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Heavy Uses of Pesticides in India: A Quantitative Analysis

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Abstract: India is an agrarian country. The pace in the use of agricultural pesticides has increased significantly over the decades. In 2020-21, Maharashtra (13243 tonnes) and Uttar Pradesh (11557 tonnes) would have the highest pesticide use, while Punjab (5193 tonnes) and Haryana (4050 tonnes) pesticide consumption slowly decreased as compared to last year. The states of Punjab, Uttar Pradesh, Maharashtra, Haryana, and Andhra Pradesh consumed 70% of all pesticides. Maximum pesticide usage is harmful to humans, animals, and plants. Many researchers discovered pesticide residue even in fishes (37.56 mg l^{-1}, 38.38 ng g^{-1}, 101.28 ng g^{-1}), and mother milk (43.40±0.064 mg kg^{-1}, 33.33±0.055 mg kg^{-1}, 3.45±0.022 mg kg^{-1}) which is an alarming situation. In this review, we try to analyze and draw the full picture related to the excessive usage of pesticides in different states of India and their hazardous impacts on the human body, water, and the environment.

Keywords: Agriculture, Pesticide residue, Insecticides, Herbicides, Health

The economy of India is predominantly based on agriculture which contributes around 18% to the total GDP (Singh and Neog 2020). Pests are estimated to cause a US $42.66 million annual loss of agricultural production in India (Subash et al 2017). Diseases (26%), insects (20%), rodents and birds (10%), weeds (33%), and some other reasons are the roots of this loss (Chauhan et al 2018). Around 30,000 species of weeds, 10,000 species of plant-eating insects, and 3,000 species of nematodes are known to affect crops. Moreover, the land under cultivation is also decreasing due to a significant rise in urbanization. The use of pesticides plays a key role in improving agricultural productivity (average crop yields per hectare) by reducing crop losses due to insects, pests, pathogens, and weeds. This ensures security for rising food demand driven by the continuously growing population, overcoming the problem of reducing arable land, and generating revenues for farmers (Pawlak and Kołodziejczak 2020, Barrett 2021). The significance of pesticides in agricultural production has led to their unregulated and uncontrolled usage depending on monsoons, pest attack incidence, and inadequate knowledge about usage and hazards of pesticides among farmers. The indiscriminate use of pesticides in improving productivity has resulted in the contamination of the environment, agricultural output foods, and bioaccumulation in animals and humans (Kumar et al 2019, Sharma et al 2020, Mishra et al 2021, Rajput et al 2021). The problem will get worse in the future as new pests, weeds and diseases will attack crops which will further increase the use of pesticides and demand for new forms of pesticides. The well-established correlation between pesticide contamination and hazardous effect on the environment and human health has necessitated the need for new effective and ecologically acceptable methods for pest control.

State-wise pesticide consumption in India: According to the Ministry of Agriculture and Farmers Welfare, Department of Agriculture, Cooperation and Farmers Welfare, Directorate of Plant Protection, Quarantine and Storage, the consumption of pesticides in India was 62193 tonnes during the year 2020-2021. The consumption of pesticides has gradually increased over the years. It has shown a sharp increase from 434 tonnes in the year 2000 to 62193 tonnes in 2021 (GOI 2021).

Similarly, per hectare consumption of pesticides has also increased over the years. It has grown to 600 grams per hectare in 2020 from 290 grams per hectare in 2014-2015 (Subash et al 2017). The increase in both total as well as per hectare consumption is corroborated by an increase in domestic production and imports of pesticides (State of Agriculture). At the global level, per hectare, pesticide consumption of India is low (600g) as compared to Japan (12kg), China (12 kg), United Kingdom (7 kg), and Germany (3kg) (Koli and Bhardwaj 2018, Parajuli et al 2021). In India, Maharashtra is the leading consumer of pesticides and the 2020-2021 consumed 13,243 tonnes of pesticide which accounts for 21.2% share of the total consumption (Table 1). Other leading consumer states include Uttar Pradesh, Punjab, Telangana, Haryana, West Bengal, and Jammu & Kashmir (Subash et al 2018, GOI 2021). A sharp increase in consumption has been observed in Jharkhand, Nagaland,

and Jammu, and Kashmir between 2016-2017 and 2020-2021 (GOI 2021). The per hectare consumption of pesticide is highest in Punjab (0.74 kg), followed by Haryana (0.62 kg) and Maharashtra (0.57 kg) during 2016-17 while the consumption levels were lower in Rajasthan, Madhya Pradesh, Karnataka, and Bihar (Sharma et al 2016, Subash et al 2017).

In India, pesticide consumption from 2016-2021, the maximum pesticide consumption was the 2020-21 meanwhile minimum consumption was in 2016-2017 (DAC&FW 2017, GOI 2021). Pesticides have proven to be a boon to farmers, increasing agricultural yields by a huge margin and providing innumerable benefits to society in terms of food security, both directly and indirectly (Mishra et al 2021). The recent increase in pesticide use is said to be because of the higher use of herbicides as the cost of manual weed control has risen due to an increase in agricultural wages (Dhaliwal et al 2000, Subash et al 2017).

In 2020-21, 38% cereals, 10% pulses and oilseeds, 14% cash crop, 11% vegetables, 9% fibres, 4% fruits, 3% other, and 1% in plantation was used pesticide for production. In 2019-20, 37% cereals, 11% pulses and oilseeds, 12% cash crop, 10% vegetables, 11% fibres, 5% fruits, 2% other, and 1% in plantation was used pesticide for production (Table 2). In 2018-19, 39% cereals, 13% pulses, 11% cash crop and oilseeds, 9% vegetables, 8% fibres, 6% fruits, 2% other, and 1% in plantation was used pesticide for production. In 2017-18, 34% cereals, 14% pulses, 9% cash crop and vegetables, 13% oilseeds, 12% fibres, 5% fruits, 3% other, 1% in plantation was used pesticide for production. During 2016-17, 40% cereals, 13% pulses, 12% cash crop, 11% oilseeds, 10% vegetables, 9% fibres, 2% fruits and other, 1% in plantation was used pesticide for production (Bodh and Yadav 2020, GOI 2021).

