Review Article

Ecotoxicology: A Review of Pesticides Induced Toxicity in Fish

Sana Ullah[1], Mohammad Jalil Zorriehzahra[2]

[1]Fisheries and Aquaculture Lab, Department of Animal Sciences, Quaid-i-Azam University, Islamabad, Pakistan; [2]Aquatic Animal Health and Diseases Dept., Iranian Fisheries Research Organization (IFRO), Tehran, Iran.

Abstract | Throughout the world pesticides are widely employed in agriculture sector in order to elevate crops' yield with low labour and efforts. Pesticides exposure leads to toxicity in many non-target organisms, fish being one of the most prominent among these. Most of the time acute concentration of these pesticides leads to mortality while sub lethal concentration of these pesticides result in different lethal changes. These changes may be in behaviour of the exposed fish such as change in feeding behaviour, attack or avoiding behaviour and reproductive behaviour, or other types of alterations such as changes in histology (liver, kidneys, gills, muscles, brain, intestine), haematology (RBCs, WBCs or Plasma), anti-oxidant defence system (Glutathione reductase, Peroxidase, Catalase, Superoxide dismutase, Glutathione peroxidase, Glutathione-S-transferase etc.), changes in nutrient profile (Protein, Lipids, Carbohydrates, Moisture content and Ash etc.) and worth of the fish, hormonal or enzymatic alterations, oxygen consumption, and DNA damage or damage at genes level (genotoxicity). Different environmental agencies are working on this aspect and that's why there are a large number of banned chemicals. Still these chemicals are available in markets. Certain newly synthesized pesticides (insecticides or fungicides etc.) and extensive use of these chemicals are always there to maximize the problem for aquatic organisms especially fish. This article focuses on the same aspect of ecotoxicology and reviews some major induced toxicological aspects of pesticides in fish including behavioural changes, histopathological damages, haematological alterations, biochemical changes, fluctuations in acetylcholinesterase activity, vicissitudes in protein contents, induced genotoxicity, alterations in feeding biology, oxygen consumption and oxygen stress all across the world.

Keywords | Pesticides, Toxicity, Fish, Behavioural changes, Biochemical changes, Histopathological changes, Haematological changes, Molecular changes.

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***Correspondence** | Sana Ullah, Quaid-i-Azam University, Islamabad, Pakistan; **Email:** sunyuop@gmail.com
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INTRODUCTION

In present era of green revolution the human population is being increasing swiftly. Forests have been utilized for abode construction, deteriorating environmental balance on one hand (Ullah, 2014). On the other hand we are faced with the emerging and increasing problem of pollutants (AusAID, 1996; Jacinto, 1997; Klumpp et al., 2002). These pollutants are domestic wastes, untreated or semi treated effluents from industries and different chemicals such as pesticides used in agriculture sector or safety measures (Gagnaire et al., 2004; Jain et al., 2005; Mustapha, 2008; Naeem et al., 2010; Abu-Darwish et al., 2011). These pollutants are supplemented with different chemicals, pesticides, organic compounds and heavy metals etc. (Meitei et al., 2004; Jabeen et al., 2011). These substances change water quality, which is home to many aquatic organisms (Donohue et al., 2006). The changed water quality adversely affects these organisms and even leads to their mortalities in acute concentrations and severe exposure (Sarwar et al., 2007; Sabae et al., 2014).

The potential harmful chemicals or substances such as heavy metals, pesticides and hydrocarbons are dumped either or released into the water bodies (Ullah et al., 2014a). When these pollutants flow into water bodies in higher concentration than permissible limits then these result in the form of heavy mortalities of all life form residing in those aquatic systems such as fish and shell fish etc. while in lower concentration these lead to bio accumulation of these pollutants and ultimately go through the food web to human beings (Xie et al., 1996; Morel et al., 1998; Abedi et al., 2013). This issue is attention seeking and should be treated and focused properly and attentively in order to ensure safer fish consumption on priority basis (Yousaf et al., 2013; Ullah et al., 2014b).

OCCURRENCE OF PESTICIDES IN AQUATIC SYSTEMS

Presence of pesticides in aquatic systems may be by different ways, but is assessed by identifying three major routes, due to which it leads to water bodies (Kosygin et al., 2007; Sarkar et al., 2008). These routes are water column, organic substrates such as mosses, algae, leaf litter, vascular hydrophytes and branches, and inorganic substrate including materials from sediments varying in size (Murthy et al., 2013). Standing water has higher concentration than lithic biotopes and water column while its quantity is negligible in sediments (Kingsbury and Kreutzweiser, 1980).

DETERMINING PESTICIDE CONTENTS

For finding pesticide contents in sediments, organic substrate, water and most important in animal or plants tissues is done chemically (APHA, 1998; Shuhong et al., 2005; Ishaq and Khan, 2013). The solid tissue of animals or plants and other solid materials are first homogenized and then extraction is done through acetone or hexane, then evaporated to a small volume, followed by cleaning and drying, and then finally analysed (Peterson and Batley, 1993; USGS, 1995; Hong et al., 2003; Hong et al., 2006; Zhou et al., 2007; Hong et al., 2008).

