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REVIEW ARTICLE

Organochlorine pesticides, their toxic effects on living organisms and their fate in the environment

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ABSTRACT

Organochlorine (OC) pesticides are synthetic pesticides widely used all over the world. They belong to the group of chlorinated hydrocarbon derivatives, which have vast application in the chemical industry and in agriculture. These compounds are known for their high toxicity, slow degradation and bioaccumulation. Even though many of the compounds which belong to OC were banned in developed countries, the use of these agents has been rising. This concerns particularly abuse of these chemicals which is in practice across the continents. Though pesticides have been developed with the concept of target organism toxicity, often non-target species are affected badly by their application. The purpose of this review is to list the major classes of pesticides, to understand organochlorine pesticides based on their activity and persistence, and also to understand their biochemical toxicity.

KEY WORDS: LD_{50}; pesticide persistence; biochemical toxicity; organochlorine (OC) pesticides

Introduction

Pesticides are a group of chemicals used for the destruction of insects, weeds, fungi, bacteria, *etc.* They are generally called insecticides, fungicides, bactericides, herbicides or rodenticides. Most of the pesticides have the ability to destroy a wide variety of pests or weeds, but some are developed against specific pests or pathogens. Most of these chemicals are designed in such a way as to disturb the physiological activities of the target organism, leading to dysfunction and reduced vitality. Pesticide residues may constitute a significant source of contamination of environmental factors such as air, water and soil. This phenomenon could become a continuous threat to the co-existence of plant and animal communities of the ecosystem. Problems caused by pest lead to loss of about one third of the world's agricultural production every year, and that despite the fact that pesticide consumption comes up to more than two million tons. In India, the loss amounts to more than Rs 6,000 crores annually, by contributing factors such as weeds (33%), diseases (26%), insects (20%), birds (10%), rodents, and others (11%). Every year the magnitude of the problem increases by the appearance of newer pests and diseases (Rajendran, 2003).

The greater use of pesticides for high agricultural production has led to increased pollution of environmental compartments – soil, water and air. The characteristics of pesticides, such as high lipophilicity, bioaccumulation, long half-life and potential of long range transport, have increased the chances of contaminating the air, water and soil, even after many years of application. A study by Pimentel (1995) showed that only a small percentage (0.3%) of applied pesticides goes into the target pest while 99.7% go somewhere else into the environment. Application of a wide variety of pesticides has been advised to increase the crop productivity in tropical countries where crop loss is severe due to high temperature and humidity, which are conductive to rapid multiplication of pests (Kannan *et al.*, 1993; Lakshmi, 1993). According to a World Health Organisation study, 80% of all pesticides are used by developing countries (Veil, 1990). Due to lack of proper legislation, improper market regulations and ignorance shown by people, agricultural workers from developing countries are prone to experience high levels of agricultural chemicals, including

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pesticides (Smith & Jong, 2001). Among agriculturalists of developing countries, pesticide exposure is the primary occupational hazard (Wasseling *et al.*, 2001; Konradsen *et al.*, 2003; Coronado *et al.*, 2004) which leads to health issues and environmental contamination associated with pesticide use (Mancini, 2005; Remor *et al.*, 2009). Although farmers are considered to be the main risk group, formulators, loaders, mixers, production workers and agricultural farm workers are all extremely susceptible groups. The non-occupational hazards may be due to pollution of the ecosystem or habitat as a whole. An estimate shows that deaths and chronic diseases due to pesticide poisoning amounts to about one million per year worldwide (Environews, 1999).

The overuse or misuse of pesticides is contributing adversely to the environmental health as well as to ecosystem services. Pesticides are reported to affect many aquatic and terrestrial species. Life in aquatic ecosystems such as microorganisms, invertebrates, plants and fish are badly affected by pesticides (Liess *et al.*, 2005; Grande *et al.*, 1994; De Lorenzo *et al.*, 2001; Castillo *et al.*, 2006; Frankart *et al.*, 2003). In the Indian situation, massive use of pesticides has started since the 1960s when the "Green Revolution" was initiated and maximum agrochemicals were used to achieve high agricultural production.

Classification of pesticides

Classification of pesticides is mainly based on:

- Chemical nature (organochlorines, organophosphates, *etc*).
- Application requirement (agriculture, public health, domestic).
- Target organism or targeted use (insecticide, herbicide, fungicide, *etc*).
- Classification of pesticides based on chemical nature is given in Table 1.

Organochlorines

Organochlorines (OC) are a group of chlorinated compounds widely used as pesticides. These chemicals belong to the class of persistent organic pollutants (POPs) with high persistence in the environment. OC insecticides were earlier successfully used in control of malaria and typhus, yet they are banned in most of the advanced countries (Aktar *et al.*, 2009). The review statistics on the use of different pesticides shows that 40% of all pesticides used belong to the organochlorine class of chemicals (Gupta, 2004; FAO, 2005). Due to their low

Table 1. Classification of pesticides based on their chemical nature.