3% of the cost of cotton cultivation, 1.9% of rice production, and even less of wheat (0.7%) and sugar cane

Table 1. Consumption of chemical pesticides in various states/Union territories (GOI 2021)

States/UTs	Total pesticide consumption (tonnes)				
	2016-17	2017-18	2018-19	2019-20	2020-21
Andhra Pradesh	2015	1738	1689	1559	1559
Bihar	790	840	850	850	995
Chhattisgarh	1660	1685	1770	1672	1639
Goa*	22	24	25	30	30
Gujarat	1713	1692	1608	1784	1573
Haryana*	4050	4025	4015	4200	4050
Himachal Pradesh	341	467	322	881	56
Jharkhand	541	619	646	681	1161
Karnataka	1288	1502	1524	1568	1930
Kerala	895	1067	995	656	585
Madhya Pradesh	694	502	540	540	691
Maharashtra	13496	15568	11746	12783	13243
Orissa	1050	1633	1609	1115	1158
Punjab	5843	5835	5543	4995	5193
Rajasthan	2269	2307	2290	2088	2330
Tamil Nadu	2092	1929	1901	2225	1834
Telangana	3436	4866	4894	4915	4986
Uttar Pradesh	10614	10824	11049	12217	11557
Uttarakhand	198	210	195	224	135
West Bengal	2624	2982	3190	3630	3630
Assam	306	241	256	410	420
Nagaland*	20	20	21	19	36
Jammu and Kashmir*	2188	2430	2459	2198	3352
Total	58145	63006	59137	61240	63143

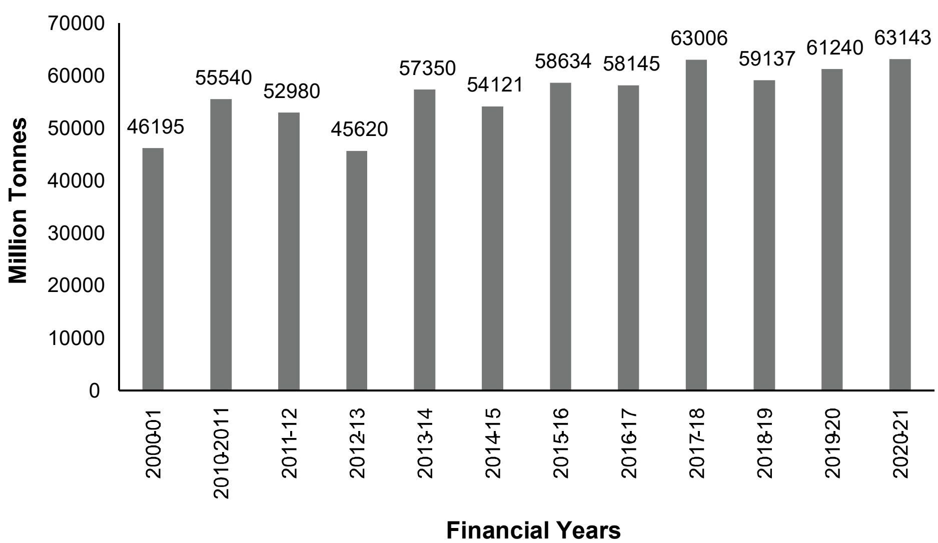
Source: States/UTs Zonal Conferences on Inputs (Plant Protection) for *Rabi* and *Kharif* Seasons
*Figures of 2019-20 for this State have been taken from inputs provided by the States/UTs during Zonal Conference (PP) for *Rabi,* 2020-21 Season

production was made up of pesticides (0.3 percent). According to statistics published by the Agricultural Input Survey (AIS), Cotton (66.70%), followed by Arhar (64.74%), Jute (53.27%), and Rice (48.62%) accounted for the largest share of the pesticide area in 2011-12 (Subash et al 2017, GOI 2021) with the introduction of Bt seed.

Quantitative Analysis of Pesticide Consumption in India

In agriculture, there has been wide use of pesticides to enhance crop yield by saving or losses caused by the pest. Availability of financial help at a low interest rate has also resulted in a hike in the use of pesticides (Krishnakumar 2019, Damalas and Koutroubas 2020). Pesticides are applied at the cultivation time as well as storage time of cereal grains, vegetables, and fruits. The indiscriminate and irrational use of pesticides is resulting in the accumulation of pesticides in food products and the environment. Some of the pesticides or their derived compounds are accumulated in the plant including the plant product (fruits, grains, nuts, vegetable oils, and vegetables) (Grewal 2017, Albuquerque et al 2020). This has finally led to the bio-magnification of pesticide residues in the food chain. Pesticide residues have been detected in fish, humans. Thus, bioaccumulation of pesticides is a serious concern. To keep a check on the quality of food or feed being consumed, the government, as well as other organizations, have set a maximum residue level (MRL) for every pesticide (Abhilash et al 2009, Charon et al 2019, Crépet et al 2021). Different countries have different authorities to regulate MRL values for different pesticides. At the global level, the MRL value remains variable. In India, the MRL value of crops, fruits, vegetables, grains, and other consumed food is set by the Food Safety and Standards Authority of India (FSSAI) (Li 2018, Koli and Bhardwaj 2018).

Water sampling collected from three locations (Palur



Source: Based on the data Ministry of Agriculture and Farmers Welfare

Fig. 1. Trend in total consumption of pesticides (GOI 2021)

Table 2. Demand of chemical pesticides on commodity basis (in million tonnes)

Crops	2016-17	2017-18	2018-19	2019-20	2020-21*
Cereal	18356	15674	17270	14937	17149
Vegetable	4683	4186	3845	3870	4773
Pulse	5837	6594	5759	4390	4567
Oilseed	4979	5707	4881	4565	4723
Fruit	1194	2171	2449	2242	1665
Plantation	327	420	432	310	338
Cash Crop	5429	4144	4995	4832	6090
Fibre	4128	5336	3567	4281	4006
Other	892	1563	1055	861	1388

*The Commodity-wise data for 2020-21 has been provided by 17 States in Zonal Conference agenda for Kh,2021 (As on 31.03.2021)