For determining the effects of pesticides such as acute toxic effect of these chemicals on aquatic organism biological methods are used, *in situ* bioassays (Akcha et al., 2003; Buschini et al., 2004; Cavas and Ergene-Gozukara, 2005; Pandey et al., 2011; Kushwaha et al., 2012). This assay is based on exposing the test animals to the field without disturbing the polluted sediments. After exposure survival percentage is determined. Sometimes when the water column is too deep or too fast, water cages are used for holding the fish in water column (Dey and Saha, 2014).

Indirect Effects of Pesticides to Fish

Pesticides greatly reduce food organisms' abundance in aquatic bodies and eco system which is necessary for fish survival (Helfrich, 2009). By this mean it indirectly interrupts the fish food supply and change the habitat of water bodies (Maskaoui et al., 2005; Chau, 2005). Besides this it can also make the fish more susceptible to predators by decreasing habitat suitability and changing their behaviour as well, which is a direct effect as a consequence of indirect effect (Holden, 1973; Prashanth et al., 2011; Gill and Raine, 2014). Results have shown that these indirect effects can be much more vital than the direct ones (Murthy et al., 2013).

Direct Effects of Pesticides to Fish

Fish is directly affected by different pesticides (Rao and Pillala, 2001). Pesticides induce different types of toxicity in fish, which these pesticides lead to, such as changes in fish behaviour (Scott and Sloman, 2004; Krian and Jha, 2009; Satyavardhan, 2013; Marigoudar et al., 2009; Ilavazhahan et al., 2010; Nwani et al., 2010; Nagaraju et al., 2011; Prashanth et al., 2011; David et al., 2012; Ullah et al., 2014c; Rani and Kumaraguru, 2014), haematological changes (Joshi et al., 1988; Agrawal and Tyagi, 1988; Bhatkar and Dhande, 2000; Svoboda et al., 2001; Joshi et al., 2002; Johal and Grewal, 2004; Gautam and Kumar, 2008; Devi et al., 2008; Saeedi et al., 2012; Ullah et al., 2014d), histopathological disturbances (Anees, 1976; Kumaraguru et al., 1982; Arora and Kulreshta, 1984; Bakthavathsalam et al., 1984; Karlsson-Norrgren et al., 1985; Dutta et al., 1994; Anitakumari and Ramkumar, 1995; Vijaylakshmi and Tilak, 1996; Chatterjee et al., 1997; Das and Mukerjee, 2000; Mohan, 2000; Cengiz and Unlu, 2002; Parashar and Banerjee, 2002; Dutta et al., 2003; Johal et al., 2007; Kunjamma et al., 2008; Velmurugan et al., 2009; Ba-Omar et al., 2011; Rani and Venkataramana, 2012; Deka and Mahanta, 2012; David and Kartheek, 2014), enzymes alteration, genotoxicity (Stahl, 1991; Helma et al., 1996; Mitchelmore and Chipman, 1998; White et al., 1998a; White et al., 1998b; Hose and Brown, 1998; Hartmann et al., 1999; Gartiser et al., 2001; Vargas et al., 2001; Çavas and Könen, 2007), biochemical modifications, endocrine system disruption (Dunier and Siwicki, 1993; Magare, 1997; Gupta et al., 1997; Steenland et al., 1997; Waring et al., 1997; Halloran et al., 1998; Kamble et al., 1999; Bols et al., 2001; Hoeger et al., 2005; Maskaoui et al., 2005; Murthy et al., 2013; Dey and Saha, 2014), nutrient profile disturbance (Palanisamy and Bhaskaran, 1995; Jha and Verma, 2002; Aguigwo, 2002; Jenkins et al., 2003; Borah, 2005; Zorriehzahra, 2008; Singh et al., 2010; Thenmozhi et al., 2011; Bose et al., 2011; Muthukumaravel et al., 2013; Bibi et al., 2014), variation in feeding biology (Roger and Bhuiyan, 1990; Chandra et al., 2008; Bhandare et al., 2011; Ravindran et al., 2012), changes in antioxidant defence system (Joshi et al., 1981; Swetharanysm, 1991; Silvia et al., 1994; Anusha et al., 1996; Cookson and Pentreath, 1996; Geetha et al., 1999; Luther et al., 1999; Kamble and Muley, 2000; Jiraungkoorskul et al., 2003; Shanker et al., 2005; Milaeva, 2006; Neto et al., 2008; Nwani et al., 2010; Muthukumaravel et al., 2013) and alteration of acetylcholinesterase activity (Minier et al., 2000; Lionetto et al., 2003; Chandrasekara and Pathiratne, 2005; Glusczak et al., 2006; Rao, 2006; Glusczak et al., 2007; Rao et al., 2007; Marigoudar et al., 2009; Singh et al., 2010; Marigoudar et al., 2010; Joseph and Raj, 2011; Bibi et al., 2014). Different fish species are susceptible to these pesticides at different concentration. The changes in different body parts have been observed to be different than each other as well as in response to different pesticides. These effects have been observed in almost all parts of the fish body and systems. Some of these changes have been summarised under different subheadings in the following in order to make it more comprehensive.

