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Impact of Deltamethrin on Aectylcholinesterase (AChE) and Acetylcholine (Ach) in Fresh Water Fish *Labeo rohita* (Hamilton)

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Abstract: Today the task of preventing human exposure to toxic chemicals might appear impossible. Indiscriminate and wide use of pesticides to wipe out pests, careless handling, accidental spillage of pesticides and pesticides released from manufacturing industrial units are carried by wind or percolate through water and finally washed down and find their way into water bodies. This would equally affect non-target organisms like fish, which represent an important component of aquatic life and serves as a staple food for human beings. Hence, it is felt necessary to conduct toxicological studies which indicates the sequence of events in physiological and biochemical systems providing information on the nature and completion of compensatory mechanisms during toxic stress. The present investigation is aimed at estimating impact of Deltamethrin on the acetylcholinesterase and acetylcholine activity in the Indian major carp *Labeo rohita.* It is evident that the levels of AChE activity elevated at 24 h as compared to control in all the organs whereas the ACh content followed an opposite trend. The levels of AChE activity goes on decreasing through 7 day and continued up to 15 day; however, the levels of ACh are elevated. From 15 day onwards the levels of AChE activity gradually elevated and came nearer to control at 30 day exposure.

Keywords: Pesticides, Pyrethroid, Water bodies, Fish, Deltamethrin, *Labeo rohita*, Aectylcholinesterase activity, Acetylcholine

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Introduction

Water is considered as polluted when it is altered in physical, chemical and biological characteristics which may cause harmful effects on human and aquatic biota (Sharma and Kaur, 1994). The problem of chemical pollution is known to occur in several ways i.e., organic and inorganic chemical wastes (Mc Kee and Wolf, 1963; Micheal, 1991), oil refineries (Dorris *et al.*, 1965), textile plant discharges (Dorn *et al.*, 1993; Lin and Peng, 1994), detergents, radioactive wastes and pesticides (Hiltibran, 1974). In addition to the agricultural practices together with pest control programmes, the surface run-off and aerial spraying form the major source for translocating pesticides into aquatic ecosystem (Baumann, 1980; Glortfelly, 1990). Wide spread transport of pesticides by air and rain was also reported by Cohen and Pinkerton (1966). The aquatic environment becomes the ultimate sink for all pollutants (Nicholson, 1967; Kerr and Vas, 1973). Any compound that has been used in large quantities ultimately reaches the aquatic ecosystem (Zitko *et al.*, 1975). Pesticides easily reach adjacent vegetation, wildlife, soil, water, air and sometimes humans. Thus the impact of pesticides is felt through the environment and public health (Pimental *et al.*, 1992). The greatest pools or sinks of chemicals in the aquatic environment occur in the sediment (Ahsanullah *et al.*, 1984, Adams *et al.*, 1992). One of the largest risk to the aquatic environment is sediment contamination considered by many regulatory agencies (Burton, 1992).

The widespread use of pesticides in agriculture has detrimental effects on lakes and rivers due to surface runoff from fields, posing risks to both animals and humans owing to their ability to bioaccumulate and disrupt the food chain (Lushchak *et al.*, 2018; Bodnar *et al.*, 2022). Fish, is the integral part of fresh water and marine ecosystems, as they play a crucial role in maintaining ecological balance (Okwuosa *et al.*, 2019). Due to their agility and relatively long lifespan, fish are considered good bioindicator of long-term toxic effects and various habitat conditions (Falfushynska *et al.*, 2014; Falfushynska *et al.*, 2019). Certain reports suggest that few teleost and zebrafish species exhibit metabolic traits resembling those of humans, making them potential alternative animal model for mechanistic research into cellular events triggered by physical and chemical stimuli (Hahn and Sadler, 2020).

