020; Ghafarifarsani et al., 2021; Bello-Medina et al., 2022). Uncontrolled oxidative stress caused alteration of several physiological activities of organisms that caused several chronic diseases that directly or indirectly affect the survival rate of organisms (Zheng et al., 2021; Sandys and Te-Velde, 2022). Malondialdehyde (MDA) level indicates the level of peroxidized lipids and has been considered as an important indicator of oxidative stress resulting from various contaminants including pesticides (Anila et al., 2021; Golomb et al., 2021). Single and combined exposure of acetamiprid and thiamethoxam in *C. catla* resulted in an enhanced level of MDA in gill tissues (Veedu et al., 2022). Ali et al. (2015) revealed that exposure of organophosphate pesticide (diazinon) significantly elevated the MDA content in rainbow trout, *Oncorhynchus mykiss* (Ali et al., 2015) and *O. niloticus* (Abdelkhalek et al., 2017; Sebaei et al., 2022) that is stated as a common response of diazinon toxicity (Akturk et al., 2006). Similarly, pyrethroid pesticides caused similar MDA increment in *D. rerio* (Al-Ghanim et al., 2020). Besides, several studies also demonstrated that heavy metals toxicity enhanced the MDA level in various fish species including medaka, *Oryzias latipes* (Li et al., 2009) and cichlid species (Ruas et al., 2008). In this context, several substances having antioxidant capacity are employed to mitigate the oxidative stress and maintain a healthy aquatic ecosystem (Halliwell and Gutteridge, 2015; Nwobi et al., 2020).

**Effective factors in reducing oxidative stress induced by pollutants**

Several enzymatic as well as non-enzymatic antioxidants play a crucial role to reduce the pollutants mediated oxidative stress. Enzymatic antioxidants, also called natural antioxidants, including superoxide dismutase (SOD), catalase (CAT), glutathione peroxidase (GPx), glutathione reductase (GR), glutathione S-transferase (GST) and non-enzymatic antioxidants known as exogenous antioxidants such as vitamin A, vitamin C, vitamin E, Zn, Se are popularly applied for this purpose (Lindshield, 2019; Irato and Santovito, 2021) that may directly or indirectly act as a rescue for the associated organisms including fish surrounded by oxidative stress. In addition, oxidative stress can be reduced by reducing the toxicants through oxidizing properties, by enhancing levels of several antioxidants (endogenous and exogenous) and by stabilizing the energy production and efficiency of mitochondria (Poljsak, 2011).

**Role of medicinal plants to reduce the toxic effects of contaminants**

Several herbal plants are applied to remediate the toxic effects of different contaminants as they contain several bioactive as well as therapeutic agents (Farzaei et al., 2013; Islam et al., 2020 b). They are very popular due to their favorable characteristics such as easy availability, lower price in comparison to modern medicines (Paryab and Raeeszadeh, 2017; Pu et al., 2017). Benefi-

cial impacts of these medicinal herbs can be categorized as (a) curative (treatment); (b) promotive (enhance body fitness); (c) preventive (boost up immunity) that significantly reduce stress and stimulate fish appetite (Citarasu, 2010). The commonly used herbs for these purposes are garlic, *Allium sativum*; milk thistle, *Silybum marianum*; cilantro, *Coriandrum sativum*; ginkgo, *Ginkgo biloba*; turmeric, *Curcuma longa*; and green algae, *Chlorophyta* sp. (Mehrandish et al., 2019). However, different plants such as *A. sativum*, *Apium graveolens*, *Artemisia absinthium*, *Carum carvi*, *Citrullus colocynthis*, *Laurus nobilis*, *Mentha pulegium*, *Myrtus communis*, *Nerium oleander*, *Ocimum basilicum*, and *Origanum majorana* can be used as an alternative to insecticides to control pests in food production (Cheraghi Niroumand et al., 2016).

**Role of algae in the bioremediation of heavy metals**

Different algal species have the capability of degrading or removing toxic heavy metals through biosorption (Cirillo et al., 2012; Abbas et al., 2014). It can be attributed to the enhanced photosynthetic capacity of algae that confirms huge availability of dissolved oxygen in aquatic environment which resulted in aerobic breakdown of several organic substances including heavy metals. Enzymatic and metabolic activities of several algae trigger the degradation, detoxification and transformation of various toxic compounds like metals (Kumar et al., 2021). Cell wall of algae contains several functional bioactive compounds such as fucoidan, alginate etc. that play active role in removing toxic metals by biosorption (Anastopoulos and Kyzas, 2015; Park et al., 2016). Besides, algae can bind several heavy metals through different mechanisms (chelation, complexation, physical adsorption) and reduce the toxicity (Mantzorou et al., 2018). Moreover, algae can detoxify several metals through their capacity of synthesizing phytochelatins which are formed by phytochelatin synthase enzymes which require post-translational activation by heavy metals (Chen et al., 1997; Perales-Vela et al., 2006). In addition, algae bear several chemical compounds like hydroxyl, carboxyl, phosphate and amide which act as binding sites for metals (He and Chen, 2014). Death cells of *Chlorella vulgaris* have exhibited excellent removal efficiency of Cd, Pb and Cu (Goher et al., 2016).

**Conclusion**

Pesticides and heavy metals contamination is a major concern to the aquatic environment as well as associated organisms including fish. Both contaminants have destructive effects on different aspects of fish which cause a huge loss for aquaculture industry. Both contaminants not only negatively affect the fish but also pose a serious threat to the final consumers due to their bioaccumulation in fish tissues. It is very unfortunate that fish become a major source of contaminants including pesticides and heavy metals which results in several carcinogenic as well as non-carcinogenic human health complexities. This review illustrates the possible routes of pesticides and heavy metals in aquatic ecosystems, their toxic impacts on fish, and finally role of medicinal plants to detoxify these potent contaminants. Regular monitoring program is a crying need to ensure safe aquatic environment and fish production as well as sustain this potential industry. And this should be implemented by legal authorities at local, state and national levels. Histopathological effects of pesticides in fishes have been studied intensively. Pathological changes occur mainly in the liver, gonads, brain, kidneys, and endocrine glands and in gills. Accordingly, for reducing the risk of pesticide and protecting water quality, pesticides can be used only when necessary, using less toxic pesticides and using safe/sensible application methods. Finally, establishment of a comprehensive framework has become the utmost necessity to protect the aquatic ecosystems as well as associated organisms. Besides, continuous researches should be carried to find out the possible remedial measures to control the aforementioned pollution.

**Data availability**

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

**Compliance with ethical standards**

All applicable international, national, and/or institutional guidelines for the care and use of animals were followed.

**Conflicts of interest**

Authors have no conflict of interest to declare for the publication of the work herein.

**Funding statement**

There is no government or organizational fund for this work.

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Received: 31 V 2023
Accepted: 14 XII 2023