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ACUTE TOXICITY OF DELTAMETHRIN (A SYNTHETIC PYRETHROID PESTICIDE) TO FISH

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ABSTRACT
In Ecotoxicology, acute toxicity tests are generally conducted to measure or evaluate the toxic effects caused by various pollutants that reach aquatic ecosystems and show their impact on one or more species. In aquatic ecosystems in general and freshwater ecosystems in particular, fish is a non-target species for the toxic impact of a xenobiotic chemical and has been extensively used as a biological indicator to evaluate the degree of the impact of the pollutant. Dose of a particular toxicant that is not high enough to kill an aquatic organism like fish are associated with other changes like physiological, morphological, behavioural and biochemical alterations. Due to the strict regulations on discharge standards or permissible limits for various toxic chemicals released into the environment, more attention is being given on toxicity bioassays in recent years. Data obtained on the concentration of a selected toxicant which is lethal to fish provide necessary information, apart from identifying a border line limit above which fish is likely to be killed. Hence, in the present review an attempt has been made to report the acute toxicity values of deltamethrin, a synthetic pyrethroid pesticide to various fish species.

KEYWORDS: Aquatic pollution, Acute toxicity, Deltamethrin, Synthetic pyrethroid, Biological indicator, Bioassay.

INTRODUCTION
Environmental pollution due to various persistent chemical pesticides has become a serious problem due to their indiscriminate and extensive usage in agriculture. Aquatic environments are more vulnerable to pollution because they are the ultimate sinks of most forms of anthropogenic waste. Many of the xenobiotic compounds ultimately reach the nearby water bodies and posing a serious threat to aquatic organisms as well as water quality.[1] It is important to consider that various concentrations of xenobiotic chemicals like pesticides can have high ecological impact, and could affect an entire population of a species in an ecosystem. Biological assays are very important for studying the toxicity and other effects of various pesticides to different species of animals. Bioassay signifies a test in which a living tissue, organism or a group of organisms are used as test material for the determination of the potency of any physiologically active substance of unknown activity.[2] In toxicity bioassays, test organisms are exposed to various concentrations of the pollutants for toxicity evaluation which is achieved by monitoring the biological integrity of the sentinel species and comparing it with those which have not been exposed to the pollutant.

Doses of different chemical contaminants such as synthetic pyrethroids in aquatic ecosystems that are not high enough to kill aquatic organisms like fish are associated with subtle changes in their physiology, morphology, behaviour and biochemistry that impair growth, immunity to diseases, predatory avoidance, survival and reproduction[3] and this is more common than mortality.[4] Since behaviour serves as the link between an animal's internal physiology and its surrounding ecological processes, it may be ideal for studying the effects of various environmental pollutants on a best sentinel species. Fish are an excellent model in this aspect, since many ecologically relevant fish behaviours are easily observed and can be measured in a controlled system. In this review, an attempt has been to document the acute toxicity of Deltamethrin to fish and its effect on fish behavior and morphology.

AUTE TOXICITY OF DELTAMETHRIN TO FISH
Several authors evaluated the acute toxicity of deltamethrin and its impact on behavior and morphology of various commercially and ecologically important fish species.