Insecticides such as pyrethroids are the synthetic analogs of naturally occurring pyrethrins from the flowers of *Chrysanthemum* species. These are considered as effective insecticides due to their high insecticidal toxicity with low mammalian toxicity (Elliott *et al.*, 1974). Synthetic pyrethroids, including the newly synthesized insecticide called Cypermethrin and Deltamethrin, are types of pesticide that has been widely used. The use of these insecticides has raised concerns as they not only affect target pests but also affect the biology of non-target species (Elliot and Janes, 1978; Reddy and Yellamma, 1991). Particularly, they are highly toxic to fish and aquatic invertebrates even at very low concentrations. While these insecticides exhibit low mammalian toxicity, they pose a significant threat to invertebrates, fish, and amphibians (Robert Edwards, 1986). This enhanced toxicity has notable consequences on the health of ecosystems and their biodiversity (Madara Ranatunga *et al.*, 2023).

Acetylcholinesterase (AChE) is an enzyme that regulates neurotransmitter Acetylcholine (Ach) at neuron junctions. The inhibitory effects of insecticides on Acetylcholine esterase activity of fish had been reported by various authors--metacid-50 and carbaryl in *Channa punctatus* (Gosh and Bhattacharya, 1992) and cypermethrin in *Channa striatus* (Ahamed *et al.*, 2015). The present investigation is aimed at estimating impact of Deltamethrin (a pyrethroid) on the Acetylcholinesterase and Acetylcholine activity in the Indian major carp *Labeo rohita.*

Materials and Methods

Animal Selected

The Indian major carp, *Labeo rohita* (Hamilton) is an economically important edible fish having great commercial value. It is abundantly available in the fresh water tanks in and around Ananthapuramu, India. Besides its wide availability and commercial importance, this carp is known to have adaptability to laboratory conditions and appear to be suitable experimental animal for toxicity studies (Sreenivasan and Swaminath, 1967; Nair and Sherief, 1998). Hence, this fish has been selected as the ideal animal for the present investigation of toxicity studies.

Pesticide Selected

The pesticide selected for the present investigation is synthetic pyrethroid-Deltamethrin, belonging to "third generation pesticides". This pesticide is widely used in and around Anantapur district on diverse agriculture crops to control pests of crops, flies and mosquitoes. It has been widely used because of its high photostability, degradability, non-persistent nature and low mammalian toxicity. Deltamethrin has commercial name Decis. The commercial grade Deltamethrin (EC 2.8%) of liquid formulation was procured from local agrochemical stores.

Experimental design

Fresh water fish *Labeo rohita*, weighing 10±2 g were procured from local fisheries department and stored in spacious aquaria. The temperature in aquaria was 28 ± 2 °C and the same is maintained as normal temperature throughout the course of this investigation. The fish were fed daily with groundnut cake as well as with rice bran. Before the experiments have been executed the fish were adapted to the laboratory conditions for a period of one week. After determination of LC_{50} for 96 h (00.1 µg/l), the fish were exposed to sublethal concentration of Deltamethrin (1/10th of 96 h LC_{50} i.e. 0.01 µg/l) for five exposure periods i.e 1, 7, 15, 20 and 30 days.

Estimation of Acetylcholinesterase (AChE) activity

1% homogenate of the brain and 5% homogenate of the other tissues were separately prepared in 0.25M ice cold sucrose solution. The AChE activity in these extracts was estimated by the method of Augustinson (1957).

Estimation of Acetylcholine Content

Acetylcholine content (ACh) is separately estimated in the gill, kidney, brain, liver and muscle in both Deltamethrin and control fish *Labeo rohita* by the Hestrin method modified by Augustinson (1957).

Results

The data on the levels of AChE activity and ACh content in brain, liver, kidney and muscle of *Labeo rohita* at 1, 7, 15, 20 and 30 days after exposure to sublethal concentration of Deltamethrin are presented Tables 1 and 2. For comparison, the differences in the levels of each parameter obtained between the controls and experimental were converted as percentages of the corresponding control and these per cent values are also presented in the same Tables.

