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Research Article

The Effects of Neonicotinoid Insecticide/Thiamethoxamin on Environmental and Aquatic Ecosystems

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Abstract – Pesticides are chemical mixtures developed to target certain organisms, kill them, control or reduce their damage. Insecticides can be classified as subgroups of pesticides. In this study, the effects of neonicotinoid insecticides and thiamethoxam, a derivative of neonicotinoid, on aquatic ecosystem were investigated. Pesticides are frequently used in the agriculture and food industry, and their unusual use poses a threat to the lives of creatures that are not a target in the ecosystem. Although they are used in small amounts, neonicotinoid-derived drugs also pose a threat to human health because they accumulate in the central nervous system and cause chronic poisoning. Similarly, as a result of industrial waste or excessive use in agriculture, the residues of these pesticides mix with the nature and cause deterioration of the aquatic ecosystem. Though its high volatility and low concentration in water pose little threat to aquatic organisms, its absorption and storage in the fat tissues of these organisms that human consume as food leads to toxicity to human health. Therefore, the definition, classification, properties and effects of pesticides were investigated in detail.

Keywords – Pesticide, Insecticide, Neonicotinoid, Thiamethoxam, Ecosystem

I. INTRODUCTION

Pesticide is derived from the origin of the word pest and is a chemical substance used to destroy harmful organisms. In general terms, they are chemicals used to destroy unwanted pests on either living or nonliving surfaces. Pesticides are potentially toxic for all living organisms due to their chemical form and should be used cautiously [1]. Pesticides should be used to protect agricultural crops from harmful and invasive insects; therefore, their use is increasing and becoming widespread around the world every day. Pesticide consumption globally has risen to 3.5 billion kg of raw materials per year in two decades, and the international market value has reached 45 billion dollars [2].

II. MATERIALS AND METHOD

This study will review the widely used thiamethoxam, one of the neonicotinoids, a subspecies of pesticides, from different sources and investigate its properties, hazards, and other effects. Besides, the main purpose of the study is to examine the effects of thiamethoxam on the environment and aquatic ecosystems by conducting the literature review.

III. RESULT AND DISCUSSION

The WHO defines pesticides as microorganisms and chemicals or chemical mixtures, including viruses, that can be administered to animals for repelling, killing, or controlling harmful organisms that may cause unwanted effects during the production, processing, storage, transport, or sale of agricultural crops, wood and forestry products, food, and animal feed, or for controlling harmful and unwanted organisms, such as pests, arthropods, and mites, whether in or on live animals, including those that carry animal and human diseases [3].

Pesticides, i.e., agricultural agents, are chemicals used to prevent harmful pests, inhibit their spread, and reduce their harm to living organisms as much as possible. Pesticides can also act as a biological agent or a disinfectant that prevents or kills microbes [4]. Besides, when pesticides are decomposed, they form CO_2, H_2O, NH_3, and mineral salts [5].

A. Classification of Pesticides

Pesticides can be classified according to their sources, where they are produced, the chemical form of their active substances, the pest group they are effective against, and their appearance [6, 7]. The table below shows their classification in detail. The most commonly used method of grouping is based on the pest group in which they are effective. Pesticides therein are called as herbicides, acaricides, aphicides, fungicides, insecticides, bactericides, etc. Fungicides, herbicides, and insecticides are commonly studied and actively used in studies [8].

Table 1. Classification of pesticides [6-8].

By their form of formulation	Dust pesticides (Dust), wettable powder pesticides (WP), emulsion concentrate pesticides (EC or EM), solution concentrate pesticides (SC), Water-soluble powder pesticides (SP), Summer and winter oils, Granules (G), pellets, tablets, powder seed pesticides, liquid seed pesticides, aerosols, toxic baits, Encapsulated formulations, Flowable concentrates (FC), Dry fluids.
By pest group for which they are used*	Insecticide: insect killer; Fungicide: fungi killer; Herbicide: weed killer; Acaricide: spider killer; Bactericide: bacteria killer; Aphicide: aphid killer; Rodenticide: Rodent killer, Nematicide: nematode killer, Molluscicide: snail killer, Algicide: algae killer, Fungistatic: fungal activity inhibitor, Avenicide: avian killer or repellent, Repellent: repellent of harmful animals such as insects and rabbits, Attractant: attractant to harmful animals, Ovicides: tick and bug egg killer, Pheromones: insect fertility inhibitors, Microbial pesticides: bactericidal to microorganisms.
By the structure of the active substance, they contain	• Organic chlorinated compounds ❖ Dichloro Diphenyl trichloroethane (DDT) ❖ Benzene hexachloride (BHC) ❖ Cyclodiene group compounds: Chlordane, Heptachlor, Aldrin, Dieldrin, Isodrin, Endrin, Endosulfan, and Toxaphene • Organic phosphorus compounds • Carbamates • Synthetic pyrethroids
By the location of the pest, it controls	• Against pests in cultivated plants • Against forest pests • For the protection of timber • Against product damage in the warehouse • Against household insects, disease carriers such as houseflies and mosquitoes • They are classified by their use against exogenous parasites in animals and humans.