Acute toxicity of deltamethrin to fish

S. No	Fish	Toxicity value	Exp. Period in Hours	Reference
1	*Carassius auratus gibelio*	6.0 µg/L	96	Wu *et al.*,2022[5]
2	*Channa punctatus*	0.26 ppm	96	Srivastava *et al.*, 2022[6]
3	*Clarias batrachus*	1.5 ppm 0.85 ppm 0.45 ppm 0.15 ppm	24 48 72 96	Kumari and Chandan, 2021[7]
4	*Anabas testudineus*	0.069 mg/L	96	Kumar, 2020[8]
5	*Clarias gariepinus*	21.244 µg/L	96	Amaeze *et al.*, 2020 [9]
6	*Microsternarchus cf. bilineatus*	2.15 µg/L	96	Chaves *et al.*, 2020 [10]
7	*Carnegiella strigata*	7.83 µg/L	96	De Souza *et al.*, 2020 [11]
8	*Colossoma macropomum*	6.69 µg/L		
9	*Hemigrammus rhodostomus*	23.63 µg/L		
10	*Paracheirodan axelrodi*	22.49 µg/L		
11	*Corydoras schwartzi*	183.51 µg/L		
12	*Ctenopharyngodon idella* **Static** Technical grade I1%EC **Continuous flow method** Technical grade I1%EC	 0.510 µg/L 0.519 µg/L 0.390 µg/L 0.379 µg/L	24	Rao *et al.*, 2018[12]
13	*Cirrhinus mrigala*	8 µl/L	96	Naik and David, 2018[13]
14	*Channa punctatus*	7.33 µg/L	96	Singh *et al.*, 2018[14]
15	*Channa punctatus*	1.3 ppm	96	Mishra *et al.*, 2018[15]
16	*Colossoma macropomum*	5.56 mg/L	96	Cunha *et al.*, 2018[16]
17	*Clarias gariepinus* Fry Fingerlings	 150 ppt 150 ppt	 72 96	Angahar, 2017[17]
	Heterobranchus bidorsalis Larvae Fry	 200 ppt 150 ppt 250 ppt 200 ppt	 24 48 24 48	
18	*Labeo rohita* Fingerlings	 0.39 µg/L 0.39 µg/L 0.38 µg/L 0.37 µg/L	 24 48 72 96	Sahoo *et al.*, 2017[18]
19	*Clarias gariepinus*	51.89 µg/L	96	Hamed, 2016[19]
20	*Oreochromis niloticus*	7 µg/L	96	Mohammed *et al.*, 2016[20]
21	*Labeo rohita*	0.438 mg/L 0.380 mg/L	24 96	Suvetha *et al.*, 2015[21]
22	*Anabas testudineus*	0.11 mg/L 0.09 mg/L 0.08 mg/L 0.07 mg/L	24 48 72 96	Devi and Gupta, 2014[22]
23	*Danio rerio*	14.43 µg/L	24	Huang *et al.*, 2014[23]
24	*Cryptoheros nigrofasciatus*	0.25 ppm 0.21 ppm 0.17 ppm 0.15 ppm	24 48 72 96	Sadeghi and Hedayati, 2014[24]
25	*Labeo rohita*	0.1 µg/L	96	Neeraja and Giridhar, 2014[25]
26	*Cirrhinus mrigala*	8 µl/L	96	David *et al.*, 2013[26]
27	*Rhamdia quelen*	1.70 mg/L	96	Galeb *et al.*, 2013[27]
28	*Pangasius hypophthalmus*	0.13 ppm	24	Hedayati *et al.*, 2013[28]