Bridge, Daya River Estuary, and Makara River) that revealed organochlorinated (OC) pesticide residues were found in nearly a quarter of the water samples (Kunwar et al 2021). So, Hexachlorocyclohexane (HCH) (&), DDD (Di-chlorodi phenyl di-chloro ethane) (op|), DDE (di-chloro di-phenyl di-chloro ethylene) (op|&pp.|), and heptachlor were detected in concentrations ranging from 0.025 to 23.4 g l^{-1}. None of the eight synthetic pyrethroid (SP) pesticides were detected in water, however chlorpyrifos (0.019–2.73 g l^{-1}) and dichlorvos (0.647 g l^{-1}) were discovered among the organophosphates (OP) (Nag et al 2020). Fish samples were found to be 55 percent polluted, predominantly with OCs and OPs residues and less with SPs. However, because their concentrations were below the allowable limit, there is no immediate harm for human health (Dey et al 2021, Kunwar et al 2021a). Sharma et al 2020 stated that in north-western Himalayan region, mother milk was contaminated with pesticide residue such as p-p'- DDE was found in Sub-mountainous subtropics range of 43.40±0.064 mg kg^{-1}, Sub-humid foot hill is 33.33±0.050 mg/kg, wet, temperate high hill is 3.45±0.022 mg kg^{-1}, p-p'-DDT found in range of Sub-humid foot hill (1.96±0.018 mg kg^{-1}), and wet, temperate high hill (3.45±0.010 mg kg^{-1}) (Table 3). Kumar et al 2020 reported that in tomato and okra pesticide residue was found near Navsari district, Gujarat such as Tomato (92.54 ng g^{-1}(acetamiprid), 87.17 ng g^{-1} (tebuconazole) and Okra (86.10 ng g^{-1} (acetamiprid), 85.94 ng g^{-1} (tebuconazole). There are a lot of growing reports on the presence of pesticides in breastmilk samples from India. Organochlorines, organophosphate, and pyrethroid pesticides have been detected in human breastmilk from the population of Haryana (Mehta et al 2020). Pesticides have been also detected from cow milk, packaged water and soft drinks (Bunch et al 2003, Năstăsescu et al 2020, Tsakiris et al 2021). Some more pesticide residue report in research articles such as:

Implications of heavy use of pesticides: In humans, the bioaccumulation of pesticides is through inhalation or dermal exposure at the pesticide production unit, at the time of use in the fields, consumption of food containing pesticides like agricultural food, fish, or meat chain or passed to infants through breast milk feeding. Occupational exposure has higher chances of resulting in bioaccumulation in humans. Owing to the lipophilic character of pesticides, they usually get in stored in adipose tissue (Pyka and Miszczyk 2005, Dhaliwal et al 2010). Toxicity effects of a pesticide are a factor of quantity and toxicological metabolized properties of pesticide. Organophosphates and pyrethroids are readily by enzymes in the body, so they do not get stored or accumulated. Bioaccumulation in humans build to harmful levels is associated with hazardous short as well as long-term effects (Sharma et al 2020, Rani et al 2020, Hassaan and El Nemr 2020). There is a great possibility binding to acetylcholinesterase of the target pest finally leads to the immune system. The mechanism of work of many pesticides which that the human nervous system will be also affected by the accumulation of pesticides in their body because of common brain chemistry (Sharma et al 2020, Amenyogbe et al 2021).

Ecological effects: The concentrations of organochlorine pesticides (OCPs) in the soil were compared with relevant soil environmental recommendations for ecological risk of OCPs in the soil to estimate the possible ecological danger of OCP residues in the soil. As a consequence, our findings were compared to soil quality requirements recommended by the Canadian government, the National Oceanography and Atmospheric Administration (NOAA) of the United States, the Italian government, and the Chinese government (Kumar et al 2018). DDT (Dichlorodiphenyltrichloroethane) concentrations of up to 1200 ng g^{-1} in commercial and industrial soil and 700 ng g^{-1} in residential and agricultural soil are allowed by the Canadian government (Chakraborty et al 2017). Hexachlorocyclohexane (HCH) levels in agricultural soil should range from 50 ng g^{-1} to 2000 ng g^{-1} in residential soil, according to NOAA (Devi et al 2015, Chakraborty et al 2017). The concentrations of HCH and DDT in all soil samples in our investigation were lower than the Canadian government's and NOAA's suggested guideline ranges. In residential and recreational zones, permissible soil concentration limits for aldrin, dieldrin, and endrin are set at 10 ng/g by Italian environmental legislation (Qu et al 2017). Endrin concentrations in eight soil samples and dieldrin concentrations in three soil samples were found to be higher than the Italian government's limit of 10 ng g^{-1} in our study. The Chinese government defined soil quality as low contaminated (less than 50 ng g^{-1}), lightly polluted (50–500 ng g^{-1}), moderately polluted (500–1000 ng g^{-1}), and seriously polluted (more than 1000 ng g^{-1}) based on HCH and DDT concentrations (Kumar et al 2018, Gereslassie et al 2019, Joseph et al 2020). The amounts of HCH and DDT in all of the soil samples in this investigation fell into the low to moderate contaminated category, according to Chinese government recommendations. For the protection of plants, invertebrates, small birds, and mammals, the maximum permitted concentrations of DDTs in soil are 10, 11 and 190 ng g^{-1}, respectively (Yu et al 2013, Qu et al 2015).The common method of pesticide application is spraying over crops. When the crop is irrigated or rain occurs after the application, the pesticides leach into the soil and finally reach the groundwater. This results in contamination of both soil and water with pesticides. Synthetic pesticides have a very

Table 3. Pesticide residue in different samples

Sample	Sites	Analytical method	Major finding	Pesticide	Reference
Ground water	Thiruvallur district, India		Value (μg L^{-1}) (Structure) 0.1-0.8 (op-DDT) 0.9-3.7 (pp-DDT)	DDT	Jayashree and Vasudevan 2007
			0.1-1.8 (αES) 0.3-3.8 (β ES)	Endosulfan	
			0.02-1.5 (α HCH) 0-0.5 (β HCH) O.1-2.3 (γ HCH) 0-0.9 (δ HCH)	HCH	
Pink lady apple		LC- MS	Value (mg kg^{-1}) (Sample Processing) 6 (No wash) 3.5 (lukewarm wash) 2 (Salted water wash)	Diphenylamine	Dasika 2012
			8 (No wash) 5 (lukewarm wash) 4 (Salted water wash)	Phosmet	
			0.14 (No wash) 0.1 (lukewarm wash) 0.08 (Salted water wash)	Chlorpyrifos	
			0.9 (No wash) 0.7 (lukewarm wash) 0.6 (Salted waterwash)	Malathion	
Pear		LC- MS	6.1 (No wash) 4.3 (lukewarm wash) 3.4 (Salted water wash)	Diphenylamine	Dasika 2012
			3 (No wash) 2.1 (lukewarm wash) 1.8 (Salted water wash)	Imazalil	
			11 (No wash) 8.9 (lukewarm wash) 8.8 (Salted water wash)	Phosmet	
			0.6 (No wash) 0.3 (lukewarm wash) 0.2 (Salted water wash)	Chlorpyrifos	
Guava		LC- MS	4.8 (No wash) 2.2 (lukewarm wash) 1.2 (Salted water wash)	Diphenylamine	Dasika 2012
			4.2 (No wash) 3.6 (lukewarm wash) 3.4 (Salted water wash)	Imazalil	
			9.3(No wash) 7.9 (lukewarm wash) 7.2 (Salted water wash)	Phosmet	
			0.43 (No wash) 0.28 (lukewarm wash) 0.18 (Salted water wash)	Chlorpyrifos	
Indian egg plant		LC- MS	9.8 (No wash) 5.3 (lukewarm wash) 4.4 (Salted water wash)	Diphenylamine	Dasika 2012
			4.2 (No wash) 2.5 (lukewarm wash) 1.8 (Salted water wash)	Imazalil	
			9 (No wash) 8. (lukewarm wash) 6.8 (Salted water wash)	Phosmet	
			1.4 (No wash) 1 (lukewarm wash) 0.8 (Salted water wash)	Chlorpyrifos	
Chinese egg plant			2.2 (No wash) 1.9 (lukewarm wash) 1.5 (Salted water wash)	Endosulfan	Dasika 2012

Cont...