Lethal Effects of Pesticides

Studies have shown that sub lethal amount of certain chemicals induced abortions (Boyd, 1964). DDT (dose of 2 mg kg1 per seven days for five months) resulted in production of more mature ova than control group while mortality in sac fries was higher, when the gametes were from DDT treated parents as compared to control fish group. In 1996 the disastrous event of mortalities in various fish species such as deaths of 92,000 steel head, 19 resident rainbow trout, 114 juvenile coho salmon and thousands of non-game fish species in a branch of Rogue River by the name of Bear Creek (Ewing, 1999) was attributed to aquatic pollution mainly from chemicals such as pesticides. Methyl parathion caused 50%, 80% and 100% mortality of *Catla catla* even at the minor concentrations of 4.8ppm, 8ppm and 10ppm respectively (Ilavazhahan et al., 2010). Dimethoate and Lambda-cyhalothrin showed to be lethal for *Labeo rohita* (Dey and Saha, 2014).

Table 1 is depicting a list of common pesticides along with their lethal concentrations for different fish species. However for further details handbook of Johnson and Finley (1980) can be consulted.

In contrast to lethality and mortalities of fish on account of lethal concentration, sublethal concentrations of these pesticides lead to subtle changes in biology of different fish and consequently effect their survival (Scott and Sloman, 2004; Rani and Kumaraguru, 2014). Laboratory experiments have shown different effect of these pesticides on different biological aspects of these fish species. DDT has shown a disastrous effect of disturbing the reproduction of certain species while some species such as cutthroat goldfish have shown no change (Allison et al., 1964). The altered physiology and other changes that take place due to sublethal concentration of pesticides are divided into behavioural, Histopathological, haematological and such other subheadings in the following.

Pesticide Induced Behavioural Changes in Fish

Pesticides have shown different alteration in behaviour of various fish species such as rendering fish sluggish and alter their swimming ability making them more susceptible to be preyed, reduce their ability to feed, maintain their position and defend their territories (Prashanth et al., 2011). Pesticides have also shown interrupting the schooling behaviour (Gill and Raine, 2014) of fish due to dangling, erratic and irregular movements and disturbed swimming (Nagaraju

Table 1: LC_{50} value of some pesticides for different specie

S. No.	Name of the pesticides	Test organism	Duration of exposure	LC50 value	Reference
1	Acephate	*Pimephales promelas*	96 hrs	>1000 mg/L	Johnson and Finley, 1980
2	Alaclor	*Salmo gairdneri*	96 hrs	2.4 mg/L	Johnson and Finley, 1980
3	Akton	*Channel catfish*	96 hrs	400 µg/L	Johnson and Finley, 1980
4	BHC	*Carassius auratus*	96 hrs	348 µg/L	Johnson and Finley, 1980
5	Carbaryl	*Salvelinus namaycush*	96 hrs	690 µg/L	Johnson and Finley, 1980
6	Carbofuran	*Perca flavescens*	96 hrs	147 µg/L	Johnson and Finley, 1980
7	DDT	*Salmo gairdneri*	96 hrs	8.7 µg/L	Johnson and Finley, 1980
8	Endosulfan	*Ictalarus punctatus*	96 hrs	1.5 µg/L	Johnson and Finley, 1980
9	Diazinon	*Channa punctatus*	96 hrs	3.09 ppm	Rahman et al., 2002
10	Diazinon	*Anabas testudineus*	96 hrs	6.55 ppm	Rahman et al., 2002
11	Diazinon	*Barbodes gonionotus*	96 hrs	2.72 ppm	Rahman et al., 2002
12	Elsan	*Channa punctatus*	48 hrs	0.43 ppm	Rao et al, 1985
13	Permethrin	*Cyprinus carpio*	24 hrs	35 µg/L	Sial et al., 2009
14	Biosal	*Cyprinus carpio*	24 hrs	4.21 mg/L	Sial et al., 2009
15	Cypermethrin	*Labeo rohita*	96 hrs	4.0µ/L	Marigoudar et al., 2009
16	Dimethoate	*Heteropneustes fossilis*	96 hrs	2.98mg/L	Pandey et al., 2009
17	Methyl parathin	*Catla catla*	96 hrs	4.8ppm	Illyazhanan et al., 2010
18	λCyhalothrin	*Danio rerio*	96 hrs	0.119µ/L	Ansari and Ahmad, 2010
19	Cypermethrin	*Colisa fasciatus*	96 hrs	0.02mg/L	Singh et al., 2010
20	Metasystox	*Nemacheilus botia*	96 hrs	7.018 ppm	Nikam et al., 2011
21	Malathion	*Labeo rohita*	96 hrs	15mg/L	Thenmozhi et al., 2011
22	Rogor	*Puntius stigma*	96 hrs	7.1ppm	Bhandare et al., 2011
23	Endosulfan	*Channa striatus*	96 hrs	0.0035ppm	Ganeshwade et al., 2012
24	Malathion	*Heteropneustes fossilis*	96 hrs	0.98ppm	Deka and Mahanta, 2012
25	Termifos	*Clarias gariepinus*	96 hrs	0.86 mg/L	Nwani et al., 2013
26	Endosulfan	*Catla catla*	96 hrs	0.98 µg/L	Ilyas and Javed, 2013
27	Endosulfan	*Cirrhinus mrigala*	96 hrs	1.06 µg/L	Ilyas and Javed, 2013
28	Endosulfan	*Labeo rohita*	96 hrs	2.15 µg/L	Ilyas and Javed, 2013
29	Dimethoate	*Labeo rohita*	96 hrs	24.55 µg/L	Dey and Saha, 2014
30	λ Cyhalothrin	*Labeo rohita*	96 hrs	0.7 µg/L	Dey and Saha, 2014
31	Karate	*Cyprinus carpio*	96 hrs	0.160 µg/L	Bibi et al., 2014

