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Challenges and constraints in chemical pesticide usage and their solution: A review

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Abstract
Population growth pressure and limited options have put enormous burden to meet food demand which is a major concern and challenge in India, where the diverse agro-climatic conditions necessitate different approaches to cultivation and protection of crops. To overcome this challenge, chemical fertilizers and pesticides were introduced in 1940s with the use of dichloro-diphenyl-trichloroethane, followed by other organophosphate and carbamates pesticides, by virtue of which the production and productivity of crops has increased many fold. Despite spectacular progress made in the area expansion and acceleration of agriculture production, the pace of development has started stumbling down due to devastating emerging challenges in pesticide usage such as target pest resistance to pesticides, killing of beneficial organisms, resurgence of pests, secondary pest outbreak, and residues in food, water, air and soil, elimination of natural enemies and disruption of ecosystem. This paper provides a brief overview on current challenges and issues related to pesticides and on available strategies to overcome these challenges.

Keywords: Pest, resistance, ecosystem, residue, resurgence, pollution

1. Introduction
Agriculture has been facing the harmful threat of numerous pests like insects and other non insect pests from time immemorial, leading to radical reduction in production. To counter these problems and to increase the production of crops, in India during the mid-sixties new and high yielding varieties of crops were introduced in agriculture, the inputs like chemical fertilizers and pesticides were recommended to increase both production and productivity of these crops (Rajendran, 2003) [1]. The agricultural scientists and extension experts worked hard to educate and convince the farming community to use these chemicals without carefully looking into their adverse effects. Realizing the quick effect of these chemicals on crops in terms of yield response, farmers reacted favourably and the use of these chemicals has increased manifold over the years. Similarly, after the farmers were convinced that chemical pesticides were effective in preventing and controlling pests and diseases, their use increased considerably. Thus their role became critically important with modernization of agriculture which implies increased use of modem inputs such as chemical fertilizer, irrigation and modern seeds, which provide a favourable climate for rapid growth of pests (Sabur & Molla, 2001) [2]. The main intention of the introduction of pesticides was to prevent and control insect pests and diseases in the field crops and of course, initially their use reduced pest attack and paved way for increasing the crop yield as expected. However, simultaneously, they resulted in contaminating the environment and the long-term implications on the society as well. Their indiscriminate and excessive use damaged not only environment and agriculture but has also entered into the food chain thereby affecting all living beings. Knowingly or unknowingly, now the farmers are addicted to using agro-chemicals indiscriminately and excessively to make the situation from bad to worse not only in India but also in other parts of world as well (Conway, 1984) [3]. A rough estimate shows that about 30% of the world's agricultural production is lost every year due to pests despite the pesticide consumption which totalled more than 2 million tons (Oerke *et al*., 1994) [4]. Of all pests, insects cause an estimated 14% of crop losses, plant pathogens 13% and weeds 13% (Pimentel, 2007) [5]. An additional 30% of the crop is destroyed by postharvest insect pests and diseases, particularly in the developing world (Kumar, 1984) [6]. In India pests cause crop loss of more than Rs 6000 crore annually, of which 33 per cent is due to weeds, 26 per cent by diseases, 20 per cent by insects, 10 per cent by birds and rodents and the remaining (11 per cent) is due to other factors (Rajendran, 2003) [1]. The magnitude of the problem would accelerate further as more and more (newer) pests and

diseases are likely to attack crops and the need to use pesticides in different forms will be necessary in the years to come. Hence, this issue needs serious attention and immediate action for social, environment and economic considerations in the context of sustainable development. Despite huge importance of this issue, very little information is available on the said topic, so an effort was made to highlight the available solutions to these challenges.

2. Results and discussions

2.1 Pesticide pollution

The pesticide after application, accumulate in the environment and cause undesirable change in the physical, chemical or biological characteristics of air, land and water which lead to pollution of various types as follows.

Soil pollution: The soil is contaminated with pesticides by deliberate application for controlling soil inhabiting pests or through runoff from plants and dumping of empty containers. Thus soil is reservoir of pesticidal pollution. Pesticides disturb the microbial activity of the soil, having adverse effect on the earthworm population, predatory mites, centipedes and scarabid beetles. Higher concentrations of DDT, HCH and carbaryl in the soil inhibit the nitrogen fixing capacity of *Rhizobium* spp. and blue green algae (Dhaliwal and Arrora, 1996) [7].

