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Monocrotophos and Glyphosate: Are They Really Matter to Fish Health?

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Fishes are the major group of vertebrates on the basis of their nutritive values and having importance in food chain.They are also a useful indicator of pollution. The consistent use of pesticides in modern agriculture has enhanced environmental risk worldwide. Indiscriminate uses of these pesticides contaminate the environment including the soil & water and might adversely affect the non-targeted organisms like fish. Monocrotophos (MCP) and glyphosate (GLY) are commonly used as insecticide and herbicide respectively,in agricultural fields to increase crop production. Runoff of these pesticides from the agricultural field may also affect the health of aquatic organisms especially fish. MCP is an acaricide of the vinyl phosphate group and its wide use provides many routes of entry into aquatic environments. GLY is broadly used to control unwanted weeds and grasses in agricultural, industrial, urban, forest and landscapes. Due to widespread use, these two agrochemicals have been usually detected in aquatic ecosystems representing a potential hazard to fish. Fish health depends on many parameters like growth, immune system, acetylcholinesterase activity, haematological parameter, reproduction, and endocrine system, etc. at different stages of life. This review aims to compile the toxic effects of these two agrochemicals on different life stages of many fish species.

(***Key words:*** *Acetylcholinesterase activity, Oxidative stress, Pesticides, Reproduction*)

The agriculture sector is one of the important components of the Indian economy. Pesticides are used widely in agricultural fields to minimize pest attacks and finally to increase crop production. At present, organophosphate compounds of pesticides are used as a replacement for organochlorines due to their less persistent nature, however, their extensive and non-regulated use is a serious threat to the environment. The use of insecticides and herbicides is a predictable management exercise for the benefit of agricultural productivity. Some anthropogenic activities can alter the aquatic ecosystem (Chambers, 2008). Among all possible controlling methods, the chemical control of weeds by applying herbicides has gained satisfactory control performance with cost-effectiveness and low environmental impacts (Marcondes *et al*., 2002). In India, about 6000 tons of herbicides were used for weed control, mainly in irrigated crops (about 77% on wheat and rice) and on plantations (about 10%) at the beginning of this century (Bhat and Chopra, 2006). Herbicides kill the plants, by affecting their biochemical and physiological process of photosynthesis, respiration, growth, cell division andprotein synthesis, carotenoids, or lipids synthesis.

Aquatic pollution due to pesticides invariably brings about loss of habitat, endangering the survival and population density of many economically important aquatic animals. Although the application of pesticides is focused on terrestrial ranges, they can spread to the aquatic system by drift, runoff, drainage, and leaching (Cerejeira *et al*., 2003).

Fisheries are a flourishing sector with varied resources and potentials and a very important economic activity in India. Total fisheries and aquaculture production in the world is 178.5 million tonnes (FAO, 2020). Fish is a rich source of protein and omega fatty acids for human nutrition (Torris *et al*., 2018). Important immunological, haematological (differential blood count, haemoglobin, lysozyme, NBT, etc.), and biochemical (Cortisol, catecholamine, GOT, GPT, AST, ALT, acetylcholinesterase, etc.) parameters indicate the health status of a fish (Agrahari *et al*., 2006; Narra *et al*., 2011).With this background present review is prepared to compile most of the work on biochemical and toxicity effect of commonly used insecticide, monocrotophos (MCP) and herbicide, glyphosate (GLY) on fish and its biodiversity. Aquatic organisms, particularly fish are

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highly sensitive to MCP and its toxicity to fish has been reported by many researchers (Rao, 2004; Mohapatra *et al*., 2020). Sublethal effects of MCP in fish were directly related to the inhibition of various metabolic processes (Ferrando *et al*., 1991). The value of LC_{50} for both the chemicals varied from species to species. MCP affects the nervous system by inhibiting acetylcholinesterase, an enzyme essential for normal nerve impulse transmission. The concentration of MCP in the rainwater sample at Hisar, India was found to be 4 $\mu g\ L^{-1}$ (Kumari *et al*., 2007). MCP concentration in surface water of Bhoj wetland was found to be 0.87 $\mu g\ L^{-1}$ in Bhopal, India (Naik and Wanganeo, 2014). Hepatorenal, teratogenic, and tumorigenic effects were caused by GLY-based herbicides through endocrine disruption (Mesnage *et al*., 2015).The detection procedure of this extensively used herbicide GLY is tough. That is why little data are available on its occurrence in the aquatic environment (Hanke *et al*., 2008). GLY could be persistent and mobile in soil and water (Ferrando *et al*., 1991). Roundup (GLY-based herbicide) has been detected at concentrations from 0.01 to 0.7 mg L^{-1} (Fred *et al*., 1996; Peruzzo *et al*., 2008) in natural water bodies. GLY-based commercial formulations are generally more toxic than pure GLY (Peixoto, 2005).