B. Significance and Effects of Pesticides

Since mankind has ever existed, the nutritional need has also risen proportionally as the population has grown. While agricultural crops are grown in order to meet rising and existing nutritional needs, product loss rises up to 65% in production due to pests and harmful weeds. The statistical information in the study showed that this loss was around 23 million metric tonnes and may meet the nutritional needs of 150 million people per year. Therefore, producers adopt various methods to prolong the food's shelf life and improve nutritional diversity and quality. One of the most common methods that producers use is chemical control in order to increase agricultural yield. The source of chemical control is the application of pesticides. Pesticides

are applied to protect agricultural crops from pests, pathogenic organisms, and weeds in order to improve the productivity and quality of the product [8].

C. Neonicotinoids and Effecst

Neonicotinoids are among the most potent insecticides among the protection products [9]. The nicotine production is based on the tobacco plant *Nicotiana tabacum* [10]. The first neonicotinoid pesticide was introduced in Europe and Japan in 1991 and its trade name back then was imidacloprid [11].

Neonicotinoid pesticides exert a stimulant effect by binding to nAChRs in the CNS; this stimulant effect is similar to the effect of nicotine. Pests also bind strongly and irreversibly to nicotinic receptors. Therefore, their toxic effects in insects are more severe than in mammals and birds [12]. Neonicotinoids exert their toxic effects by binding to and affecting acetylcholine receptors in the CNS of insects. They bind to the postsynaptic nAChR in the CNS and, inhibit its functioning and increase the nerve conduction velocity. This leads to involuntary contraction, hyperactivity and mortality [13-16].

The use of neonicotinoid pesticides has been actively banned and restricted in many countries in the EU and abroad due to their negative ecosystem effects, such as the decrease of bird colonies, bee swarms, and insect populations, etc. [17].

D. Neonicotinoid Types

Imidacloprid is the most widely used neonicotinoid pesticide, followed by nithiazine, thiamethoxam, clothianidin, thiacloprid, nitenpyram, and acetamiprid [18, 19].

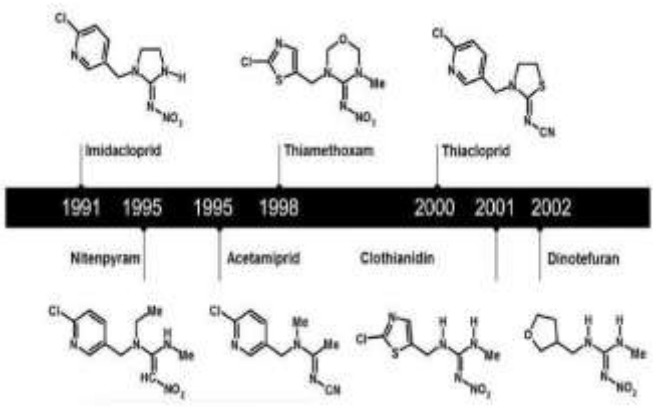

Figure 1. Neonicotinoid insecticides and dates of their introduction to international markets [20].

E. Thiamethoxam

Thiamethoxam-a new synthetic insecticide developed from 3-(2-chloro-thiazol-5ylmethyl)-1,3,5-oxadiazinan-4-ylidene-Nnitroamine- is an important member of the neonicotinoid group [21]. It is one of the most widely applied pesticides in the fight against agricultural pests worldwide. Thiamethoxam was discovered in 1985 during an optimisation programme on neonicotinoids. Among the new variations, thiamethoxam (CGA 293433) was identified as the best compound and selected thereafter for worldwide development. The compound can be synthesised in only a few steps and yields highly from readily available starter materials. The compound has been commercially marketed under the trademarks Actara® for leaf processing and tillage and Cruiser® for seed processing. The compound features broad-spectrum insecticidal activity and offers excellent control of a wide range of commercially important pests in many crops. Low application rates, flexible methods of application, excellent efficacy, long-lasting persistent activity, and proper safety profile have made this new insecticide highly suitable for pest control programmes in many crop systems [22]. We will examine the properties of thiamethoxam under two headings: physical and chemical properties.