Table 3. Pesticide residue in different samples

Sample	Sites	Analytical method	Major finding	Pesticide	Reference
			9.8 (No wash) 7.3 (lukewarm wash) 6.1 (Salted water wash)	Diphenylamine	
			3.8 (No wash) 2.9 (lukewarm wash) 2.4 (Salted water wash)	Imazalil	
			9.3 (No wash) 6.9 (lukewarm wash) 6.4 (Salted water wash)	Phosmet	
Vegetables and Fruits	Bangalore Rural District		Value (mg/kg) (Sample) 0.057-2.818 (Potato) 0.05-2.241 (Tomato) 0.003-0.009 (Grapes)	Endosulfan	Ramesh and Murthy 2013
			0.013-0.372 (Potato) 0.04-0.078 (Tomato) 0.039-0.068 (Grapes)	MethylParathion	
			0.115-0.513 (Potato) 0.02-2.047 (Tomato)	Malathion	
			0.01-0.09 (Potato) ND (Tomato)	Chlorpyrifos	
			0.003-0.009 (Grapes)	Acephate	
			0.039-0.068 (Grapes)	Cypermethrin	
Mango and Grapes		HPLC	Value ($\mu g\ kg^{-1}$) (Collection area) Mango 13.64± 0.43 (Garden) 10.65± 0.28 (Local market) 8.54± 0.55 (Reliance fresh) Grapes 14.85± 0.34 (Garden) 11.27± 0.50 (Local market) 8.63± 0.24 (Reliance fresh)	Methyl parathion	Rao and Kumar 2012
			Mango 7.38± 0.34 (Garden) 6.39± 0.67 (Local market) 5.35± 0.28 (Reliance fresh) Grapes 9.37± 0.09 (Garden) 8.81± 0.64 (Local market) 7.67± 0.45 (Reliance fresh)	Fenvalerate	
Ornamental Plants	(Pakkam, Thiruvallur district, Chennai, Tamil Nadu) Depth of Soil Surface Soil (0-15 cm) Sub-surface soil (15-30 cm) Sub-surface soil (30-40 cm)	GC	Value ($mg\ kg^{-1}$) (Collection range) 1.42±0.16 (0-15cm) 0.6±0.14 (15-30cm) 1.5±0.28 (30-40 cm)	α-Endosulfan	Odukkathil & vasudevan 2016
			1.28±0.04 (0-15 cm) 0.3±0.14 (15-30 cm) 0.9±0.14 (30-40 cm)	β-Endosulfan	
			ND (0-15 cm) 0.0005±0.54 (15-30 cm) ND (30-40 cm)	α-BHC(mg/g)	
			ND (0-15 cm) ND (15-30 cm) ND (30-40 cm)	γ-BHC(mg/g)	
			ND (0-15 cm) ND (15-30 cm) 0.013±0.21 (30-40 cm)	β-Cyfluthrin	

Cont...

Table 3. Pesticide residue in different samples

Sample	Sites	Analytical method	Major finding	Pesticide	Reference
Rice		GC	4.6±0.14 (0-15 cm) 1.4±0.28 (15-30 cm) 1.3±0.28 (30-40 cm)	α-Endosulfan	Odukkathil and vasudevan 2016
			3.1±0.08 (0-15 cm) 0.63±0.25 (15-30 cm) 0.34±0.04 (30-40 cm)	β-Endosulfan	
			0.39±0.06 (0-15 cm) 0.23±0.18 (15-30 cm) ND (30-40cm)	α-BHC	
			0.3±0.44 (0-15 cm) Nil (15--30 cm) Nil (30-40 cm)	γ-BHC	
			ND (0-15 cm) ND (15-30 cm) 6.64±0.0 (30-40 cm)	β-Cyfluthrin	
Mother Milk	North- western, Himalayan Region Zone I: Sub-mountainous subtropics Zone II: Sub-humid foot hill Zone III: Wet, temperate high hill Zone IV: Dry and temperate high hill	GC-MS	Value (mg kg^{-1}) Zone I 43.40±0.064 Zone II 33.33±0.050 Zone III 3.45±0.022 Zone IVNil	p-p'- DDE	Sharma et al (2020)
			Zone I Nil Zone II 1.96±0.018 Zone III 3.45±0.010 Zone IV Nil	p-p'- DDT	
Tomato	Navsari District, Gujarat	GC-ECD/LC-MS/MS	Value (ng kg^{-1}) 92.54	Acetamiprid	Kumar et al (2020)
			87.17	Tebuconazole	
Okra			86.10	Acetamiprid	
			85.94	Tebuconazole	
Andrographispaniculata (kalmegh)	Coimbatore(Tamil Nadu)	GC-ECD/FPD	72.3	Chlorpyriphos	Saha et al (2020)
	Maharashtra (Ahmednagar)		79.3	Deltamethrin	
Water (A)	Tapi River, Gujarat	GC	0.86 mg L^{-1} (A) Nil (B) 0.392 ng g^{-1} (C)	Chlorpyrifos	Hashmi et al (2020)
Sediment (B)			0.43 mg L^{-1} (A) 0.77 ng g^{-1} (B) 3.49 ng g^{-1} (C)	Methyl parathion	
Fish (C)			37.56 mg L^{-1} (A) 38.38 ng g^{-1} (B) 101.28 ng g^{-1} (C)	Endosulfan	
Carrot	Karnataka, India	HPLC	Value (mg kg^{-1}) 86.4	Acephate	Gowdaand Ramesh (2020)
			94.6	Chlorpyriphos	
			92.2	Dichlorvos	
			92.1	Phorate	
			86.9	Cyfluthrin-β	
			88.8	Fenvalerate	

low rate of degradation and remain persistent pollutants of the environment. Contaminated soil results in damage to the microflora and other soil organisms like nematodes (earthworms) which play important role in the fertility of the soil. Pesticide residues have been reported to cause a decline in amphibians. Kittusamy et al (2014) reported the presence of pesticide residue to be a reason for deformity in frogs.