Characteristics and use of MCP and GLY

Characteristics of MCP and GLY

MCP is a colorless crystal with a mild ester odor and it is soluble in water, methanol, acetone, etc. When heated it emits very toxic fumes (PubChem). IUPAC name of MCP is Dimethyl (E)-1-methyl-2 (methyl carbamoyl) vinyl phosphate (Fig. 1). It is used in agriculture for crop protection and is usually spread aerially. GLY is an odorless white powder and its decomposition begins at approximately 419°F. It is water soluble and when heated to decomposition it emits very toxic fumes (PubChem). GLY is used as a herbicide to control undesirable weeds, grasses in the agricultural field, urban area, forestry, and

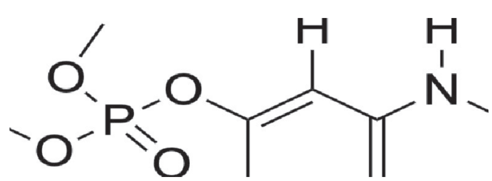

Fig. 1. 2D structure of monocrotophos: Dimethyl (E)-1-methyl-2-(methylcarbamoyl) vinyl

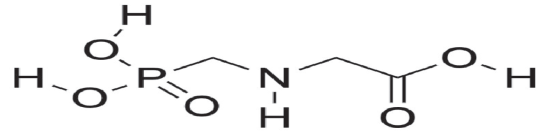

Fig. 2. 2D structure of glyphosate: N-(Phosphonomethyl) glycine

aquatic systems (Cavas and Konen, 2007). It's IUPAC name is N-(phosphonomethyl) glycine (Fig. 2). GLY inhibits the biosynthesis of aromatic amino acids that are used in the synthesis of essential proteins for plant growth and survival.

Mechanism of exposure

Fish and aquatic animals are exposed to pesticides in three ways (i) dermally, direct absorption through skin by swimming in pesticide-contaminated water, (ii) breathing by direct uptake of pesticide through the gills during respiration, (iii) orally by drinking pesticide-contaminated water or feeding on pesticide-contaminated prey (Casarett *et al*., 1991).

Source of exposure

During the spray operation, these two agrochemicals may drift near rivers and ponds creating the potential for exposure on the aquatic organisms (Ferrando *et al*., 1991; Rao, 2004). In Bhoj wetland the concentration of MCP was found to be 0.9 $\mu g\ L^{-1}$ and 1 $\mu g\ L^{-1}$ during pre-monsoon (March to May) and post-monsoon (September to December) period respectively (Naik and Wanganeo, 2014). The MCP residue was found to be 4 $\mu g\ L^{-1}$ in rainwater from Hisar, India (Kumari *et al*., 2007). There are diversified productions from agriculture in Asia-Oceania because of different climatic zones across the region. Annual GLY use (million kg a_i) in seven countries in the region are the following: Australia, 24.1; China, 20.1; Thailand, 15.3; India, 14.2; Indonesia, 9.7; Vietnam, 3.2; Philippines, 2.1 (Brookes, 2019). In Australia, GLY use is greatest in cotton, cereal, and canola cropping systems, as well as vineyards (Brookes, 2019). In Indonesia and Malaysia, GLY resistant weeds such as goosegrass (*Eleusine indica* (L.) Gaertn.) have been selected in palm oil and rubber plantations (Heap, 2019). The bioaccumulation of GLY was found in terrestrial snails (*Helix aspersa*) fed a diet infected with GLY (Druart *et al*., 2011), water hyacinth (*Eichhornia crassipes*) exposed to pure GLY, and also found in the tissue of carp (*Cyprinus carpio*) and tilapia (*Oreochromis mossambicus*) that were exposed to environmentally relevant concentration (Wang *et al*., 1994). These results support the contamination of the food chain in an aquatic environment.

Effects of monocrotophos and glyphosate on early life stages of fish

Many developmental abnormalities like pericardial edema, altered heart development, spinal and vertebral anomalies were found in a concentration-dependent manner in the case of zebra fish embryos, when exposed to MCP. In this study reduction in length and heartbeat was also observed in hatchlings exposed to LC_{10} and LC_{50} concentrations at 96 h exposure (Pamanji *et al*., 2015).

