An Overview on the Potential Hazards of Pyrethroid Insecticides in Fish, with Special Emphasis on Cypermethrin Toxicity

Mayada R. Farag 1, Mahmoud Alagawany 2, Rana M. Bilal 3, Ahmed G. A. Gewida 4, Kuldeep Dhama 5, Hany M. R. Abdel-Latif 6, Mahmoud S. Amer 7, Nallely Rivero-Perez 8,9, Adrian Zaragoza-Bastida 5,6, Yaser S. Binnaser 9, Gaber El-Saber Battha 10 and Mohammed A. E. Naiel 11,*

Abstract: Pesticides are chemicals used to control pests, such as aquatic weeds, insects, aquatic snails, and plant diseases. They are extensively used in forestry, agriculture, veterinary practices, and of great public health importance. Pesticides can be categorized according to their use into three major types (namely insecticides, herbicides, and fungicides). Water contamination by pesticides is known to induce harmful impacts on the production, reproduction, and survivability of living aquatic organisms, such as algae, aquatic plants, and fish (shellfish and finfish species). The literature and information present in this review article facilitate evaluating the toxic effects from exposure to various fish species to different concentrations of pesticides. Moreover, a brief overview of sources, classification, mechanisms of action, and toxicity signs of pyrethroid insecticides in several fish species will be illustrated with special emphasis on Cypermethrin toxicity.

Keywords: harmful effects; oxidative stress; neurotoxicity; mortalities; health
1. Introduction

The present era of the green revolution, witnessing a swift increase in human populations across the globe, depicts the dependency of human beings on available natural resources. The current scenario has led to efforts for technological advancements to cope with the need of societies. This, in turn, is ensured by evolving ever-increasing dissolution of different synthesized chemicals in the environment, which induce pollution, specifically in aquatic bodies used as dumping sites in most parts of the world [1–3]. Pollution is the critical universal off-putting factor, which is worsened by the hasty growth of human populaces and rapid industrialization [4,5]. The polluted aquatic environment is a hazardous worldwide problem, and the drainage of agricultural, industrial, and commercial chemicals into the aquatic environment has induced several harmful effects on living aquatic organisms [1]. Moreover, these pollutants could directly accumulate in fish flesh and contaminate the food chain, which will consequently affect human consumers [6].

A pest refers to a rodent, insect, nematode, weed, fungus, or any other form of terrestrial or aquatic plant or animal virus, bacteria, or other microorganisms that harm the foodstuffs, garden plants, household articles, or trees, as a vector of diseases [6,7]. For farmers, pests include mites and insects that feed on crops and aquatic plants, and cause animal and plant diseases, such as fungi, viruses, bacteria, snails, nematodes, and rodents [8]. On the other hand, pesticides are referred to as many chemical compounds that possess various biological activities and chemical natures, which are clustered together to increase their capability to eradicate pests [9–13]. Thus, as a broad definition, pesticides are all those substances or their mixture used for prevention, destruction, repelling, deterring, resisting, or controlling pests [8,9].

Water pollution with pesticides may be due to direct application of these chemicals for controlling aquatic flora and/or seepage from agricultural lands through agricultural runoffs [14]. These are widely spread in both urban and agricultural landscapes [15]; this simply regards the pesticide residues or pesticides as major contributors to water pollution [16,17]. Across the globe, different types of pesticides are being used in different ratios, such as insecticides, which make up approximately 80% of all pesticides, herbicides (15%), and fungicides (1.46%) [9].

Pesticide residues can be sustained for long periods in the fields after application due to their decreased biodegradation properties [18], which could be absorbed by aquatic organisms, such as fish, leading to negative influences on their health and meat quality, which will negatively affect human health [7]. Furthermore, they have a quick biodegradation rate in the aquatic environment where algae and macrophytes exist [19]. These pesticides are over 100 times more poisonous for fish due to the increased sensitivity of fish to toxic agents, due to their direct contract to water via gills and absence or the insufficient hydrolytic enzymes for pyrethroids [20]. These chemicals are transformed in the hepatocytes, bile, and blood cells to sulfates and glucuronides, causing undesirable effects on meat quality and the survival rate of fish [21–23].

Pyrethroids are from commonly used insecticides worldwide [4,24–26]. Synthetic pyrethroid insecticides (such as permethrin, deltamethrin, resmethrin, tetramethrin, γ-cyhalothrin, and cypermethrin) can cause serious toxicological impacts on the exposed aquatic organisms [27]. Cypermethrin (CYP) can be defined as a fourth generation pyrethroid insecticide that is broadly used to constrain cotton pests and can also be recommended as a “pour-on treatment” to control ectoparasites of farm animals (such as ticks and mites) [28].

Studies showed that CYP induced genotoxicity and oxidative stress in the exposed zebrafish (Danio rerio) [29,30], malformations in rohu (Labeo rohita) during the early developmental stages [31], immunotoxic effects in common carp (Cyprinus carpio) [32], DNA damage, apoptosis, and histopathological alterations in C. carpio [33], hepatotoxicity in the Catla (Catla catla) [34], and neurotoxicity and apoptotic changes in the brain of C. catla [35].
Therefore, this review discusses the most toxic impacts of pesticides on fish, specifically pyrethroids, emphasizing CYP-induced toxicity.

2. Detrimental and Toxic Effects of Pesticides in Fish: A General Overview

Exposure to pesticides in sub-lethal and lethal doses produces toxic effects in aquatic organisms, including fish [33,36,37], which can be categorized into the following.

2.1. Behavioral Changes

Pesticides may induce behavioral responses, such as schooling behavior, higher mucus production from the goblet cells of the skin (sliminess), jumping, motionlessness, modification in the migration behavior, vertical (upside down) positions, sinking to the bottom, non-responsiveness with hyperexcitability, rapid, jerky movements, higher opercular rate (increased respiration rate), and changes in the body color of several fish species, such as Tor putitora, C. carpio, Mozambique tilapia (Oreochromis mossambicus), L. rohita, C. catla, Cirrhinus mrigala, Clarias batrachus, and Channa punctatus [38–41]. Moreover, they could modify and disturb the swimming behavior in aquatic vertebrates, such as fish and amphibians, and depress their growth rates [4,25]. Reports showed that exposure to pyrethroids downregulated the dopamine active transporter activity, leading to irregular behavior characteristics [42].

2.2. Reproductive Disorders and Malformations

Pesticides may also induce some reproductive disorders in brown trout (Salmo trutta) and Atlantic salmon (Salmo salar) [43]. Moreover, some studies reported several developmental alterations in fish exposed to the pesticide [31]. Several studies have proved the toxic effects of pyrethroids in fish reproduction and during early developmental stages. For instance, the bifenthrin and permethrin pyrethroids can delay synthesizing egg proteins (vitellogenin, choriogenin) in juvenile fish [44]. At the same trend, Wu et al. [45] stated that DLM at concentrations of 20 or 40 µg/L showed toxic effects on swim bladder development in zebrafish embryos.

2.3. Histopathological Alterations

Pesticides, such as malathion, carbofuran, diazinon, and dichlorvos, caused several histopathological alterations, and affected the biological functions of some vital organs such as the kidney, liver, gills, testis, and ovaries of different fish species, in the form of necrotic changes, loss of the granularity of cytoplasm, shrinkage of cells in various tissues, nuclear pycnolic alterations, vacuolation in the cytoplasm (in gill lamellae, kidneys, and filaments), degeneration of glomerulus, shrinkage of nuclear materials, ruptured epithelial lining, cytoplasm clumping, altered tubular line size, degeneration of follicular cells, collecting duct damage, and changes in ovigerous lamellae in many fish species, including L. rohita, Heteropneustes fossilis, C. carpio, Channa punctatus, O. mossambicus, Nile tilapia (O. niloticus), and Cirrhinus mrigala [33,46–48].

2.4. Haemato-Biochemical Alterations

Several reports demonstrated that the blood profile of fish species, such as Tor putitora, L. rohita, O. niloticus, C. carpio, O. mossambicus, Channa punctatus, rainbow trout (Oncorhynchus mykiss), and C. batrachus, may be impacted by pesticide exposure [2,49]. Furthermore, reports also explain that some well-known organophosphates, such as malathion and endosulfan, pose adverse effects on the enzyme activity, i.e., L-Keto acid-activated–glutaminase, lactate dehydrogenase (LDH) level, citrate-synthase (CS), glucose 6-phosphate phosphate dehydrogenase (G6-PDH) in the brain, liver, skeletal muscles, and the gills of C. batrachus and L. rohita [2,50,51].
2.5. Neurotoxicity

It was also observed that pesticides may impact acetylcholine esterase (AChE) activity, resulting in adverse effects on the nervous system of fish and, thus, produce various neurotoxic effects (neurotoxicity) [49,52]. Pesticides modified the actions of AChE in *C. carpio*, *L. rohita*, *O. mossambicus*, *Rhamdia quelen*, and *Colisa fasciatus* [53–55]. Furthermore, CYP-induced neurotoxicity and apoptotic changes in the brain of *C. catla* [35].

2.6. Endocrine Disruption

Pesticides also have an endocrine-disrupting effect on fish [56]. When used in higher concentrations, these chemical compounds may induce molecular toxicity in various types of fish, such as goldfish (*Carassius auratus*), *L. rohita* and, *Cirrhinus mrigala* [2,40,57]. In addition, histopathological studies revealed that pesticides might negatively influence the endocrine system of *L. rohita* and *O. mykiss* [58,59]. Moreover, bifenthrin has been revealed to reduce the 17-β estradiol levels in the bloodstream, consequently decreasing the ovarian follicle diameter in *O. mykiss* [60]. Moreover, bifenthrin showed higher binding capacity with thyroid hormones through the downregulation of hypothalamus-pituitary-thyroid (HPT) axis-related genes in zebrafish embryos [61].