Overuse of Pesticides: Prevention Strategy

The implementation of appropriate remedial measures aids in the reduction of pesticide toxicity and other health issues associated with pesticide use. The government is concerned about the negative effects of pesticides on human health and has taken several steps to address this, including banning most toxic pesticides, implementing a national implementation plan, implementing integrated pest management, and limiting the use of toxic chemicals (Yadav et al 2015). The irrational use of pesticides resulting in hazards to animals and the environment can be reduced by practising (Fig. 2) the following strategies:

Awareness of pesticide use: Farmers are unaware of the dangers of severe pesticide poisoning, but it is vital to underline the long-term impacts, which can cause a variety of neurological illnesses. Farmers are unfamiliar with the usage of contemporary pesticide spraying techniques (Ali et al 2020; Bant et al 2020). In India, Modern technology has been adopted by certain educated farmers, the majority of farmers are unable to do so due to a lack of education or money. Farmers are now required to be trained by agricultural producing firms because they are the primary users of the crops. This knowledge aids in the creation of local training programmes tailored to the needs of farmers. Farmers ignore health and environmental hazards in their pursuit of controlling pests and increasing productivity (Ataei et al 2021, Rani et al 2020).

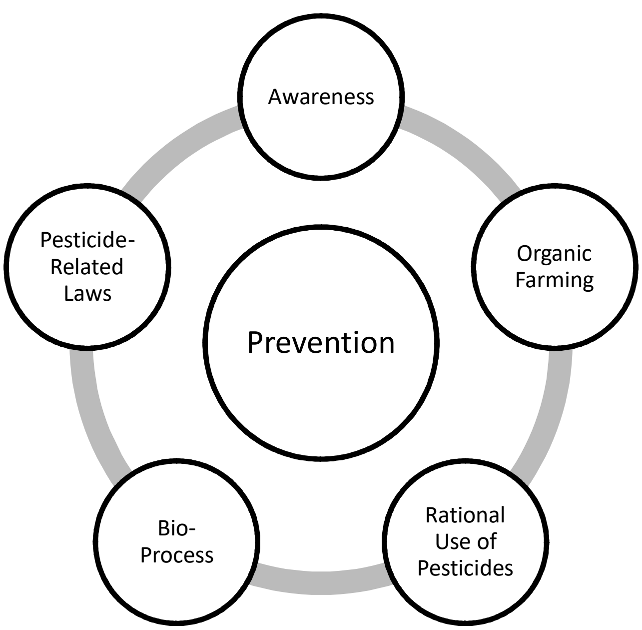


Fig. 2. Prevention of pesticide consumption

Rational use of pesticides (RUP): RUP focused mostly on the subset of IPM (Integrated Pest Management) and integrated Crop management (ICM), which aims to mitigate the negative effects of pesticide use via improved specificity and accuracy in pesticide usage with space and time of the products themselves. The benefits of RUP are boosted by combining all three, and the prospective benefits include lower costs (for pesticides as well as labour), reduced environmental impact (by more efficient spray application and use of selective chemicals such as biopesticides), and improved safety (Gupta et al 2010, Rani et al 2020). Thus, farmers were able to found accurate use of dosages and frequency of application of pesticides for controlling pesticides (GC and Palikhe 2021, Sarker et al 2020).

Green alternative approach: Organic farming is an environmentally adaptable approach, which is based on growing plants that have pest repellent properties. The most important aspect of organic farming is to inspire and increase organic cycles within agriculture structures in order to preserve and enhance extended soil fertility, minimise all types of hazards caused by fertiliser and pesticide use, and harvest food of superior quality in sufficient quantities. Pesticide residues in the food can be reduced by eating organic foods (Thakur et al 2020). Organic crops have more antioxidants, and greater intake of antioxidant-rich diets protects against long-term illnesses including cardiovascular disease, cancer, and neurological diseases (Garay et al 2020).

Bio-processes: Bioremediation is a crucial approach for removing pesticides from polluted areas. It has been regarded as an environmentally beneficial and economically viable method of cleaning the environment. It also doesn't produce any harmful byproducts. Microorganisms are often useful during the bioremediation process in converting pesticides into non-toxic chemicals, and as a result, their widespread usage has been recorded for the onsite breakdown of pollutants present in environmental systems. Microorganisms capable of degrading pesticides are commonly isolated from sludge, dirt, or aqueous solutions such as bio-pesticide, bio-fertilizers, etc (Tian et al 2018, Sharma et al 2016a, Zhu et al 2016). Furthermore, pesticide biodegradation has been done using a variety of fungal strains and bacteria (Maqbool et al 2016). Bioaugmentation involves adding microorganisms to contaminated locations with specified catabolic capacities or into a bioreactor to start the bioremediation process (Perelo 2010). In biostimulation, appropriate physiological conditions and nutrients must be provided for the proper growth of locally available microbes (Baker et al 2020, Fahad et al 2021, Kaur and Kaur 2020).

Implementation and amendment of pesticide-related laws: In India, the production of pesticides is governed by the Ministry of Chemical and Fertilizers, and their usage is monitored by the Ministry of Agriculture (Balkrishna et al 2021). Pesticides should be strictly regulated, and the bill should include measures prohibiting the sale and use of Class I pesticides. The World Health Organization classifies pesticides as extremely dangerous (Class Ia) or very hazardous (Class Ib) based on acute toxicity (Class Ib) (Buckley et al 2021). A clause in the bill should make it unlawful for a pesticide manufacturer to sell a pesticide without providing personal protection equipment or safety gear. There should also be mechanisms and standard operating procedures in place for acute medical crises. Before a pesticide registration application is processed, the registration-related provisions of the pesticide should explicitly contain a need and alternatives assessment. The use of organochlorine pesticides has been banned in 1990 but DDT, OCP, and HCH are still in use in India (Mehta 2020). India lacks defined government rules and regulations on the use of pesticides. Strict regulations should use be set by the government for the use of pesticides (Bonvoisin et al 2020, Hussin and Perbawati 2021). The proper test for efficacy, persistence, degradation rate, and toxicology of pesticides should be done before registering it legalized should be regular testing of environmental samples like soil and water to check for pesticide residues (Oudejans et al 2020).

CONCLUSION

The intended use of pesticides was to enhance crop production but its indiscriminate and excessive use had led to severe implications for humans and the environment. The pesticide residues have been reported to be present in the agricultural product at a concentration that exceeds the maximum permissible limit and have contaminated soil and water components of the environment. They even have entered the food chain and thus have serious long-term consequences. In order to achieve the balance between enhanced crop yields and be a healthy environment, different strategies including integrated pest management should be a major part of our agricultural practices. A nation like India, where there is such a wide array of plants, desperately needs more organic fertilizer that can also be used for pesticide management. If we take small steps toward organic farming, then we will overcome the effect of pesticides.