Various studies were performed on the effect of GLY and GLY based herbicides at different concentrations on zebra fish (*Danio rerio*) embryos. They found the morphological defects and acetylcholinesterase reduction at 5.23, 37.44 mg L^{-1}, alteration in larval behaviour along with morphological defects at 0.01, 0.065, 0.5 mg L^{-1} concentration in 4 hours post fertilization and 3 days post fertilization embryo stage, mortality and alteration in hatching rate at 10 mM and alteration in embryogenesis at 58.3 mg L^{-1} concentration in fertilized eggs of zebra fish.

Effects of monocrotophos and glyphosate on adult phase of fish

Researchers performed many experiments on the adult fish exposed to different concentrations of MCP and GLY and investigated their effect on fish health and population.

Effects on fish growth

Fish growth is a concern of behavioral and physiological events, and it is presumed that the stress has a negative control on organisms due to prolonged activation of the hypothalamic-pituitary-interrenal (HPI) axis (Bernier *et al*., 2004). Different stressors like environmental, social, and physical stressors mediated by components of the HPI axis, can affect fish growth by inhibiting food intake, absorption, or conversion efficiency of food into the body (Smagin *et al*., 1998; Heinrichs and Richard, 1999; Benoit *et al*., 2000; Bernier *et al*., 2004).

No information is available on the effects of MCP on the growth of fish, but researchers performed various experiments on the effects of GLY and GLY-based herbicides on the growth of fish. Exposure of the fertilized eggs of Java medaka (*Oryzias javanicus*) to different concentration of GLY-based herbicides until hatching, resulted in a decrease in hatching % and also an absence of pectoral fin, cornea, permanently bent tail, irregularly shaped abdomen, cell disruption in fin, head and abdomen, etc. (Yusof *et al*., 2014). So the growth of fish was inhibited by this herbicide. Giaquinto *et al*. (2017) studied the effects of a GLY-based herbicide on feeding behavior in Pacu (*Piaractus mesopotamicus*). They exposed the fishes to three sub-lethal concentrations of a GLY-based herbicide for 15 days and found that at two lower concentrations, food intake decreased on day 13 and then returned to normal on day 15. But highest GLY-based herbicide concentration decreased the food consumption and finally, growth was inhibited in fishes.

Genotoxic effects and oxidative stress

Many compounds in polluted water are reported to be capable of damaging the DNA of living cells and therefore cause genotoxic effects. (Houk, 1992) and (White *et al*., 1996) detected genotoxicity in wastewater from chemical industries. Oxidative stress is an imbalance between the production of reactive oxygen species (ROS) and the body's ability to detoxify the reactive intermediates or repair the resulting damage. Peroxides and free radicals can damage all the components of the cell, including proteins, lipids, DNA, and RNA (Muniz *et al*., 2008), and ROS also disrupt the function of DNA repair proteins (Shimura-Miura *et al*., 1999). To counteract ROS-induced damage, cells evolved antioxidant systems. Thus, variations in the antioxidant defences can be very sensitive in revealing a prooxidantcondition and have been proposed as indicators of pollutant - mediated oxidative stress (Ahmad *et al*., 2006; Oliveira *et al*., 2008). Many researchers studied the genotoxic and oxidative stress of different fish species by exposure to MCP and GLY (Table 2).

Effects on the nervous system

The acetylcholinesterase (AChE) activity is normally determined in brain and muscle tissue because the neuromuscular system of fish is principally cholinergic and this is essential for normal muscle behavior and function (Payne *et al*., 1996). In brain inhibition of AChE activity produces alterations in