No	Chemical Group	Chemical names
1	Organochlorines	DDT,DDD, Dicofol, Eldrin, Dieldrin, Chlorobenziate, Lindane, BHC, Methoxychloro Aldrin, Chlordane, Heptaclor, Endosufan, Isodrin, Isobenzan, Toxaphene, Chloro propylate
2	Organophosphates	Dimefox, Mipafox, Methyl Parathion, Ronnel, enitrothion, Bidrin, Phorate, Fenthion, caumphos, Abate, Dichlorovas, Diptrex, Phosphomidon, Demetox, Oxydemeton-methyl, Malathion, Dimethoate, Trichlorofan
3	Carbamates	**Methyl** Carbaryl, Carbanolate, Prupoxur, Dimethan, Dimetilan, Isolan, Carbofuran, Pyrolan, Aminocarb, Aldicarb **Thio** Vernolate, Pebulate, Diallate, Monilate, Butylate, Cycloate, Trillate, Thiourea **Dithio** Methan, Thiram, Ferban, Amoban, Naban, Zineb, Maneb, Ziram Polyran, Dithane M- 45
4	Pyrethroids	Allethrin, Bonthrin, Dimethrin, Tetramethrin, Ptrethrin, Cyclethrin Furethrin, Fenevelerate, Alphamethrin, Decamethrin, Cypermethrin
5	Phenyl amides	**Carbanilates** Barban, Carbetamide, Chlororprofan, Prophan, Phenyl Urea, Fenuron, Monuron, Diuron,Flumeturon, Chloroxuron, Neburon, Bromuron **Acylanalide** Propanil, Solan, Dicryl, Karsil, Propachlor, Alachlor, Butachlor **Toluidines** Trifluralin, Dipropanil, Benefin, Oryzalin, Isopropanil, Nitralin **Acetamide** Diphenamid
6	Phenoxy alkonates	2,4-D(2,4 Dichloro phenoxy acetic acid) 2,4 5 T(2,4 5 Trichloro Phenoxy acetic acid) Dichloroprop, Mecoprop, Erbin, Sesone
7	Trazines	Atrazine, Simazine, Ametryn, Atratone, Chlorazine, Cynazine, Cyprazine, Metribuzin, Propazine, Turbutryn, Simetryn
8	Benzoic acid	Dicamba, Dichlorobenil, Chloroambin, Tricamba, Neptalan, Bromoxynil
9	Phtalimides	Captan, Diflotan, Folpet
10	Dipyrids	Paraquat, Diaquat
11	Others	Pentachlorophenol, Floroacetate, Phenyl mercuric acetate, Ethyl mercuric Phosphate,Methyl mercuric chloride, Sodium arsenate, Calcium arsenate, Lead arsenate, Cacodylic acid, Aluminium phosphide, Zinc phosphide

Table 2. Major organochlorine pesticides, their chemical structures, toxicity, use and persistence.