Water pollution: The water sources are being contaminated by surface runoff, sediment transport from treated soil, industrial and municipal wastes and direct application of pesticides for the control of aquatic insects. Water contaminated with insecticides not only kills the aquatic insects which are food to fish, but also accumulate in fish, body by million fold. Contamination of drinking water with DDT and HCH has been reported from the different states like Haryana, Gujarat, UP and Delhi (Kumari *et al.*, 1996) [8].

Air pollution: Insecticides enter the air by spray drift or volatilization from soil or water. During insecticidal application only a small portion of insecticide sprayed on the crop reach the target, the rest either fall on ground or taken up into the atmosphere by air currents or turbulence. People around the pesticidal factories are affected by leakage of toxic gases and pesticidal pollution causing different kinds of diseases. More than 3000 people died by inhaling the vapours of methyl iso-cyanate, leaked from carbaryl manufacturing plant in Bhopal in 1984. More than 30000 people were disabled in varying degrees. The surviving population is still expressing teratogenic, mutagenic, carcinogenic and other effects involving vital body organs. More than 100 people died in Kerala in 1958 due to consumption of wheat flour and sugar contaminated with parathion leakage during shipment from Mumbai to Cochin.

Bioaccumulation: The accumulation of insecticides in various biological systems is called bioaccumulation. The insecticide enters a biological system mainly by aerial, terrestrial and aquatic routes. When an insecticide enters the food chain its bio magnification takes place at different tropic levels. Maximum accumulation of toxicant is found at the top of the food chain or the last tropic level.

Remedial measures to pesticidal pollution:

- Pesticide manufacturing industries should have safety arrangements.
- Pesticide industry should have separate team to handle disastrous situation.
- Government should enforce standards of emission and effluents.
- Proper training for workers and users for handling hazardous pesticides should be organised from time to time.
- Well equipped laboratories for pesticide residue estimation should be set up in different parts of the country.
- Regular field demonstrations for safe handling of plant protection equipment should be arranged for the farmers.
- Brining awareness among people about storing, handling and marketing of hazardous pesticides.
- Use of recommended pesticides at selective dose at appropriate time.

2.2 Hazards to pollinators and other non-target organisms

Non-target organisms constitute all the organisms excluding the target insect pest species against which the insecticide has been applied. It includes wildlife, birds, honeybees, beneficial insects and natural enemies.

Honeybees: Honeybees are very important because they are major pollinators. Some insecticides kill honeybees, causing severe economic loses to beekeepers and loss of cross-pollinated crops due to poor pollination. The danger of insecticides to bees results not only from direct contact with poison, but also from taking poisoned nectar, pollen and water. Indiscriminate use of insecticides on honey yielding crops has resulted in wide spread mortality of honeybees. Field studies in Punjab revealed that application of carbaryl; fluvalinate and monocrotophos for bollworm control caused 94%, 44% and 100% mortality respectively of the bees in cotton fields (Dhaliwal and Arrora, 1996) [7]. Impact of pesticides on bees was projected by Hameed and Singh (1998) [9] and Sihag (1995) [10].

Natural enemies: Many natural enemies are susceptible to a variety of pesticides used in crop protection. Such susceptibility often results in pest resurgence and outbreaks of secondary pests in treated crops.

Wildlife: Pesticides such as parathion, malathion, aldrin, dieldrin, heptachlor and several other organochlorine are reported to affect severely the metabolism of birds. Wild birds like crow, egret, kite and vulture were reported to show more HCH residues in blood plasma and brain when compared to DDT and its metabolites (Kaphalia *et al.*, 1981) [11]. HCH was predominant pollutant in certain wild bird species in Tamil Nadu (Regupathy and Kuttalam, 1992) [12].