2.7. Effects on Proximate Body Composition

Results of Lakshmanan et al. [62], Muthukumaravel et al. [63], and Bibi et al. [54] revealed that pesticides negatively influenced the values of proximate body composition of fish (such as crude protein, crude lipids, ash, moisture, etc.), including *O. niloticus*, *H. fossilis*, *C. batrachus*, *L. rohita*, *Colisa fasciatus*, *C. carpio*, and African catfish (*C. gariepinus*). Furthermore, a notable rise in the concentration of ascorbic acid and cholesterol in the kidney, liver, and muscles and depression in the level of glycogen, albumin, and protein contents were also recorded.

2.8. Oxidative Stress Injury

Exposure of fish to pesticides reduced the antioxidant defense enzyme activities, such as catalase (CAT), glutathione peroxidase (GPX), superoxide dismutase (SOD), reduced glutathione content (GSH), glutathione reductase (GR), glutathione-s-transferase (GST), and lipid peroxidation marker malondialdehyde (MDA) of *L. rohita*, *O. niloticus*, *Hoplias malabaricus*, *C. gariepinus*, *Lepomis macrochirus*, and *Tor putitora* [2,40,51,63].

2.9. Genotoxicity

Pesticides usage exhibit carcinogenic and genotoxic effects, which cause different forms of nuclear abnormalities, such as chromosome and chromatid breaks, centromeric attenuation, extra fragments of DNA (DNA fragmentations), pyknosis, stubbed arms besides changing the DNA replication, which leads to different kinds of mutations and cell proliferation [64]. Moreover, it was reported that increased DNA fragmentation of hepatocytes and gill cells was found in *C. carpio* exposed to sub-lethal CYP levels [33].

2.10. Immunotoxicity

It was reported that pesticides negatively impact the immune status of various fish species. They pose immune deficiency responses by a low level of granulocytes and lymphocytes, by inhibition of B and T cell proliferation, a decrease in phagocytic cell functions, and lower leucocytes number, which lead to reducing the resistance of fish to combat infections and diseases [65,66]. For instance, Soltanian and Fereidouni [32] clarified that chronic CYP toxicity in common carp induced immunotoxic effects, which manifested by increased mortalities after experimental challenges with pathogenic *Aeromonas hydrophila*.

The experiential changes in the above-stated factors have been found in various fish classes, including their body parts. Moreover, observations recorded in the light of the above parameters suggest the occurrence of different levels of harmful impacts for different kinds of pesticides on various tissues of exposed fish species [67].
3. Pyrethroid Insecticides

Pyrethroid insecticides are synthetic derivatives from pyrethrins, which some plants naturally produce, such as *Tanacetum cinerariaefolium* or *Chrysanthemum cinerariifolium* [68,69]. Chemically, the pyrethroid derives from acids and alcohols of chrysanthemum acid (ethyl 2,2-dimethyl-3-(1-isobutenyl) cyclopropane-1-carboxylate) [70,71]. Pyrethroids have been widely used for controlling insects in the agriculture and ectoparasitic infections in humans and animals [69,72,73]. Both pyrethroids and pyrethrins are highly toxic and rapidly degrade in the environment under proper temperature, light, and moisture levels [74]. The degradation process usually occurs in one or two days in sunlight and proper atmosphere. Pyrethroids are considered promising alternatives to conventional pesticides because they do not contaminate groundwater [75].

3.1. Classification and Types of Pyrethroids

Pyrethroids are synthetic organic insecticides divided into two distinct groups (type I and type II). Type I pyrethroids lack a cyano moiety and type II pyrethroids are with an alpha-cyano group [76]. Permethrin pesticides include bioremethrin, resmethrin, allethrin (Allyl analog), and tetramethrin, as examples of type I pyrethroids, whilst type II pyrethroids include CYP, cyphenothrin, deltamethrin (DLM), cyfluthrin, and fenvalerate. Both types of pyrethroids inhibit spontaneous activity in the neurons of target organisms [77]. Type I pyrethroids produce reflex hyperexcitation and fine tremors, while type II involves more complex syndromes, such as higher gill mucus secretions and clonic seizures. In addition, type I alters the sodium channel actions in different ways, while type II modifies transitions to the sodium channel in inactivated and open states [78].

DLM, CYP, and lambda-cyhalothrin are commonly used synthetic forms of pyrethroid insecticides worldwide. Kumar et al. [79] reported that DLM is highly effective against malaria vectors, making it efficient in the manufacture of mosquito evictor nets. It is categorized as a type II pyrethroid and is soluble in organic solvents (acetone and alcohol), but insoluble in water [80]. Besides, it is created from natural pyrethrins compounds, which quickly affect the nervous system of insects, inducing a fast knockdown influence [81]. Furthermore, DLM is linked with the prolonged opening of voltage-gated sodium channels, which causes depolarization in neuron membranes, repetitive discharges, and produced synaptic disorders [71,80]. It also diminishes the ion exchange process between chloride and calcium channels of the neurons [75,80].

CYP is an active synthetic pesticide expansively applied to households, industrial, and agricultural fields to control many insect pests. It is also categorized as a type II pyrethroid that displays stability in neutral and acidic solutions. It could prohibit the transportation process of sodium ions through the cell membrane [82].

Lambda-cyhalothrin is a synthetic acaricide pyrethroid insecticide that is used to prevent a broad spectrum of crop pests [83]. It is synthesized from a mixture of cyhalothrin isomers, which altered the nervous system functions [84]. It was restricted due to its higher toxicity to fish [85].

3.2. Modes of Action of Pyrethroids

Pyrethroids are categorized as neurotoxins targeting the peripheral and central nervous system axons by intermitting with sodium channels in insects [83]. In this concern, Bradberry et al. [75] reported that the selective toxin activity of pyrethroids towards insects is 2250 times higher than animals. This may be attributed to the presence of more active sodium channels and lower body temperature in insects. The toxic effects of pyrethroids in fish species, e.g., shellfish, and finfishes have been reported in several studies, and that related to the disturbing action of pyrethroids on the ion exchange process neuronal and mitochondrial membranes [86–89].

In mammals, sodium channels are the major proteins of the nervous system concerned with electrical signaling and the supporting of essential functions such as osmoregulation, heart pulse, and the activity of the brain. Some fish species, such as zebrafish, showed ex-
pression patterns of voltage-gated sodium channel genes similar to those in mammals [90]. All pyrethroid compounds caused prolonged sodium outflow with delaying in sodium activation gate closure resulting in decreased and extended sodium tail discharge [91]. Some pyrethroids increased the neurotransmitter release in the postsynaptic gap by prohibiting the calmodulin proteins responsible for connecting calcium ions and the intracellular membrane, and limiting the calcium removal process from the nerve endings, leading to reduced spontaneous neurotransmitter release [92]. The toxic effects of pyrethroids may depend on the sequences of the amino acid in sodium channels, specifically at position 918 (methionine), thereby making a difference in sensitivity [93]. Moreover, it has been shown that the toxicity of pyrethroids, such as bifenthrin, depends on the relative proportion of negative and positive pairs, with the negative pairs being more active than the positive and the neutral ones [94].

The long-term exposure to pesticides excites the outer cell membrane and the nervous system. Furthermore, some pyrethroids have an adverse effect on the γ-aminobutyric acid (GABA) receptors in the nervous filaments [27,95,96]. Moreover, they could prevent chloride ions from transportation into the nerve cells and modulate the activity of voltage-gated calcium channels [97]. There were minor preventing effects of pyrethroids towards the Ca-ATPase, Ca–Mg ATPase neurotransmitters, and the peripheral benzodiazepine receptors [98].

Pyrethroids could penetrate the epidermis and be combined directly with a carrier protein in blood or lymph. Consequently, the diffused pyrethroids and the epidermis cells directly affect the central nervous system via the connection with sensory organs of the peripheral nervous system [99]. Moreover, the pyrethroids may enter the body in a small portion through the breathing process in a vapor phase. Besides, they could penetrate the blood or hemolymph through the digestive tract during the digestion process [100].

3.3. Biotransformation and Acute Lethality of Pyrethroids to Fish

Several studies have documented the sensitivity of fish towards pyrethroids pesticides [95,101–103]. Unlike most mammals, fish are not able to produce the enzymes that hydrolysis the insecticides. The lipophilicity properties of pyrethroid compounds make them susceptible to the non-water-soluble components of the cells. They can also be quickly absorbed by the gills, even though water containing a small portion of these compounds [101]. The lethal effects of pyrethroids in fish may be due to their biotransformation properties.

Pyrethroid compounds are partly broken down in the gut by non-specific esterase, reducing their absorption rate. While in fish, many toxin levels are absorbed by gills, then rapidly enter the circulatory system [104]. In the hepatocytes, the hydrolysis of pyrethroids depends on oxidation by cytochrome P450 or carboxylesterase. It produces a high level of non-bioactive metabolites secreted via the urine and the bile [105].

It was found that the 96 h LC50 value of CYP was 27.07 µg/L on the guppy fish [74], 38.38 µg/L on Poecilia reticulata males [106], and 3.14 µg/L on rainbow trout [107]. Moreover, the lambda-cyhalothrin recorded 96 h LC50 of 81.83 µg/L [74], 1.6 µg/L on C. carpio fingerlings [84] and 1.72 µg/L for L. rohita [108]. For DLM, the 96 h LC50 in the guppy fishes was 31.51 µg/L [74], which doubled 15.47 µg/L or 14.9 µg/L in O. niloticus fingerlings [109,110]. The fish mortality percentage was depended on pesticide type, exposure time, bioavailability, mode of action, and concentration.

Pyrethroids pesticides induce different types of toxicity in fish. Some of these toxic impacts in the form of alterations in various physiological, behavioral, anatomical, biochemical, hematological, enzymatic, molecular, and hormonal aspects, are briefly illustrated in Table 1.