		0.13 ppm 0.11 ppm 0.1 ppm	48 72 96	
29	*Channa punctatus*	0.75 mg/L	96	Jayaprakash and Shettu, 2013[29]
30	*Brycon amazonicus*	2.60 µg/L	96	Moraes *et al.*, 2013[30]
31	*Alburnoides bipunctatus* Fingering Larvae	3.73 ppm 1.21 ppm 0.65 ppm 0.27 ppm 0.031 ppm 0.021 ppm 0.012 ppm 0.006 ppm	24 48 72 96 24 48 72 96	Vajargah *et al.*, 2013a[31]
32	*Tinca tinca* Fingering Larvae	0.39 ppm 0.23 ppm 0.15 ppm 0.07 ppm 0.028 ppm 0.180 ppm 0.011 ppm 0.005 ppm	24 48 72 96 24 48 72 96	Vajargah *et al.*, 2013b[32]
33	*Trichogaster trichopterus*	0.293 ppm 0.280 ppm 0.236 ppm 0.223 ppm	24 48 72 96	Hedayati *et al.*, 2012a[33]
34	*Poecilia reticulata*	0.297 ppm 0.236 ppm 0.204 ppm 0.195 ppm	24 48 72 96	Hedayati *et al.*, 2012b[34]
35	*Xiphophorus helleri*	2.87 ppm	24 48 72 96	Khalili *et al.*, 2012[35]
36	*Danio rerio*	0.25 µg/L	96	Sharma *et al.*, 2012[36]
37	*Danio rerio*	0.056 ppm 0.052 ppm 0.052 ppm 0.050 ppm	24 48 72 96	Tarkhani *et al.*, 2012[37]
38	*Catla catla*	4.84 µg/L	96	Vani *et al.*, 2011[38]
39	*Danio rerio*	0.016 µg/L	96	Sharma and Ansari, 2010[39]
40	*Heteropneustes fossilis*	1.87 µg/L	96	Srivastav *et al.*, 2010[40]
41	*Danio rerio*	0.121 µg/L	96	Ansari and Sharma, 2009[41]
4 2	*Oreochromis niloticus* Larvae Fry	 1.17 µg/L 1.70 µg/L	48	Benli *et al.*, 2009[42]
43	*Puntius chrysopterus*	0.0142 mg/L	96	Pawar *et al.*, 2009[43]
44	*Labeo rohita*	1.00 mg/L	96	Rathnamma *et al.*, 2008[44]
45	*Poecilia reticulata*	0.0024 mg/L 0.0021 mg/L 0.0020 mg/L 0.0019 mg/L	24 48 72 96	Stalin *et al.*, 2008[45]
46	*Channa punctata*	0.1425 ppm	96	Venkataramudu *et al.*, 2008[46]
47	*Oreochromis niloticus*	14.6 µg/L	96	El-Sayed *et al.*, 2007[47]
48	*Danio rerio*	0.078 µg/L	48	Osti *et al.*, 2007[48]
49	*Hyphessobricon bifasciatus*	0.082 µg/L		
50	*Geophagus brasiliensis*	0.594 µg/L		
51	*Oreochromis niloticus*	0.954 µg/L		
52	*Cyprinus carpio*	0.020 mg/L	96	Velisek *et al.*, 2007[49]
53	*Oreochromis mossambicus*	0.25 mg/L	96	Vijayavel and Balasubramanian,

				2007[50]
54	*Oreochromis niloticus*	15.47 µg/L	96	Boateng *et al.*, 2006[51]
55	*Cyprinus carpio*	0.058 mg/L	96	Cengiz, 2006[52]
56	*Silurus glanis*	1.446 µg/L 1.215 µg/L 0.866 µg/L 0.686 µg/L	24 72 48 96	Köprücü *et al.*, 2006[53]
57	*Oreochromis niloticus*	5.14 µg/L 4.85 µg/L	24 48	Yildirim *et al.*, 2006[54]
58	*Oncorhynchus mykiss*	3.1856 µg/L 1.658 µg/L 0.9800 µg/L 0.6961 µg/L	24 48 72 96	Ural and Saglam, 2005[55]
59	*Cyprinus carpio*	9.41 µg/L 4.47 µg/L 2.37 µg/L 1.65 µg/L	24 48 72 96	Calta and Ural, 2004[56]
60	*Cyprinus carpio* Embryo Larvae	0.213 µg/L 0.074 µg/L	48	Koprucu and Aydin, 2004[57]
61	*Cyprinus carpio* (Soft Water) (Hard water)	0.102 µg/L 0.495 µg/L	96	Datta *et al.*, 2003[58]
62	*Clarias gariepinus*	0.015 µg/L 0.004 µg/L	24 96	Datta and Kaviraj, 2003[59]
63	*Channa punctatus*	1.5 µg/L	48	Sayeed *et al.*, 2003[60]
64	*Cyprinus carpio*	0.058 mg/L	96	Svobodova *et al.*, 2003[61]
65	*Poecilia reticulata*	5.13 µg/L	48	Viran *et al.*, 2003[62]
66	*Heteropneustes fossilis*	1.86 µg/L	96	Srivastav *et al.*, 2002[63]
67	*Heteropneustes fossilis*	0.52 mg/L	96	Kumar *et al.*,1999[64]
68	*Heteropneustes fossilis*	3.10 µg/L 2.30 µg/L 2.10 µg/L 1.86 µg/L	24 48 72 96	Srivastav *et al.*, 1997[65]
69	*Oreochromis niloticus*	14.9 µg/L	96	Golow and Godzi, 1994[66]
70	*Poecilia reticulata*	0.016 ppm	24	Mittal *et al.*, 1994[67]
71	*Oncorhynchus mykiss*	0.39 µg/L	96	Mestres and Mestres, 1992[68]
72	*Cyprinus carpio*	1.84 µg/L		
73	*Sarotherodon mossambica*	3.50 µg/L		
74	*Oncorhynchus mykiss*	2.50 µg/L 2.30 µg/L 2.30 µg/L	24 48 96	Lakota *et al.*, 1989[69]
75	*Cyprinus carpio*	3.50 µg/L 3.50 µg/L 3.50 µg/L	24 48 96	
76	*Cyprinus carpio*	4.00 µg/L 2.30 µg/L	48 96	Sun, 1987[70]
77	*Cyprinus carpio*	0.86 ppb	96	Bocquet and Hotellier, 1985[71]
78	*Gambusia affinis*	1.0 ppb		
79	*Salmo gairdneri*	0.5 ppb		
80	*Brachydanio rerio*	2.0 µg/L	96	Lapalleur and Chambon, 1984[72]
81	*Salmo gairdneri*	0.59 µg/L	96	Zitko *et al.*, 1979[73]

