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Effect of Pesticides on Crop, Soil Microbial Flora and Determination of Pesticide Residue in Agricultural Produce: A Review

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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Review Article

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ABSTRACT

The review is carried out to represent the effect of pesticide exposure of plant on its growth and metabolism. Decades ago, pesticides were introduced aiming to increase the crop yields and protecting crops from pests. Pesticides are highly toxic chemicals and toxicity does not remain restricted to the target organisms only but also have negative impact on the environment's non-target organisms. Pesticide inhibit seed germination and enzymatic activity, reduces the growth, rate of photosynthesis and yield. Excessive use of pesticide results in pesticide residue in fruit, vegetable, seeds and in soil. Accumulation of pesticide in soil disturbs the microorganisms, soil enzymes such as hydrolases, oxidoreductases, dehydrogenase, phosphatase activities and other physiochemical characteristics of the soil which in turn affect the soil fertility. Therefore, the main goal of this paper was to examine how the pesticide application influence plant growth and

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development, altering biochemical and physiological processes as well as various enzymatic and non-enzymatic antioxidants which ultimately affect the yield and results in residues in plant, fruits and vegetables.

Keywords: Pesticide; micro-organism; soil enzymes; pesticide residue; yield.

1. INTRODUCTION

In agriculture, application of pesticide has become a common trend all over the world and this practice is increasing with the growing population. Pesticide use dates back to 2500 BC, when Sumerians used sulphur compounds to repel insects and mites by rubbing them on their bodies. Pesticides were introduced in agriculture to meet the demand of growing global population. India currently ranks 12th in the world for pesticide production and is Asia's second-largest manufacturer after China. The three Indian states, Haryana, Punjab and Uttar Pradesh have the largest pesticide consumption, using 45000 tons of (technical grade) pesticides in 2000-2001. About 4.6 million tons of chemical pesticides with about 500 different types are annually used across the world [1]. About 85 % of the total pesticides used in the world are applied on agricultural crops while the remaining 15 % are used for other purposes [2]. In order to manage weeds, insects, fungi, and other unwanted pests that could harm high agricultural output levels and quality, pesticides are among the most commonly utilized chemicals [3]. Among pesticides, herbicides account for 42% followed by insecticides 27%, fungicides 22%, disinfectants and other agrochemicals 9% of world’s pesticide sales. In India, insecticides account for 76% of all pesticide use, while herbicide and fungicide use is significantly less common. Farmers are not aware of pesticide poisoning and use pesticides unwisely in higher concentration than the recommended dosage [4]. The recommended dosage of pesticides in relation to their target is shown in Table 3. The indiscriminate and unskillful use of pesticides stunts growth of plant and animal, leaves residue in fruits and vegetables, increases pest resistant to pesticides, destroys biodiversity and declines natural habitats [5]. Pesticides are extremely toxic and toxicity does not remain restricted to their intended target organisms but can also affect environment's non-target organisms [6]. Pesticide affects non target organism by reducing the growth, rate of photosynthesis, yield, inhibiting seed germination and enzymatic activity. Pesticides accumulation have an impact on soil microbial communities, which are crucial to the breakdown of plant and animal leftovers that may lead to stimulation, decrease, or modification of soil biological and other processes vital for soil fertility, health, productivity, and crop yield [7]. It is estimated that a very small part (<0.1%) of the entire amount of pesticides applied reach to the sites of action [8], with the larger proportion being lost via runoff, off-target deposition, spray drift, photodegradation, and other factors.

Pesticides used on crops are largely either absorbed by plants and animals or broken down through microbial or chemical processes. Many pesticides are difficult to break down; they remain in the soil, seep into groundwater and surface water, and contaminate large areas of the environment. Degradation of the pesticide depends upon the soil property, type of the soil, pH and moisture content of the soil [9,10]. Degradation of pesticide occurs by mainly two processes one is phytoremediation and other is bioremediation. Biodegradation of organic pollutants is a natural process whereby; bacteria and other organisms decay organic molecules into simple substances such as carbon dioxide and water or methane. The ultimate goal of the biodegradation is to entirely transform the organic contaminants into harmLess constituents such as the carbon dioxide and water. Phytoremediation is a process to clean up contaminants by making use of plants. Certain pesticides leach into the lower layers of the soil, are absorbed by plant roots, accumulate in the food chain, and ultimately become biomagnified in the food web because they are more resistant to degradation by abiotic (physical, chemical, and other factors) and biotic (living organisms, such as the micro-, meso-, and macroorganisms of the soil food web) agencies [11].

2. TYPES OF PESTICIDES

2.1 Organophosphate Pesticides

Organophosphate are the compounds which works by inhibiting an enzyme, acetyl cholinesterase at cholinergic junctions of the nervous system. Organophosphate are highly toxic to insects as compare to humans and domestic animals. Examples of organophosphates include the following insecticides: Malathion, parathion, diazinon, fenthion, dichlorvos, chlorpyrifos, ethion, coumaphos [12].

2.2 Organochlorine Insecticides

Organochlorine compounds are chlorinated hydrocarbons. It includes pesticides like aldrin, chlordane, dieldrin, heptachlor, DDT, etc. compounds. Organochlorine insecticide are a group of pesticides that are not easily degradable so most of them have been banned but few are still registered for use.