3.4. Cypermethrin as a Pyrethroid Model

Cypermethrin (CYP) [(RS)-cyano-(3-phenoxyphenyl) methyl-(IRS)-cis -Trans-3-(2, 2 dichloroethenyl)-2, 2-dimethyl-cyclopropane carboxylate], is one of extensively used and highly effective synthetic pyrethroids. It is lipophilic and synthetically obtained from a natural source known as pyrethrin. CYP is broadly engaged mainly in commercial
agriculture, forestry, gardens, buildings, and farmyards to prevent and control insects [2]. CYP is used as an insecticide in a broader range of crops, such as wheat, sugarcane, brinjal, okra, cabbage, onion, lettuce, cotton, and sunflower [2,111]. Interestingly, it is thought that CYP is immobile and does not be expected to be biomagnified through the food chain. Furthermore, CYP is commercially registered to kill soybean and cotton pests successfully [112,113]. The report of Bekele [114] suggests that proper application of this unique insecticide may effectively repel and control mosquitos, whilst the most effective results were found in preventing many kinds of malarial parasites. Moreover, globally, aquaculturists apply this insecticide to control parasitic infections, such as planktonic marine copepods [115]. Furthermore, the possible negative impacts of CYP on natural aquatic ecosystems were also reported [33,116]. CYP is the most broadly used pesticide during the past two decades in various parts of the world [117]. CYP readily enters the nervous system of the animal body and elicits cellular oxidative damage by inducing the production of free radicals and reducing the antioxidant effects of the body [118].

The study conducted by Laabs et al. [119] revealed CYP in rainwater at 0.376 µg/L concentration. The available literature is widely known and confirmed that CYP concentration is higher than the permissible range in water bodies, which can be harmful to all forms of aquatic life. Jaensson et al. [43] reported high levels of CYP in the surface water. On account of its higher lipophilicity property, it has a higher absorption rate [15]. This renders fish the most subtle, penetrating, and sensitive organism to CYP [120].

Table 2 summarizes the toxic effects of CYP in the exposed fish species. It was found that CYP exposure induced haemato-biochemical alterations in several fish species such as Nile tilapia [121], common carp [122], Brycon amazonicus [123], Anabas testudineus [124], rohu [125], Heteropneustes fossilis [120], Prochilodus lineatus [126], and C. batrachus [127]. Moreover, CYP induced behavioral changes in Nile tilapia [128], developmental toxicity of zebrafish [129], immunotoxicity of common carp [32], neurotoxicity of Catla [35], genotoxicity [29,30,33,130], and oxidative stress damage [131,132]. Furthermore, CYP induced serious histopathological alterations of African catfish [133], Nile tilapia [134], common carp [33], and Catla [34].
**Table 1.** Summary of toxic effects of some selected pyrethroid pesticides in some fish species.

| Pyrethroids | Exposure Doses | Exposure | Fish Species | Toxic Effects | References |
|-------------|----------------|----------|--------------|--------------|------------|
| Bifenthrin (BF) \(\lambda\)-cyhalothrin (\(\lambda\)-CH) | 1, 3, and 10 \(\mu\)g/L | 72 h | Zebrafish (Danio rerio) embryos | Alterations in T4 and T3 levels (disruption of endocrine thyroid system) | [61] |
| Esfenvalerate | 0.02, 0.2, 2 mg/L | 96 h | Zebrafish (Danio rerio) | Acceleration hatching time exposed to 2 mg/L Behavioral changes correlated with impaired dopamine signaling | [42] |
| Permethrin (PM) \(\beta\)-cypermethrin (\(\beta\)-CP) | 0.025, 0.125, and 0.750 \(\mu\)M | 24 h | Zebrafish (Danio rerio) | Developmental toxicities, abnormal vascular development, changed locomotor activities, and thyroid disruption | [135] |
| Meothrin, Lambdacyhalothrin, Permethrin, Fenpropathrin, Esfenvalerate | 0.0023–5.232, 0.00008–0.3465, 0.0015–0.0038, 0.0–0.0098 and 0.0053–0.2888 min–max values | – | Mugil capito | ↑ serum creatinine and urea ↑ hepatic GSH and MDA | [136] |
| Deltamethrin (DLM) | CYP at 0.07, 0.014, 0.028, 0.056 \(\mu\)g/L | 7, 14, 21 and 28 d | African catfish (Clarias gariepinus) | Negative effects on reproductive, biochemical, and physiological health of the exposed fish | [137] |
| Bifenthrin | 0.5, 5, and 50 ng/L | 14 and 21 d | Menidia beryllina | Hinder with metabolic processes and endocrine signals ↓ reproductive performance | [138] |
| \(\lambda\)-cyhalothrin | 5, 50, 250, and 500 ng/L | 96 h | Prochilodus lineatus | Oxidative stress, osmoregulatory disorders, and DNA damage | [139] |
| Fenvalerate EC 20% | 0.92 ppm | 96 h | Walking catfish (Clarias batrachus) | Significant damage at the hematological and biochemical levels | [140] |
| Beta-cyfluthrin | 32, 48, 72, 180, and 450 ng/L | 14 d | Rainbow trout (Oncorhynchus mykiss) | Impairment of feeding behavior (reduced food intake) At higher concentrations, the constant exposure led to death | [141] |
| Deltamethrin | 15 \(\mu\)g/L | 30 d | Nile tilapia (Oreochromis niloticus) | ↑ CORT and GLU levels Downregulation CAT, GPX, IL-1\(\beta\) and IL-8 gene expressions Damage in histological structure of gills, intestine, spleen, and liver | [142] |
Table 1. Cont.

| Pyrethroids | Exposure Doses | Exposure | Fish Species | Toxic Effects | References |
|-------------|----------------|----------|--------------|---------------|------------|
| Deltamethrin | 0.25, 0.5, 1, and 2 µg /L | 15 d | Zebrafish (*Danio rerio*) | Effects on aggressive behavior and swimming performances (highly neurotoxic compound) | [143] |
| Deltamethrin | 5.2 µg /L | 48 h | Zebrafish (*Danio rerio*) | Caused significant damage to the gills and liver | [144] |
| Deltamethrin | 7.33 µg/L | 96 h | *Channa punctatus* | Inhibited AChE activity in brain, muscle, and gills | [146] |
| Deltamethrin | 20 and 40 µg/L | 24–96 h | Zebrafish (*Danio rerio*) embryos | Failed swim bladder inflation | [42] |

Abbreviations: AChE: acetylcholinesterase, CAT: catalase, CORT: cortisol, GLU: glucose, GSH: reduced glutathione, GPX: glutathione peroxidase, IL-1β: interleukin 1 beta, IL-8: interleukin 8, MDA: malondialdehyde T3: triiodothyronine, T4: thyroxin. ↑ above arrow indicated to increase, ↓ down arrow indicating to decrease.

Table 2. Summary of the toxic effects of Cypermethrin (CYP) in several fish species.

| Exposure Doses | Exposure Period | Fish Species | Toxic Effects | References |
|----------------|-----------------|--------------|---------------|------------|
| 25, 50, 75, 100, and 125 ppm | 96 h | African catfish (*Clarias gariepinus*) | Erratic movement, erosion, and hemorrhages of secondary gill lamellae Hyperplastic hepatic cells necrosis of hepatic cells in the liver tissues. | Andem et al. [133] |
| 1.25, 2.5 µg/L | 14–28 d | Nile tilapia (*Oreochromis niloticus*) | ↓ hepatic glycogen ↓ the activities of ALP, AChE, and CAT in liver ↑ of plasma GLU level and activities of hepatic ACP, AST, and ALT Anemia | Kaviraj and Gupta [121] |
| 0.22 and 0.44 µg/l | 20 d | Nile tilapia (*Oreochromis niloticus*) | Histopathological alterations in gills Haemato-biochemical changes | Korkmaz et al. [134] |
| 5.99 µg/L | 96 h | Nile tilapia (*Oreochromis niloticus*) | Behavioral changes | Sarikaya [128] |
| 0.186 ppm | 35 d | Common carp (*Cyprinus carpio*) | ↓ ion levels (Na+, K+ and Cl−) in blood ↓ gill Na+/K+-ATPase activity | Suvetha et al. [122] |
| 0.4134 µg/L | 30 d | Common carp (*Cyprinus carpio*) | Genotoxicity (=↑ DNA fragmentation) Histopathological alterations and apoptotic changes Hepatorenal injury | Khafaga et al. [33] |
Table 2. Cont.