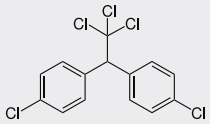
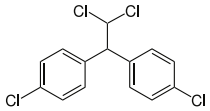
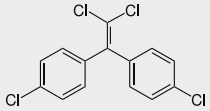
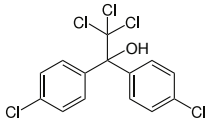
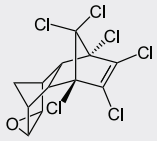
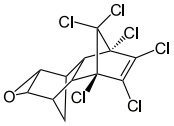
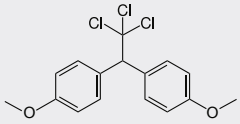
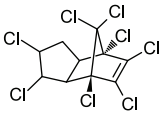
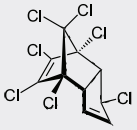
No.	Chemical name	Structure	Toxicity LD_{50}	Use	Persistence in environment	WHO classification based on rat oral LD_{50}
1	Dichlorodiphenyltrichloroethane (DDT) $C_{14}H_9Cl_5$		**Rat** Oral: 113–130 mg/kg Dermal: 2510 mg/kg **Mice** Oral: 150–300 mg/kg **Gunia Pigs** Oral: 300 mg/kg **Rabbit** Oral: 400 mg/kg	Acaricide Insecticide	High Persistence Half life: 2–15 years	Moderately hazardous
2	1,1-dichloro-2,2bis (p-chlorophenyl)ethane (DDD)		**Rat** Oral: 4000 mg/kg	Insecticide	High Persistence Half life: 5–10 years	Acute hazard is unlikely
3	Dichloro diphenyl dichloroethane (DDE)		**Rat** Oral: 800–1240 mg/kg	Insecticide	High Persistence Half life: 10 years	Slightly hazardous
4	Dicofol $C_{14}H_9Cl_5O$		**Rat** Oral: 684–1495 mg/kg **Rabbit** Oral: 1810 mg/kg Dermal: 2.1 g/kg	Acaricide	Moderate persistence Half life: 60 days	Moderately hazardous
5	Endrin $C_{12}H_8Cl_6O$		**Rat** Oral: 3 mg/kg Dermal: 15 mg/kg **Mouse** Oral: 1.37g/kg Intravenous: 2300 g/kg **Goat** Oral: 50 mg/kg **Rabbit** Oral: 60–94 mg/kg	Avicide insecticide	Moderate Persistence Half life: 1Day to 12 Years	Highly hazardous
6	Dieldrin $C_{12}H_8Cl_6O$		**Rat** Oral: 46 mg/kg Dermal: 50–120 mg/kg **Mouse** Oral: 38–77 mg/kg **Dog** Oral: 56–120 mg/kg **Rabbit** Oral: 45–50 mg/kg **Cow** Oral: 25 mg/kg **Duck** Oral: 381 mg/kg	Insecticide	High Persistence Half life: 9 months	Highly hazardous
7	Methoxychlor $C_{16}H_{15}Cl_3O_2$		**Rat** Oral: 5000–6000 mg/kg **Mice** Oral: 2000 mg/kg **Monkey** Oral: 2500 mg/kg	Insecticide	High Persistence Half life:< 120 Days	Acute hazard is unlikely
8	Chlordane $C_{10}H_6Cl_8$		**Rat** Oral: 200 to 700 mg/kg Dermal: 530–690 mg/kg **Mice** Oral: 145– 430 mg/kg Dermal: 153 mg/kg **Rabbit** Dermal: 780 mg/kg	Insecticide	High Persistence Half life: 10 years	Moderately hazardous
9	Heptachlor $C_{10}H_5Cl_7$		**Rat** Oral: 40– 220 mg/kg Dermal: 119–320 mg/kg **Mouse** Oral: 30–68 mg/kg **Guinea pigs** Oral: 116 mg/kg Dermal: 1000 mg/kg **Rabbit** Dermal: 2000 mg/kg	Insecticide	High Persistence Half life: 2 years	Highly – Moderately hazardous

Table 2. *Table continues ...*

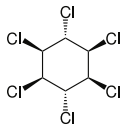
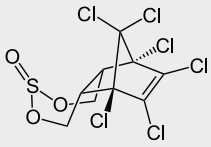
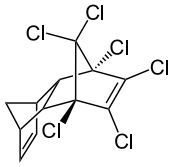
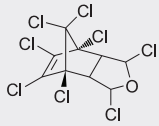
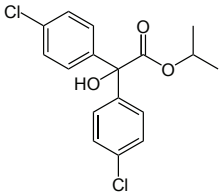
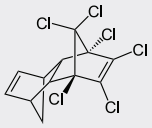
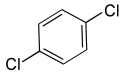
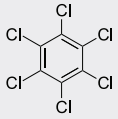
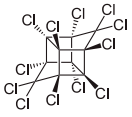
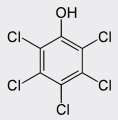
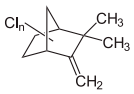
No.	Chemical name	Structure	Toxicity LD_{50}	Use	Persistence in environment	WHO classification based on rat oral LD_{50}
10	Lindane $C_6H_6Cl_6$		**Rat** Oral: 88 – 270 mg/kg **Mouse** Oral: 59–246 mg/kg	Acaricide Insecticide Rodenticide	High Persistence Half life: 15 months	Moderately hazardous
11	Endosulfan $C_9H_6Cl_6O_3S$		**Rat** Oral: 18 to 220 mg/kg Dermal: 74 mg/kg **Rabbits** Dermal: 200–359 mg/kg **Ducks** Oral: 33 mg/kg	Insecticide	Moderate Persistence Half life Alpha Isomer:35days Beta Isomer:150days	Highly hazardous
12	Isodrin $C_{12}H_8Cl_6$		**Rat** Oral: 8.8 mg/kg	Insecticide	High Persistence Half life: 0.5–6 years	Highly hazardous
13	Isobenzan $C_9H_4Cl_8O$		**Rat** Oral: 4.8 mg/kg **Rabbit** Dermal: 12 mg/kg **Mouse** Oral: 8.4 mg/kg	Insecticide	High Persistence Half life: 2.8 years	Highly hazardous
14	Chloropropylate $C_{17}H_{16}Cl_2O_3$		**Rat** Oral: 5000 mg/kg **Birds** Oral: 2500 mg/kg **Rabbit** Oral: 10200 mg/kg	Insecticide Acaricide	Moderate Persistence Half life: 50 days	Acute hazard is unlikely
15	Aldrin $C_{12}H_8Cl_6$		Oral: 39 to 60 mg/kg Dermal: 100 mg/kg **Mouse** Oral: 44 mg/kg **Dog** Oral: 65–95 mg/kg	Insecticide	Moderate Persistence Half life: 4–7 years	Highly hazardous
16	1,4- dichlorobenzene $C_6H_4Cl_2$		**Rat** Oral: 1516–2138 mg/kg		Moderate Persistence Half life: < 50 days	Moderately hazardous
17	Benzene hexachloride (BHC) $C_6H_6Cl_6$		**Rat** Oral: 10,000 mg/kg **Guinea pigs** Oral: < 3000 mg/kg **Rat** Oral: 4000 mg/kg	Acaricide Insecticide Rodenticide	High Persistence Half life: 3 – 6 years	Acute hazard is unlikely
18	Mirex $C_{10}Cl_{12}$		**Rat** Oral: 600–740 mg/kg	Insecticide	High Persistence Half life: 10 years	Acute hazard is unlikely
19	Pentachlorophenol C_6Cl_5OH		**Rat** Oral: 27–211 mg/kg Dermal: 96–330 mg/kg **Mice** Oral: 74–130 mg/kg **Rabbit** Oral: 70–300 mg/kg Dermal: < 100 mg/kg	Fungicide Herbicide Insecticide	Moderate Persistence Half life: 45 days	Highly – Moderately hazardous
20	Toxaphene (Camphechlor) $C_{10}H_{10}Cl_8$		**Rat** Oral: 80–293 mg/kg Dogs: 25 mg/kg	Acaricide Insecticide	Moderate Persistence Half life 11 Years	Slightly hazardous