2.3 Carbamate Pesticides

Carbamate insecticides are derivative of carbamic acids and the first carbamate insecticide was carbazyl [15]. They inhibit acetyl cholinesterase enzyme and cause over stimulation of nervous system. Several subcategories within the carbamates are carbosulfan, aldicarb, carbofuran, carbaryl, etc. Carbamate and OP insecticides are often used in combination to achieve synergistic interaction and controlling a wide range of insects, including those that are resistant.

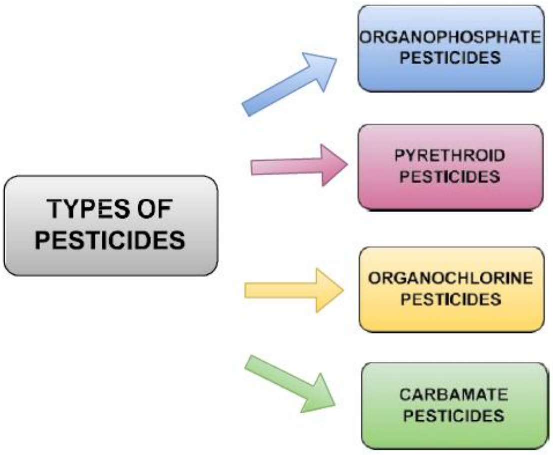

Fig. 1. Different types of pesticides (by author)

Table 1. Toxicity and physical properties of pesticides

Class of pesticide	Example	Physical property	Toxicity
Organo-phosphate pesticide (lipid soluble, low vapour pressure, a high water–oil partition coefficient)	Dichlorvos C4H7Cl2O4P	Clear, slightly yellow liquid with a mild odour, combu stible	Suspected carcinogen, may affect the central nervous system
	Ethion C9H22O4P2S4	Colourless or light brown to pale yellow liquid or dust	Affect central nervous system and nose, chest, gastrointestinal system
	Malation C10H19O6PS2	Clear brown to colourless liquid with mild skunk-like odou	Affects eye, skin, respiratory and central nervous system, nose irritant
	Chlorpyrifos C9H11Cl3NO3	White or colourless granular crystals, gas like odour	May affect the liver and central nervous system
	Diaznon C12H21N2O3PS	Oliy colourless liquid	Skin and eye irritant, can cause gastrointestinal symptoms
Organo-chlorine pesticide (High persistence, low polarity, high lipid solubility, low aqueous solubility)	Chlordane C10H6Cl8	Viscous amber to colourless liquid with a mild odour	Affect central nervous system, liver and gastrointestinal tract, Suspected carcinogen,
	DDT C14H9Cl5	Colourless solid or white to slightly offwhite powder with faint odour	Probable carcinogen, eye, liver, nose, throat, skin and kidney problems.
	Lindane C6H6Cl6	White or colourless	Suspected carcinogen,

Class of pesticide	Example	Physical property	Toxicity
		crystalline solid with slight musty odour	affects reproductive, central nervous and respiratory systems
	Pentachloro phenol C_6Cl_5OH	Colourless to white crystalline solid with benzene-like odour	Affect eye, nose, skin, throat irritant, liver and kidney damage, Possible carcinogen,
Carbamate pesticide (relatively polar, highly soluble in water, and chemically reactive)	Methomyl $C_5H_{10}N_2O_2S$	Colorless to white crystalline solid, Slight sulfurous odour	nausea, abdominal cramps, chest discomfort, affect central nervous system
	Bendiocarb $C_{11}H_{13}NO_4$	White solid, Odourless	Nasal vomiting, discharge, diarrhea, muscle twitching, and problems with coordination
Pyrethroid pesticide (high octanol-water partition coefficients, Highly nonpolar nature of low water solubility, low volatility)	Permethrin $C_{21}H_{20}Cl_2O_3$	Clear, slightly yellow liquid with a mild odour, combu stible	Negative impact on eye, skin, central nervous system and respiratory irritant,

[13,14]

2.4 Pyrethroid Pesticides

Pyrethroids are synthetic derivates of pyrethrins, which are natural organic insecticides produced from the flowers of Chrysanthemum flowers. Some of the commonly used pyrethroid are permethrin, cypermethrin, deltamethrin.

3. TREND IN PESTICIDE PRODUCTION AND CONSUMPTION IN INDIA AND ASIAN COUNTRIES

With an annual production of 90,000 tonnes, India is one of the leading producers of pesticides in Asia and holds the 12th position globally in terms of pesticide production, having begun producing them in 1952 [16]. The Standing Committee on Chemicals and Fertilizers of India (2013) estimates that both total as well as per hectare consumption of pesticides in India show significant increase after the year 2009-10. Pesticides are produced in the country on an annual basis in amounts of roughly '8000 crore, of which '6000 crore worth of pesticides are used domestically and the remainder is exported. According to the government, the amount of technical grade chemical pesticides consumed has decreased from 72,130 tonnes in 1991–1992 to 56,090 tonnes in 2012–2013. This extensive fluctuation over time could be due to weather parameters and availability in the market [17].