DELTAMETHRIN INDUCED BEHAVIOURAL AND MORPHOLOGICAL ALTERATIONS IN FISH

Kumari and Chandan[7] observed increased swimming, rapid surfacing, hyperactivity, restlessness, gulping of air, loss of balance, jerky movements and weakened school formation in *Clarias batrachus* when exposed to deltamethrin. They also reported peeling of skin, colour fading and mucous secretion on body and gills, formation of ulceration on trunk, base of caudal and pectoral fins in the fish due to deltamethrin stress. De souza *et al.*[11] observed darkening in body color, agitation, erratic swimming, vigorous body thrusts, loss of equilibrium, lying at the bottom with ventral region facing upwards and performing rapid movements of their opercula in 5 Amazonian fishes (*Carnegiella strigata, Colossoma macropomum Hemigrammus rhodostomus Paracheirodan axelrodi* and *Corydoras schwartzi*). Chaves *et al*.[10] observed rapid and circular swimming, spasms, permanence on the water surface and increased opercular activity in *Microsternarchus* cf. *bilineatus*.

Singh *et al*.[14] reported increased opercular movements, hyper activity of all fins, increased rate of swimming, loss of balance and caudal bending in *Channa punctatus*. Naik and David[13] observed irregular, erratic and darting swimming movements, hyper excitability, capsizing / overturning, cork screw pattern rotation, attaching to the surface, restlessness, difficulty in breathing, loss of equilibrium in *Cirrhinus mrigala*. They also reported a change in colour of the gill lamellae from reddish to light brown with coagulation of mucus on gill lamellae in the test fish. Angahar[17] observed increased opercular movements, loss of equilibrium, erratic swimming, sudden swimming followed by interruption, circular swimming and loss of colour in *Clarias gariepinus.* Turgut[74] reported trembling movements, fasciculation, poising at upright, tendency to swim to the water surface and gulping for air in *Oncorhynchus mykiss.* Mohammed *et al*.[20] observed swimming near the water surface, rapid gill movement (gasping) and hyperactivity in *Oreochromis niloticus*. They also observed various deltamethrin induced morphological changes such as color darkening of the body surface, slight erosions and / or rotting of fins and tail, slimness, general loss of fish scales, eye cataract and sometimes exophthalmic and congestion of anal opening in the test fish. Suvetha *et al*.[21] observed vigorous swimming and jumping, loss of equilibrium, and secretion of copious amounts of mucus in *Labeo rohita*.