Table 3. Biochemical effects of major organochlorine pesticides.

Sl.No	Chemical name	Organism	Biochemical effects	References
1	Aldrin and Dieldrin	Human	Neurotoxic, reproductive, developmental,immunological, genotoxic, tumerogenic effects, nausea, vomiting, muscle twitching and aplastic anemia	USEPA, 2003
		Mouse, rat, guniea pig, rabbit and dog	Convulsions, loss in body weight, depression, increased irritability, salivation, hyperexitability, prostration and death	
2	Chlordane	Human	Convulsions, tremor, mental confusion and incoordination	ATSDR, 1997
		Mice	Reduced fertility, liver cancer	
		Seals	Cancer, trauma, meningocephalitis	Kajiwara *et al*., 2000
3	BHC/ DDE	Human	Cyst in hands, itching, psoriasis, eczema, leucoderma, skin rashes	Subramaniam & Solomon, 2006
4	DDT	Human	Prickling sensation of the mouth, nausea, dizziness, confusion, headache, lethargy, incoordination, vomiting, fatigue, tremors in the extremities, anorexia, anemia, muscular weakness, hyperexcitability, anxiety, and nervous tension	Klaassen *et al*., 1996
		Mice	Liver tumors, liver changes including hepatocellular hypertrophy, margination and formation of lipospheres.	WHO, 1979
		Birds	Egg shell thinning	
		Fish	Affects membrane function and enzymes	USEPA, 1975
		Salmons	Impaired behavioral development	
5	Diazion	Rats	Neurotoxicity	USEPA, 2000 Peterson & Talcot, 2006
		Reptiles, fishes and Mammals	Lacrimation, salivation, anorexia, bradycardia, abdominal pain, hyperactivity, anxiety, depression and vomiting	
		Birds	Wing spasms, wing drop, hunched back, tenesmus, diarrhea, ptosis of eyelid, prostration, opisthotonos-like seizures or wing-beat convulsions.	
		Human	Dark or blurred vision, anxiety and restlessness, as well as psychiatric symptoms such as depression, memory loss, and confusion and acute pancreatitis.	Reigert & Roberts, 1999 Wagner, 1997 USEPA, 2000
6	Dicofol	Rats	Decrease in body weight and acute neurotoxicity	Phang *et al*., 1996
		Dogs	Inhibition of ACTH (Adrenal cortical tropic hormone)	
7	Endosulfan	Human	Decreases the white blood cell count and macrophage migration, adverse effects on humoral and cell-mediated immune system. Affects semen quality, sperm count, spermatogonial cells, sperm morphology and other defects in male sex hormones DNA damage and mutation	Pandey *et al*., 1990 Susan & Sania, 1999 Singh *et al*., 2007
		Rats	Immunosuppression, neurological disorders, congenital birth defects, chromosomal abnormalities, mental retardation, impaired learning and memory loss and glomerulonephritis	Stockholm Convention, 2009
8	Lindane	Human	Damage human liver, kidney, neural and immune systems, and induces birth defects cancer, cause neurotoxicity, reproductive toxicity and hepatotoxicity	Sahoo *et al*., 2008, Bano & Bhatt, 2010 Vijaya Padma *et al*., 2011
		Rats	Alters gene expression of liver and hepatotoxicity	Sumida *et al*., 2007 Videla *et al*., 2004
9	Methoxychlor	Sea Urchins	Fertilization and early development of eggs	Pesando *et al*., 2004
		Rats	Reduced fertility	Cummings & Gray, 1989
10	Polychlorinated Biphenyls (PCB)	Human	Neurological disorders and short term memory	Jacobson & Jacobson, 1996
		Fishes, rats, monkeys and mice	Cancer, Hodgkins lymphoma, decreased birth weight and decreased size of thymus gland	USEPA, 1996
11	Pentachlorophenol	Human	Inflammation of the upper respiratory tract and bronchitis, blood effects such as aplastic anemia, effects on the kidney and liver, immunological effects, and irritation of the eyes, nose, and skin	ATSDR, 1999
		Rats and Mice	Effects the cardiovascular system, blood, liver, immune system, and central nervous system (CNS)	