The pesticides usage in Pakistan started in 1954 and the pesticides production in Pakistan increased to 78,132 tonnes per annum in 2003 [16]. In Sri Lanka, the DDT was the first pesticide used after World War II for malaria eradication [18]. Pesticides were introduced in Thailand and Vietnam around the middle of the 1950s. Pesticide use in Vietnam increased in the middle of the 1980s with the country's economic liberalisation (Table 2).

Table 2. Annual pesticide consumption in different Asian Countries [19]

Sl. No.	Country	Pesticide used (tonnes)
1	China	1807000
2	India	56120
3	Malaysia	49199
4	Pakistan	27885
5	Thailand	21800
6	Vietnam	19154
7	South Korea	19788
8	Bangladesh	15833
9	Myanmar	5583
10	Nepal	454
11	Bhutan	12

State-level consumption of chemical pesticides in India in 2012–13, Uttar Pradesh, Maharashtra, Andhra Pradesh, Punjab, and Haryana account for 70% of the nation's overall pesticide usage. Each year, twelve states utilise more than 1000 tonnes. The largest user, with 9035 tonnes, is

Uttar Pradesh. Pesticide use is relatively low in Sikkim, Mizoram, Goa, Meghalaya, Nagaland, Manipur, and Arunachal Pradesh (less than100 tonnes each). The remaining states (Kerala, Madhya Pradesh, Jharkhand, Bihar, Himachal Pradesh, Chattisgarh, Odisha, Uttarakhand, and Assam can be categorised asmedium users, where the consumption of pesticides ranges from 100 to 1000 tonnes [20].

3.1 Effect of Pesticides on Plants

The ultimate aim of pesticide is to kill or control the growth of target organism by various mechanism such as inhibition of photosynthesis, cell division, enzyme function, root and shoot growth, leaf formation; interference with the synthesis of pigments, proteins or DNA; destruction of cell membranes; or the promotion of uncontrolled growth [21]. Plants responses differently to the stress induced by different pesticides. Application of pesticides impact a variety of enzymatic and non-enzymatic, physiological and biochemical processes in a plant's life, early from germination to growth and excessive dose of pesticide leads residues in plant, fruits, vegetables and other non-target organism [22,23].

Table 3. List of commonly used pesticides with their recommended dosage in relation to target organism

Pesticide type	Chemical Composition	Active ingredient	Recommended dose	Against
Insecticides	Cypermethrin	25% EC	0.5mL/L	Borer, bollworm, sucking pests
	Chlorpyrifos	20% EC	1.5-2.5 mL/L	Leaf hopper, BPH, termites, sucking pests
	Deltamethrin	2.8% EC	1mL/L	Leaf minor, white flies
	Methomyl	40%	1 mL/L	Bollworms, borer, succing pests
	Profenofos	50% EC	1.5-2 mL/L	Bollworm, sucking pests
	Thiamethoxam	25%	0.2g/L	Sucking pest, Aphids, Hoppers, WF,Root grub
	Melathion	50% EC	1 mL/L	Caterpillars, fruitborer, gallmidge fly, leaf eating caterpillar, stem borer
	Flubendiamide	39.35%	1 mL/l	Borer & Caterpillar
	Carbosulfan	25% EC	1-1.5 mL/L	Aphid, borer, hoppers
	Imidacloprid	17.80%	0.25-0.5 mL/L	Sucking pests
	Phorate	10%, 10%G	25-30 kg/Ha	Termites, nematodes
	Abamectin	1.90%	0.25 - 0.5 mL	Spoders & mites in ornamentals
	Carbofuron	3%G	5 kg/acre	stem borer, cutworm white grub, termite, shootfly, stem borer, aphids, thrips, jassids
	Deltamethrin + Triazophos	1%+35%	1.5mL/L	Succing pests, bollworm & leaf minor
	Lambda-cyhalothrin	5% EC	0.5mL/L	Borer, weevils, aphids, jossids, thrips, whiteflies
	Dimethoate	30%	1-1.3 mL/L	Borer, mites, catterpillars, sucking pests
	Quinolphos	25%	0.5-1.5 mL/L	Sucking pests, borer,
Fungicides and Bactericide	Carbendaziem	50%	2 g/Kg or 0.5 g/L	Blasts, blight, PM, rots, wilts
	Benomyl	50% WP	0.5 mL/L	Powdary mildew, Anthrachnose, leaf spot, rots, rust
	Captan	50%	WP 2 - 2.5 g/L	Daming off, rots
	Hexaconozole	5%	0.5-1 mL/L	Powdary mildew
	Tebuconazole	25.9%	2.5 mL/L	Tikka, Rust, Sheath blight,Dieback, Anthracnose, Spots

Pesticide type	Chemical Composition	Active ingredient	Recommended dose	Against
	Iprodione + Carbendazime	25% +25%	1 g/L	Sheath blight & blast in rice
	Metalaxyl + Mancozeb	4%+ 64%	1-1.5 g/L	Wilts, leaf spots, downy mildew, fruit rot, late blight
	Streptomycin sulphate +Tetracycline	90%+ 10%	0.1 g/L	Bacterial diseases
Herbicides	Paraquat dichloride	24% SL	2.5-4 mL/L	Weeds
	Anilofos	30% EC	1-1.5 mL/L	Weeds
	Glyphosate	41% SL	2 mL/L	Weeds
	Atrazine	50% WP	1-2 g/kg	Weeds
	Oxyfluorfen	23.5% EC	2 mL/Lit	Weeds