Table 1. *Effect of monocrotophos (MCP) and glyphosate (GLY) on embryos of fish*

Agrochemical	Sl. no.	Concentration used	Experimental period	Stages of embryo taken	Fish	Author and year	Impact
MCP	1	5.23 &37.44 mg L^{-1}	96 h	4 hours post fertilization	*Danio rerio*	Pamanji *et al*. (2015)	Morphological defects & acetylsholineesterase reduction.
GLY and GLY based herbicide	1	0.01, 0.065 & 0.5 mg L^{-1}	96 h	3 days post fertilization	*Danio rerio*	Bridi *et al*. (2017)	Morphological defects &alteration in behaviour of larva.
	2	0.0, 0.1, 0.2, 0.5, 2.0 & 5.0 or 10.0 mg L^{-1}	96 h	Fertilized eggs	*Cyprinus carpio*	Lugwska (2018)	Elongation in hatching, reduction in survival.
	3	10 mM and 10 mM	96 h	Fertilized eggs	*Danio rerio*	Schweizer *et al*. (2019)	Altered hatching rate, mortality.
	4	58.3 mg L^{-1}	96 h	Fertilized eggs	*Danio rerio*	Panetto *et al*. (2019)	Alteration in embryogenesis.
	5	100, 200, 300, 400 & 500 mg L^{-1}	96 h	Fertilized eggs	*Orizas zavonicus*	Yosuf *et al*. (2014)	Morphological impairement, decreased hatching rate.
	6	0.1 & 1.0 mg L^{-1}	3 weeks	Eyed stage embryo	*Oncorhynchus mykiss*	Santos *et al*. (2019)	Developmental abnormalities,hatching success, larval biometry, swimming activity, genotoxicity, lipid peroxidation (TBARS), protein carbonyls and target gene transcription.
	7	2, 9, 30, 97, 310 mg L^{-1}	96 h	Juvenile	*Oreochromis niloticus*	Ayoola *et al*. (2008)	Developmental abnormalities, histopathological changes in gill, liver & brain.

Table 2. *Effect of monocrotophos (MCP) and glyphosate (GLY) on genotoxicity and oxidative stress of adult fish*

Agrochemical	Sl. no.	Concentration used	Experimental period	Fish	Author and year	Impact
MCP	1	0.125, 0.625 & 1.25 µl L^{-1}	72 h	*Danio rerio*	Costa *et al*. (2018)	Significant DNA damage in blood cells.
	2	20.49 mg L^{-1}	96 h	*Gambusia affinis*	Kavitha and Rao (2007)	Increase in oxidative stress.
	3	0.625, 1.3 & 2.3 ppm	35 days	*Catla catla*	Anbumani and Mohankumar (2015)	genotoxic damages in blood cells.
	4	4.78, 2.39 & 1.59 mg L^{-1}	21 days	*Channa punctatus*	Ali and Kumar (2008)	DNA damage in blood, gill & kidney cells.
GLY and GLY based herbicide	1	10 mg L^{-1}	96 h	*Prochilodus lineatus*	Cavalcante *et al*. (2008)	Genotoxic damages in blood and gill cells.
	2	0.7, 7, 70 and 700 µM	20 h	*Oreochromis niloticus*	Moya *et al*. (2014)	Genetic damage in blood cells.
	3	3.9, 7.8 & 11.8 mg L^{-1}	96 h	*Cnesterodon demaculatus*	Vera-Candioti *et al*. (2013)	Genetic damage in blood cells.
	4	58 & 96 µgL^{-1}	3 days	*Anguilla anguilla*	Guilherme *et al*. (2010)	DNA damage in blood cells and no difference in oxidative stress.
	5	6.67 & 3.20 µgL^{-1}	9 days	*Corydoras paleatus*	Ghisi and Cestari (2013)	DNA damage in blood and hepatic cells.
	6	58 & 96 µgL^{-1}	3 days	*Anguilla anguilla*	Guilherme *et al*. (2012)	DNA damage in gill & liver cells .
	7	58 & 116 µgL^{-1}	14 days	*Anguilla anguilla*	Marques *et al*. (2014)	DNA damage in hepatic cells.
	8	0.15, 0.75 & 15.0 mg L^{-1}	24 h	*Prochilo duslineatus*	Navarro and Martinez (2014)	DNA damage in blood cells.
	9	2.5 & 5.0 mg L^{-1}	96 h	*Rhamdia quelen*	Murussi *et al*. (2016)	Induction of oxidative stress.

behavior, and in muscle, it leads to hyperstimulation of muscle fibers. These changes may cause titania, paralysis, and death (Kirby *et al*., 2000).

Exposure to MCP at 3 sublethal concentrations (0.052 ml L^{-1}, 0.074 ml L^{-1} and 0.12 ml L^{-1}) for 30, 45 and 60 days decreased acetylcholinesterase activity in the liver and brain of fish *Cyprinus carpio communis* (Johal, 2010). In 2010, some researchers (Modesto and Martinez, 2010) also observed inhibition of AChE in brain and muscle of fish *Prochilodus lineatus* upon exposure to the GLY-based herbicide. Researchers have also recorded a significant inhibitory effect on AChE activity of the fish species *Cnesterodon decemmaculatus* (Menendez-Helman *et al*., 2012) when exposed to sublethal concentrations of pure GLY.