et al., 2011). Disruption of schooling behaviour also renders the fish more susceptible and easily preyed. On account of stress due to pesticides, fish became stressed and immunocompromised, which make them more susceptible and vulnerable to diseases, secondary infections and pathogens (Satyavardhan, 2013; Nwani et al., 2010). Methyl parathion resulted in increased movements of opercula, rapid jerk movement, equilibrium loss, body colour alterations, frequent surfacing, and elevated mucus secretion in *Catla catla* (Ilavazhahan et al., 2010). Cypermethrin caused darting, erratic and irregular swimming movements, equilibrium loss, hyper excitability and sinking to bottom in *Labeo rohita* (Marigoudar et al., 2009).

Pesticides also alter the migratory behaviour of migratory fish (Nagaraju et al., 2011), thus result in disturbing their life cycle such as it can disturb the ability of salmonid fish to transit from fresh water to sea water. However this phenomenon is seeking further researchers to place particular emphasis on critical period of transition, which occurs in estuaries. Yet studies have shown that adult salmon use to circumvent pollutants and contaminated areas during their migration, altering their migratory pattern, which result in postponement of spawning (Satyavardhan, 2013). Cypermethrin resulted in jumping, increased surface activity, balance loss, increased air gulping, equilibrium loss, abrupt swimming, sluggishness, motionlessness, adopting vertical positions and internal haemorrhage in *Tor putitora* (Ullah et al., 2014c). Sodium cyanide induced certain behavioural changes such as hypexcitability, darting and erratic movements, and imbalance swimming, in *Oreochromis mossambicus, Catla catla*, *Cirrhinus mrigala*, *Labeo rohita*, and *Cyprinus carpio* (David et al., 2012). There are many other studies confirming behavioural changes in fish due to pesticides (Scott and Sloman, 2004; Krian and Jha, 2009; Prashant et al., 2011; Rani and Kumaraguru, 2014).

Pesticide Induced Histopathological Changes in Fish

Histopathological changes due to various pesticides have been extensively studied in different fish species. These changes have been traced in liver, gills, blood vessels, brain, kidneys and muscles of the studied fishes. The changes documented are quite various such as partial loss of liver plate radial orientation, cytoplasmic granularity and shrinkage of liver cell mass in liver cells; pycnotic alteration of cell nuclei, atrophy and cytoplasm vocalization in kidneys; gill lamellae and filaments have shown precipitated masses that plugged to the central capillaries and in large blood vessels various changes have also been observed such as alteration in morphology, haematocrit levels and blood cells' quantity (Kennedy et al., 1970).

Histopathological changes were also observed in ovary when expose to Malathion altered ovigerous lamellae, follicular cell degeneration, atrectic oocytes increment, clumping of cytoplasm, ruptured follicular epithelial lining and nuclear materials' shrinkage, which was attributed to endocrine and hormonal imbalance, while carofuran caused degeneration of connective tissues, follicular walls and vacuolization in the ooplasm during stage second and third (Mohan, 2000; Chatterjee et al., 1997; Dutta et al., 1994) and diazinon exposure resulted in different alterations in ovaries such as primary follicles adhesion, atretic oocytes increment, cytoplasmic retraction in oocyte II, damages to oocyte IV, vitellogenic membrane destruction, increased intrafollicular spaces, cytoplasmic degeneration, cytoplasmic necrosis, karyoplasm extrusion and vacuolated cytoplasm (Dutta et al., 2003). Malathion also resulted in changes in histology of liver, ovary and kidney in *Heteropneustes fossilis* (Deka and Mahanta, 2012). Sodium cyanide also resulted in histopathological changes such as variation in histoarchitecture of kidneys including necrosis, degeneration of glomerulus, lymphocytes infilteration, cytoplasmic vacuolation, blood congestion, damage to collecting duct and size change of tubular lumen, in *Cyprinus carpio* after exposure to sub lethal concentration (David and Kartheek, 2014).