| Exposure Doses       | Exposure Period | Fish Species           | Toxic Effects                                                                 | References                          |
|----------------------|-----------------|------------------------|-------------------------------------------------------------------------------|-------------------------------------|
| 0.042, 0.085, and 0.17 µg/L | 21 d            | Common carp (Cyprinus carpio) | Immunotoxicity (↓ LYZ activity and PA)‡ Mortalities after challenge with Aeromonas hydrophila | Soltanian and Fereidouni [32]       |
| 20% of LC50          | 96 h            | Brycon amazonicus      | ↑ liver and gill LPO 62 and 100%, respectively.                               | de Moraes et al. [123]              |
|                      |                 |                        | ↑ SOD and CAT activities in the liver                                        |                                     |
|                      |                 |                        | ↑ Plasma Na⁺, Cl⁻ and GLU concentrations                                      |                                     |
|                      |                 |                        | ↑ HCT, Hb and RBCs                                                          |                                     |
|                      |                 |                        | Hypertrophy and proliferation of chloride cells, blood vessels dilation,      |                                     |
|                      |                 |                        | aneurysms, and hemorrhage of the lamella                                     |                                     |
| 0.015, 0.030, 0.045 µg/L | 21 d            | Anabas testudineus     | ↓ RBCs, Hb, HCT levels and thrombocyte (platelet) counts                     | Babu Velmurugan et al. [124]        |
| 30 µg/L              | 5 d             | Rohu (Labeo rohita)    | ↑ SOD, CAT and LPO in gills, liver, and kidney                               | Vijayakumar et al. [132]            |
| 1/10 and 1/50 of 96 h LC50 | 45 d            | Rohu (Labeo rohita)    | Haemato-biochemical alterations                                               | Das et al. [125]                    |
| (The 96 h LC50 = 0.139 ppm) |                |                        |                                                                              |                                     |
| 0.124 and 0.41 µg/L  | 45 d            | Catla (Catla catla)    | Neurotoxicity (↓ AChE activity in brain)                                     | Jindal and Sharma [35]              |
| 0.21 and 0.41 µg/L   | 45 d            | Catla (Catla catla)    | ↑ MDA and GSH content (oxidative stress)                                    | Sharma and Jindal [34]              |
|                      |                 |                        | Hepatic histopathological alterations                                       |                                     |
| 0.6 µg/L             | 9 d             | Zebrafish (Danio rerio) | Genotoxicity of retinal cells                                               | Paravani et al. [30]                |
|                      |                 |                        | Oxidative stress damage of retinal cells                                    |                                     |
|                      |                 |                        | ↑ SOD and CAT activities                                                     |                                     |
|                      |                 |                        | ↑ Sod and Cat mRNA levels                                                    |                                     |
| 0.6 µg/L             | 9 d             | Zebrafish (Danio rerio) | Genotoxicity of gill cells                                                   | Paravani et al. [29]                |
|                      |                 |                        | Oxidative stress damage of gill cells                                        |                                     |
| 1 and 3 µg /L        | 4 or 8 d        | Zebrafish (Danio rerio) | Hepatic oxidative stress                                                     | Jin et al. [131]                    |
|                      |                 |                        | DNA damage and apoptosis                                                     |                                     |
| 0, 25, 50, 100, 200, and 400 µg / L | 96 h | Zebrafish (Danio rerio) embryos | Developmental toxicity                                                       | Shi et al. [129]                    |
Table 2. Cont.

| Exposure Doses | Exposure Period | Fish Species       | Toxic Effects                                                                 | References               |
|----------------|-----------------|--------------------|-------------------------------------------------------------------------------|--------------------------|
| 0.3 and 0.5 µg/L | 4 h             | *Heteropneustes fossilis* | ↑ plasma GLU level, ↓ in the level of liver glycogen, ↓ ACP and ALP activities of liver, ↓ ascorbic acid levels of blood, liver, and kidney | Saha and Kaviraj [120]   |
| 0.4, 0.8 and 1.2 µg/L | 48 and 72 h     | *Channa punctata*   | Oxidative stress and genotoxicity in fish erythrocytes                         | Ansari et al. [130]      |
| 0.08 and 0.265 ppm | 2, 4 or 8 d     | *Rhamdia quelen*    | Haemato-biochemical alterations                                                | Borges et al. [147]      |
| 0.07 mg/L     | 10 d            | *Clarias batrachus* | Inhibition in the activities of total Mg+2, and Na+K+ATPase enzyme and glycogen content, A significant induction in the levels of glycogen phosphorylase | Begum [127]              |
| 0.3 and 0.6 µg/L | 2, 5 and 8 d    | *Prochilodus lineatus* | ↓ RBCs, Hb, HTC and MCHC values, ↑ MCV and MCH values                        | Parma et al. [126]       |

Abbreviations: AChE: acetylcholinesterase, ACP: acid phosphatase, ALP: alkaline phosphatase, ALT: alanine aminotransferase, AST: aspartate aminotransferase, Cat: catalase gene, CAT: catalase enzyme, GLU: glucose, GPX: glutathione peroxidase, GSH: reduced glutathione, Hb: hemoglobin, HTC: hematocrit, LPO: lipid peroxidation, LYZ: lysozyme, MCH: mean corpuscular hemoglobin, MCHC: mean corpuscular hemoglobin concentration, MCV: mean corpuscular volume, MDA: malondialdehyde, PA: phagocytic activity, RBCs: red blood cells, Sod: superoxide dismutase gene, SOD: superoxide dismutase enzyme, WBCs: white blood cells. ↑ above arrow indicated to increase, ↓ down arrow indicating to decrease.
4. Conclusions

Our rapidly growing population requires intensification of crop production. Thus, it is essential to control pests and insects that cause economic losses in crop production. Pesticides have become a necessary part of the production cycle for eliminating plant diseases and killing pests that can drastically reduce harvestable products. Moreover, a polluted environment with a high concentration of synthetic pyrethroids has caused several adverse effects in living aquatic organisms. This literature explained the biological modes of action of some pyrethroids in fish species and the underlying biological impacts of pyrethroid-contaminated water on reared fish. Furthermore, toxicological experiments showed individual responses against pyrethroid lethality. This review article provides insight for future research studies to evaluate the toxic effects of pyrethroid insecticides and sheds light on CYP toxicity mechanisms in fish.

Author Contributions: Conceptualization, M.R.F. and M.A.E.N.; data curation, M.R.F., M.A., A.G.A.G.; validation, M.A.E.N.; visualization, H.M.R.A.-L. and M.A.E.N.; investigation, M.A. and M.A.E.N.; supervision, R.M.B., K.D. and G.E.-S.B.; resources, H.M.R.A.-L., M.S.A.; software, M.S.A. and M.A.E.N.; project administration, N.R.-P., A.Z.-B., Y.S.B. and G.E.-S.B.; funding acquisition, N.R.-P., A.Z.-B.; writing—original draft, M.R.F., M.A. and M.A.E.N.; writing—review and editing, M.R.F., M.A., R.M.B., A.G.A.G., H.M.R.A.-L., N.R.-P., A.Z.-B., Y.S.B., G.E.-S.B. and M.A.E.N. All authors have read and agreed to the published version of the manuscript.

Funding: The authors received no specific funding for this work.

Informed Consent Statement: Not applicable.

Data Availability Statement: All data sets collected and analyzed during the current study are available from the corresponding author upon fair request.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Jabeen, F.; Chaudhry, A.S.; Manzoor, S.; Shaheen, T. Examining pyrethroids, carbamates and neonicotinoids in fish, water and sediments from the Indus River for potential health risks. Environ. Monit. Assess. 2015, 187, 29. [CrossRef] [PubMed]
2. Ullah, S.; Zorrieiehzahra, M.J. Ecotoxicology: A review of pesticides induced toxicity in fish. Adv. Anim. Vet. Sci. 2015, 3, 40–57. [CrossRef]
3. Albano, M.; Panarello, G.; Di Paola, D.; D’Angelo, G.; Granata, A.; Savoca, S.; Capillo, G. The mauve stinger Pelagia noctiluca (Cnidaria, Scyphozoa) plastics contamination, the Strait of Messina case. Int. J. Environ. Stud. 2021, 1–6. [CrossRef]
4. Stehle, S.; Schulz, R. Agricultural insecticides threaten surface waters at the global scale. Proc. Natl. Acad. Sci. USA 2015, 112, 5750–5755. [CrossRef]
5. Albano, M.; Panarello, G.; Di Paola, D.; Capparucci, F.; Crupi, R.; Gugliandolo, E.; Spanò, N.; Capillo, G.; Savoca, S. The Influence of Polystyrene Microspheres Abundance on Development and Feeding Behavior of Artemia salina (Linnaeus, 1758). Appl. Sci. 2021, 11, 3352. [CrossRef]
6. Naiel, M.A.E.; Shehata, A.M.; Negm, S.S.; Abd El-Hack, M.E.; Amer, M.S.; Khafaga, A.F.; Bin-Jumah, M.; Allam, A.A. The new potential biological indicators of the contamination, bioaccumulation and health risks caused by organochlorine pesticides in a large, shallow Chinese lake (Lake Chaohu). Ecol. Indic. 2016, 60, 335–345. [CrossRef]
7. Naiel, M.A.E.; Ismael, N.E.M.; Abd El-hameed, S.A.A.; Amer, M.S. The antioxidative and immunity roles of chitosan nanoparticles and vitamin C-supplemented diets against imidacloprid toxicity on Oreochromis niloticus. Aquaculture 2020, 523, 735219. [CrossRef]
8. Liu, W.-X.; Wang, Y.; He, W.; Qin, N.; Kong, X.-Z.; He, Q.-S.; Yang, B.; Yang, C.; Jiang, Y.-J.; Jorgensen, S.E.; et al. Aquatic biota as potential biological indicators of the contamination, bioaccumulation and health risks caused by organochlorine pesticides in a large, shallow Chinese lake (Lake Chaohu). Ecol. Indic. 2016, 60, 335–345. [CrossRef]
9. Marigoudar, S.R.; Ahmed, R.N.; David, M. Ultrastructural responses and oxidative stress induced by cypermethrin in the liver of Labeo rohita. Chem. Ecol. 2013, 28, 296–308. [CrossRef]
10. Abd El-hameed, S.A.A.; Negm, S.S.; Ismael, N.E.M.; Naiel, M.A.E.; Soliman, M.M.; Shukry, M.; Abdel-Latif, H.M.R. Effects of Activated Charcoal on Growth, Immunity, Oxidative Stress Markers, and Physiological Responses of Nile Tilapia Exposed to Sub-Lethal Imidacloprid Toxicity. Animals 2021, 11, 1357. [CrossRef]
11. Ismael, N.E.M.; Abd El-hameed, S.A.A.; Salama, A.M.; Naiel, M.A.E.; Abdel-Latif, H.M.R. The effects of dietary clinoptilolite and chitosan nanoparticles on growth, body composition, haemato-biochemical parameters, immune responses, and antioxidative status of Nile tilapia exposed to imidacloprid. Environ. Sci. Pollut. Res. 2021. [CrossRef]
12. Dawood, M.A.O.; Abdel-Tawwab, M.; Abdel-Latif, H.M.R. Lycopene reduces the impacts of aquatic environmental pollutants and physical stressors in fish. Rev. Aquac. 2020, 12, 2511–2526. [CrossRef]
13. Dawood, M.A.O.; El-Salam Metwally, A.; Elkomy, A.H.; Gewaily, M.S.; Abdoo, S.E.; Abdel-Razek, M.A.S.; Soliman, A.A.; Amer, A.A.; Abdel-Rahim, N.I.; Abdel-Latif, H.M.R.; et al. The impact of menthol essential oil against inflammation, immuno-suppression, and histopathological alterations induced by chlorpyrifos in Nile tilapia. *Fish Shellfish Immunol.* 2020, 102, 316–325. [CrossRef] [PubMed]

14. Özkara, A.; Akyil, D.; Koruk, M. Pesticides, environmental pollution, and health. In *Environmental Health Risk-Hazardous Factors to Living Species*; IntechOpen: London, UK, 2016.