Effects on the immune system

Fish has an immune system to fight diseases, although the system is by no means as advanced as ones found in mammals. With increasing evidence for the effects of Roundup on fish immune responsiveness, the question of its impact on cytokine gene expression has emerged (Evrard *et al*., 2010). Cytokines are soluble mediators and they coordinate the immune response to pathogen intrusion. Amongst the cytokines, interleukin-1b (IL-1b) and interleukin-10 (IL-10) are of particular importance.

There is no report on the effects of monocrotophos on the immune system of fish, but researchers have observed the effects of GLY on the immune system of fish. Kreutz *et al*. (2011) reported a significant reduction on the phagocytic index, serum bacteria agglutination, and total peroxidase was observed in glyphosate exposed fish. They also found that glyphosate had no effect on serum bactericidal and complement natural hemolytic activity of fish. Researchers studied the effect of glyphosate-based herbicides roundup on the expression of interleukin1b (il-1b), interleukin-10 (il-10), and heme-oxygenase-1 (ho-1) in the gills, intestines, and spleen of young European sea bass (*Dicentrachus labrax*). Alteration of gene expression levels of il-1b and il-10 cytokine was not found in the intestines, but alterations in the gills were founded in sublethal dose- treated fishes. Significant alteration in expression of the ho-1 gene was also found in herbicide-treated fishes. These changes may in turn negatively impact the immune system of European sea bass exposed to roundup (Richard *et al*., 2014).

Effects on haematological parameter

The haematological system consists of the blood and bone marrow. Blood delivers oxygen and nutrients to all tissues, removes wastes, and transports gases throughout the body. Blood components are blood plasma and blood cells. Blood is a pathophysiological indicator of the body as it is highly susceptible to internal and external environmental fluctuations. Details of the effects of MCP and GLY on the haematological parameter of fish were represented in Table 3.

Histopathological effects

Histopathological changes of a fish vital organ due to pesticide effect isreportedby many researchers such as histopathological changes such as necrosis, pycnotic nuclei in the tubular epitheliumof gill tissue in *Cirrhinus mrigala* exposed to MCP is reported by (Velmurugan *et al*., 2007). MCP exposed Cirrhinus mrigala showed hypertrophied epithelial cells of renal tubules, contraction of the glomerulus, expansion of space inside the Bowman's capsule in kidney and edema, necrosis & atrophy of epithelial cells in the intestine (Velmurugan *et al*., 2007). Necrotic and proliferative lesions in gill, congestion, degenerative foci, hyaline droplets and lipidic vacuolization of the hepatocytes in the liver, mild hyperplasia of mucous cells in the stomach & also in the skin was detected inherbicide-exposed juveniles of *Piaractus brachypomus* (Eslava-Mocha, 2008). In the brain, they also observed degenerative foci of neuronal bodies in the telencephalon associated with gliosis and infiltration of eosinophilic granule cells/mast cells. When exposure to GLY, filament cell proliferation, lamellar fusion, lamellar cell hyperplasia, and epithelial lifting in gills, vacuolation of hepatocytes and necrosis in the liver, kidney lesions and generalized neuronal degeneration, and spongiosis in the brain was observed (Ayoola, 2008) in juveniles of nile tilapia (*Oreochromis niloticus*) and respiratory stress, erratic swimming, and instant death was also reported in exposed fish. They also found histopathological damages in GLY exposed African catfish *Clarias gariepinus*. Researchers also observed histopathological lesions in the stomach & intestine (Samanta *et al*., 2018) of freshwater teleostean fish, *Anabas testudineus* (Bloch) when exposed to GLY-based herbicide, Excel Mera 71 for 30 days.

Effects on biochemical parameter

Decrease in total protein, free amino acid and

Table 3. *Effect of monocrotophos (MCP) and glyphosate (GLY) on hematological parameter of adult fish*