REFERENCES

Abhilash PC and Singh N 2009. Pesticide use and application: An Indian scenario. *Journal of Hazardous Materials* **165**(1-3): 1-12.

Albuquerque TG, Nunes MA, Bessada SM, Costa HS and Oliveira MBP 2020. Biologically active and health promoting food components of nuts, oilseeds, fruits, vegetables, cereals, and legumes. In *Chemical Analysis of Food*: 609-656. *Academic Press*.

Ali MP, Kabir MMM, Haque SS, Qin X, Nasrin S, Landis D, Holmquist B and Ahmed N 2020. Farmer's behavior in pesticide use: Insights study from smallholder and intensive agricultural farms in Bangladesh. *Science of the Total Environment* **747:** 141160.

Amenyogbe E, Huang JS, Chen G and Wang Z 2021. An overview of the pesticides' impacts on fishes and humans. *International Journal of Aquatic Biology* **9**(1): 55-65.

Ataei P, Gholamrezai S, Movahedi R and Aliabadi V 2021. An analysis of farmers' intention to use green pesticides: The application of the extended theory of planned behavior and health belief model. *Journal of Rural Studies* **81:** 374-384.

Baker BP, Green TA and Loker AJ 2020. Biological control and integrated pest management in organic and conventional systems. *Biological Control* **140**: 104-195.

Balkrishna A, Pandey JK, Tripathi, PK, Joshi R and Arya V 2021. Chemical fertilizers and pesticides in Indian Agriculture: Effect on human health and environment. *Biological Forum – An International Journal* **13**(3): 407-422.

Bant DD, Lokare L and Kapfo TU 2020. Assessment of safety practices of pesticide use among the farmers in Adargunchi and Noolvi, Karnataka: A cross sectional study. *Executive Editor* **11**(7): 212.

Barrett CB 2021. Overcoming global food security challenges through science and solidarity. *American Journal of Agricultural Economics* **103**(2): 422-447.

Bodh SP and Yadav RK 2020. India Agricultural Outlook Forum 2020. Available online: https://farmer.gov.in/iaof/iaof_admin/Data/1014_Programme%20Brochure%20IAOF%202020.pdf (accessed on 22 August 2021).

Bonvoisin T, Utyasheva L, Knipe D, Gunnell D and Eddleston M 2020. Suicide by pesticide poisoning in India: A review of pesticide regulations and their impact on suicide trends. *BMC Public Health* **20**(1): 1-16.

Buckley NA, Fahim M, Raubenheimer J, Gawarammana IB, Eddleston M, Roberts MS and Dawson AH 2021. Case fatality of agricultural pesticides after self-poisoning in Sri Lanka: A prospective cohort study. *The Lancet Global Health* **9**(6): 854-e862.

Bunch MJ, Suresh VM and Kumaran TV 2003. Environment and health aspects of pesticides use in Indian agriculture. In *International Conference on Environment and Health* **15**: 17.

Chakraborty P, Khuman SN, Kumar B and Loganathan B 2017. HCH and DDT residues in indian soil: Atmospheric input and risk assessment. In *Xenobiotics in the Soil Environment* (pp. 21-40). Springer, Cham.

Charon M, Robin D and Marchand PA 2019. The major interest for crop protection of agrochemical substances without maximum residue limit (MRL). *Biotechnology, Agronomy and Society and Environment* **23**(1): 22-29.

Chauhan A, Ranjan A and Jindal T 2018. Biological control agents for sustainable agriculture safe water and soil health. In *Paradigms in Pollution Prevention* (pp. 71-83). Springer, Cham.

Crépet A, Luong TM, Baines J, Boon PE, Ennis J, Kennedy M, Massarelli I, Miller D, Nako S, Reuss R and Yoon HJ 2021. An international probabilistic risk assessment of acute dietary exposure to pesticide residues in relation to codex maximum residue limits for pesticides in food. *Food Control* **121**: 107-563.

DAC&FW (Department of Agriculture, Cooperation & Farmers' Welfare): Annual Report 2017. Available online: https://agricoop.nic.in/sites/default/files/pocketbook_0.pdf (accessed on 27 August 2021).

Damalas CA and Koutroubas SD 2020. Botanical pesticides for eco-friendly pest management: Drawbacks and limitations. *Pesticides in Crop Production: Physiological and Biochemical Action*: 181-193.

Dasika R, Tangirala S and Naishadham P 2012. Pesticide residue analysis of fruits and vegetables. *Journal of Environmental Chemistry and Ecotoxicology* **4**(2): 19-28.

Devi NL, Yadav IC, Raha P, Shihua Q and Dan Y 2015. Spatial distribution, source apportionment and ecological risk assessment of residual organochlorine pesticides (OCPs) in the Himalayas. *Environmental Science and Pollution Research* **22**(24): 20154-20166.

Dey P, Gola D, Chauhan N, Bharti RK and Malik A 2021. Mechanistic insight to bioremediation of hazardous metals and pesticides from water bodies by microbes. In *Removal of Emerging Contaminants Through Microbial Processes* (pp. 467-487). Springer, Singapore.

Dhaliwal GS, Arora R, Dhawan AK and Singh B 2000. Intensive agriculture and pest problems: A case study of Punjab. *Indian Journal of Ecology* **27**(2): 109-130.

Dhaliwal GS, Jindal V and Dhawan AK 2010. Insect pest problems and crop losses: changing trends. *Indian Journal of Ecology* **37**(1): 1-7.

Fahad S, Sau S, Akhter A, Bajwa AA, Hassan S, Battaglia M, Adnan M, Wahid F, Datta R, Babur E and Danish S 2021. Bio-based integrated pest management in rice: An agro-ecosystems friendly approach for agricultural sustainability. *Journal of the Saudi Society of Agricultural Sciences* **20**(2): 94-102.

Garay J, Brennan, T and Bon D 2020. Essential oils a viable pest control alternative. *International Journal of Ecotoxicology and Ecobiology* **5**(2): 13-15.

GC Y and Palikhe BR 2021. From The Field To Dining Table: Pesticides Residues. *The Journal of Agriculture and Environment* **22**: 1-251

Gereslassie T, Workineh A, Atieno OJ and Wang J 2019. Determination of occurrences, distribution, health impacts of organochlorine pesticides in soils of central China. *International Journal of Environmental Research and Public Health* **16**(1): 1-18.