From the data presented in the Tables 1 and 2 it is seen that the levels of AChE activity elevated at 24 h relative to control in all the organs whereas the ACh content followed an opposite trend. The levels of AChE activity goes on decreasing through 7 day and continued up to 15 day whereas the levels of ACh goes on elevation. From 15 day onwards the levels of AChE activity gradually elevated and became close to control at 30 day exposure, whereas the levels of ACh content followed an opposite trend and came nearer to control at the end of 30 day exposure period and the values were found to be significant (P<0.001).

Discussion

Acetylcholine neurotransmitter substance at nerve cell junction will be acted upon by a substrate enzyme acetylcholinesterase (O' Brien, 1967; Rainsford, 1978). AChE is one of the hydrolytic enzymes disturbing the normal nervous functions finally resulting in the death of animals (Eto, 1974).

The organophosphorus (OP) pesticides inhibit the cholinesterase activity in almost all animal tissues (O'Brien, 1969; Goodman *et al.,* 1979). Inhibition of AChE activity was regarded as a significant parameter in assessing complex toxicogenic effects of various toxicants, including pesticides (Mukherjee and Bhattacharya, 1974; Olson and Christesen, 1980; Bhattacharya and Jash, 1981; Bhagylakshmi *et al.,* 1984b, 1985). In normal conditions, the enzyme AChE initially forms a complex with the substrate ACh, which then acetylates the enzyme with the release of choline. Deacetylation occurs by the reaction of

Table 1: Acetyl cholinesterase (AChE) activity in Deltamethrin treated *Labeo rohita* at different sublethal exposure periods. Mean is a pool of six individual measurements. The percent change in AChE activity at different periods is calculated in relation to the AChE activity in control medium (fresh water without Deltamethrin). The per cent recovery in AChE activity at 30-day exposure period is calculated relative to the level of the control medium which is fixed at 100%

S. No.	Organ	Control	Exposure period in days				
			1 day	7 day	15 day	20 Day	30 Day
I	**Brain**						
	Mean	1462.8	1832.4	1098.6	848.2	1002.6	1178.6
	±SD	2.16	1.82	1.96	0.94	1.54	1.2
	% Change	-	25.26	-24.89	-42.01	-31.46	-19.42
	% Recovery	-	-	-	-	-	68.53
	t- Test	-	P< 0.01	P< 0.01	P< 0.01	P< 0.01	P< 0.01
II	**Gill**						
	Mean	572.2	680.4	462.6	392.8	432.6	441.2
	±SD	2.82	1.98	1.12	1.26	0.82	0.96
	% Change	-	18.90	-19.15	-31.35	-24.39	-22.89
	% Recovery	-	-	-	-	-	7.10
	t- Test	-	P< 0.01	P< 0.01	P< 0.01	P< 0.01	P< 0.01
III	**Kidney**						
	Mean	182.4	214.6	150.8	127.4	132.6	140.2
	±SD	0.42	0.36	0.78	0.62	0.28	0.32
	% Change	-	17.65	-17.32	-30.15	-27.30	-23.13
	% Recovery	-	-	-	-	-	76.86
	t- Test	-	P< 0.01	P< 0.01	P< 0.01	P< 0.01	P< 0.01
IV	**Liver**						
	Mean	241.4	289.2	216.6	160.4	172.6	191.8
	±SD	0.62	0.36	0.28	0.76	0.42	0.22
	% Change	-	19.80	-10.27	-3.69	-28.50	-20.54
	% Recovery	-	--	-	-	-	79.45
	t- Test	-	P< 0.01	P< 0.01	P< 0.01	P< 0.01	P< 0.01
V	**Muscle**						
	Mean	974.2	1158.4	886.6	674.2	744.2	760.2
	±SD	1.12	1.36	0.95	1.04	0.96	0.74
	% Change	-	18.90	-8.97	-30.79	-23.56	-21.96
	% Recovery	-	-	-	-	-	78.03
	t- Test	-	P< 0.01	P< 0.01	P< 0.01	P< 0.01	P< 0.01

water with the acetylate enzyme and form acetic acid and the original free enzyme, whereas in the presence of pesticides, particularly OP compounds, the enzyme reacts with them in a way precisely analogous to that of the normal substrate and forms a pesticide-enzyme complex, instead of acetylated enzyme (Corbett *et al.*, 1984).