Agrochemical	Sl no.	Conc. used in experiment (mg L^{-1})	Experimental period	Fish	Author and year	Impact
MCP	1	1.9 & 9.5	7, 14 & 21 days	*Anabas testudineus*	Santhakumar *et al*. (1999)	Decrease in RBC, haemoglobin content, Hct, MCHC& increase in WBCs.
	2	0.96 & 1.86	15 & 60 days	*Channa punctatus*	Agrahari *et al*. (2006)	Decrease in RBC, haemoglobin content, PCV, MCV, MCH, MCHC & increase in ESR, WBCs.
	3	2.5,5 & 7.5	30 & 60 days	*Cyprinus carpio*	Vaiyanan *et al*. (2015)	Decrease in RBC, haemoglobin content, increase in WBCs.
	4	45.1	24, 48, 72 & 96 h &10, 20, 30 days	*Labeo rohita*	Devi *et al*. (2015)	Decrease in RBC, haemoglobin content, MCV, MCH, PCV, increase in WBCs.
	5	0.40	24, 48, 72 & 96 h	*Labeo rohita*	Ravichandran *et al*. (2019)	Decrease in RBC, haemoglobin content, MCH, increase in WBCs.
GLY and GLY based herbicide	1	1,5	96 h	*Prochilodus lineatus*	Kathya and Cláudia (2010)	Increase in RBCs & WBCs.
	2	0.73	96 h	*Rhamadia quelen*	Kreutz *et al*. (2011)	Reduction in blood cells.
	3	0.46	96 h	*Catla catla*	Felix and Saradhamani (2015)	Decrease in TLC, TEC, Hb, MCV, MCH, MCHC.

ammonia content in gill, kidney, liver, and muscle and recovered in slight when exposed to freshwater, elevation in glutamine and urea level, protease, transaminase and phosphatase enzymes in all tissues of *Clarius batrachus* on 28 days exposure to MCP (Narra *et al*., 2011). Addition in cholesterol, alkaline phosphatase in plasma, triglyceride in plasma, serum bilirubin, serum creatinine, SGPT and SGOT and reduction in plasma glucose, total protein and lipid peroxidation were found in 0.072 ppm MCP exposed fish Channagachua (Koul *et al*., 2006). Total carbohydrate, lipid, and protein decreased in muscle, liver and kidney tissues of *Catla catla*, when exposed to MCP (Tamizhazhagan, 2017). MCP showed a significant decrease in carbohydrate, protein, and lipid content at the end of 10, 20, and 30 days as compared to control in Mystusgolio (Sathick *et al*., 2019).The decreased amount of protein, lipid, and carbohydrate were found in gill, kidney, liver and muscle of *Cyprinus carpio* when exposed to GLY at concentration of 0.02 ppm (Juginu, 2018). The decrease in protein and lipid content, increase in ALT & AST activity of *Cyprinus carpio* liver, when exposed to 2 sub-lethal concentration of GLY- based herbicide for 28 days (Bawa *et al*., 2017).

Effects on reproduction

Nearly all fish reproduce by sexual reproduction that means the fusion of sperm produced from testes and eggs produced from ovaries. Most species have separate female and male sexes, but many species are hermaphrodites, meaning that an individual has both testes and ovaries. Different endocrine-disrupting chemicals affected reproduction in fish (Sundaray *et al*., 2007). Structural damages in the ovary like decreased vitellogenesis, disruption of follicular wall, and oocyte atresia were found in all MCP and GLY treated groups of Anabas at 45 days exposure (Mohapatra *et al*., 2020). Maqbool and Ahmed (2013) concluded that sublethal doses of MCP also showed inhibitory effects on ovarian development and oocyte maturation in *Channa punctatus* which can lead to reduced fecundity and abnormal offsprings. Harayashiki *et al*. (2013) evaluated the effects of Roundup (GLY-based herbicide) on reproduction of adult guppies *Poecilia vivipara* and observed poorer sperm quality in exposed fishes. Some researchers also studied the effect of GLY on the reproduction of zebra fish (*Danio rerio*) and observed no significant difference in sperm concentration, but a reduction in sperm motility and motility period in exposed fishes (Lopes *et al*., 2014).

The endocrine system controls the reproductive process. The endocrine system release carefully-measured amounts of hormones into the bloodstream that act as natural chemical messengers, traveling to different parts of the body to regulate sexual development and the seasonal reproductive cycles. The endocrine system may be disrupted in one of the three ways (Fig. 3); (a) a substance may mimic a natural hormone and lock onto a receptor within the cell, (b) a substance can bind to a receptor within the cell and thus prevent the correct hormone from binding, and (c) the disruptors can interfere or block the way natural hormones and receptors are made or controlled. Alteration in the endocrine system of fish is depicted in Table 4.

Effects on gonadosomatic index and spawning performance

A significant ($P \leq 0.05$) decrease of gonadosomatic index (GSI) in both sexes of *Anabas testudineus* at different sub-lethal concentrations on 30^{th} and 45^{th} - day exposure of MCP (Mohapatra *et al*., 2020). Maqbool and Ahmed (2013) observed the decrease in GSI of *Channa punctatus*, when exposed to MCP at concentrations of 1 ml L^{-1} and 2 ml L^{-1} for 45 days. In a fish, the GSI is generally used to know the maturity and periodicity of spawning. A significant ($P \leq 0.05$) decrease of spawning performance (fertilization and hatching rate) was observed in *Anabas testudineus* at different sub-lethal concentrations on 30^{th} and 45^{th} - day exposure of MCP (Mohapatra *et al*., 2020). The hatching rate of *Oryzias javanicus* also decreased in different concentrations of GLY exposure groups (Yusof *et al*., 2014). GSI and spawning performance are important to know the reproductive fitness of fish.