GOI 2021. Directorate of Plant Protection, Quarantine and Storage. Available online: http://ppqs.gov.in/statistical-database (accessed on 20 August 2021).

Gowda A and Ramesh HL 2020. Analysis of pesticide residues in carrot retailed in vegetable markets in five districts of Karnataka, India. *GSC Biological and Pharmaceutical Sciences* **10**(3): 27-38.

Grewal AS 2017. Pesticide residues in food grains, vegetables and fruits: A hazard to human health. *Journal of Medicinal Chemistry & Toxicology* **2**(1): 1-7.

Gupta S and Dikshit A.K 2010. Biopesticides: An ecofriendly approach for pest control. *Journal of Biopesticides* **3**(Special Issue): 186.

Hashmi TA, Qureshi R, Tipre D and Menon S 2020. Investigation of pesticide residues in water, sediments and fish samples from Tapi River, India as a case study and its forensic significance. *Environmental Forensics* **21**(1): 1-10.

Hassaan MA and Nemr EA 2020. Pesticides pollution: Classifications, human health impact, extraction and treatment techniques. *The Egyptian Journal of Aquatic Research* **46**(3): 207-220.

Hussin MH and Perbawati EK, 2021. The effect of the international code of conduct on pesticide management on the use of pesticide in Kerala, India (2003-2017). In *4th International Conference on Sustainable Innovation 2020–Social, Humanity, and Education (ICoSIHESS 2020)* (183-191). Atlantis Press.

Jawale CA, Rajput KH and Ugale BJ 2017. Assessing the impact of pesticides: An overview. *International Journal of Life Sciences* **5**(3): 474-479.

Jayashree R and Vasudevan N 2007. Organochlorine pesticide residues in ground water of Thiruvallur district, India. *Environmental Monitoring and Assessment* **128**(1): 209-215.

Jeyanthi H and Kombairaju S 2005. Pesticide use in vegetable crops: frequency, intensity and determinant factors. *Agricultural Economics Research Review* **18**(2): 209-221.

Joseph L, Paulose SV, Cyril N, Santhosh SK, Varghese A, Nelson AB, Kunjankutty SV and Kasu S 2020. Organochlorine pesticides in the soils of Cardamom Hill Reserve (CHR), Kerala, India: Geo spatial distribution, ecological and human health risk assessment. *Environmental Chemistry and Ecotoxicology* **2**: 1-11.

Kaur T and Kaur M 2020. Integrated pest management: A paradigm for modern age, pests, weeds and diseases in agricultural crop and animal husbandry production, Dimitrios Kontogiannatos, Anna Kourti and Kassio Ferreira Mendes, IntechOpen, DOI: 10.5772/intechopen.92283.

Kittusamy G, Kandaswamy C, Kandan N and Subramanian M 2014. Pesticide residues in two frog species in a paddy agroecosystem in Palakkad district, Kerala, India. *Bulletin of Environmental Contamination and Toxicology* **93**(6): 728-734.

Koli P and Bhardwaj NR 2018. Status and use of pesticides in forage crops in India. *Journal of Pesticide Science* **43**(4): 225-232.

Krishnakumar T 2019. *Agrarian Crisis and Food Security in India*. Technical Report.

Kumar A, Thakur A, Sharma V and Koundal S 2019. Pesticide residues in animal feed: Status, safety and scope. *Journal of Animal Feed Science and Technology* **7**(2): 73-80.

Kumar B, Mishra M, Verma VK, Rai P and Kumar S 2018. Organochlorines in urban soils from Central India: probabilistic health hazard and risk implications to human population. *Environmental Geochemistry and Health* **40**(6): 2465-2480.

Kumar P, Singh S, Gandhi KD and Umeretia NG 2020. Pesticide residues in vegetables collected from different markets of Navsari district of India. *International Research Journal of Pure and Applied Chemistry* **21**(24): 87-99.

Kunwar PS, Parajuli K, Badu S, Sapkota B, Sinha AK, De Boeck G and Sapkota K 2021. Mixed toxicity of chlorpyrifos and dichlorvos show antagonistic effects in the endangered fish species golden mahseer (Tor putitora). *Comparative Biochemistry and Physiology Part C: Toxicology & Pharmacology* **240**: 1-9.

Kunwar PS, Sapkota B, Badu S, Parajuli K, Sinha A, De Boeck G and Sapkota K 2021a. Chlorpyrifos and dichlorvos in combined exposure reveals antagonistic interaction to freshwater fish mrigal, *Cirrhinus mrigala*. DOI:10.21203/rs.3.rs-896260/v2

Li Z 2018. Evaluation of regulatory variation and theoretical health risk for pesticide maximum residue limits in food. *Journal of Environmental Management* **219**: 153-167.

Maqbool F, Mostafalou S, Bahadar H and Abdollahi M 2016. Review of endocrine disorders associated with environmental toxicants and possible involved mechanisms. *Life sciences* **145**: 265-273.

Mehta RV, Sreenivasa MA, Mathew M, Girard AW, Taneja S, Ranjan S, Ramakrishnan U, Martorell R, Ryan PB and Young MF 2020. A mixed-methods study of pesticide exposures in Breastmilk and Community and Lactating Women's perspectives from Haryana, India. *BMC Public Health* **20**(1): 1-14.

Mishra AK, Arya R, Tyagi R, Grover D, Mishra J, Vimal SR, Mishra S and Sharma S 2021. Non-judicious use of pesticides indicating potential threat to sustainable agriculture. *Sustainable Agriculture Reviews* **50**: 383-400.

Nag SK, Saha K, Bandopadhyay S, Ghosh A, Mukherjee M, Raut A, Raman RK, Suresh VR and Mohanty SK, 2020. Status of pesticide residues in water, sediment, and fishes of Chilika Lake, India. *Environmental Monitoring and Assessment* **192**(2): 1-10.

Năstăsescu V, Mititelu M, Goumenou M, Docea AO, Renieri E, Udeanu DI, Oprea E, Arsene AL, Dinu-Pîrvu CE and Ghica M 2020. Heavy metal and pesticide levels in dairy products: Evaluation of human health risk. *Food and Chemical Toxicology* **146**: 111-844.

Odukkathil G and Vasudevan N 2016. Residues of endosulfan in surface and subsurface agricultural soil and its bioremediation. *Journal of Environmental Management* **165**: 72-80.

Oudejans L, Mysz A, Snyder EG, Wyrzykowska-Ceradini B, Nardin J, Tabor D, Starr J, Stout II D and Lemieux P 2020. Remediating indoor pesticide contamination from improper pest control treatments: Persistence and decontamination studies. *Journal of Hazardous Materials* **397**: 122-743.