15. Fetoui, H.; Maïni, M.; Mouildi Garoui, E.; Zeghal, N. Toxic effects of lambda-cyhalothrin, a synthetic pyrethroid pesticide, on the rat kidney: Involvement of oxidative stress and protective role of ascorbic acid. *Exp. Toxicol. Pathol.* 2010, 62, 593–599. [CrossRef]

16. Hua, J.; Relyea, R. Chemical cocktails in aquatic systems: Pesticide effects on the response and recovery of 20 animal taxa. *Environ. Pollut.* 2014, 189, 18–26. [CrossRef] [PubMed]

17. Molina-Ruiz, J.M.; Cieslik, E.; Cieslik, I.; Walkowska, I. Determination of pesticide residues in fish tissues by modified QuEChERS method and dual-d-SPE clean-up coupled to gas chromatography–mass spectrometry. *Environ. Sci. Pollut. Res.* 2015, 22, 369–378. [CrossRef] [PubMed]

18. Biswas, S.; Mondal, K.; Haque, S. Review on Effect of the Type II Synthetic Pyrethroid Pesticides in Freshwater Fishes. *Environ. Ecol.* 2019, 37, 80–88.

19. Bälint, T.; Ferencyz, J.; Kátai, F.; Kiss, I.; Kráčer, L.; Kufcsák, O.; Láng, G.; Polyhos, C.; Szabó, I.; Szegletes, T.; et al. Similarities and Differences between the Massive Eel (*Anguilla anguilla L.*) Devastations That Occurred in Lake Balaton in 1991 and 1995. *Ecotoxicol. Environ. Saf.* 1997, 37, 17–23. [CrossRef]

20. Aydn, R.; Köprücü, K.; Dörçü, M.; Köprücü, S.;: Pala, M. Acute Toxicity of Synthetic Pyrethroid Cypermethrin on the Common Carp (*Cyprinus carpio L.*) Embryos and Larvae. *Aquac. Int.* 2005, 13, 451–458. [CrossRef]

21. Gautam, P.; Gupta, A. Toxicity of cypermethrin to the juveniles of freshwater fish *Poecilia reticulata* (Peters) in relation to selected environmental variables. *Indian J. Nat. Prod. Resour.* 2008, 7, 314–319.

22. Yang, Y.; Ma, H.; Zhou, J.; Liu, J.; Liu, W. Joint toxicity of permethrin and cypermethrin at sublethal concentrations to the embryo-larval zebrafish. *Chemosphere 2014*, 96, 146–154. [CrossRef]

23. Richterova, Z.; Machova, J.; Stara, A.; Tomova, J.; Velisek, J.; Sevcikova, M.; Svobodova, Z. Effects of a cypermethrin-based pesticide on early life stages of common carp (*Cyprinus carpio L.*). *Vet. Med.* 2015, 60, 423–431. [CrossRef]

24. Kuivila, K.M.; Hladik, M.L.; Ingersoll, C.G.; Kemble, N.R.; Calhoun, D.L.; Nowell, L.H.; Gilliom, R.J. Occurrence and Potential Sources of Pyrethroid Insecticides in Stream Sediments from Seven U.S. Metropolitan Areas. *Environ. Sci. Technol.* 2012, 46, 4297–4303. [CrossRef]

25. Alonso, M.B.; Feo, M.L.; Corcellas, C.; Vidal, L.G.; Bertozzi, C.P.; Marigo, J.; Secchi, E.R.; Bassoi, M.; Azevedo, A.F.; Dorneles, P.; et al. Pyrethroids: A new threat to marine mammals? *Environ. Int.* 2012, 47, 99–106. [CrossRef] [PubMed]

26. Stara, A.; Pagano, M.; Capillo, G.; Fabrello, J.; Sandova, M.; Albano, M.; Zuskova, E.; Velisek, J.; Mattozzo, V.; Faggio, C. Acute effects of neonicotinoid insecticides on Mytilus galloprovincialis: A case study with the active compound thiacloprid and the commercial formulation calypso 480 SC. *Ecotoxicol. Environ. Saf.* 2020, 203, 110980. [CrossRef] [PubMed]

27. Coats, J.R.; Symonik, D.M.; Bradbury, S.P.; Dyer, S.D.; Timson, L.K.; Atchison, G.J. Toxicology of synthetic pyrethroids in aquatic organisms: An overview. *Environ. Toxicol. Chem.* 1989, 8, 671–679. [CrossRef]

28. Muenstermann, S.; Rinkanya, F.G.R.; Tome, N.R. Tick control in small ruminants with a Cypermethrin ‘pour-on’ in Kenya. *Trop. Pest Manag.* 1988, 34, 399–401. [CrossRef]

29. Paravani, E.V.; Simonelli, M.F.; Poletta, G.L.; Casco, V.H. Cypermethrin induction of DNA damage and oxidative stress in zebrafish gill cells. *Ecotoxicol. Environ. Saf.* 2019, 173, 1–7. [CrossRef]

30. Paravani, E.V.; Simonelli, M.F.; Poletta, G.L.; Zolesi, F.R.; Casco, V.H. Cypermethrin: Oxidative stress and genotoxicity in retinal cells of the adult zebrafish. *Mutat. Res./Genet. Toxicol. Environ. Mutagen.* 2018, 826, 25–32. [CrossRef]

31. Dawar, F.U.; Zuberi, A.; Azizullah, A.; Khan Khattak, M.N. Effects of cypermethrin on survival, morphological and biochemical aspects of rohu (*Labeo rohita*) during early development. *Chemosphere 2016*, 144, 697–705. [CrossRef]

32. Soltanian, S.; Fereidouni, M.S. Immunotoxic responses of chronic exposure to cypermethrin in common carp. *Fish Physiol. Biochem.* 2017, 43, 1645–1655. [CrossRef] [PubMed]

33. Khafaga, A.F.; Naiel, M.A.E.; Dawood, M.A.O.; Abdel-Latif, H.M.R. Dietary *Origarnum vulgare* essential oil attenuates cypermethrin-induced biochemical changes, oxidative stress, histopathological alterations, apoptosis, and reduces DNA damage in Common carp (*Cyprinus carpio*). *Aquat. Toxicol.* 2020, 228, 105624. [CrossRef] [PubMed]

34. Sharma, R.; Jindal, R. Assessment of cypermethrin induced hepatic toxicity in *Catla catla*: A multiple biomarker approach. *Environ. Res.* 2020, 184, 109359. [CrossRef] [PubMed]

35. Jindal, R.; Sharma, R. Neurotoxic responses in brain of *Catla catla* exposed to cypermethrin: A semiquantitative multibiomarker evaluation. *Ecol. Indic.* 2019, 106, 105485. [CrossRef]

36. El Euony, O.I.; Elblehi, S.S.; Abdel-Latif, H.M.; Abdel-Daim, M.M.; El-Sayed, Y.S. Modulatory role of dietary *Thymus vulgaris* essential oil and *Bacillus subtilis* against thiamethoxam-induced hepatorenal damage, oxidative stress, and immunotoxicity in African catfish (*Clarias garipenus*). *Environ. Sci. Pollut. Res.* 2020, 27, 23108–23128. [CrossRef]

37. Sabra, F.S.; Mehana, E.-S.E.-D. Pesticides toxicity in fish with particular reference to insecticides. *Asian J. Agric. Food Sci.* 2015, 3, 40–60.