cost and the need against various pests, organochlorine insecticides such as DDT, hexachlorocyclohexane (HCH), aldrin and dieldrin are among the most widely used pesticides in developing countries of Asia (FAO, 2005; Gupta, 2004; Lallas, 2001).

Organophosphates

Organophosphates (OP) are esters of phosphoric acid. The OP group of pesticides asserts its effects through irreversible inactivation of the enzyme acteylcholinesterase,

which is essential for nerve function in humans, insects and many other animals. OP samples degrade rapidly by hydrolysis on exposure to light, air and soil, however small amounts are detected in food and drinking water.

Carbamates

Carbamates are organic compounds derived from carbamic acid (NH_2COOH). The functional group present in carbamate insecticides are carbamate esters. Their mechanism of action is by reversible inactivation of the enzyme acteylcholinesterase. Carbamates break down in the environment within weeks or months (Goel & Aggarwal, 2007).

Pyrethroides

Pyrethroides and pyrethrins are similar organic compounds isolated from the flowers of pyrethrums *(Chrysanthemum Coccineum* and *C. cinerariaefolium*). The insecticidal properties of pyrethrins are derived from ketoalcoholic esters of chrysanthemic and pyrethroic acids (Reigert and Roberts, 1999). Pyrethroides affect the sodium channels and lead to paralysis of the organism. Pyrethroides have a comparatively slight level of mammalian toxicity and have a fast biodegradation capacity. Exposure to very high levels of the compounds in air, food or water may cause giddiness, headache, vomiting, muscle twitching, low energy, convulsions and loss of consciousness (Goel & Aggarwal, 2007).

Phenylamides

Phenylamide fungicides are systemic compounds that show potent eradicative anti-fungal activity (Schwinn & Staub, 1987). When added to the soil, they enhance plant growth and yield; in addition, these fungicides affect the homeostastis of the soil system (Monkiedje & Spiteller, 2002). These chemicals affect nutrient cycling and enter the food chain, and have thus been reported to affect higher organisms including humans. They affect nucleic acids by inhibiting the activity of RNA polymerase I system. They are known to impact mitosis and cell division in target fungi (Chao *et al.*, 2011)

Phenoxyalkonates

Phenoxyalkonates are a widely used family of herbicides. These pesticides are mainly used to control weeds in agriculture. Nearly all compounds of this group are degraded by microorganisms (Viltos, 1952).

Triazines

The compounds that fall under this category are herbicidal pesticides. They include desmetryne, chlorazine, atriazine, propazine, *etc.* These compounds are known to have potential use as insect chemosterilants. Higher concentrations of these herbicides were found to inhibit plant catabolism pathway (Evan *et al.*, 2007).

Benzoic acid

Benzoic acid herbicides include dicamba, dichlobenil, chlorambin, bromoxynil, ioxynil and naptalam. Little information is available regarding their degradation by soil microbes. Ioxynil is found to precipitate in acid soils (Zaki *et al.*, 1967).

Phthalimide

Phthalimides include three fungicides, captan, folpet and captafol which together represent the second most important group of organic fungicides used in American agriculture. They represent about half the usage of the dithiocarbamates (NAS, 1975). The fungicides difolatan, captan and folpet react with thiols such as cysteine and glutathione at acidic pH levels of 4.0 to 5.0.