In the present investigation, the changes in AChE activity and ACh content during synthetic pyrethroid, Deltamethrin exposure was undertaken. The data on AChE activity and ACh content revealed the inhibition in the enzyme activity followed by a concomitant increase of ACh content in all the tissues like gill, kidney, brain, liver and muscle of *Labeo rohita* exposed to Deltamethrin (Tables 1, 2). From the data, it is evident that the AChE activity suddenly elevated at 24 h exposure. The enhancement in activity of AChE might be due to the pollution stress.

Satyadevan *et al.* (1993) reported an initial elevation in acetylcholinesterase activity of the brain of *Cyprinus carpio* exposed to an organophosphorus dimethoate. Kufesak *et al.* (1994) reported an initial elevation in

Table 2: Acetylcholine (ACh) content in Deltamethrin treated *Labeo rohita* in different sublethal exposure periods. Mean is a pool of six individual measurements. The percent change in ACh content at different periods is calculated in relation to the ACh content in control medium (fresh water without Deltamethrin). The percent recovery in ACh activity at 30-day exposure period is calculated relative to the level of the control medium which is fixed at 100%

S. No.	Organ	Control	Exposure period in days				
			1 day	7 day	15 day	20 Day	30 Day
I	**Brain**						
	Mean	846.8	620.2	820.6	985.2	876.7	830.5
	±SD	0.96	1.16	1.32	1.08	0.86	0.42
	% Change	-	30.40	12.28	26.51	7.01	4.14
	% Recovery	-	-	-	-	-	96.04
	t- Test	-	P< 0.01	P< 0.01	P< 0.01	P< 0.01	P< 0.01
II	**Gill**						
	Mean	312.6	248.2	368.6	426.4	416.2	398.2
	±SD	1.198	0.96	1.12	0.98	1.86	1.32
	% Change	-	-18.64	5.08	26.80	12.79	-3.55
	% Recovery	-	-	-	-	-	96.44
	t- Test	-	P< 0.01	P< 0.01	P< 0.01	P< 0.01	P< 0.01
III	**Kidney**						
	Mean	804.6	662.4	780.2	890.5	836.6	798.5
	±SD	2.12	1.08	0.86	0.98	1.16	1.32
	% Change	-	-17.6	3.03	10.67	3.97	0.75
	% Recovery	-	-	-	-	-	99.24
	t- Test	-	P< 0.01	P< 0.01	P< 0.01	P< 0.01	P< 0.01
IV	**Liver**						
	Mean	432.2	300.8	485.3	546.8	462.5	413.3
	±SD	1.18	1.32	0.86	2.10	1.10	0.97
	% Change	-	26.75	3.09	16.34	3.53	1.92
	% Recovery	-	--	-	-	-	95.85
	t- Test	-	P< 0.01	P< 0.01	P< 0.01	P< 0.01	P< 0.01
V	**Muscle**						
	Mean	286.7	222.4	310.4	360.8	323.6	270.4
	±SD	0.32	0.64	0.74	0.96	0.82	0.56
	% Change	-	22.42	8.33	25.84	12.87	5.68
	% Recovery	-	-	-	-	-	94.31
	t- Test	-	P< 0.01	P< 0.01	P< 0.01	P< 0.01	P< 0.01

acetylcholinesterase activity in carp after exposure to pesticides. Nisar Ahmed (1994) reported an initial elevation and further inhibition of ACHE activity in the major carp *Catla catla* after exposure to Deltamethrin. Abdul Subhan (2000) reported an initial elevation and further inhibition of AChE activity in *Catla catla* exposed to synthetic pyrethroid fenvalerate. An initial elevation in AChE activity was reported in the snail *Stagnicola species* after exposure to malathion (Martinez-Tabche *et al.*, 2002). These studies are in conformity with the present elevation in AChE activity. Similarly Venkateswara Rao *et al*. (2005) observed inhibition of AChE enzyme activity in the brain of *Gambusia affinis* on exposure to chlorpyrifos. Mushigeri and David (2005) and Patil and David (2008) observed darting movements and loss of equilibrium of fish which may be due to inhibition of AChE activity leading to accumulation of acetylcholine in cholinergic synapses ending up with hyper-stimulation.