(Ministry of Agriculture & Farmers Welfare, 2022)

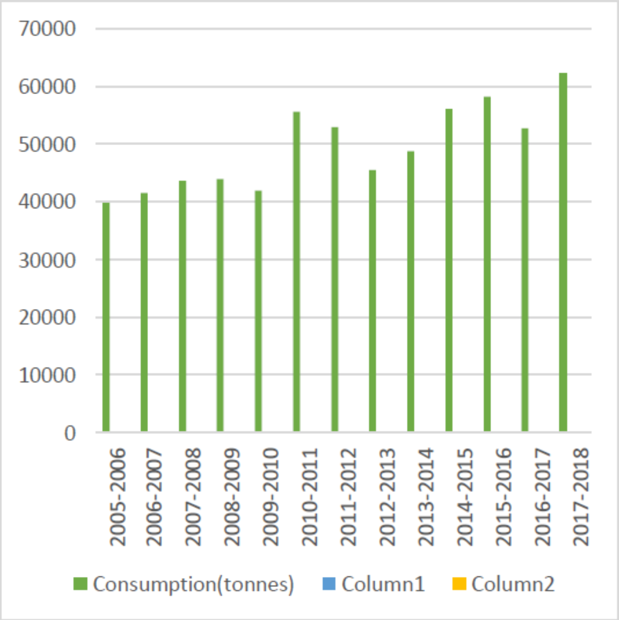

Fig. 2. Trend in consumption of pesticides in India: 2005-2006 to 2017-18
(Source: Based on data from Ministry of Chemicals and Fertilizers.)

3.1.1 Germination

Several workers have studied the adverse effects of pesticides on seed germination. When seeds were treated with insecticides such as Emamectin benzoate, Imidacloprid, Alpha-cypermethrin, Lambda-cyhalothrin, a stimulatory effect at low concentration was observed in Lycopersicon esculentum, tomato [24]. Similarly grain of Triticum aestivum (wheat) showed improved germination when soaked in thiamthoxam, difenoconazole and metalaxyl at concentration 325mL/100kg seed [25]. Some insecticides were found to effect negatively as in Cenchrus setigerus, Pennisetumn pedicellatum., when seeds were treated with chlorpyrifos, cypermethrin, fenvalerate, a significant reduction in seed germination at concentration 0–100 mg/Kg was found [22].

3.1.2 Growth

Pesticide effect on growth vary according to different concentration and generally stimulate the growth at low concentration and inhibit at high concentration. Dhanamanjuri et al. [26]) reported increase in radical and plumule growth when seeds of Cicer arietinum were treated with a fungicide Carbendazim (bevistin) at 10mg/L and seeds of Zea mays were treated at 1mg/L. Likewise, A study was carried out by Hassan et al. 2018 in which grain of Triticum aestivum (ARRI-2011, Millat-2011) were treated with insecticide (Imidacloprid, Thiamethoxam) and fungicide (Tebuconazole) alone as well as in combination and found significant increase in root and shoot length of both varieties treated with Imidacloprid+ Tebuconazole and Thiamethoxam + Tebuconazole compared to seeds treated with Imidacloprid and Thiamethoxam alone.

3.1.3 Antioxidant activity

It has been observed in many studies that accumulation of pesticides produces Reactive oxygen species (ROS) such as superoxide anion O 2- which damage the membrane lipids but also stimulates the production of antioxidant enzymes, including glutathione reductase, peroxidase, ascorbate peroxidase, catalase, glutathione S-transferase and superoxide dismutase. When Tomato (*Lycopersicon esculentum*) was exposed to insecticides Imidacloprid, Emamectin benzoate and alpha cypermethrin by foliar spray, higher concentrations significantly increased ROS levels, caused reduced cell viability and membrane damage both in root and shoot tissues. To cope with oxidative stress shoot tissues produced more antioxidants as compared to root tissues [23]. This effect was also observed by application of herbicides as simetryne in Triticum aestivum caused accumulation of ROS and leads to membrane damage but also enhanced antioxidant enzymes production.

3.1.4 Biochemical and physiological changes

The herbicide pendimethlin treated seeds at concentration 0-10 mg/L resulted in high content of seed reserves as total protein, carbohydrate, starch and reducing sugar in the endosperms of Zea mays [28]. In a similar study [29] seeds of Vigna radiata were treated with insecticide chlorpyrifos at concentrations 0-1.5mM and found that 0.6 and 1.5 mM showed greater toxicity by decreasing soluble sugar, protein, nitrate, and nitrate reductase activity, whereas at low concentration (0.3 mM) chlorpyrifos act as stimulant for same parameters. Many pesticides have been found to inhibit the physiological processes such as photosynthesis, chlorophyll and carotenoid content.