Dipyrids

The dipyridyl herbicides include paraquat and diquat. They are strongly adsorbed as organic cations in the soil (Funderburk, 1969; Funderburk & Bozarth, 1967). Microorganisms metabolize paraquat as the main source of nitrogen (Baldwin *et al.*, 1966).

Others

There are many more pesticides used in agricultural practice. Heavy metals have found vast use as pesticides. Elements like iron, lead, sulphur, arsenic, mercury, zinc, tin, *etc.* have been used in inorganic or organic metal form. Methyl mercuric chloride, sodium arsenate, calcium arsenate, zinc phosphide are some of the compounds that fall under this category. Table 1 gives a comprehensive classification of pesticides based on their chemical nature. Among the various classes of pesticides, organochlorines and organophosphates are widely used. Organochlorines are known for their high persistence and toxicity characteristics. These pesticides cause neurological damage, endocrine disorders, and have acute and chronic health effects. Hence contamination of the environment with organochlorine pesticides drastically affects the ecosystem.

Organochlorine pesticides – chemistry, persistence and hazard classification

The basic characteristics of organochlorine pesticides are high persistence, low polarity, low aqueous solubility

and high lipid solubility. Organochlorine pesticides can enter the environment after pesticide applications, polluted wastes discarded into landfills, and discharges from industrial units that synthesize these chemicals. They are volatile and stable; some can adhere to the soil and air, thus increasing the chances of high persistence in the environment, and are identified as agents of chronic exposure to animals and humans. Table 2 provides a comprehensive summary of major organochlorine pesticides with their chemical name, structure, toxicity, use and persistence in environmental medium.

They have a related chemical structure, showing chlorine substituted aliphatic or aromatic rings. Due to their structural resemblances, these compounds share certain physicochemical characteristics such as persistence, bioaccumulation and toxicity. One basic character that they share across the spectrum is persistence, where persistence is defined as half-life greater than two months in water or six months in soil sediment. The persistence of OC compounds varies from moderate persistence with half-life of approximately 60 days to high persistence with half-life up to 10–15 years. The most commonly used pesticide in agricultural practice is dichlorodiphenyltrichloroethane (DDT), which is moderately hazardous, with high persistence and a half-life of 2–15 years (Augustijn-Beckers *et al.*, 1994). The use of DDT is now banned in many countries but it is illegally used in most of the developing countries. This applies also to endosulphan, an insecticide which is highly hazardous and has moderate persistence with a half-life of fifty days and is used in the production of cashew (Quijano, 2002).

Due to the high persistence and bioaccumulation potential, the Stockholm Convention has classified most of the OC compounds as environmental hazards and banned the use of many of them. However in many developing countries they are still in use making the ban ineffective.

Biochemical toxicity of organochlorines

Organochlorine toxicity is mainly due to stimulation of the central nervous system (Table 3). Cyclodines, such as the GABA antagonists endosulphan and lindane, inhibit the calcium ion influx and Ca- and Mg-ATPase causing release of neurotransmittors (Mathew, 2012). Epidemiological studies have exposed the etiological relationship between Parkinson's disease and organochlorine pollutants.

Effect in humans

Examination of effects of different classes of pesticides leads to the conclusion that many of them are responsible for hypertension, cardiovascular disorders and other health related problems in humans. Organochlorines act as endocrine disrupting chemicals (EDCs) by interfering with molecular circuitry and function of the endocrine system (Sohail *et al.*, 2004). Farm workers, their families and those who pass through a region applied with pesticides can absorb a measurable quantity of pesticides. The presence of pesticide residues has been detected in blood plasma of workers in agricultural farms. Direct or indirect exposure to pesticides leads to neuromuscular disorders and stimulation of drug and steroid metabolism (Subramaniam and Solomon, 2006).

Another mode of exposure to these pesticides is through diet. Among food items, fatty food such as meat, fish, poultry, and dairy products serve as main causes (Rusiecki *et al.*, 2008). Many of the organochlorine molecules are carcinogens and neurotoxic (Kaiser, 2000). The hazardous nature of organochlorines was explained by citing different examples. The menace caused by endosulfan is of great concern. Endosulfan remains in the environment for longer periods and bio-accumulates in plants and animals which leads to contamination of food consumed by humans (Briz *et al.*, 2011). It affects mainly the central nervous system and was found to have higher acute inhalation toxicity than dermal toxicity. Gastrointestinal absorption of endosulfan is very high (USEPA, 2010).