In the present study, at later periods like 7th day and 15th day exposure the AChE activity was reduced, with maximal reduction at 15th day exposure period of Deltamethrin. The inhibition in AChE activity resulted in the accumulation of acetylcholine (ACh) at different sublethal exposure periods of Deltamethrin. Similarly Health (1961) and O'Brein (1967) have reported that OP insecticides react with AChE to form phosphorylated enzyme, this phosphorylated enzyme inhibits the AChE for several weeks (Coppage and Duke, 1971; Post and Leasure, 1974). These reports provide strength to the present study regarding inhibition of AChE.

In addition Bhagyalakshmi and Ramamurthy (1980) reported inhibition of AChE activity in *O. sensex sensex* exposed to fenitrothion. Gosh and Bhattacharya (1992) reported significant inhibition of brain AChE activity accompanied by a concurrent increase in Ach content in *Channa punctatus* exposed to carbaryl and metacid-50. A significant inhibition in AChE activity was reported in prawn, *Macrobrachium malcolmsonii* on exposure to carbaryl (Bhavan and Geraldine, 2002). These studies support the present finding regarding the inhibition in AChE activity. These findings i.e. activation of enzyme during early period and inhibition during later exposure period depend on the concentration of the pesticides and coincides with that of findings of various authors (Joseph and Raj, 2011; and Jindal and Kaur, 2014).

The measurement of brain AChE activity in the aquatic animals indicates the extent of pollution of that environment which they inhabit. The inhibition of AChE activity is directly related to the concentration of pesticides and the length of exposure (Coppage, 1972; Macek *et al.*, 1972). Koundinya and Ramamurthy (1979) also reported a greater inhibition in AChE activity, with higher elevation in Ach content in the brain than in the muscle of *Tilapia mossambica* exposed to sumithion.

According to Coppage *et al.,* (1975) inhibition of brain AChE activity to the level of 70-80% is critical to the fishes. The inhibition in AChE activity may result in the accumulation of Ach content and this led to consequent loss of muscular and nervous coordination. Bradbury (1973) has observed the prostration and massive muscular tetanus followed by death in *Carcinus maenus* after parathion administration. Ramana Rao (1978) reported inhibition of muscle AChE activity in snails exposed to pesticide toxicity.

In the current study however, at 30th day exposure the inhibitory activity was decreased and came nearer to normal level. Thus, the fish *Labeo rohita* fairly recovered from the inhibitory activity in tissues of fish. The concomitant recovery in AChE activity during 30th day exposure period might be due to active metabolism of Deltamethrin which is being removed from the site of action and thus enabling the enzyme to resume unhindered hydrolysis of ACh.

Conclusion

Indiscriminate and wide use of pesticides to wipe out pests, careless handling, accidental spillage of pesticides and pesticides released from manufacturing industrial units are carried by wind or percolate through water and finally washed down and find their way into water bodies. This would equally affect non-target organisms like fish, which represent an important component of aquatic life and serves as a staple food for human beings. The present investigation is aimed at estimating impact of Deltamethrin on the acetylcholinesterase and acetylcholine activity in the Indian major carp *Labeo rohita.* It is evident that the levels of AChE activity elevated at 24 h as compared to control in all the organs whereas the ACh content followed an opposite trend. The levels of AChE activity goes on decreasing through 7 day and continued up to 15 day; however, the levels of ACh are elevated. From 15 day onwards the levels of AChE activity gradually elevated and came nearer to control at 30 day exposure. In the present investigation the shifts in enzymatic studies such as Acetylcholinestrase(AChE) and Acetylcholne (Ach) metabolism might be to compensate with situation shown by the fish for its survival to the imposed toxic stress.