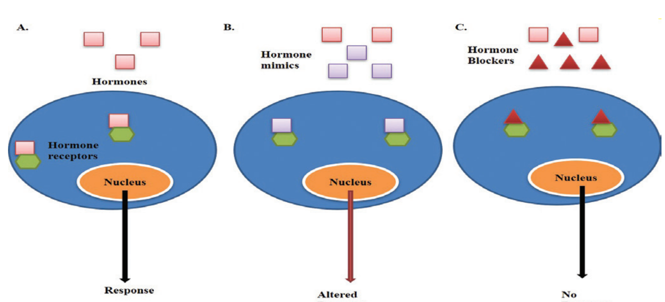

Fig. 3. *Disruption of endocrine system. A. Normal response when the correct hormone binds to the receptor, B. Altered response when hormone mimics bind to the receptor, C. No response when hormone blockers bind to the receptor.*

Table 4. *Effect of monocrotophos (MCP) on endocrine system of adult fish*

Agrochemical	Sl. no.	Conc. used in experiment (mg L^{-1})	Experimental period	Fish	Author and year	Impact
MCP	1	0.01, 0.10 and 1.00	21 days	*Carassius auratus*	Zhang *et al.* (2014)	Decrease in plasma level of 3,39,5-triiodo-L-thyronine.
	2	0.001,0.01, and 0.1	40 days	*Danio rerio*	Zhang *et al.* (2013)	Modulates expression of sex differentiation genes phenotypic feminization.
	3	0.01,0.1, and 1.0	21 days	*Carassius auratus*	Tian *et al.* (2010)	Altered plasma steroid level in female fish.
	4	0.01,0.1, and 1.0	21 days	*Carassius auratus*	Tian *et al.* (2016)	Affected synthesis and conversion of sex steroids in male fish.
	5	0.01,0.1, and 1.0	21 days	*Carassius auratus*	Tian *et al.* (2009)	Estrogenic effects in male fish.
	6	0.01,0.1, and 1.0	90 days	*Poecilia reticulata*	Tian *et al.* (2012)	Feminization in male fish and reduction in reproductive success.
	7	0.1, 10, and 100	21 days	*Dani orerio*	Zhang *et al.* (2015)	Decreased whole body cortisol level in female fish, but no response in males.

Degradation of monocrotophos and glyphosate

MCP is relatively stable in sunlight and is non-volatile. The half-life for MCP in solution is 23 days at pH 7 and 38°C. GLY is dissipated rapidly from water bodies by microbial activity, adsorption in suspended sediments, and bottom sediments of water bodies (Giesy, 2000). In sterilized water, the degradation of GLY is very slow but in presence of microflora in water, it is rapidly degraded into AMPA and CO_2 (Rueppel *et al*., 1977). These end products do not have an herbicidal property and would not be toxic to aquatic organisms at concentrations (Liu *et al*., 1991). According to (Giesy, 2000), the half-life of GLY in agricultural fields ranged from 2 - 197 days with an average of 32 days and he also reported that the water lacking vegetation cover can have a maximum 3.7 mg L^{-1} GLY.

Testing strategies for monocrotophos and glyphosate

The detection of monocrotophos can be done by thin-layer chromatography (TLC), high-performance liquid chromatography (HPLC), and gas chromatography-mass spectrometry (GS-MS) methods (Gurusamy and Thangadurai, 2019).

Glyphosate can be detected by liquid chromatography (LC) or high-performance liquid chromatography (HPLC), gas chromatography (GC), ion chromatography (IC), and also by chromatography-mass spectrometer was also used (Valle *et al*., 2018).

MCP and GLY are commonly used in agricultural fields, urban areas, forestry to increase crop production. This study showed that these two agrochemicals altered different parameters at early life, adult and also reproductive phases of fish, which affected fish health and ultimately fish population. The effect of MCP and GLY on fish health condition is represented in Fig. 4.