According to Zheryakov and I Zheryakova, [36] When herbicides were treated with micro-fertilizers, the amount of chlorophyll a and b pigments was 4% greater and in contrast, the chlorophyll content of the leaves was 0.350% by weight. Inhibitory effect of dimethoate was observed by Mishra et al. [37] in which dimethoate inhibited photosynthetic reaction by acting on PSII. The stimulatory dose of dimethoate 50mg/L also caused inhibition in PSII and complete chain reaction that may be due to the damage of oxygen evolving complex (OEC). Further increase in dimethoate concentration to 100 and 200mg/L leads to interruption of reduction site of PSII, plastoquinone. Similarly, Kana et al. [38] treated Hordeum vulgare L. with Clomazone (0.25 and 0.5 mM) and observed reduction in carotenoid, chl a and b content and increase in chl a/b ratio. In the study of Gomes et al. [33] a negative effect of herbicide treatment was reported where application of Glyphosate and aminomethyl-phosphonic acid (AMPA) caused reduction in chlorophyll content and process of photosynthesis.

3.2 Effect of Pesticide on Soil Microbial Flora

Soil quality maintenance depends on the activities of soil microorganisms for organic matter breakdown, residue degradation, and nutrient transformations [39-41]. The pesticide residual in soil disrupts soil microorganisms, soil enzymes like hydrolases, phosphatase, oxidoreductases and dehydro- genases as well as physicochemical soil characteristics, which in turn affects soil fertility [42]. On the other hand, pesticides like cypermethrin (pyrethroid), monocrotophos, and quinalphos (organophosphates) have a tendency to boost the activity of the amylase and cellulase enzymes. Therefore, pesticide residue has a negative impact on soil microbial flora, activity, and processes like ammonification, nitrogen fixation, nitrification (driven by ammonia-oxidizing archaea [AOA], ammonia-oxidizing bacteria [AOB]), and microbial nitrogen-fixation processes (driven by N2-fixing bacteria), which compromises the soil's normal capacity to supply nitrogen [43,44].

In soil, there are many distinct types of microbes, including bacteria (eubacteria, archaebacteria), cyanobacteria, actinomycetes, fungus, and algae. Depending on the chemical dosage, the soil's characteristics, and other environmental factors, different pesticides have different effects on soil microorganisms. Mehjin et al. [45] studied the effect of herbicide glyphosate and insecticide cypermethrin and found the inhibitory effect on growth and activities of micro-organism such as

Table 4. Effect of pesticide on germination, growth and various physiological parameters of plants

Chemical used	Pesticide type	Class	Crop/plant	Mode of application	Conc. /dosage	Effect	References
Chlorpyrifos, Cyper- methrin, Fenvalerate.	Organophosphate Pyrethroids	Insecticide	Cenchrus setigerus Pennisetumn pedicellatum	Soil	0–100 mg/Kg	Compared to cypermethrin and fenvalerate, seed germination is reduced and delayed at higher concentrations of chlorpyrifos (75 and 100 mg/kg).	Dubey and Fulekar, [22]
Chlorpyrifos	Organophosphate	Insecticide	Vigna radiata	Foliar	0-1.5mM	Height, branch count, leaf count, leaf area, and biomass of the plant increased. All of the above characteristi cs were negatively impacted by further increase in pesticide level.	Parween et al. [30]
Chlorpyrifos	Organophosphate	Insecticide	Vigna radiata	Foliar	0–1.5mM	At low concentration (0.3 mM) chlorpyrifos act as stimulant whereas deleterious impact was observed at concentrations of 0.6 and 1.5 mM by lowering nitrate, NR activity, soluble sugar content, and protein content.	Parween et al. [29]
Pendime- thalin	_	Herbicide	Zea mays	In Hoagland Solution	0-10mg/L	With an increase in pendimethalin concentration, treated seeds showed a significant decrease in germination, length of the radical, and plumule, as well as a high total protein,	Rajashekhar et al. [28]

Chemical used	Pesticide type	Class	Crop/plant	Mode of application	Conc. /dosage	Effect	References
						carbohydrate, starch, and reducing sugar in endosperm.	
Thiamthoxam, Difenoconazole Metalaxyl	Neonicotinoid	Insecticide	Triticum aestivum (wheat)	Treated seeds in plots	325mL/100kg seed	Improved freezing tolerance and germination of spring wheat	Larsen and falk. [25]
TOPIK, EC	_	Herbicide	Zea mays L. Triticum aestivum L. Secale cereale L.	Foliar	8–800 µg/L.	Intensification of lipid peroxidation (LPO), production of superoxide anion (O2), total antioxidant activity (AOA), and activity of the enzymes catalase (CAT) and ascorbate peroxidase (APOX).The leaves of maize and winter wheat treated with 800 lg/L CP showed the highest degree of O2- generation. Winter rye and wheat had the highest levels of antioxidant enzyme activity while maize had the lowest levels.	Lukatkin et al. [31]
Carben- dazim (bevistin)	_	Fungicide	Cicer arietinum, Zea mays	Seeds treated in petri plates	10mg/L 1mg/L	Stimulated germination, growth of radical and plumule	Dhanamanj uri et al. [26]
Emamectin Benzoate, Imidacloprid Alphacyper methrin, Lambda-cyhalothrin	Neonicotinoidsz Pyrethroids	Insecticide	Tomato (Lycopersicon esculentum)	Seeds soaked in pesticide solution	10-60mg/L, 125- 2000 mg/L 30-500mg/L	At low conc. have stimulatory effect on germination, root and shoot biomass and length but inhibitory effect at high conc.	Shakir et al. [24]