F. Physical Properties

It can be argued that thiamethoxam is rapidly absorbed in mammals, is highly dispersible in the body, and accumulates mostly in the liver. Besides, it causes more toxicity for the kidney and liver in continuous contact, induces CNS depression at high doses, increases tumour formation in mice, and leads to loss of mobility in the musculoskeletal system in acute neurotoxicity studies [23].

Table 2. Physical properties of Thiamethoxam [24].

PHYSICAL APPEARANCE	CRYSTAL
Colour	White
Odour	There is a light characteristic odour.
Hazard	In case of skin and eye contact, wash with plenty of water and soap. In case of inhalation or ingestion, contact the nearest health institution.
Storage	Must be kept in a cool and dry place.
Areas of Application	Thiamethoxam is a solid raw material with a chemical formula as active substance $C_8H_{10}CIN_5O_3S$ and a molecular weight of 291.71 gr/mol, white in colour and in powder form, with a characteristic odour. Thiamethoxam is used in different concentrations in pesticides as the main active ingredient of some pesticides produced against insecticides. It is applied against cotton aphids, aphids on tomatoes, and whiteflies on aubergines and peppers.

G. Chemical Properties

Neonicotinoids act on neurotransmitter acetylcholine-responsive receptors (nAChRs) at the postsynaptic site. While they induce neuromodulation at low doses, they block receptors at high doses and lead to stroke and mortality. Neonicotinoids bind to nicotinic acetylcholine receptors more strongly than in vertebrates; therefore, they produce a more toxic effect in insects in particular than in other organisms (Tomizawa and Casida, 2005). Today, thiamethoxam accounts for 36.7% of neonicotinoids and has a share of more than 25% of total insecticide sales in the global market [20].

Table 3. Chemical properties of Thiamethoxam [24].

Chemical Formula	$C_8H_{10}CIN_5O_3S$
Molecular Weight	291.71 G/Mol
Solubility	Hardly Soluble In Water
Melting Point (C)	140
Ph Range	9 – 9.4
Density	1.57 Gr / Cm^3

Figure 2. 2D Chemical Structure/Formula of Thiamethoxam [25].

H. Areas of Application and Effects of Thiamethoxam

Thiamethoxam is a second-generation nicotinic insecticide and is classified in the subgroup of thianicotils. This insecticide is reported to be the safest chemical compound developed for controlling many harmful pests in terms of the safety of agricultural crops globally [26]. Thiamethoxam is an insecticide with a wide range of action among neonicotinoid compounds. It is used globally for many insects with piercing-sucking mouthparts on many plants, such as fruits, cotton, citrus fruits, rice, flowers, and agricultural crops. It is an insecticide that can be used by direct spraying on the plant or by direct contact with the entire seed surface in seed coating. Thiamethoxam-a member of the thianicotil subclass-is a nicotinoid used commercially for the first time on house flies in agriculture [14, 27].

Thiamethoxam is absorbed from all parts of plants on which insects feed, including pollen. Due to its mechanism of action, it can be applied in all seed and irrigation processes, mixed into the soil, and

applied to the trunks of trees. It affects the insect either from the stomach after feeding through respiratory system or by absorption through the skin by direct contact. Thiamethoxam acts as a neurotransmitter between post-synaptic acetylcholine receptors and nerve cells and inhibits muscle movements. It acts by binding to nAChRs in the entire nervous system. Due to the difference in receptors, it has a less toxic effect on insects and mammals. In 2010, the report of the Joint Meeting on Pesticide Residues (JMPR) of the Food and Agriculture Organisation (FAO) and the World Health Organisation (WHO) identified thiamethoxam as a novel chemical compound with improved bioaccumulation and toxicity. The Food and Agriculture Organisation (FAO) has classified thiamethoxam as 'moderately hazardous' as it appears to be toxic upon exposure. It has been determined that it causes no damage to the skin and eye mucosa and is not mutagenic as a result of in vitro and in vivo toxicology tests. The Food and Agriculture Organisation (FAO) stated that thiamethoxam did not cause toxic effects in aquatic organisms, algae, or fish; it was moderately toxic in birds but highly toxic in winged insects [16].

i. Environmental Effects of Thiamethoxam and Its Effects on Aquatic Ecosystem

Thiamethoxam has been reported to be one of the most useful insecticides developed against many agricultural pests to boost productivity in agriculture globally. Thiamethoxam was first introduced to the global market as an agrochemical in 1991. According to current studies, widely used neonicotinoid derivative pesticides such as thiamethoxam, clothianidin, and imidacloprid have been discussed due to their highly toxic effects against honey bees [28]. Therefore, it has been demanded to restrict its application due to the damages it causes as a result of recent studies [29]. WHO defines thiamethoxam as a third-degree hazardous chemical compound [30].