Parajuli S, Mahatara B, Budhathoki S, Paudel M, Parajuli K and Adhikari A 2021. Scenario of pesticide import, formulation, consumption and the residue status among agricultural crops in Nepal. *Big Data in Agriculture* **3**(2): 94-99

Pawlak K and Kołodziejczak M 2020 The role of agriculture in ensuring food security in developing countries: Considerations in the context of the problem of sustainable food production. *Sustainability* **12**(13): 54-88.

Perelo LW 2010. In situ and bioremediation of organic pollutants in aquatic sediments. *Journal of Hazardous Materials* **177**(1-3): 81-89.

Pujeri US, Pujar AS, Pujari KG, Kumar MI and Yadawe MS 2016. Quantitative analysis of pesticide residues in vegetables. *International Journal of Scientific and Engineering Research* **7**(5): 386-393.

Pyka A and Miszczyk M 2005. Chromatographic evaluation of the lipophilic properties of selected pesticides. *Chromatographia* **61**(1): 37-42.

Qu C, Albanese S, Lima A, Li J, Doherty AL, Qi S and De Vivo B 2017. Residues of hexachlorobenzene and chlorinated cyclodiene pesticides in the soils of the Campanian Plain, southern Italy. *Environmental Pollution* **231**: 1497-1506.

Qu C, Qi S, Yang D, Huang H, Zhang J, Chen W, Yohannes HK, Sandy EH, Yang J and Xing X 2015. Risk assessment and influence factors of organochlorine pesticides (OCPs) in agricultural soils of the hill region: A case study from Ningde, southeast China. *Journal of Geochemical Exploration* **149**: 43-51.

Saha A, Makwana C and Manivel P 2020. QuEChERS-based gas chromatography-electron capture/flame photometric detection method for multi-pesticide residues analysis in Andrographispaniculata: A popular Indian medicinal herb. *International Journal of Environmental Analytical Chemistry* **100**(15): 1669-1690.

Sarker MNI, Islam MS, Murmu H and Rozario E 2020. Role of big data on digital farming. *International Journal of Scientific & Technology Research* **9**(4): 1222-1225.

Sharma A, Gangola S, Khati P, Kumar G and Srivastava A 2016a. Novel pathway of cypermethrin biodegradation in a *Bacillus* sp. strain SG2 isolated from cypermethrin-contaminated agriculture field. *Biotech* **6**(1): 45.

Sharma A, Shukla A, Attri K, Kumar M, Kumar P, Suttee A, Singh G, Barnwal RP and Singla N 2020. Global trends in pesticides: A looming threat and viable alternatives. *Ecotoxicology and Environmental Safety* **201**: 110812.

Sharma ID, Chandel RS, Brar SS and Joginder S 2016. Monitoring of soils and water for pesticide contamination in apple growing regions of Himachal Pradesh, India. *Indian Journal of Ecology* **43**(1): 55-59.

Sharma ND, Chandel RS, Sharma ID, Sharma PL and Gurung B 2020. Pesticides contamination of lactating mothers' milk in the north-western Himalayan region of India. *Journal of Environmental Biology* **41**(1): 23-28.

Singh MK and Neog Y 2020. Contagion effect of COVID-19 outbreak: Another recipe for disaster on Indian economy. *Journal of Public Affairs* **20**(4): 2171.

Singh R, Kumar M, Mittal A and Mehta PK 2016. Microbial enzymes: industrial progress in 21st century. *Biotech* **6**(2): 1-15.

Subash SP, Chand P, Pavithra S, Balaji SJ and Pal S 2017. Pesticide use in Indian agriculture: Trends, market structure and policy issues. ICAR – National Institute of Agricultural Economics and Policy Research. Available online: https://krishi.icar.gov.in/jspui/bitstream/123456789/19955/2/pb43.pdf (accessed on 26 August 2021).

Rajput S, Sharma R, Kumari A, Kaur R, Sharma G, Arora S and Kaur R 2021. Pesticide residues in various environmental and biological matrices: Distribution, extraction, and analytical procedures. *Environment, Development and Sustainability* 1-21. DOI: https://doi.org/10.1007/s10668-021-01722-4

Ramesh HL and Murthy VY 2013. Evaluation of pesticide residual toxicity in vegetables and fruits grown in Bangalore rural district. *International Journal of Pharmaceutical Sciences Review and Research* **21**(2): 52-57.

Rani L, Thapa K, Kanojia N, Sharma N, Singh S, Grewal AS, Srivastav AL and Kaushal J 2020. An extensive review on the consequences of chemical pesticides on human health and environment. *Journal of Cleaner Production* **283**: 124-657.

Rao CR and Kumar LCA 2012. Qualitative and quantitative analysis of fenvalerate, and methyl parathion pesticides in mango and grapes collected by HPLC method. *International Journal of Science and Innovative Technology* **1**(1): 56-68.

Thakur N, Kaur S, Tomar P, Thakur S and Yadav AN 2020. Microbial biopesticides: current status and advancement for sustainable agriculture and environment. In *New and Future Developments in Microbial Biotechnology and Bioengineering* (pp. 243-282). Elsevier.

Tian J, Long X, Zhang S, Qin Q, Gan L and Tian Y 2018. Screening cyhalothrin degradation strains from locust epiphytic bacteria and studying *Paracoccus acridae* SCU-M53 cyhalothrin degradation process. *Environmental Science and Pollution Research* **25**(12): 11505-11515.

Tsakiris I, Kokkinakis E and Tzatzarakis E 2021. Introduction to pesticide exposure monitoring and practical guidance. In *Exposure and Risk Assessment of Pesticide Use in Agriculture* (pp. 87-102). Academic Press.

Yadav IC, Devi NL, Syed JH, Cheng Z, Li J, Zhang G and Jones KC 2015. Current status of persistent organic pesticides residues in air, water, and soil, and their possible effect on neighboring countries: A comprehensive review of India. *Science of the Total Environment* **511**:123-137.

Yu HY, Li FB, Yu WM, Li YT, Yang GY, Zhou SG, Zhang TB, Gao YX and Wan HF, 2013. Assessment of organochlorine pesticide contamination in relation to soil properties in the Pearl River Delta, China. *Science of the Total Environment* **447**: 160-168.

Zhu Y, Li J, Yao K, Zhao N, Zhou K, Hu X, Zou L, Han X, Liu A and Liu S 2016. Degradation of 3-phenoxybenzoic acid by a filamentous fungus Aspergillus oryzae M-4 strain with self-protection transformation. *Applied Microbiology and Biotechnology* **100**(22): 9773-9786.

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