Chemical used	Pesticide type	Class	Crop/plant	Mode of application	Conc. /dosage	Effect	References
Simetryne (s-triazine herbicide)	_	Herbicide	Triticum aestivum	Soil	0.8 to 8.0 mgkg_1	Suppressed growth and decreased chlorophyll content. Accumulation of simetryne produced ROS which injured the membrane lipids but also stimulated the production of antioxidant enzymes, including superoxide dismutase, catalase, peroxidase, glutathionereductase and glutathione S-transferase.	Jiang et al. [32]
Glyphosate and Aminomethylphosphonic acid (AMPA)	_	Herbicide	Salix miyabeana	Foliar spray	0- 2.8 kg ha−1	Both chemicals showed accumulation of ROS, decrease in chlorophyll content and rate of photosynthesis.	Gomes et al. [33]
Malathion	Organo- phosphate	Insecticide	Allium cepa	In Hoagland's nutrient solution	50- 375 mg/L	Malathion-induced mitotic alterations as breakage and laggard formation. Malathion at 375 mg/L showed higher levels of malondialdehyde content, catalase and superoxide dismutase than the control, while the activity of peroxidase was low. The effective concentration for root growth was 250 mg/L, whereas the stronger inhibition was observed at 375 mg/L	Singh and Roy, [34]

Chemical used	**Pesticide type**	**Class**	**Crop/plant**	**Mode of application**	**Conc. /dosage**	**Effect**	**References**
Imidacloprid Thiamethoxam Tebuconazole	Neonicotinoids	Insecticide Fungicide	Triticum aestivum (ARRI-2011, Millat-2011)	Seed	Imidacloprid+Tebuconazole@ 4 mL/kg seed Actara +Tebuconazole @ 0.6 g + 1.57 mL/kg seed Imidacloprid @ 2.5 g/kg seed Actara (Thiamethoxam) @ 0.6 g/kg seed	Significant increase in germination of seeds, root and shoot length and yield of both varieties treated with Imidacloprid+ Tebuconazole and Thiamethoxam + Tebuconazole compared to seeds treated with Imidacloprid and Thiamethoxam alone.	Hassan et al. [27]
Emamectin Benzoate, Imidacloprid Alpha-cypermethrin	Neonicotinoids Pyrethroids	Insecticide	Lycopersicon esculentum	Foliar spray	Emamectin-10-160mg/L, Cypermethrin-30-500mg/L Imidacloprid- 125-2000 mg/L	In root and shoot tissues, higher amounts of pesticides intensified ROS levels, damaged membranes by forming TBARS, increased cell injury, and decreased cell viability. Shoot tissues produced more antioxidants than root tissues did to combat oxidative stress.	Shakir et al. [23]
DDTs (DDT + DDE + DDD)	Organochlorine	Insecticide	Lycopersicon esculentum and Cucurbita pepo	Soil	63.5–101.3 ng g^{-1} dry weight of DDT and 381.4–455.3 ng g^{-1} dry weight of DDE	No effect on CAT activity or protein content in any of the species. When exposed to DDTs, tomato plants produced more GR and GPX in their stems and leaves and less GST in their roots. No impact was seen in zucchini.	Mitton et al. [35]

Table 5. Effect of pesticide on soil microbial flora

Chemical used	Class	Micro-organism	Concentration /dosage	Effect	Reference
Chlorpyrifos	Insecticide	Bacteria, fungus	Dilution 10-1-10-4	There was no significant impact or decrease of the bacterial population in the soil of the marigold rhizosphere and the bacterial population in canna rhizosphere crashed in presence of pesticide.	Hindumathy and Gayathri, [54]
Chlorpyrifos, Cypermethrin and Azadirachtin	Insecticide	Bacteria, fungus	For chlorpyrifos and cypermethrin 3.6 mg/kg-18 mg/kg for azadirachtin 0.26 mg/kg-1.13g/kg	Azadirachtin mimics cypermethrin and chlorpyrifos at high concentrations. At various phases of plant growth, a negative impact was seen on the bacterial and fungal populations. Numerous genes and transcripts involved in nitrogen fixation (nifH), nitrification (amoA), and denitrification (narG, nirK, and nirS) also exhibited negative effects.	Singh et al. [55]
Hexaconazole	Fungicide	Soil microbes	0.6 – 6 mg kg−1	At 6 mg/kg, soil basal respiration (RB) and microbial biomass carbon (MBC) were negatively impacted, whereas NO3-N concentration and populations of ammonia-oxidizing bacteria temporarily increased.	Chao Ju et al. [56]
Imidacloprid	Insecticide	Phosphate solubilizing bacteria, Actinomycetes, Biological nitrogen fixers and fungus Soil enzymes	RD i.e. 25 g a.i. ha−1 to 10 RD 250 g a.i. ha−1,	A higher dose (10RD) significantly reduces bacterial and fungal populations. Actinomycetes and asymbiotic biological nitrogen fixers were found in varying numbers. Control soil was found to have the largest BNF population, whereas soil treated with 2RD was found to have the lowest BNF population. However, as compared to the beginning population of the corresponding treatments, the BNF population reduction was greatest in the 5RD and 10RD treatments.	Mahapatra et al. [57]
Carbendazim, Imidacloprid Glyphosate	Fungicide Insecticide Herbicide	Pseudomonas putida and Bacillus amyloliquefaciens	Imi(10 to 2.09 %) Gly(10 to 0.15 %) Car (1 to 0.15 %)	These bacteria showed the ability to tolerate the pesticide at as Imidacloprid (3.27%), Carbendazim (0.512%), and Glyphosate (3.27%). Increase in PGP activities like, exopolysachchride production, IAA production biofilm synthesis, phosphate	Kumar et al. [58]