Certain other studies also support the toxic effects of pesticides in various tissues and organs of different fish, such as atrazine to *Labeo rohita* (Jayachandran and Pugazhendy, 2009), Cypermethrin to *Tor putitora* (Ullah et al., 2014d), *Corydoras melanistius* (Santos et al., 2012), dimethoate to *Putius ticto* (Marutirao, 2012), hostathion to *Channa gachua* (Jha et al., 2014), malathion to *Heteropnuestes fossilis* (Adhikar et al., 1998) and many other such studies support these histopathological changes (Anees, 1976; Kumaraguru et al., 1982; Arora and Kulreshta, 1984; Bakthavathsalam et al., 1984; Karlsson-Norrgren et al., 1985; Anitakumari and Ramkumar, 1995; Vijaylakshmi and Tilak, 1996; Das and Mukerjee, 2000; Cengiz and Unlu, 2002; Parashar and Banerjee, 2002; Johal et al., 2007; Kunjamma et al., 2008; Velmurugan et al., 2009; Ba-Omar et al., 2011; Rani and Venkataramana, 2012).

Pesticide Induced Haematological Changes in Fish

Different conducted studies showed lethal effect of various pesticides including Aldrin, dieldrin, DDT, BHC, chlordane, cypermethrin, permethrin, sulfane, endosulfane, karate, delmethrin etc. on haematology such as characteristics of blood and histological changes in WBCs and RBCs, haemoglobin contents and packed cell volume of different fish species such as *Cyprinus carpio* and *Puntius ticto* (Satyanarayan et al., 2004), *Tor putitora* (Ullah et al., 2014d), *Oreochromis mossambicus* due to potassium chlorate and potassium dichromate (Sivanatarajan and Sivaramakrishnan, 2013) and lead (James et al., 1993), *Onchorhynchus mykiss* (Saeedi et al., 2012) and *Cyprinus carpio* (Svoboda et al., 2001) in response to Diazinon, *Mystus keletius* to methyl parathion (Sampath et al., 2003), *Channa punctatus* (Abidi and Shrivastava, 1980) and *Ophiocephalus punctatus* (Agrawal and Tyagi, 1988) to endosulfan, *Labeo rohita* to Cypermethrin (Adhikari et al., 2004), chlordane caused chronic disfunction of hemopoietic system in *Labeo rohita* (Bansal et al., 1979), and dimecron (Anandkumar et al., 2001) and endosulfan (Bhatia et al., 2002, 2004) to *Heteropneustes fossilis* and *Channa punctatus* (Devi et al., 2008) and furadon to *Labeo rohita* (Bhatkar and Dhande, 2000). There are many other studies conducted showing haematological changes taken place due to different pesticides (Joshi et al., 1988; Joshi et al., 2002; Johal and Grewal, 2004; Gautam and Kumar, 2008).

Pesticide Induced Toxic Effects in Acetylcholinesterase of Fish

AChE (AChE) activity is very much sensitive for carbamate pesticides and organo phosphates as compare to other types of pesticides and contaminants (Murthy et al., 2013). Various studies have been shown that inhibition of this enzyme has been associated with the effects and exposure of fish with other contaminants such as crude oil addition to brain homogenate inhibited AchE activity (Rodriguez-Fuentes, 2000). AChE activity was inhibited by 40% in muscles of flounder on account of abode in polluted sites (Minier et al., 2000); heavy metals and pesticides also reduced AChE activity in brain by 40% in three polluted sites in Italy (Lionetto et al., 2003). AChE activity in *Labeo rohita* was inhibited by Cypermethrin significantly, brain being the most altered followed by muscles, gills and liver tissues (Marigoudar et al., 2010).

By affecting the AChE activity in fish, the swimming capability and performance of fish is ultimately reduced and disturbed which can attribute to more harmful consequences (Rao, 2006; Rao et al., 2007). Significant change in AChE activity has been observed in different tissue of different species after exposure to single and multiple expositions such as tilapia to chlorpyrifos, carbosulfan (Chandrasekara and Pathiratne, 2005; Joseph and Raj, 2011). Cypermethrin resulted in AChE inactivation which led to accumulation of acetylcholine within the cholinergic synapses, which ultimately led to hyperstimulation in *Labeo rohita* (Marigoudar et al., 2009; Marigoudar et al., 2010). Cypermethrin induced alterations in AChE, succinic dehydrogenase and lactic dehydrogenase activities in nervous tissue of *Colisa fasciatus* (Singh et al., 2010). Glyposate induced AChE change in *Leporinus obtusidens* (Glusczak et al., 2006) and *Rhamdia quelen* (Glusczak et al., 2007) while karate decreased AChE activity in *Cyprinus carpio* (Bibi et al., 2014).