Measures to reduce hazards to pollinators and other non-target organisms:

- Use pesticides only when the pest infestation is high and warrants chemical treatment.
- Select the insecticide which is safer for bees and other non-targets (Table- 1& 2).
- Avoid spraying plants in blooming stage.
- Read and carefully follow label instructions
- Give advance information to the beekeeper about the spray programme.
- Resort to late evening or early morning spraying when bees and natural enemies are not active to minimize the hazard.
- Unused pesticides must be disposed in an environmentally safe manner.

Table 1: Insecticides tested comparatively safe to natural enemies.

S. No.	Natural enemy	Insect pest	Safe pesticide identified
A	**Egg parastoids**		
1.	*Telenomus remus* Nixon	Tobacco caterpillar	Monocrotophos, phosalone
2.	*Trichogramma achaeae*	Spotted bollworm	Deltamethrin, monocrotophos, permethrin, phosalone
3.	*Trichogramma brasiliense*	Gram pod borer	Cypermethrin, deltamethrin, endosulfan, fenvalerate, monocrotophos, phosalone
4.	*Trichogramma japonium*	Top borer of sugarcane	Endosulfan, Lindane
5.	*Trichogramma perkinsi*	Tissue borer of sugarcane	Lindane, Phosphamidon, DDT, Diazinon, endosulfan
B	**Egg larval parastoids**		
7.	*Chelonus blackburnii*	Cotton bollworms	Diflubensuron, Dimethoate, Fenpropathrin
8.	*Tetrastichus pyrillae*	Sugarcane pyrilla	Endosulfan, Quinalphos
C	**Larval parastoids**		
9.	*Allorhogas pyralophagus*	Tissue borers of sugarcane	Dicofol, Mancozeb, mosalone, zineb
10.	*Apantelles angaletic*	Pink bollworm	Deltamethrin, fenvalerate, permethrin, phosalone, Phosphamidon
11.	*Apanteles papilionis*	Lemon butterfly	Fenvalerate, permethrin, phosalone
12.	*Apanteles plutellae*	Diamond back moth	Cypermethrin, permethrin, fenvalerate, monocrotophos, phosalone.
13.	*Bracon brevioornis*	Coconut black headed caterpillar	Endosulfan, phosalone
14.	*Bracon kirkpatricki*	Pink bollworm	Cypermethrin, deltamethrin, permethrin
D.	**Predators**		
15.	*Chrysoperla carnea*	Jassids, aphids	Endosulfan, fenvalerate, phosalone
16.	*Coccinella septempunctata*	Aphids	Methyldemeton
17.	*Cryptolaemus moritrouzieri*	Mealy bugs	Endosulfan, Endrin, Methyl demeton
18.	*Menochilys sexmaculatus*	Aphid, whitefly	Endosulfan.

[**Source:** Navarajan and Thyarajan, 1992] [13]

Table 2: Classification of insecticides on the basis of their toxicity to honeybees.

Highly toxic (LD50 0.001-1.99 µg/bee	
Aldrin	Dimethoate
Calcium arsenate	Fenvalerate
Carbaryl	Monocrotophos
Carbofuron	Oxydometon methyl
Chlorpyriphos	Parathion
Cypermethrin	Permethrin
Deltamethrin	Phorate
Dichlorvos	Phosphamidon
Quinalphos	
Moderately toxic (LD50 2.0-10.0 µg/bee)	
DDT	Lindane
Diazinon	Malathion
Dieldrin	Metasystox
Endrin	Methyldemeton
Ethyl parathion	Methyl parathion
Fenitrothion	Mevinphos
HCH	
Relatively non-toxic (LD50 > 11.0 µg/bee)	
Bt	Methoxychlor
Chlorobenzilate	Nicotine
Dicofol	NPV
Dimite	Phoralone
Endosulfan	Pyrethrum
Ethion	

[**Source:** Modified after Abrol, 1997] [14]

2.3 Pesticide residues

Pesticide residue refers to remains of active substances and their degradation products in or on food after waiting period. It has been demonstrated that less than one per cent of the pesticide applied to a crop reaches the target pests and the remaining quantity gets into different components of the environment. Since most of the pesticides are non-biodegradable, they leave excessive residues in various food commodities. The presence of residues of these pesticides in food commodities and other components of the environment is a matter of serious concern.