Disproportion of thyroid hormones can lead to a variety of disorders. Serum concentrations of p-p'-DDE and HCB were found to be associated with abnormal thyroid hormone levels. p,p'-DDE was reported to increase free thyroxine (T4) and total triiodothyronine (T3) levels, and to be inversely associated with thyroid-stimulating hormone (TSH) (Meeker *et al.*, 2007). On exposure to dioxin-like organochlorines, a dose-dependent decrease in total T4 was also reported (Turyk *et al.*, 2006). Organochlorine pesticides were reported to increase the risk of hormone-related cancers including breast, prostate, stomach and lung cancer (Wolff *et al.*, 1993). Recently dioxins have been found in human ovarian follicular fluid, which may lead to the development of endometriosis. Exposure to dioxins can cause several autoimmune diseases, including multiple sclerosis and eczema (Sinaii *et al.*, 2002). Organochlorines can function as xenoestrogens and compounds such as TCDD, methoxychlor and alachlor were reported to exert effects on human and experimental animals due to inhibited synthesis and increased degradation of thyroid hormones.

Analysis of the National Health and Nutrition Examination Survey 1999–2004 studying the relation between organochlorine pesticides and prostate and breast cancers has shown that serum concentrations of b-HCH, trans-nonachlor, and dieldrin were significantly associated with prostate cancer prevalence (Xu *et al.*, 2010). In children, exposure to dioxins showed significant positive associations with learning disability (LD) (Lee *et al.*, 2007). Risk of attention deficit hyperactivity disorder (ADHD) at higher levels of p,p'-DDE and PCBs exposure was reported (Sagiv *et al.*, 2010). Prenatal exposure to p,p'-DDE and its presence in cord serum was found to lead to disappearance of neuronal development after 12 months of infant age (Torres-Sánchez *et al.*, 2009). Epidemiological studies have shown that exposure to persistent organic pollutants, mainly organochlorine

pesticides, is strongly associated with type 2 diabetes. Some persistent organic pollutants, as highly chlorinated PCBs and trans-nonachlor, were associated with the incidence of type 2 diabetes in obese people (Lee *et al.*, 2006).

Selected persistent organic pollutants are reported to induce divergent actions on blood pressure, suggesting a chemical structure based association of pesticides (Henríquez-Hernández *et al.*, 2014). In a population based study, different persistent organic pollutants and pesticides were reported to be associated with liver dysfunction biomarkers such as bilirubin, ALT and ALP, suggesting that these environmental pollutants can cause adverse effects on liver functions (Kumar *et al.*, 2014a). A study conducted in Costa Rica reported that occupational pesticide exposure to dialdrin could be partly responsible for the increased risk of Parkinson's disease seen in the population (Steenland *et al.*, 2014). Studies showed that the change of lipids over time, especially LDL-cholesterol, is linked to POP exposure (Penell *et al.*, 2014). Increased oxidative stress markers in plasma were found to be associated with exposure of POPs and could be a causative agent for oxidative stress (Kumar *et al.*, 2014b). Persistent organic pollutants were reported to influence the complement system, leading to activation of the immune system in humans (Kumar *et al.*, 2014a). Detection of organochlorine pesticides from human breast milk was reported from many places in the world. In Croatia, p,p'-DDE was found to be the dominant organochlorine pesticide in human breast milk (Klinčić *et al.*, 2014). Exposure of infants to chlordanes via breast milk was reported as a potential health risk in Korea (Lee *et al.*, 2013). Another study from Korea also revealed the presence of organochlorine pesticides (OCPs) chlordanes, aldrin, dichlorodiphenyltrichloroethanes (DDTs), dieldrin, heptachlors, endrins, hexachlorocyclohexanes (HCHs), hexachlorobenzene (HCB), toxaphenes and mirex, in milk (Kim *et al.*, 2013). Organochlorine pesticides HCB, β-HCH, pp'DDE, pp'DDT, pp'DDT, Σ-DDT were present in breast milk of the population in Guerrero, Mexico, proportionally to exposure (Chávez-Almazán *et al.*, 2014).

A study conducted in China showed that prenatal exposure to DDT, β-BHC, HCB and mirex caused decrease in birth weight of infants (Guo *et al.*, 2014). A number of studies were published on the effect of organochlorine pesticides on induction of diabetes mellitus in humans. A recent study reported that POP exposure is a risk factor contributing to insulin resistance (Arrebola *et al.*, 2015). Chronic exposure to chlordecone was found to cause hypertensive disorders in pregnancy and gestational diabetes mellitus among French Caribbean women (Saunders *et al.*, 2014). In a study conducted in Slovakia, highly increased blood levels of diabetes (fasting glucose and insulin) and obesity markers (BMI, triglyceride and cholesterol) were found in large groups of males and females in highly polluted areas. A significant decrease in testosterone level was also observed in males (Langer *et al.*, 2014). Prevalence of type 2 diabetes and exposure to persistent organic pollutants has been established (Airaksinen *et al.*, 2011). Recent studies on organochlorine pesticides have shown that β-HCH, HCB and DDT residues bio-accumulate in maternal and cord sera and from maternal blood they can be transferred through the placenta and affect thyroid hormone levels in the newborn (Li *et al.*, 2014). OC pesticides have been suggested to affect the thyroid system through gender-specific mechanisms; the extent of the effect may differ among compounds (Freire *et al.*, 2013). A report from Brazil had shown that OC compounds are reported to trigger anti-androgenic effects in men and estrogenic effects in women (Freire *et al.*, 2014). OC pesticide heptachlor was reported to induce mitochondria-mediated cell death via impairing electron transport chain complex III, thus acting as a neurotoxicant with possible association with Parkinson's disease (Hong *et al.*, 2014)