Devi and Gupta[22] reported increased mucus secretion, depigmentation and increased defecation in *Anabas testudineus* during deltamethrin acute exposure. Huang *et al*.[23] reported hyperactivity, surfacing, increased swimming speed, higher swimming depth, rapid gill movement, erratic swimming, swimming in a corkscrew manner, rapid opercular movement, swimming at the water surface and gulping for air in *Danio rerio*. David *et al*.[26] reported caudal bending in *Cirrhinus mrigala*. Galeb *et al*.[27] observed rapid opercular movements, irregular or surface swimming, inactivity, remaining vertically in the water or laid on one side and lying at bottom of the pesticide treated tank in *Rhamdia quelen*. He also reported darkening of the surface of the body, tail and wattles erosion and hemorrhagic spots on the body surface as the post-mortem signs in test fish. Goulding *et al*.[75] reported reduced swimming activity leading to increased susceptibility to predators and consequent death in *Oncorhynchus mykiss* Moraes *et al*.[30] observed increased opercular movement, loss of equilibrium, erratic swimming, sudden swimming followed by interruption and circular swimming in *Brycon amazonicus*.

Amin and Hashem[76] identified less general activity, loss of equilibrium, vertical hanging in water, rapid gill movement, erratic swimming, swimming and air gulping at the water surface in *Poecilia reticulata* Velisek *et al*.[77] observed accelerated respiration, loss of movement and coordination, fish lying at the tank bottom and moving in one spot, subsequent short excitation periods with convulsions and movement in circles during acute exposure of deltamethrin to *Oncorhynchus mykiss*. Benli *et al*.[42] observed fast swimming, swimming sideways with head shaking and a spiral twist in tail region and gulping in larvae and fry of *Oreochromis niloticus*. Pawar *et al*.[43] observed rapid and erratic swimming with random movements, toxic seizures, imbalance in posture, increase in surfacing activity and opercular movements, and loss of equilibrium in *Puntius chrysopterus* exposed to lethal concentration of deltamethrin. Morphological alterations such as appearance of mucous covering over the gills, change in colour of the gill lamellae from red to brown were also reported from their study. El-Sayed and Saad[78] observed rapid opercular movement, swimming at the water surface, gasping, less activity, laying down on the sides or remained hanging vertically in the water and occasionally remaining motionless on the aquarium bottom until death in *Oreochromis niloticus*. Rathnamma *et al*.[44] found increased swimming activity and disrupted shoaling behavior in *Labeo rohita*.

El-Sayed *et al*.[47] reported rapid opercular movement, erratic and hysteric swimming, swimming at the water surface, circling movement, gasping from the water, less activity or generally inactivity, remained hanging vertically in the water or lay down on their sides and sometimes remained motionless on the aquarium bottom prior to death in *Oreochromis niloticus* exposed to various deltamethrin concentrations. Color darkening of the body surface, erosion or rotting of fins and tails, slimness, loss of fish scales and haemorrhagic patches on the body surface were also observed in the test fish due to deltamethrin poisoning. Osti *et al*.[48] observed opercular frequencies, irregular swimming, mucus formation and constant presence in the surface of the aquarium in *Danio rerio, Hyphessobricon bifasciatus, Geophagus brasiliensis and Oreochromis niloticus* exposed to deltamethrin. Velisek *et al*.[49] identified that *Oncorhynchus mykiss* exposed to Decis showed accelerated respiration, loss of movement, coordination, fish laydown at their flank and moving in this direction. There was a subsequent short excitation stage (convulsions, jumps above the water surface, movement in circles) changed into a resting stage and another short-time excitation followed again. Boateng *et al*.[51] observed inactiveness, fish laying down on their sides or remaining vertical position in *Oreochromis niloticus.*