Monitoring surveys in different parts of India have revealed widespread pesticidal contamination of all types of food materials including cereals, pulses, vegetables, fruits and animal products (Kang, 2002 and Gupta, 2005) [15, 16]. Among 458 samples of milk collected from different parts of the country under All India Coordinated Research Projects (AICRP) on pesticide residues 87 per cent samples were contaminated with DDT out of which 43 per cent above the MRL of 0.05 mg/kg. Similarly, 90 per cent of the samples were contaminated with HCH, 78 per cent of which were above MRL of 0.1 mg/kg. In contrast 1-2 per cent samples of food commodities have been found to be contaminated with pesticide residues, above MRL at the global level (Atwal and Dhaliwal, 2005) [17].

Strategies to minimize pesticide residues:

Keep the farm clean: A clean farm usually has fewer pests, so keep the farm free of weeds and carefully dispose of diseased plants and old plant matter. These can be buried, composted with animal manures or if the material has a high water content (e.g. lettuce) plants can be placed in black plastic bags, sealed and placed in the sun. After the plant matter has broken down it can be used as mulch.

Avoid calendar spraying: Calendar spraying means when pesticides are applied on a schedule without considering the actual presence or extent of pests. This practice can increase pesticide application and thereby increase the residues on crops.

Monitor pests: Regularly check your crop for pests by carefully checking plants with a magnifying glass or hand lens for the presence of pests. Sticky traps can also be used to check for the presence of specific pests. Regular monitoring ensures problems are found early, making control easier and saving time and money.

Use pest threshold: The presence of a pest does not automatically mean financial loss. In some situations, the cost of applying pesticides may be greater than the loss if no action was taken. So go for control measures only if pest crosses the economic threshold level. By using action thresholds one can more accurately time pesticide applications and may even reduce the number of applications made thus can also reduce the risk of pesticide residues.

Integrated control measures: Use of combination of measures to control pests including cultural, physical, mechanical, biological and chemical measures. There is wide range of natural enemies commercially available for biological control of pests. They can be used in conjunction with pesticides but the choice of pesticide is critical to ensuring that these natural enemies survive.

Prevent spray drift: Preventing spray drift between young and old plants and different crops is also critical in reducing the risk of pesticide residues. Make sure there is adequate protection (i.e. screens and windbreaks) between production areas to reduce spray drift onto non-target plants from within the site and from any neighbouring farms.

- Increase the withholding period (WHP).
- By plucking ripe fruits and vegetables before pesticide application.
- By washing and peeling vegetables and fruits.

2.4 Pesticide resistance

It is the adaptation of pest population targeted by a pesticide resulting in decreased susceptibility to that chemical. In other words, pests develop a resistance to a chemical through natural selection and the most resistant organisms are the ones that survive and pass on their genetic traits to their off springs (PBS, 2007) [18]. It also refers as a heritable change in the sensitivity of a pest population that is reflected in the repeated failure of a pesticide to achieve the expected level of control when used according to the label recommendation for that pest species (IRAC, 2007) [19]. It is the development of an ability in a strain of insects to tolerate doses of toxicant which would prove lethal to majority of the individuals in a normal population of the same species. Resistance genes are usually autosomal. This means that they are located on autosomes (as opposed to sex chromosomes). As a result resistance is inherited similarly in males and females. Also resistance is usually inherited as an incompletely dominant trait.

2.5 Management of pesticide resistance

Monitor pests: Scouting is one of the key activities in the implementation of an insecticide resistance management strategy. Monitor insect population development in fields to determine if and when control measures are warranted. Monitor and consider natural enemies when making control decisions. After treatment, continue monitoring to assess pest populations and their control.

Focus on economic thresholds: Insecticides should be used only if insects are numerous enough to cause economic losses that exceed the cost of the insecticide plus application. An exception would be in-furrow in planting treatments for early season pests that usually reach damaging levels each year. Consult local crop advisors about economic thresholds for target pests in your area.

Table 3: Most resistant arthropod orders to insecticides.