Ethical Statement

The authors confirm that all ethical issues have been dealt with the research ethics guidelines provided by the [1]Department of Zoology, Govt. College (A), Ananthapuramu, Andhra Pradesh, India

Author Contributions

Each author has contributed equally to the study's planning, analysis, writing, and editing. All authors have read and agreed to the published version of the manuscript.

Conflict of Interest

The authors declare no conflicts of interest.

References

Adams WJ, Kimerle RA and Barnett JW Jr. (1992) Sediment quality and aquatic life assessment. Environ Sci Technol. 26: 1865-1875.

Ahmed O, Mastan SA, Rabia Banu S. and Indira P. (2015) Sub-lethal effect of cypermethrin on acetylcholinesterase (AChE) activity and acetylcholine (Ach) content in selected tissues of *Channa striatus.* J Toxicol Environ Hlth Sci. 7(4): 31-37.

Ahsanullah M, Mobley MC and Negilski DS. (1984) Accumulation of cadmium from contaminated water and sediments by the shrimp, *Collianassa australiensis*. Mar Biol. 82: 191-197.

Baumann F. (1980) Draft Environmental Report on India. Washington, D.C., Library of Congress, Science and Technology Division. Prepared under the U.S. Agency for International Development (USAID), Office of Science and Technology.

Bhagyalakshmi A and Ramamurthy R. (1980) Recovery of acetylcholinesterase activity from fenitrothion induced inhibition in the freshwater field crab *O. senex senex.* Bull. Environ Contam Toxicol. 24: 866-869.

Bhattacharya S and Jash NS. (1981) In vivo inhibition and recovery of acetylcholinesterase in the brain of the freshwater teleost, *Channa punctatus* (Bloch) during and after exposure to carbofuran. Comp Physiol Ecol. 6: 330-332.

Bhavan SP and Geraldine P. (2002) Carbaryl induced alternations in biochemical metabolism of the prawn, *M. molcolmsonii*. J Environ Biol. 23(2): 157-162.

Bodnar O, Horyn O, Soroka O, Nimko K and Falfushynska H. (2022) Pesticide pollution of aquatic ecosystems: environmental risks and mechanisms of impact on aquatic organisms (a review). Hydrobiol J. 58: 62-78.

Bradbury SJ. (1973) The effect of parathion on crustacean skeletal muscle. 1. The mechanical threshold and dependence on Ca^{2+} ions. Comp Biochem Physiol. 44A: 1021-1032.

Burton GA Jr. (1992) Assessing contaminated aquatic sediments. Environ Sci Technol. 26: 1862-1863.

Cohen JM and Pinkerton C. (1966) Wide spreads translocation of pesticides by air transport and rain out. In: Organic pesticides in the environment, American Chemical Society Advances in Chemistry Series 60. Washington D.C., pp. 163-176.

Coppage DL. (1972) Organophosphorus pesticides: specific level of brain AChE inhibition related to death in sheep head minnows. Trans Am Fish Soc. 101: 534-536.

Coppage DL and Duke TW. (1971) Effects of 2,4-D on estuarine animals. In: Proceedings of the 2nd Gulf Coast Conference on Mosquito Suppression and Wildlife Management, (ed.) Schmidt C. H., National Mosquito Control-Fish and Wildlife Management Coordinating Committee, pp. 24-31.

Coppage DL, Matthews E, Cook GH and Knight J. (1975) Brain acetylcholinesterase inhibition in fish as a diagnosis of environmental poisoning by malathion, 0-0 dimethyl S-(1-2 Dicharbethoxythy!) phosphorodiathioate. Pestic Biochem Physiol. 5: 536-542.

Corbett JR, Wright K and Bailic AC. (1984) The biochemical mode of action of pesticides. Academic Press, London.

Dom PB, Salanitro JP, Evans SH and Kravetz L. (1993) Assessing the aquatic hazard of some branched and linear non-ionic surfactants by degradation and toxicity. Environ Toxicol Chem. 12: 1751-1762.