Pesticide Induced Biochemical Changes/ Oxidative Stress in Fish

Various studies have shown devastating effects of pesticides in various biochemical activities (Ullah et al., 2014c). These changes in antioxidants systems of fish are often tissue specific such as these changes have been traced in brain, gills, muscles, kidneys, lungs and viscera of different fish and have shown varying results in different organs and different fish species such as peroxidase activities was found higher in brain, viscera, gills, and muscles of tilapia but gills was the organ received highest disturbance in peroxidase (Ahmad et al., 2000). Similarly changes in lipid peroxidase have been observed on account of different pesticides as well as environmental pollutants.

Studies on *Labeo rohita* by applying organophosphates in sub-lethal concentration led to disturbance in various enzymes such as glutaminases including phosphate activated glutaminase and L-Keto acid activated glutaminase in brain tissue, which were associated with the involvement of these brain regions with metabolism (Mastan and Shaffi, 2010). Endosulfan led to reduction in the activities of citrate synthase and glucose 6 phosphate dehydrogenase in skeletal muscle, liver and brain, while lactate dehydrogenase activity in brain of *Clarius batrachus* (Tripathi and Verma, 2004). Malathion resulted in disturbed Catalase and Glutathione-S-transferase activities in gills, liver and muscles of *Labeo rohita* (Thenmozhi et al., 2011) and also induced biochemical changes in *Clarias batrachus* (Khare et al., 2000).

Cypermethrin induced very much change in Catalase, Glutathion Reductase, Peroxidase, and Lipid peroxidase in brain, liver, gills and muscle tissues of *Tor putitora* (Ullah et al., 2014c) while catalase, hydrogen peroxide, malondialdehyde, protein carbonyls and free amino acid in liver of *Labeo rohita* (Marigoudar et al., 2012). Sodium cyanide caused steady decreased with time in different enzymatic activities such as succinate dehydrogenase, lactate dehydrogenase, phosphorylase, glucose-6-phosphate dehydrogenase, acid phosphates and alkaline phosphatase in different tissues such as liver, gills and muscles of *Labeo rohita* (Dube et al., 2013) and catalase in *Cyprinus carpio* (David et al., 2008). Many other studies are depicting pesticides as inducer of anomalous biochemical changes in fish (Joshi et al., 1981; Swetharanysm, 1991; Silvia et al., 1994; Anusha et al., 1996; Cookson and Pentreath, 1996; Geetha et al., 1999; Luther et al., 1999; Kamble and Muley, 2000; Jiraungkoorskul et al., 2003; Shankar et al., 2005; Milaeva, 2006; Neto et al., 2008; Nwani et al., 2010; Muthukumaravel et al., 2013).

Pesticide Induced Molecular Changes in Fish (Genotoxicity)

Chromosomal aberrations have been observed after exposure of fish species to different chemicals. Exposure of *Channa punctatus* to Dichlorvos (0.01 ppm chromosome) caused chromatid gaps, centromeric gaps, attenuation, chromatid breaks, pycnosis, extra fragments, and stubbed arm in kidney cells (Rishi and Grewal, 1995) while exposure of the same species to fenvalerate caused chromatid separation, chromatid break, deletion, fragments, gaps, and ring type chromosomes (Saxena and Chaudhari, 2010). The toxicity of different pesticides has been associated with changes in replication of DNA and DNA aberration that leads to mutation (Gilot-Delhalle et al., 1983), and hyperproliferation of cells due to local irritation (Mirsalis et al., 1989; Oshiro et al., 1991; Benford et al., 1994). Interestingly longer exposure was associated with lower frequency of DNA aberrations. Cypermethrin caused changes in nucleic acids (RNA and DNA) in gonadal tissue of *Colisa fasciatus* (Singh et al., 2010). Profenofos caused significant change in tail of marine fish, *Therpon jarbua* (Devi et al., 2011).

In fish DNA repairing took place at a much lower speed than in mammals (Walton et al., 1984; Espina and Wesis, 1995), which render fish as sentinel organism as for as bio-monitoring studies are concern (Landolt and Kocan, 1983; Gernhofer et al., 2001). Different species of fish have been employed for analysing erukaryotic gentoxicity as well as for mutagenicity tests. These included comet assay (Sumathi et al., 2001; Kushwaha et al., 2012), chromosal aberration test (Al-Sabti, 1985; Rishi and Grewal, 1995), micronucleus assay (De Flora et al., 1993; Saotome and Hayashi, 2003; Pantaleao et al., 2006), DNA repair synthesis (Grummt, 2000), and sister chromatid exchange test (Kligerman et al., 1984; Sahoo et al., 1998).