Order	Number of species	
	Total	**Per cent**
Diptera	184	34
Acari	83	15
Lepidoptera	82	15
Coleopteran	73	13
Homoptera	58	11
Others	68	12
Total	548	100

[**Source:** Atwal and Dhaliwal, 2005] [17]

Table 4: Eight most resistant arthropod species to pesticides.

S. No.	Common name	Scientific name	Host	Number of pesticides
1.	Two spotted spider mite	*Tetranychus urticae* Koch	Cotton, fruits, ornamentals	72
2.	Diamondback moth	*Plutella xylostella* (Lin.)	Crucifers	69
3.	Peach potato aphid	*Myzus persicae* (Sulz)	Vegetables, fruits tobacco	68
4.	Colardo potato beetle	*Leptinotarsa decemlineata* (Say)	Brinjal, Pepper, Potato, Tomato	40
5.	Red spider mite	*Panonychus ulmi* (Kock)	Fruit trees	40
6.	Tobacco bud worm	*Heliothis virescens*	Chick pea, corn, cotton, tobacco	37
7.	House fly	*Musca domestica* (Lin)	Urban	36
8.	Red flour beetle	*Tribolium casteneum*	Stored products	34

[**Source:** Clark and Yamaguchi, 2002] [20]

Table 5: Documented cases of resistance to insects and mite according to pesticides.

S. No.	Pesticide	Pesticide class	No. of resistant species
1.	DDT	Organochlorine	257
2.	BHC/Cydodienes	-do-	149
3.	Malathion	-do-	120
4.	Dieldrin	-do-	100
5.	Aldrin	-do-	87
6.	Lindane/BHC	-do-	76
7.	Parathion	-do-	76
8.	Diazinon	-do-	58
9.	Carbaryl	Carbamate	51
10.	Fenitrothion	Organophosphate	47

[**Source:** Atwal and Dhaliwal, 2005] [17]

Integrate control strategies: Use as many different control measures as possible. Effective IPM based programmes will include the use of synthetic insecticides, biological insecticides beneficial arthropods (predators and parastoids), cultural practices, transgenic plant varieties, crop rotation, pest resistant crop varieties and chemical attractants or deterrents. Select insecticides with care and consider their impact on future pest populations and the environment. Avoid broad-spectrum insecticides when a narrow spectrum or more specific insecticide will work.

Use insecticide mixtures: A mixture of two insecticides with different mode of action gives good control of resistant strains. White flies developed resistance against synthetic pyrethroids on cotton, mixture of cypermethrin and profenfos is used to overcome the problem (Prasad, 2009) [21].

Mixtures available

- Chloropyriphos 50% +Cypermethrin 5% EC – Nurell D 505
- Profenphos 40% + Cypermethrin 4% EC – Polytrin C 44 EC
- Deltamethrin 0.8% + Endosulfan 32% EC – Decidan 32.8 EC.

Apply pesticide at correct time: Apply insecticides when the pests are most vulnerable. For many insects this may be when they have just emerged. Use application rates and intervals recommended by the local pest management expert. When controlling larval stages, target younger larval instars, if possible, because these stages usually are more effectively controlled by insecticides than older stages.
Alternate different insecticide classes: Avoid the repeated use of the same insecticide or insecticides in the same chemical class, which can lead to resistance and/or cross resistance. Rotate insecticides across all available classes to slow resistance development. In addition do not tank-mix products from the same insecticide class. Rotate insecticide classes and mode of action.
Protect beneficial arthropods: Select insecticides in a manner that is the least damaging to populations of beneficial arthropods. For example, applying insecticides in furrow at planting or in a band over the row rather than broadcasting will help in protecting certain natural enemies.
Preserve susceptible genes : Preserve susceptible individuals within the target population by providing a haven for them, such as unsprayed areas within treated fields, adjacent "refuge" fields, or habitat attractions within a treated field that facilitate immigration. These susceptible individuals may outcompete and interbreed with resistant individuals, deleting the resistant genes and therefore the impact of resistance.
Use of synergists: Synergists enhance the toxicity of the insecticides by blocking their detoxification enzymes. Resistance to OP's, carbamates and pyrethrum is overcome by addition of synergists such as piperonyl butoxide (POB). Malathion resistance is overcome by use of synergists such as triphenyl phosphate and tributyl phosphorotrithioate.
Use of insect pheromones and hormones: Pheromones modulate the insect behaviour and hormones regulate growth and reproduction of insects thus can be successfully used against resistant insects.
Data in Table-6 indicated that since 1991, the resistance development has been significantly delayed in IRM demonstration areas (Chang *et al.*, 1995) [22]. Between 1991 and 1994 *Helicoverpa* resistance to fenvalerate and cypermethrin were reversed in the IRM area while resistance increased 2.9 and 1.5 fold respectively in the control area. *Helicoverpa* resistance to deltamethrin and cyhalothrin increased in the IRM area by 1.8 and 1.1 fold respectively but in the control area, resistance increased more than twice that rate (3.8 and 2.5, respectively).