Ural and Saglam[55] observed loss of equilibrium, vertical hanging, gill flailing, erratic swimming, swimming at the water surface, air gulping from the water surface or staying motionless on the aquarium bottom in *Onchorhynchus mykiss*. Calta and Ural[56] observed loss of equilibrium, hanging vertically in the water, rapid gills movement, erratic swimming, swimming at the water surface, air gulping from the water surface, or staying motionless on the aquarium bottom in *Cyprinus carpio* Datta *et al*.[58] observed erratic swimming, dashing to the sides of the container, frequent surfacing to gulp air followed by sideward movements in *Cyprinus carpio*. Svobodova *et al*.[61] observed accelerated respiration, loss of movement coordination, fish lay down at their flank and move in this position in *Cyprinus carpio*. Viran *et al.*[62] observed less general activity, loss of equilibrium, vertical hanging in the water, rapid gill movement, erratic swimming, swimming at the water surface, gulping for air, prolonged and motionless laying down on the aquarium bottom in *Poecilia reticulata*.

DISCUSSION AND CONCLUSIONS

As evident by the above toxicity table, there is no universal LC_{50} value for fish exposed to Deltamethrin. The toxicity of deltamethrin to various fish species is dependent on concentration and exposure time. Variations in the LC_{50} values reported by various researchers in various fish species are mainly attributed to the differences in test conditions; species specificity of test chemicals, external factors influencing pesticide toxicity like dissolved oxygen, ambient temperature of water, pH, hardness of water etc. Variations in the LC_{50} values within the same species are due to the differences in the size and age of the test animal.[9] Acute toxicity of deltamethrin is higher in fish larvae and fry than fingerlings as pyrethroids are more toxic to smaller fish than larger ones which evident from various studies.[17, 31, 32, 42] According to Datta *et al*.[58], acute toxicity of deltamethrin is low in hard water than soft water. Solubility is another important factor that determines the toxicity of pesticides in water.[79] As the hardness of water increases, concentrations of $C1^{-1}$, SO_4^{2-}, $CO_3^{2-}$and HCO_3^{-c}salts of calcium and magnesium increase which may cause lower solubility of deltamethrin due to the salting out effect and thus, lower the toxicity. High level of calcium in very hard water generally protects fish gills from pesticide damage.

It is evident that, Delatemethrin exposure induces various abnormal behavioral patterns in fish. These abnormalities are concentration and exposure period dependant. The observed abnormal swimming behaviours in test fishes are probably due to caudal bending which in turn affected the normal swimming pattern of the fish. Loss of equilibrium in all the fish studied is due to the region in the brain that is associated with the maintenance of equilibrium might be affected.[80] The increased ventilation rate by rapid, repeated opening and closing of the mouth and opercular coverings accompanied by coughing could be due to clearance of the accumulated mucus in the gill region for proper breathing.[81] Disruption of schooling behaviour of the test fish is due to the lethal and sub lethal stress of the toxicant. Deltamethrin results in increased swimming activity, and entails increased expenditure of energy.[82] The hyperexcitability of the fish observed in all the studies due to lethal and sub lethal exposure of deltamethrin may probably be hindered the functioning of the enzyme AChE in relation to nervous system. The surfacing phenomenon of fish observed in above studies under deltamethrin exposure might be due to hypoxic condition of the fish.[83] Deltamethrin usually attacks the nervous system of fish when it comes into contact. The neurotoxic effects of deltamethrin is attributed to the blocking of sodium channels and inhibiting the gamma-aminobutyric acid (GABA) receptors in the nervous filament which results in an excessive stimulation of the central nervous system that something can lead to brain hypoxia.[47]

With the knowledge of LC_{50} value it would be possible to establish tolerable limits and safe concentrations of toxicants for the aquatic biota and one can protect the aquatic environment and its associated fauna. The present review on the acute toxicity of deltamethrin towards various fish species is helpful to evaluate the extent of aquatic pollution and its impact on various non-target aquatic fauna including fish. It is recommended to conduct toxicity bioassay tests to document LC_{50} values and other relevant information for various xenobiotic chemicals which can help environmental authorities to come up with dosage requirements. With the adequate information, decisions can be made about the use of chemicals to minimize the risk to human health and the environment.

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