Pesticides can pass into the aquatic environment in many ways. They can pass through both natural events (rainfall, groundwater) and wastewater systems (sewage systems, disposed contaminated wastewater, and hazardous wastes) and can even be transported as dust for kilometres by wind [31]. Pesticides undergo various processes in aqueous environments. These are physical, chemical, and biochemical processes (sediment accumulation, oxidation, and biological degradation), leading to the proliferation of pesticides as well as their high toxicity. If pesticides cause accumulation in the aquatic ecosystem, the hazards they may pose would be irreversible [32].

Chemicals that contaminate the environment, including pesticides, disrupt fish's oxygen consumption and metabolism (oxidative stress). The recent studies have indicated that reactive oxygen species (ROS), increasing as a result of pesticide poisoning in fish, disrupt the mechanism of oxygen consumption [33].

A study showed that bumblebees are more susceptible to pesticides than honey bees [34]. Most of the pesticides applied for agricultural control pose a significant threat to beneficial insects [35]. It is known that neonicotinoid insecticides produce harmful effects on social bugs even at concentrations below the lethal dose [36].

Insecticides that pollute aquatic environments not only produce toxic effects on fish but can also negatively affect organisms at higher trophic levels of the chain and humans through the nutrient cycle. Therefore, investigating the effects of insecticides on aquatic organisms is of great importance for the progress of fish and aquatic ecosystems. Although insecticides have been developed to improve the quality and productivity of agricultural crops, it is hardly possible to argue that the chemicals produced thereby intended for such purposes appear to be friendly to the ecosystem, as proven by studies [37].

IV. CONCLUSION and RECOMMENDATIONS

Pesticides have been used for many years, and as the need for production in the field of agriculture grew, their use against pests gradually increased. While mostly plant-based products were used until the 1930s, various active ingredients were developed with the advances in the field of chemistry after the 1930s, and pesticides came along with these substances.

In the 1970s, neonicotinoid derivatives were discovered by coincidence. In the early 1990s, the neonicotinoid derivative was developed under the name Imidacloprid, licenced as a pesticide by the American Agrochemical Market, and began to be actively and extensively used against agricultural pests. Thus, crop productivity and quality were improved by fighting against target organisms.

However, it has been observed that pesticides also disrupted and have still disrupted the ecosystem by causing undesirable toxic effects and chronic intoxication in other environmental and aquatic organisms in the ecosystem.

Pesticides penetrate the ecosystem and thus cause chemical pollution in the terrestrial and aquatic environment, and consequently, they may come into contact with agricultural crops and foodstuffs. For example, more than 98% of sprayed pesticide particles and 95% of herbicide particles come into contact with air, water, and soil beyond the area of application and kill harmless and irrelevant organisms in the ecosystem. Some groups of pesticides persist on land and in the aquatic environment for many years without losing their toxic effects. Pesticides lead to mass mortality in winged flying bugs, birds, and arthropods, which rank first when it comes to the destruction of pests in the ecosystem. It is known that 67 million birds die annually in the USA due to pesticide use [38]. An earlier study found that three-quarters of honey samples from different parts of the world contained pesticide residues [39]. This study revealed that pesticides are geographically distributed in all parts of the world.

Thiamethoxam is one of the most important insecticides for agriculture, the food industry, and public health. It is one of the protective insecticides that fight at the forefront in the fight against harmful insects and pests in the agriculture and food industries and in the fight against vectors that threaten human health in public health. However, while this protective action protects human health, unfortunately, it negatively affects other living things in the environmental and aquatic ecosystems. It eradicates living things in the ecosystem. The present review research also shows that this is the conclusion of many studies. Consequently, since thiamethoxam poses a danger to other living organisms in the ecosystem and extincts their generations, its use should be reduced, controlled and supervised.

Conflict of Interests/Competing Interests: None.

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