38. Pavlov, D.; Kasumyan, A. Patterns and mechanisms of schooling behavior in fish: A review. *J. Ichthyol.* 2000, 40, S163.
39. Luschi, P. Long-distance animal migrations in the oceanic environment: Orientation and navigation correlates. *Int. Sch. Res. Not.* 2013, *2013*, 631839. [CrossRef]
40. Ullah, S.; Hasan, Z.; Zuberi, A.; Younus, N.; Rauf, S. Comparative Study on Body Composition of Two Chinese Carps, Common Carp (*Cyprinus carpio*) and Silver Carp (*Hypophthalmichthys molitrix*). *Glob. Vet.* 2014, *13*, 867–876.
41. Tang, Z.-H.; Huang, Q.; Wu, H.; Kuang, L.; Fu, S.-J. The behavioral response of prey fish to predators: The role of predator size. *PeerJ* 2017, *5*, e3222. [CrossRef]
42. Wang, H.; Meng, Z.; Liu, F.; Zhou, L.; Su, M.; Meng, Y.; Zhang, S.; Liao, X.; Cao, Z.; Lu, H. Characterization of bosalcid-induced oxidative stress and neurodevelopmental toxicity in zebrafish embryos. *Chemosphere* 2020, *238*, 124753. [CrossRef]
43. Jaensson, A.; Scott, A.P.; Moore, A.; Kylin, H.; Olsén, K.H. Effects of a pyrethroid pesticide on endocrine responses to female odours and reproductive behaviour in male parr of brown trout (*Salmo trutta L*). *Aquat. Toxicol.* 2007, *81*, 1–9. [CrossRef]
44. Brander, S.M.; He, G.; Smalling, K.L.; Denison, M.S.; Cherr, G.N. The in vivo estrogenic and in vitro anti-estrogenic activity of permethrin and bifenthrin. *Environ. Toxicol. Chem.* 2012, *31*, 2848–2855. [CrossRef]
45. Wu, Y.; Li, W.; Yuan, M.; Liu, X. The synthetic pyrethroid deltamethrin impairs zebrafish (*Danio rerio*) swim bladder development. *Sci. Total Environ.* 2020, *701*, 134870. [CrossRef]
46. Deka, S.; Mahanta, R. A study on the effect of organophosphorus pesticide malathion on hepato-renal and reproductive organs of *Heteropneustes fossilis* (Bloch). *Science* 2012, *1*, 1–13.
47. David, M.; Kartheek, R. Biochemical changes in liver of freshwater fish *Cyprinus carpio* exposed to sublethal concentration of sodium cyanide. *Indo Am. J. Pharm. Res.* 2014, *4*, 3669–3675.
48. Mohammed, A.; Farag, M.; El-Hakim, A.; Elhady, W. Sources and Toxicological impacts of Surface Water Pollution on Fish in Egypt. *Zagazig Vet. J.* 2019, *47*, 103–119. [CrossRef]
49. Banaee, M.; Mirvaghefi, A.; Patode, P.; Amiri, B.M.; Rafiee, G.; Nematdost, B. Hematological and histopathological effects of diazinon poisoning in common carp (*Cyprinus carpio*). *J. Fish.* 2011, *64*, Pe1–Pe12.
50. Mastan, S.; Shaffi, S. Sub-lethal Effect of Pesticides on the Distribution of Glutaminases in the Brain of *Labeo rohita* (Ham.). *Int. J. Toxicol.* 2010, *7*, 1–6.
51. Thenmozhi, C.; Vignesh, V.; Thirumurugan, R.; Arun, S. Impacts of malathion on mortality and biochemical changes of freshwater fish *Labeo rohita*. *J. Environ. Health Sci. Eng.* (IJEHSE) 2011, *8*, 387–394.
52. Sharbidre, A.A.; Metkari, V.; Patode, P. Effect of *Diazinon* on Acetylcholinesterase Activity and Lipid. *Res. J. Environ. Toxicol.* 2011, *5*, 152–161.
53. Marigoudar, S.R.; Ahmed, R.N.; David, M. Cypermethrin induced: *In vivo* inhibition of the acetylcholinesterase activity in functionally different tissues of the freshwater teleost, *Labeo rohita* (Hamilton). *Toxicol. Environ. Chem.* 2009, *91*, 1175–1182. [CrossRef]
54. Bibi, N.; Zuberi, A.; Naeem, M.; Ullah, I.; Sarwar, H.; Atika, B. Evaluation of acute toxicity of karate and its sub-lethal effects on protein and acetylcholinesterase activity in *Cyprinus carpio*. *Int. J. Agri. Biol.* 2014, *16*, 731–737.
55. Joseph, B.; Raj, S.J. Impact of pesticide toxicity on selected biomarkers in fishes. *Int. J. Zool. Res.* 2011, *7*, 212. [CrossRef]
56. Brodeur, J.C.; Sassone, A.; Hermida, G.N.; Codugnello, N. Environmentally-relevant concentrations of atrazine induce non-monotonic acceleration of developmental rate and increased size at metamorphosis in *Rhinella arenarum* tadpoles. *Ecotoxicol. Environ. Saf.* 2013, *79*, 10–17. [CrossRef]
57. Čavaš, T.; Könen, S. Detection of cytogenetic and DNA damage in peripheral erythrocytes of goldfish (*Carassius auratus*) exposed to a glyphosate formulation using the micronucleus test and the comet assay. *Mutagenesis* 2007, *22*, 263–268. [CrossRef]
58. Dogan, D.; Can, C. Hematological, biochemical, and behavioral responses of *Oncorhynchus mykiss* to dimethoate. *Fish Physiol. Biochem.* 2011, *37*, 951–958. [CrossRef]
59. Dey, C.; Saha, S. A comparative study on the acute toxicity bioassay of dimethoate and lambda-cyhalothrin and effects on thyroid hormones of freshwater teleost fish *Labeo rohita* (Hamilton). *Int. J. Environ. Res.* 2014, *8*, 1085–1092.
60. Forsgren, K.L.; Riar, N.; Schlenk, D. The effects of the pyrethroid insecticide, bifenthrin, on steroid hormone levels and gonadal development of steelhead (*Oncorhynchus mykiss*) under hypersaline conditions. *Gen. Comp. Endocrinol.* 2013, *186*, 101–107. [CrossRef]
61. Tu, W.; Xu, C.; Lu, B.; Lin, C.; Wu, Y.; Liu, W. Acute exposure to synthetic pyrethroids causes bioconcentration and disruption of the hypothalamus–pituitary–thyroid axis in zebrafish embryos. *Sci. Total Environ.* 2016, *542*, 876–885. [CrossRef]
62. Lakshmanan, S.; Rajendran, A.; Sivasubramaniyan, C. Impact of dichlorvos on tissue glycogen and protein content in freshwater fingerlings, *Oreochromis mossambicus* (Peters). *Int. J. Res. Environ. Sci. Technol.* 2013, *3*, 19–25.
63. Muthukumaravel, K.; Sivakumar, B.; Kumarasamy, P.; Govindarajan, M. Studies on the toxicity of pesticide monocrotophos on the biochemical constituents of the freshwater fish *Labeo rohita*. *Int. J. Curr. Biochem. Biotechnol.* 2013, *2*, 20–26.
64. Banaee, M.; Suresha, A.; Mirvaghefi, A.R.; Ahmadi, K. Effects of diazinon on biochemical parameters of blood in rainbow trout (*Oncorhynchus mykiss*). *Pestic. Biochem. Physiol.* 2011, *99*, 1–6. [CrossRef]
65. Narra, M.R. Single and cartel effect of pesticides on biochemical and haematological status of *Clarias batrachus*: A long-term monitoring. *Chemosphere* 2016, *144*, 966–974. [CrossRef]
66. Abdel-Latif, H.M.R.; Dawood, M.A.O.; Menanteau-Ledouble, S.; El-Matbouli, M. The nature and consequences of co-infections in tilapia: A review. *J. Fish Dis.* 2020, *43*, 651–664. [CrossRef]
Animals 2021, 11, 1880

67. Murugan, S.S.; Karuppasamy, R.; Poongodi, K.; Puvaneswari, S. Bioaccumulation pattern of zinc in freshwater fish Channa punctatus (Bloch) after chronic exposure. Turk. J. Fish. Aquat. Sci. 2008, 8, 55–59.

68. Vázquez, P.P.; Mughari, A.R.; Galera, M.M. Solid-phase microextraction (SPME) for the determination of pyrethroids in cucumber and watermelon using liquid chromatography combined with post-column photochemically induced fluorimetry derivatization and fluorescence detection. Anal. Chim. Acta 2008, 607, 74–82. [CrossRef] [PubMed]

69. Anadón, A.; Martínez-Larrañaga, M.R.; Martínez, M.A. Use and abuse of pyrethrin and synthetic pyrethroids in veterinary medicine. Vet. J. 2009, 182, 7–20. [CrossRef] [PubMed]

70. Soderlund, D.M. Molecular mechanisms of pyrethroid insecticide neurotoxicity: Recent advances. Arch. Toxicol. 2012, 86, 165–181. [CrossRef]

71. Costa, L.G. Chapter 9—The neurotoxicity of organochlorine and pyrethroid pesticides. In Handbook of Clinical Neurology; Lotti, M., Bleecker, M.L., Eds.; Elsevier: Amsterdam, The Netherlands, 2015; Volume 131, pp. 135–148.

72. Nascuti, C.; Cantalamessa, F.; Falcioni, G.; Gabbianelli, R. Different effects of Type I and Type II pyrethroids on erythrocyte plasma membrane properties and enzymatic activity in rats. Toxicology 2003, 191, 233–244. [CrossRef]

73. Wakeling, E.N.; Neal, A.P.; Atchison, W.D. Pyrethroids and their effects on ion channels. In Pesticides—Advances in Chemical and Botanical Pesticides; InTech: Rijeka, Croatia, 2012; pp. 39–66.

74. Salako, A.F.; Amaeze, N.H.; Shobajo, H.M.; Osuala, F.I. Comparative acute toxicity of three pyrethroids (Deltamethrin, cypermethrin and lambda-cyhalothrin) on guppy fish (Poecilia reticulata peters, 1859). Sci. Afr. 2020, 9, e00504. [CrossRef]

75. Bradberry, S.M.; Cage, S.A.; Proudfoot, A.T.; Vale, J.A. Poisoning due to Pyrethroids. [PubMed]

76. Nasuti, C.; Cantalamessa, F.; Falcioni, G.; Gabbianelli, R. Development of an analytical method for the determination of the residues of pyrethroids in meat by GC–ECD and confirmation by GC–MS. Anal. Bioanal. Chem. 2007, 389, 1791–1798. [CrossRef] [PubMed]

77. Chrustek, A.; Hołyńska-Iwan, I.; Dziembowska, I.; Bogusiewicz, J.; Wróblewski, M.; Cwynar, A.; Olszewska-Słonina, D. Current research on the safety of pyrethroids used as insecticides. Medicina 2018, 54, 61. [CrossRef]

78. Naumann, K. Synthetic Pyrethroid Insecticides: Structures and Properties; Springer: Berlin/Heidelberg, Germany, 1990.