Exposure to organochlorine pesticide residues was reported as a potential risk factor for gallstone disease in humans (Su *et al.*, 2012). Potential neurotoxic effects of organochlorine compounds were reported on early psychomotor development even at low doses (Forns *et al.*, 2012). A positive correlation was observed of exposure to some OC pesticides and vitamin D deficiency in humans (Yang *et al.*, 2012). Early exposure to certain environmental chemicals, especially organochlorine compounds, with endocrine-disruption activity were reported to interfere with neonatal thyroid hormone status (Freire *et al.*, 2011).

Toxic effect of pesticides in fauna

Wild birds are of great importance to the ecosystem. Decline in the bird community serves as an indicator of environmental pollution. Continuous use of pesticides is one of the major causes for the reduction of birds. In many cases the impact is not direct, however repetitive use of pesticides like DDT in soil is taken up by earthworms which are then ingested by birds and thus their accumulation may result in a large loss in bird population (Fry, 1995). Subsequent research has also identified other pesticides and industrial chemicals that cause mortality and reproductive impairment, which affects both embryos and adult birds. The effects on embryos include mortality or reduced hatchability, wasting syndrome and teratological effects that produce skeletal abnormalities and impaired differentiation of the reproductive and nervous systems through mechanisms of hormonal mimicking of estrogens. The range of chemical effects on adult birds covers acute mortality, sub-lethal stress, reduced fertility, suppression of egg formation, eggshell thinning and impaired incubation and chick rearing behaviors (Gilman *et al.*, 1979). Pesticides cause extinction, behavioral changes, loss of safe habitat and population decline in several birds. Prolonged use of pesticides causes a drastic decrease in birds like the peregrine falcon, sparrow hawk and bald eagle (Mitra *et al.*, 2011). The levels of organochlorines in seabird eggs were indicated by forming a deposit of pollutants in the body, thus serving as a useful indicator of environmental contamination (Pearce *et al.*, 1989).

Toxic effect in farm animals

The prolonged use of pesticides in agriculture has caused serious health problems as these pesticides accumulate and affect the food chain. Organochlorine compounds are highly lipophilic and can accumulate in fat-rich food such as meat and milk (Hernandez *et al.*, 1994). Pesticides are introduced into cattle mainly through fodder or contaminated water used for household and public purposes (Sabbah and Bouguerra 1997). Amphibians and insectivorous reptiles, like lizards, have an important function in linking invertebrates with vertebrates in the food chain. They serve as a food source for some organisms and are also a means by which chemical residues, especially residues of organochlorine pesticides taken in with contaminated prey, can enter food chains. Amphibians consume these pesticides by a number of ways, including inhalation, contact and through ingestion. Amphibians in open water bodies may also be exposed to pesticides due to run-off from adjacent agricultural land on which chemicals are used to control crop pests. Continuous exposure of honey bees to pesticides affects the quality of honey. The routes of honey contamination with pesticides are direct and indirect. The direct is treatment of beehives with pesticides (Tsipi *et al.*, 1999). Wild animals, including the grasscutter (*Thryonomys swinderianus*), which are a good source of protein, are seriously affected by the use of pesticides. Grasscutters are a source of food for the people of Ghana in Africa (Sarah *et al.*, 2011). As pesticides have high effect on the animal and bird community, ultimately humans also take up pesticides as meat, milk and crops derived from these animals and plants are consumed by humans.

Conclusion

The use of pesticides in order to improve agriculture has not only affected the crop, it has also altered the food chain and the ecosystem. These chemicals not only affect the crop, animals and birds in a specific area but also badly affect the ecosystem balance. Pesticides are causes of high morbidity and mortality. Hence the use of chemical pesticides should be controlled and more use of bio-pesticides should be employed. Many alternatives are available to reduce the effects of pesticides on the environment. Alternatives include manual removal, applying heat, covering weeds with plastic, placing traps and lures, removing pest breeding sites, maintaining healthy soils that breed healthy and more resistant plants, cropping native species that are naturally more resistant to native pests and supporting bio-control agents such as birds and other pest predators. Consumer awareness should be brought up among people in concern with the long-term harm caused by pesticides.

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