Chemical used	**Class**	**Micro-organism**	**Concentration /dosage**	**Effect**	**Reference**
				solubilization and siderophore production was observed.	
Glyphosate Alphacype- rmethrin Malathion	Herbicide Insecticide	Bacteria, actinomycetes, Fungi, algae	0-200mg/L	The amount of pesticides added to the soil had an adverse relationship with the microbial activity and the quantity of bacteria, actinomycetes, and fungi. The number of micro-organism were decreased in all the concentration of pesticides but highest reduction was observed at 200mg/L.	Mehjin et al. [45]

Table 6. Effect of pesticides exposure on residues of different plant species

Plant species	**Pesticide detected**	**Class**	**Range of detected residues**	**References**
Bhindi	Cypermethrin	Insecticide	0.001 mg/L	Shinde et al. [52]
Rice	Chloripyrifos Ethion Bifenthri Profenofos Malathion Aldrin	Insecticides	0.05 mg/kg 0.01 mg/kg 0.01 mg/kg 0.01 mg/kg 0.02 mg/kg 0.01 mg/kg	Jagadish et al. [53]
Wheat	Chlorpyrifos Profenofos Malathion Aldrin Cypermethrin Dichlorovos Cyhalothrin-L	Insecticides	0.05 mg/kg 0.01 mg/kg Not available 0.01 mg/kg 2.0 mg/kg Not available 0.05 mg/kg	Jagadish et al. [53]
Red gram	Chlorpyrifos Ethion Triazofos Malathion Cypermethrin	Insecticides	0.05 mg/kg 0.01 mg/kg 0.01 mg/kg Not available 0.05 mg/kg	Jagadish et al. [53]
Ch. Cabbage	Acetamiprid Azoxystrobin Cypermethrin Deltamethrin Dimethoate Diflubenzuron	Insecticides and fungicides	1.5 mg/kg 6 mg/kg 1.0 mg/kg 0.5 mg/kg	Kocourek et al. [59]

Plant species	**Pesticide detected**	**Class**	**Range of detected residues**	**References**
			0.2 mg/kg 1.0 mg/kg	
Cauliflower	Acetamiprid Azoxystrobin Cypermethrin Deltamethrin Dimethoate Diflubenzuron	Insecticides and fungicides	0.4 mg/kg 5 mg/kg 0.5 mg/kg 0.1 mg/kg 0.2 mg/kg 1.0 mg/kg	Kocourek et al. [59]
Cowpea	Dieldrin aldrin hexachloride pp-DDE Endrin Endosulfan	Insecticides	20.14 mg/kg 7.81 mg/kg 1.23 mg/kg 1.82 mg/kg 13.49 mg/kg	Olutona, [60]
Beans	Diel-drin Endosulfan II Endrin CHO	Insecticides	0.99 mg/kg 1.02 mg/kg 1.66 mg/kg	Olutona, [60]
Orange	Chlorpyrifos, Diazinon	Insecticides	7.05 mg L−1 6.66 mg L−1	Kashi et al. [61]
	Malathion		12.38 µgL−1	
Apple	Chlorpyrifos, Diazinon Malathion	Insecticides	0.74 mgL−1 0.70 mgL−1 1.10 µgL−1	Kashi et al. [61]
Tomato	Chlorpyrifos, Diazinon Malathion	Insecticides	0.60 mgL− 0.57 mgL−1 0.89 µgL−1	Kashi et al. [61]
Chilli	Chlorpyrifos Dimethoate	Insecticides	0.74 mg kg-1 0.61 mg kg-1	Megawati et al. [62]