Dorris TC, Copeland BJ and Lauer CR. (1965) Limnology of the middle Mississippi River. IV. Physical and chemical limnology of river and chute. In: Biological Problems in Water Pollution: Third Seminar, August 13-17, 1962. Environmental Health Series: Water Supply and Pollution Control, 999-WP-25, pp. 71-81.

Elliot M and Janes NF. (1978) Synthetic pyrethroids - a new class of insecticides. Chem Soc Rev. 7: 473-505.

Elliott M, Famham AW, Janes NF, Needham PH and Pluman DA. (1974) Synthetic insecticide with a new order of activity. Nature (London) 248: 710-711.

Eto M. (1974) Organophosphorus pesticides: organic and biological chemistry. CRC Press, Cleveland. Ohio, USA.

Falfushynska H, Gnatyshyna L, Turta O, Stoliar O, Mitina N, Zaichenko A and Stoika R. (2014) Responses of hepatic metallothioneins and apoptotic activity in *Carassius auratus gibelio* witness a release of cobalt and zinc from waterborne nanoscale composites. Comp Biochem Physiol C Toxicol Pharmacol. 160: 66-74.

Falfushynska H, Horyn O, Brzozowska A, Fedoruk O, Buyak B, Poznansky D, Poniedziałek B, Kokociński M and Rzymski P. (2019) Is the presence of Central European strains of *Raphidio psis* (*Cylindrospermopsis*) *raciborskii* a threat to a freshwater fish? An *in vitro* toxicological study in common carp cells. Aquat Toxicol. 206: 105-113.

Glotfelly DE, Majewski MS and Seiber JN. (1990) Distribution of several organo-phosphorus insecticides in a foggy atmosphere, Environ Sol Technol. 24: 353-357.

Goodman LR, Henson DJ, Coppage DL, Moore JC and Methews E. (1979) Diazion chronic toxicity and brain acetylcholinesterase inhibition in the sheep headed minnow, *Cyprinodon variagatus*. Trans Am Fish Soc. 108: 479-488.

Gosh P and Bhattacharya S. (1992) In vivo and in vitro AChE inhibition by metacid-50 and carbaryl in *Channa punctatus* under field condition. Biomed Environ Sci. 5(1): 18-24.

Hahn ME and Sadler KC. (2020) Casting a wide net: Use of diverse model organisms to advance toxicology. Dis Model Mech. 13: 043844.

Health DF. (1961) Organophosphorus poisons anticholinesterase and related compounds. Pergman Press, New York.

Hiltibran RC. (1974) Oxygen and phosphate metabolism of Blue gill liver mitochondria in the presence of some insecticides. Trans III Acad Sci. 67: 660-703.

Jindal R and Kaur M. (2014) Acetylcholinesterase inhibition and assessment of its recovery response in some organs of *Ctenopharyngodon idellus* induced by chlorpyrifos. Int J Sci Environ Technol. 3(2): 473- 480.

Joseph B and Raj SJ. (2011) Impact of pesticides toxicity on selected biomarkers in fishes. Int J Zool Res. 7: 212-222.

Kerr SR and Vas WP. (1973) Environmental Pollution. Plenum Press, New York.

Koundinya PR and Ramamurthy R. (1979) Comparative study of inhibition of AChE activity in the fresh water teleost, *S. mossambica* (Peters) by Sevin (Carbamate) and Sumithion (organophosphate). Curr Sci. 48: 832.

Kufesak O, Szeglets T, Lang G, Halasay IR, Benedeezky Y and Manesok J. (1994) Investigation of effects of pesticides on molecular form of AChE in alimentary canal of carp. Pestic Biochem Physiol. 49: 155163.

Lin SH and Peng CF. (1994) Treatment of textile waste water by electrochemical method. Water Res. 28: 277-282.

Lushchak VI, Matviishyn TM, Husak VV, Storey JM and Storey KB. (2018) Pesticide toxicity: A mechanistic approach. EXCLI J. 17: 1101-1136.