Various studies conducted have shown that pollutants cause carcinogenesis (Dunn, 1991; Weishburger and Williams, 1991; El Adlouni et al., 1995; Erickson and Larsson, 2000), teratogenesis, clastogenesis and mutation in fish (Obiakor et al., 2012) which ultimately lead to reduced growth, malignancies, reduction in survival of fish in early life stages as well as adult stage, abnormal development and different deformities of body organs (Akpoilih, 2012). There is rich documented literature witnessing research on molecular level of different fish species showing ill effects of pesticides on genes and DNA levels (Stahl, 1991; Helma et al., 1996; Mitchelmore and Chipman, 1998; White et al., 1998a; White et al., 1998b; Hose and Brown, 1998; Hartmann et al., 1999; Gartiser et al., 2001; Vargas et al., 2001; Çavas and Könen, 2007).

Pesticide Induced Changes in Protein Contents of Fish

Experiments have shown higher effect of pesticides in protein contents, in different tissue such as gills, liver, blood, intestine and muscle of various fish species, such as nickel caused decrease in protein level of *Heteropneustes fossilis* (Nanda et al., 2000), nickel chloride caused appreciable decrease in gonads, liver and muscles of *Anabus testudineus* (Jha and Jha, 1995), phenyl mercuric acetate caused reduction of protein level in muscles and liver of *Channa punctatus* (Karuppasamy, 2000) while the same species showed low protein level when exposed to oleandrin (Tiwari and Singh, 2004) and arsenic (Hota, 1996). Nuwan decreaded protein contents in liver of *Mystus vittatus* (Tazeen et al., 1996), copper in *Lepidocephalicthus thermails*, lead acetate in *Cirrhinus mrigala* (Ramalingam et al., 2000), endosulfan in *Cyprinus carpio* (Jenkins et al., 2003), cypermethrin in *Labeo rohita* (Veeraiah and Durga-Prasad, 1998), petroleum oil in *Heteropneustes fossilis* (Borah, 2005), and lead, mercury and cadmium in *Channa straiatus* (Palanisamy and Bhaskaran, 1995).

Cypermethrin exposure resulted in significant decrease in protein contents in *Tor putitora* (Ullah et al., 2014c) and *Colisa fasciatus* (Singh et al., 2010). Malathion decreased protein contents in *Labeo rohita* (Thenmozhi et al., 2011) and *Clarias batrachus* (Khare and Singh, 2002). Thiamethoxan affected liver total protein of *Oreochromis niloticus* (Bose et al., 2011), thiodon significantly affected liver total protein in *Clarias gariepinus* (Aguigwo, 2002) while dichlorvos showed significant impact in total protein, tissue glycogen and albumen content in muscles, liver and kidneys of *Oreochromis mossambicus* (Lakshmanan et al., 2013). A pesticidal mixture used againat *Clarias batrachus* induced changes in protein content (Jha and Verma, 2002), karate decreased protein contents in *Cyprinus carpio* (Bibi et al., 2014) while monocrotrophs decreased protein, lipid and carbohydrate content in various tissues of *Labeo rohita* (Muthukumaravel et al., 2013). Also, in a complex pathway, dioxin interacts with DNA to alter how genes control protein synthesis, for example the protein called vitellogenin which is involved in egg development (Zorriehzahra, 2008).

Pesticides induced changes in Immune Systems and Endocrine Disruptors

Pesticides have shown disruption of immune system in fish (Bols et al., 2001; Maskaoui et al., 2005). Studies have shown serious ill impact of pesticides on immune system, which results in disease initiation and eventually can lead to death (Dunier and Siwicki, 1993; Halloran et al., 1998). Fish are also vulnerable to endocrine disrupting impacts during early life stages or stages of development (Magare, 1997; Gupta et al., 1997; Kamble et al., 1999). Pesticides also act as sex hormones' blockers, which leads to anomalous and atypical sexual development, irregular sex ratios, males' feminization and disturbed mating behaviour. Susceptible fish reproductive behaviour depicts its vulnerability by different pollutants such as pesticides (Hoeger et al., 2005). It can also alter other hormonal processes of fish like development of bones and proper thyroid functioning (Murthy et al., 2013). Dimethoate and Lambda-cyhalothrin showed lethal effect on Thyroid hormone of *Labeo rohita* (Dey and Saha, 2014). Several studies have shown that environmental chemicals disturb levels plasma thyroid hormone (Steenland et al., 1997). Disturb plasma thyroid hormone level leads to thyroid dysfunction in fishes (Waring et al., 1997).

Pesticides Induced Changes in Oxygen Consumption

Different studies conducted put forth the results of reduction or increase in oxygen consumption by various fish species when exposed to different pesticides. These fish showed these changes with different time and duration of exposure such as Dimethoate (Shereena et al., 2009) and lead (James et al., 1993) induced toxic changes in oxygen consumption in *Oreochromis mossambicus*. Dimethyl parathion disturbed the oxygen consumption in *Labeo rohita* (Bengeri et al., 1984), DDT induced disturbance in *Lepidocephalichthys thermalis* (Gurusamy and Ramadoss, 2000), endrin in *Lepomis machrochirus* (Huner et al., 1967) and different pesticides in *Puntius ticto* (Magare and Patil, 2000).