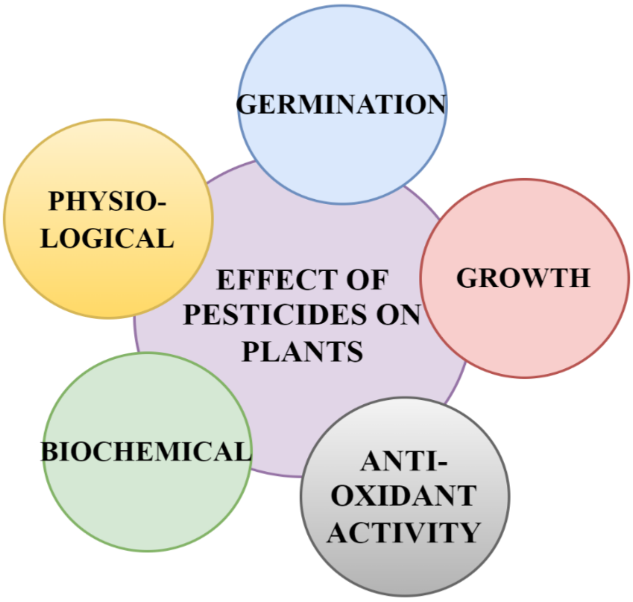

Fig. 3. Effect of pesticides on plants (by author)

nitrifying, ammonifying, denitrifying bacteria, algae, fungi and actinomycetes.

3.3 Pesticide Residue in Agricultural Produce

The use of pesticide has been increased due to increasing population and hence demand of food. Excessive use of pesticide leaves harmful residues in grain, fruits and vegetables which has become the part of food chain and now is the major public health concern. When the food contaminated with pesticide is consumed over long period of time, it leads to increase in body fat. Thus, determining the level of pesticide residue and mitigating the potential health risks from pesticide residues are crucial. Maximum residue levels (MRLs) for specific crops have been established by the European Union in Regulation of European Commission [46], and MRLs for all crops and all pesticides can be found in the MRL database on the Commission website [47]. The Maximum Residue Limits (MRLs) for pesticides vary greatly even for the same product, between nations as well as with the international Codex Committee standards [48]. However, because the majority of chemical messengers in our bodies function at incredibly low concentrations of mg/L or even ppb, it is impossible to say with certainty that there is ever a "safe" amount of pesticide residues in food [49]. Due to environmental persistence and accumulation in plants, animals and sediments, few pesticides such as OCP have been banned since1970s. The determination of pesticide residues is generally performed by GC and HPLC using specific detectors, such as MS and ECD [50]. Fernandes et al. [51] studied pesticide residue in strawberries when pesticide sprayed in the range of 0.005-0.250 mg/kg. They found Lindane and β-endosulfan above the MRL in Organic farming and Integrated Pest Management while other OCP (aldrin, o,p 0-DDT and their metabolites, and methoxychlor) were found below the MRL. In another study Cypermethrin was applied separately in three different concentrations i.e., 50mg/L, 75mg/L, 100mg/L on okra crops and the residue were determined 0,1,3,5, 7,9,11,13,15,17,19 and 21 days after application [52]. The results indicate that the residue below the detectable level were found after 17 days. The residue of different pesticides such as Organochlorines (OC), Organophosphates (OP), Synthetic pyrethroids (SP) and carbamate were also monitored by Jagadish et al. [53]. They examined 250 samples, among them 80 samples were found to be contaminated with various pesticide groups.

In 22 samples, pesticide residue level was found to be higher than the Maximum Residue Limit (MRL), while below MRL in 58 samples.

3.4 Pesticides Banned in India

There are many pesticides which are banned (Ministry of Agriculture & Farmers Welfare, central insecticide board & registration committee, Faridabad 2022) [63-65] and have been categorized as:

3.4.1 Pesticides banned for manufacture, import and use

Aldrin, Benzene hexachloride, Calcium cyanide, Chlorbenzilate, Chlordane, Chlorfenvinpho,s Copper acetoarsenite, Dibromochloropropane, Dieldrin, Endrin, Ethyl mercury chloride, Ethyl parathion, Ethylene dibromide, Heptachlor, Lindane, Maleic hydrazide, Menazon, Metoxuran, Nitrofen, Paraquat dimethyl sulphate, Pentachloro nitrobenzene, Pentachlorophenol, Phenyl mercury acetate, Sodium methane arsonate, TCA, Tetradifon, Toxaphene.

3.4.2 Pesticide formulations banned for import, manufacture and use

Carbofutran 50% SP, Methomyl 12.5% L, Methomyl 24% formulation, Phosphamidon 85% SL, Alachlor 50% EC, Dichlorvos 76.00% EC.

3.4.3 Pesticide formulations banned for use but continued to manufacture for export

Captafol 80% Powder, Nicotin sulfate.

3.4.4 Pesticides withdrawn

Dalapon, Ferbam, Formothion, Nickel Chloride, Paradichlorobenzene, Simazine, Warfarin.

4. CONCLUSION AND FUTURE PERSPECTIVE

It can be concluded from present review that the use of pesticides is a practical means of controlling pests. However, using pesticides in excess of the dosage advised has negative effects on both target and non-target crop growth. It is necessary to inform pesticide dealers and farmers about the proper and ideal applications of pesticides in light of their side effects. The edible part of crop has been found to be contaminated with multi pesticide residue above the MRL and hence more efficient techniques should be developed for dissipation of pesticide residues from food grains. Use of organic chemicals, such as: biopesticides and integrated pest management can be the alternative to pesticide. These poses lower or no risk to the environment and human health. Further, the impacts of these pesticides on non-target host plants should be examined at biochemical, anatomical and molecular level to identify the mechanism by which they induce toxicity.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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