There is very little information on the effect of these two agrochemicals on the early life stages of fish, but the early life stage is important for the growth of the fish population. Indian fisheries and aquaculture is main sector for food production providing nutritional security. This also provides livelihood support and useful service to more than 14 million people, and contributes to agricultural exports. According to the National Fishery Development Board (NFDB), the total fish production was 12.60 million metric tonnes during 2017-18 and about 50% of the total production is from

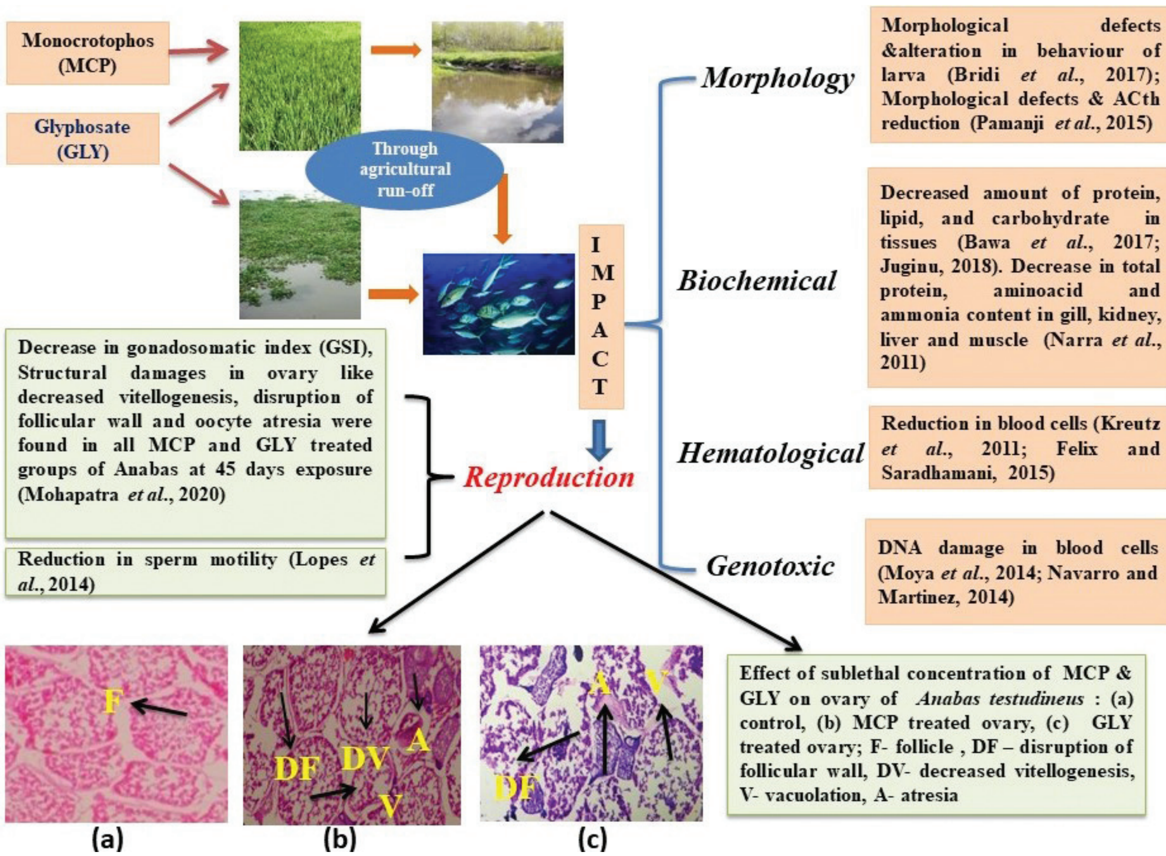

***Fig. 4.** Effect of MCP and GLY on fish health*

culture fisheries. For safe use of these pesticides, more experimental work should be performed to detect the concentration and time of exposure that does not induce toxic effects on aquatic organisms.

Way forward

Regulatory mechanism

A rule should be followed to regulate the extensive use of these two agrochemicals

Policy initiatives

Now it has become necessary to formulate strict rules against extensive use of these pesticides and their formulations. We suggest that a policy can be made by the government on the use of these two agrochemicals.

Awareness

There should be an awareness among farmers about the use and effect of these two agrochemicals on animals and the ecosystem. The Government should condut awareness programmmes on the amount of use of different pesticides in agricultural fields.

Ecosystem services

More of the pesticide exposure studies were performed on the model fish zebra. Thus there is a need to investigate the effect of pesticides in many economically important fish and ecosystems.

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CONFLICTS OF INTEREST

There are no conflicts of interest among the authors.

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