79. Kumar, S.; Thomas, A.; Pillai, M.K.K. Deltamethrin: Promising mosquito control agent against adult stage of Aedes aegypti L. Asian Pac. J. Trop. Med. 2011, 4, 430–435. [CrossRef]

80. Maund, S.J.; Hamer, M.J.; Warinton, J.S.; Kedwards, T.J. Aquatic ecotoxicology of the pyrethroid insecticide lambda-cyhalothrin: Considerations for higher-tier aquatic risk assessment. Pestic. Sci. 1998, 54, 408–417. [CrossRef]

81. Nasuti, C.; Cantalamessa, F.; Falcioni, G.; Gabbianelli, R. Different effects of Type I and Type II pyrethroids on erythrocyte plasma membrane properties and enzymatic activity in rats. Toxicology 2003, 191, 233–244. [CrossRef]

82. Barbi, D.A.; Vanni, F.; Girolimetti, S.; Dommarco, R. Development of an analytical method for the determination of the residues of four pyrethroids in meat by GC–ECD and confirmation by GC–MS. Anal. Bioanal. Chem. 2007, 389, 1791–1798. [CrossRef] [PubMed]

83. WHO. Toxicological Evaluation of Certain Veterinary Drug Residues in Food; World Health Organization: Geneva, Switzerland, 2006; Volume 57.

84. Habeeba, U.; David, M. Studies on acute and behavioural toxicity of lambda-cyhalothrin on fresh water fish, Cyprinus carpio. Int. J. Toxicol. Appl. Pharmacol. 2016, 6, 1–6.

85. Maund, S.J.; Hamer, M.J.; Warinton, J.S.; Eds.; Elsevier: Amsterdam, The Netherlands, 2015; Volume 131, pp. 135–148.

86. Bradberry, S.M.; Cage, S.A.; Proudfoot, A.T.; Vale, J.A. Poisoning due to Pyrethroids. [PubMed]

87. Barbini, D.A.; Vanni, F.; Girolimetti, S.; Dommarco, R. Development of an analytical method for the determination of the residues of four pyrethroids in meat by GC–ECD and confirmation by GC–MS. Anal. Bioanal. Chem. 2007, 389, 1791–1798. [CrossRef] [PubMed]

88. Christuk, A.; Holyńska-Iwan, I.; Dziembowska, I.; Bogusiewicz, J.; Wróblewski, M.; Cwynar, A.; Olszewska-Słonina, D. Current research on the safety of pyrethroids used as insecticides. Medicina 2018, 54, 61. [CrossRef]

89. Kumar, S.; Thomas, A.; Pillai, M.K.K. Deltamethrin: Promising mosquito control agent against adult stage of Aedes aegypti L. Asian Pac. J. Trop. Med. 2011, 4, 430–435. [CrossRef]

90. Christuk, A.; Holyńska-Iwan, I.; Dziembowska, I.; Bogusiewicz, J.; Wróblewski, M.; Cwynar, A.; Olszewska-Słonina, D. Current research on the safety of pyrethroids used as insecticides. Medicina 2018, 54, 61. [CrossRef]

91. Nasuti, C.; Cantalamessa, F.; Falcioni, G.; Gabbianelli, R. Different effects of Type I and Type II pyrethroids on erythrocyte plasma membrane properties and enzymatic activity in rats. Toxicology 2003, 191, 233–244. [CrossRef]

92. Wakeling, E.N.; Neal, A.P.; Atchison, W.D. Pyrethroids and their effects on ion channels. In Pesticides—Advances in Chemical and Botanical Pesticides; InTech: Rijeka, Croatia, 2012; pp. 39–66.

93. Boiteux, C.; Allen, T.W. Chapter Six—Understanding Sodium Channel Function and Modulation Using Atomistic Simulations of Bacterial Channel Structures. In Current Topics in Membranes, 182, 2012, 291395. [CrossRef]
Animals 2021, 11, 1880

94. DeMicco, A.; Cooper, K.R.; Richardson, J.R.; White, L.A. Developmental neurotoxicity of pyrethroid insecticides in zebrafish embryos. *Toxicol. Sci.* 2010, 113, 177–186. [CrossRef]

95. Bradbury, S.P.; Coats, J.R. Comparative Toxicology of the Pyrethroid Insecticides. In *Reviews of Environmental Contamination and Toxicology*; Ware, G.W., Ed.; Springer: New York, NY, USA, 1989; pp. 133–177.

96. Richterova, Z.; Svobodova, Z. Pyrethroids influence on fish. *Slov. Vet. Res.* 2012, 49, 63–72.

97. Soderlund, D.M. State-dependent modification of voltage-gated sodium channels by pyrethroids. *Pestic. Biochem. Physiol.* 2010, 97, 78–86. [CrossRef]

98. Breckenridge, C.B.; Holden, L.; Sturgess, N.; Weiner, M.; Sheets, L.; Sargent, D.; Soderlund, D.M.; Choi, J.-S.; Symington, S.; Clark, J.M.; et al. Evidence for a separate mechanism of toxicity for the Type I and the Type II pyrethroid insecticides. *NeuroToxicology* 2009, 30, S17–S31. [CrossRef]

99. Neal, A.P.; Yuan, Y.; Atchison, W.D. Allethrin differentially modulates voltage-gated calcium channel subtypes in rat PC12 cells. *Toxicol. Sci.* 2010, 116, 604–613. [CrossRef]

100. Prusty, A.K.; Meena, D.K.; Mohapatra, S.; Panikkar, P.; Das, P.; Gupta, S.K.; Behera, B.K. Synthetic pyrethroids (Type II) and freshwater fish culture: Perils and mitigations. *Int. Aquat. Res.* 2015, 7, 163–191. [CrossRef]

101. Moore, A.; Waring, C.P. The effects of a synthetic pyrethroid pesticide on some aspects of reproduction in Atlantic salmon (*Salmo salar L.*). *Aquat. Toxicol.* 2001, 52, 1–12. [CrossRef]

102. Günde, E.G.; Erli, S.V. A comparative study on the acute toxicity of cyfluthrin and tetramethrin on carp (*Cyprinus carpio* L. 1758). *J. Black Sea/Mediterr. Environ.* 2011, 17, 260–268.

103. Bille, L.; Binato, G.; Gabrieli, C.; Manfrin, A.; Pascoli, F.; Pretto, T.; Toffan, A.; Dalla Pozza, M.; Angeletti, R.; Arcangeli, G. First report of a fish kill episode caused by pyrethroids in Italian freshwater. *Forensic Sci. Int.* 2017, 281, 176–182. [CrossRef] [PubMed]

104. Nebbia, C. Pyrethroids are not the most appropriate remedy for tackling fleas and ticks in cats, and may be dangerous for fish too. *Vet. J.* 2009, 182, 1–2. [CrossRef] [PubMed]

105. Wheelock, C.E.; Shan, G.; Ottea, J. Overview of carboxylesterases and their role in the metabolism of insecticides. *J. Pestic. Sci.* 2005, 30, 75–83. [CrossRef]

106. Dangi, J.; Gupta, A.K. Short-term toxicity of cypermethrin-EC25 to males and females of a freshwater fish, *Poecilia reticulata* for selected levels of hardness and pH of water. *Res. Environ. Life Sci.* 2012, 5, 87–90.

107. Velisek, J.; Wlasow, T.; Gomulka, P.; Svobodova, R.; Novotny, L.; Dudzik, M. Effects of cypermethrin on rainbow trout (*Oncorhynchus mykiss*). *Vet. Med.* 2006, 51, 469. [CrossRef]

108. Gadhave, P.; Brar, R.; Banga, H.; Dhwaw, A. Studies on acute toxicity of synthetic pyrethroid λ-cyhalothrin on freshwater fish *Labeo rohita*. *Vet. World* 2014, 7, 7–9. [CrossRef] [PubMed]

109. Golow, A.; Godzi, T. Acute toxicity of deltamethrin and dieldrin to *Oreochromis niloticus* (Lin). *Bull. Environ. Contam. Toxicol.* 1994, 52, 351–354. [CrossRef]

110. Boateng, J.O.; Nunoo, F.; Dankwa, H.; Ocran, M. Acute toxic effects of deltamethrin on tilapia, *Oreochromis niloticus* (Linnaeus, 1758). *West Afr. J. Appl. Ecol.* 2006, 9, 1–5. [CrossRef]

111. Carriquiriborde, P.; Diaz, J.; Mugni, H.; Bonetto, C.; Ronco, A.E. Impact of cypermethrin on stream fish populations under field-use in biotech-soybean production. *Chemosphere* 2007, 68, 613–621. [CrossRef] [PubMed]

112. Dutta, J. Effect of cypermethrin on the growth of ciliate protozoan *Paramecium caudatum*. *Toxicol. Int.* 2015, 22, 100. [CrossRef] [PubMed]

113. Koch, R.L.; Hodgson, E.W.; Knodel, J.J.; Potter, B.D. Management of insecticide-resistant soya bean aphids in the Upper Midwest of the United States. *J. Integr. Pest Manag.* 2018, 9, 23. [CrossRef]

114. Bekele, D. Review on insecticidal and repellent activity of plant products for malaria mosquito control. *Biomed Res Rev.* 2018, 2, 1–7. [CrossRef]

115. Boxshall, G.A.; Defaye, D. Global diversity of copepods (*Crustacea: Copepoda*) in freshwater. In *Freshwater Animal Diversity*; Springer: Berlin/Heidelberg, Germany, 2007; pp. 195–207.