Macek KJ, Walsh DF, Hogan JW and Holz DD. (1972) Toxicity of the insecticide dursban to fish and aquatic invertebrates in ponds. Trans Am Fish Soc. 101: 420-427.

Madara Ranatunga, Claudette K and Vincent P. (2023) Toxicological impacts of synthetic pyrethroids on non-target aquatic organisms: A review. Environ Adv. 12: 100388.

Mukherjee S and Bhattacharya S. (1974) Effect of some industrial pollutants on fish brain acetylcholinesterase activity. Environ Physiol Biochem. 4: 226-231.

Mushigeri SB and David M. (2005) Fenvalerate induced changes in the ACh and associated AChE activity in different tissues of fish, *Cirrhinus mrigala* (Hamilton) under lethal and sub-lethal exposure period. Environ Toxicol Pharmacol. 20: 65-72.

Nicholson HP. (1967) Pesticide pollution control. Science 158(3803): 871-876.

Nisar Ahmed G. (1994) Biochemical responses of *C. catla* subjected to deltamethrin toxicity in relation to size. Ph.D. Thesis, S.K. University, Anantapur, A.P., India.

O'Brien RD. (1967) Insecticides: Action and Metabolism. New York: Academic Press.

O'Brien (1969). Cholinester Biochemical effects. Phospharylation and carbomylation of cholinesterase. An NY Acad Sci. 160: 204-214.

Okwuosa OB, Eyo JE and Omovwohwovie EE. (2019) Role of fish as bioindicators: A review. Iconic Res Eng J. 2: 354-368.

Olson DL and Chirstersen GM. (1980) Effects of water pollutants and other chemicals on fish acetylcholinesterase (in vitro). Environ Res. 21: 327-335.

Patil VK and David M. (2009) Hepatotoxic potential of malathion in the freshwater teleost, *Labeo rohita* (Hamilton). Veterinarski Arhiv 79(2): 179-188.

Post G and Leasure RA. (1974) Sublethal effects of malathion on three salmonid species. Bull Environ Contam Toxicol. 12: 312-319.

Rainsford KD. (1978) Toxicity in the brain of organophosphate insecticide; Comparison of the toxicity of metabolites with parent compounds using intra cerebral injection method. Pestic Biochem Physiol. 8: 302.

Ramana Rao MV. (1978) Studies on some aspects of metabolism in the freshwater snail, *Pila globosa* (Swainson) with special reference to pesticide impact. M.Phil. dissertation. S.V. University, Tirupati, India.

Reddy AT and Yellamma K. (1991) Perturbations in carbohydrate metabolism during cypermethrin toxicity in fish *Thilapia mosssambica* (Peters). Biochem Int. 23(4): 633-638.

Robert Edwards, Peter M and David HH. (1986) Comparative toxicity of cis-cypermethrin in rainbow trout, frog, mouse, and quail. Toxicol Appl Pharmacol. 84(1): 512-522.

Sathyadevan S, Kumar S and Tembhre M. (1993) AChE activity and enzyme kinetics in the brain of common carp, *Cyprinus carpio* subjected to sublethal exposure to dimethoate. Biosci Biotech Biochem. 57(9): 1566-1567.

Sharma BK, and Kaur H. (1994) Water Pollution. Goel Publishing House, Meerut, India.

Venkateswara Rao J, Begum G, Pallela R, Usman PK and Rao RN. (2005) Changes in behavior and brain acetylcholinesterase activity in mosquito fish, *Gambusia affinis* in response to the sub-lethal exposure to chlorpyrifos. Int J Environ Res Public Health 2(3-4): 478-483.

Zitko, V. (1975) Potentially persistent industrial organic chemicals other than PCB. In: Ecological Toxicology Research: Effects of Heavy Metal and Organohalogen Compounds: Proceedings of a NATO Science Committee Conference, (eds.) Mcintyre A.D. and Mills C.F., Springer, New York, NY, pp. 197-206.