Pesticides Induced Changes in Larvivorous Potential of Fish

Organophosphorous pesticides, on account of high insecticidal property, lesser persistence, less toxic to mammals and rapidly biodegradable, are frequently used (Bhandare et al., 2011) but unfortunately these also affects non-target life forms both indirectly as well as directly including larvivorous fish species (Roger and Bhuiyan, 1990).

Pesticides have been concluded as an agent of alteration in fish physiology. Different studies conducted have shown pesticides lowering the larvivorous potential of different fish species. Hostathion (Triazophos) and Kitazin (Iprobenfos) lowered down the larvivorous capability of *Oryzias carnaticus*. The larvivorous potential of *Oryzias carnaticus* decreased by 3.1 and 4.1 times on day first and day second respectively for Hostathion treated group than control while it lowered down 4.6 and 4.8 times for Kitazin treated group as compared to control group (Ravindran et al., 2012). Instead of these pesticides, larvivorous fish can be used for biological control of vector mosquito (Chandra et al., 2008). It is safer and environmental friendly approach instead of using these pesticides which often lead to higher mortalities and reduction of fish population (Ravindran et al., 2012).

Dioxin as typical model for side effects of Pesticides on Fish Health

Fish show a wide range of sensitivity to some chemical substances such as dioxin. Trout are very sensitive to the effects of dioxin. These fish are not only being used to tell scientists about what is happening in the environment but as models of what may happen to humans exposed to these chemicals. In experimental study in University of Wisconsin, researchers have injected very small quantities of dioxin and dioxin-like chemicals into newly fertilized lake trout eggs. Dramatic changes in the development of the embryo have been observed in this fish (Guiney et al., 1996). Very small amounts of dioxin into lake trout embryos causes a condition called "blue-sac disease" in which there is a disruption of both the yolk sac and blood vessels. Normal embryos of lake trout have large yolk sacs and good blood vessel formation. Rate of mortality could be reached in 25% in affected farms (Peterson et al., 1993). But when fry mortality syndrome occurred after stage of yolk sac absorption, above mentioned disorder signs could not be observed.

Furthermore, Dioxins are highly toxic to both freshwater and marine fish, particularly to early life stage fish, although the saltwater fish species tested so far are more tolerant to TCDD (2,3,7,8-tetrachlorodibenzo-p-dioxin) exposure than most freshwater species (Walker and Peterson,1994) Previously exposed saltwater fish are also more tolerant than un-adapted fish. Lake trout were the most sensitive to TCDD, the most toxic form of dioxin. (Peterson et al., 1993) discovered that TCDD levels in lake trout eggs as low as 30 parts per trillion caused observable increases in yolk-sac fry mortality, and 100 percent mortality occurred at TCDD levels above 100 parts per trillion. The yolk-sac fry die from an accumulation of excess fluid in the yolk-sac (yolk sac edema) and around the heart (pericardial edema), obstructed blood flow (ischemia), hemorrhages, and a deformed skull (craniofacial malformations) conditions resembling blue sac disease. Typical toxic responses in early-stage fish following exposure to TCDD include yolk sac edema, hemorrhaging, arrested development, and head and spinal deformities, and in older fish include lesions, fin necrosis and death.

Dioxin and dioxin-like chemicals such as PCBs and polyaromatic hydrocarbons (PAHs) are sometimes called xenoestrogens. This means that these chemicals can either mimic or disrupt the function of the sex hormone estrogen. They may also affect development and the immune system or cause cancer. Dioxin has its toxic effect at the level of the cell (Walker and Peterson, 1991). In a complex pathway, dioxin interacts with DNA to alter how genes control protein synthesis, for example the protein called vitellogenin which is involved in egg development (Zorriehzahra, 2008).

CONCLUSION

This article concluded that pesticides can create a great economic loss by fish mortalities on one hand and on the other hand rendering them unfit for human consumption. If consumed, these fish can cause health hazard situation for those who utilized these fish. From a health perspective this article depicts that one should take necessary precautionary measure when selecting fish. From a pesticides standpoint such pesticides should be avoided or should be used to minimum for protecting aquatic life. Researchers all across the globe have worked on the toxic effects of pesticides in fish such as behavioural change, Histopathological alterations, haematological and biochemical change, AChE activities inhibition, decrease in protein and lipid contents, change in life cycle, carcinogenesis, mutagenic changes, physiological changes and change in reproductive process. On account of differences in susceptibility of different fish species to various pesticides and other pollutants, fish that are less susceptible and vulnerable to these chemicals and pollutants should be stocked in water bodies. Beside this such species should be stocked that accumulate less quantity of pesticides, heavy metals and other pollutants. Further studies and research regarding new introduced pesticides and other chemicals should be carried out in both natural as well as laboratories. This will be helpful in documenting the toxic effects of these contaminants and on the basis of these experiments, nontoxic or less toxic as well as environmental friendly chemicals can be employed.

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