116. Selamoglu, Z. Pyrethrum as Synthetic Pyrethroid and Environmental Threatening. *SF J. Environ. Stud.* 2018, 1, 2.

117. Corcellas, C.; Eljarrat, E.; Barceló, D. First report of pyrethroid bioaccumulation in wild river fish: A case study in Iberian river basins (Spain). *Environ. Int.* 2015, 75, 110–116. [CrossRef]

118. Afolabi, O.K.; Aderibigbe, F.A.; Folarin, D.T.; Arinola, A.; Wusu, A.D. Oxidative stress and inflammation following sub-lethal oral exposure of cypermethrin in rats: Mitigating potential of epicatechin. *Helilogy* 2019, 5, e02274. [CrossRef]

119. Laabs, V.; Amelung, W.; Pinto, A.A.; Wantzen, M.; da Silva, C.J.; Zech, W. Pesticides in Surface Water, Sediment, and Rainfall of the Northeastern Pantanal Basin, Brazil. *J. Environ. Qual.* 2002, 31, 1636–1648. [CrossRef]

120. Saha, S.; Kaviraj, A. Effects of cypermethrin on some biochemical parameters and its amelioration through dietary supplementation of ascorbic acid in freshwater catfish *Heteropneustes fossilis*. *Chemosphere* 2009, 74, 1254–1259. [CrossRef] [PubMed]

121. Kaviraj, A.; Gupta, A. Biomarkers of Type II Synthetic Pyrethroid Pesticides in Freshwater Fish. *Biomed Res. Int.* 2014, 2014, 928063. [CrossRef]

122. Suvetha, L.; Ramesh, M.; Saravanan, M. Influence of cypermethrin toxicity on ionic regulation and gill Na+/K+-ATPase activity of a freshwater teleost fish *Cyprinus carpio*. *Environ. Toxicol. Pharmacol.* 2010, 29, 44–49. [CrossRef]

123. de Moraes, F.D.; Venturini, F.P.; Rossi, P.A.; Avilez, I.M.; da Silva de Souza, N.E.; Moraes, G. Assessment of biomarkers in the neotropical fish *Brycon amazonicus* exposed to cypermethrin-based insecticide. *Ecotoxicology* 2018, 27, 188–197. [CrossRef]
124. Babu Velmurugan, E.I.C.; Senthilkumar, P.; Uysal, E.; Satar, A. Hematological parameters of freshwater fish Anabas testudineus after sublethal exposure to cypermethrin. Environ. Pollut. Prot. 2016, 1, 32–39. [CrossRef]
125. Parma, M.; Loteste, A.; Campana, M.; Bacchetta, C. Changes of hematological parameters in Prochilodus lineatus (Pisces, Prochilodontidae) exposed to sublethal concentration of cypermethrin. J. Environ. Biol. 2007, 28, 147–149. [PubMed]
126. Parma, M.; Loteste, A.; Campana, M.; Bacchetta, C. Changes of hematological parameters in Prochilodus lineatus (Pisces, Prochilodontidae) exposed to sublethal concentration of cypermethrin. J. Environ. Biol. 2007, 28, 147–149. [PubMed]
127. Bekem, G. Enzymes as Biomarkers of Cypemethrin Toxicity: Response of Clarias batrachus Tissues and Fluoride and Glycerol Phosphorylase as a Function of Exposure and Recovery at Sublethal Level. Toxicol. Mech. Methods 2009, 19, 29–39. [CrossRef] [PubMed]
128. Sarikaya, R. Investigation of acute toxicity of alpha-cypermethrin on adult Nile tilapia (Oreochromis niloticus L.). Turk. J. Fish. Aquat. Sci. 2009, 9, 85–89.
129. Shi, X.; Gu, A.; Ji, G.; Li, Y.; Ji, J.; Jin, J.; Hu, F.; Long, Y.; Xia, Y.; Lu, C.; et al. Developmental toxicity of cypermethrin in embryo-larval stages of zebrafish. Chemosphere 2011, 85, 1010–1016. [CrossRef] [PubMed]
130. Ansari, R.A.; Rahman, S.; Kaur, M.; Anjum, S.; Raisuddin, S. In vivo cytogenetic and oxidative-stress-inducing effects of cypermethrin in freshwater fish, Channa punctata Bloch. Ecotoxicol. Environ. Saf. 2011, 74, 150–156. [CrossRef] [PubMed]
131. Jin, Y.; Zheng, S.; Pu, Y.; Shu, L.; Sun, L.; Liu, W.; Fu, Z. Cypermethrin has the potential to induce hepatic oxidative stress, DNA damage and apoptosis in adult zebrafish (Danio rerio). Chemosphere 2011, 82, 398–404. [CrossRef]
132. Vijayakumar, A.; Thirnvakkarasu, N.; Jayachandran, K.; Susiladevi, M. Attenuating properties of atropine against the cypemethrin toxicity in the oxidative stress in the fresh water fish Labeo rohita (Hamilton). Int. J. Mod. Res. Rev. 2016, 4, 1088–1093.
133. Andem, A.; Ibor, O.; Joseph, A.; Eyo, V.; Edet, A. Toxicological evaluation and histopathological changes of synthetic pyrethroid pesticide (Cypermethrin) exposed to African Clarid mud Cat fish (Clarias gariepinus) fingerlings. J. Toxicol. Pharmacol. Res. 2016, 8, 360–367.
134. Korkmaz, N.; Cengiz, E.I.; Unlu, E.; Uysal, E.; Yanar, M. Cypermethrin-induced histological and biochemical changes in Nile tilapia (Oreochromis niloticus), and the protective and recuperative effect of ascorbic acid. Environ. Toxicol. Pharmacol. 2009, 28, 198–205. [CrossRef]
135. Yu, C.; Li, X.; Jin, M.; Sun, N.; Niu, L.; Lin, C.; Liu, W. Early life exposure of zebrafish (Danio rerio) to synthetic pyrethroids and their metabolites: A comparison of phenotypic and behavioral indicators and gene expression involved in the HPT axis and environmental system. Environ. Sci. Pollut. Res. 2018, 25, 12992–13003. [CrossRef]
136. El Megid, A.A.; Abd Al Fatah, M.E.; El Aselyn, A.; El Senosi, Y.; Moustafa, M.M.A.; Dawood, M.A.O. Impact of pyrethroids and organochlorine pesticides residue on IGF-1 and CYP1A genes expression and muscle protein patterns of cultured Mugil capito. Ecotoxicol. Environ. Saf. 2020, 188, 109876. [CrossRef]
137. Eni, G.; Ibor, O.R.; Andem, A.B.; Oku, E.E.; Chukwuka, A.V.; Adeogun, A.O.; Arukwe, A. Biochemical and endocrine-disrupting effects in Clarias gariepinus exposed to the synthetic pyrethroids and deltamethrin. Comp. Biochem. Physiol. Part C Toxicol. Pharmacol. 2019, 225, 108584. [CrossRef]
138. Brander, S.M.; Jeffries, K.M.; Cole, B.J.; DeCourten, B.M.; White, J.W.; Hasenbein, S.; Fangue, N.A.; Connon, R.E. Transcriptomic changes underlie altered egg protein production and reduced fecundity in an estuarine model fish exposed to bifenthrin. Aquat. Toxicol. 2016, 174, 247–260. [CrossRef]
139. Vieira, C.E.D.; dos Reis Martinez, C.B. The pyrethroid λ-cyhalothrin induces biochemical, genotoxic, and physiological alterations in the teleost Prochilodus lineatus. Chemosphere 2018, 210, 958–967. [CrossRef]
140. Kumari, P.; Paul, D.K. Bioremedial effect of turmeric (Curcuma longa) on haematological and biochemical parameters against fenvalerate induced toxicity in air-breathing fish Clarias batrachus. Int. J. Aquac. Fish. Sci. 2020, 6, 056–060.
141. Zimmer, E.I.; Preuss, T.G.; Norman, S.; Minten, B.; Ducrot, V. Modelling effects of time-variable exposure to the pyrethroid beta-cyfluthrin induced in rainbow trout early life stages. Environ. Sci. Eur. 2018, 30, 36. [CrossRef] [PubMed]
142. Dawood, M.A.O.; Abd, S.E.; Gewaily, M.S.; Moustafa, E.M.; SaadAllah, M.S.; AbdEl-kader, M.F.; Hamouda, A.H.; Omar, A.A.; Alwakeel, R.A. The influence of dietary β-glucan on immune, transcriptomic, inflammatory and histopathology disorders caused by deltamethrin toxicity in Nile tilapia (Oreochromis niloticus). Fish Shellfish Immunol. 2020, 98, 301–311. [CrossRef]
143. Strungaru, S.-A.; Plavan, G.; Ciobica, A.; Nicoara, M.; Robea, M.A.; Solcan, C.; Petrovici, A. Toxicity and chronic effects of deltamethrin exposure on zebrafish (Danio rerio) as a reference model for freshwater fish community. Ecotoxicol. Environ. Saf. 2019, 171, 854–862. [CrossRef] [PubMed]
144. Zhang, X.; Yang, H.; Ren, Z.; Cui, Z. The toxic effects of deltamethrin on Danio rerio: The correlation among behavior response, physiological damage and AChE. RSC Adv. 2016, 6, 109826–109833. [CrossRef]
145. Naik, V.R.; David, M. Impact of deltamethrin toxicity on the changes in behavioural aspects of a freshwater fish, Cirrhinus mrigala. Int. J. Fish. Aquat. Stud. 2018, 6, 273–277.
146. Singh, S.; Tiwari, R.K.; Pandey, R.S. Evaluation of acute toxicity of triazophos and deltamethrin and their inhibitory effect on AChE activity in Channa punctatus. Toxicol. Rep. 2018, 5, 85–89. [CrossRef]
147. Borges, A.; Scotti, L.V.; Siqueira, D.R.; Zanini, R.; Amaral, F.D.; Juriniitz, D.F.; Wassermann, G.F. Changes in hematological and serum biochemical values in juveniles Rhamdia quelen due to sub-lethal toxicity of cypermethrin. Chemosphere 2007, 69, 920–926. [CrossRef]