Table 6: The change in response *Helicoverpa armigera* to four pyrethroid from 1991-1994 in the IRM area compared to the control area.

Area	Insecticide	Resistance ration		Overall response
		1991	1994	
Control	Fenvalerate	9.8	28.4	2.9
	Cypermethrin	13.7	20.9	1.5
	Deltamethrin	15.5	58.5	3.8
	Cyhalothrin	9.7	24.4	2.5
IRM	Fenvalerate	23.1	18.0	0.8
	Cypermethrin	27.6	21.0	0.8
	Deltamethrin	20.1	36.5	1.8
	Cyhalothrin	18.5	20.4	1.1

[**Source:** Chang *et al*. 1995] [22]

2.5 Insect resistance to transgenic plants

The most common strategy in inducing pest resistance through transgenic is to insert various forms of an endotoxin gene from *Bacillus thuringiensis* (Bt.) into plants. There are more than 80 Bt. insecticidal cry genes so far discovered. Susceptibility to each class of Bt. toxin is determined by the presence of specific receptors in the insect-gut epithelial cells, and such receptors are not present in mammals including human beings (Kumar & Bambawale, 2002) [23]. Bt. products have been used for more than 40 years without any evidence of resistance in field situations until a report from the Philippines indicated control failures of the Diamond back moth (DBM), *Plutella xylostella*. Subsequent studies in Hawaii and Florida documented the genetic basis of resistance to Bt. in DBM. Laboratory populations of at least 10 species of moths, two species of beetles and four species of flies have been exposed to selection against Bt. toxins and ten-fold increases in tolerance have occurred in nine of the sixteen species. These findings warn of the possibility of insects developing resistance to transgenic insecticidal plants containing Bt. toxins. Under laboratory conditions, significant resistance to Bt. was developed by a *Plodia interpunctella* strain and *Heliothis virescens*. More over the development of field resistance of *Plutella xylostella* to Bt. has indicated that this may be a real problem.

Management strategy

- Mortality source diversification or gene pyramiding (two or more highly fatal toxins with different mode of action could be combined in the same plant).
- Use of refugia (combination of seed products containing Bt. insecticidal protein with a small proportion that lacks the insecticidal protein) to reduce the selection pressure.
- Destruction of carry over population that have been exposed to Bt. crops in previous generations.
- Following appropriate crop rotation
- Observing a crop free season and other resistance strategies
- Alternate use of chemical pesticide and crops containing Bt. insecticidal protein.

2.6 Pest resurgence

It is the situation where a population after having been suppressed rebounds to numbers greater than before suppression occurred. Abnormal increase in pest population or damage following insecticide application, often far exceeding the economic level is called as resurgence. The tremendous increase in the pest population brought about by the insecticides, in spite of good initial kill at the time of treatment is called as "resurgence" or "flare blacks". Maximum cases of resurgence belong to Hemipterans (44%) followed by phytophagous mites (26%) and Lepidopterans (24%). Maximum reports of resurgence pertain to plant hoppers especially brown plant hopper (BPH) of rice.

Measures to minimize resurgence

By avoiding Hormoligosis: Sub-lethal doses can be minimized by applying insecticides on target and avoiding drift. In other words following the rules of good pesticide practice including right type of insecticide, dosage, time and method of application can play a significant role in reducing the risk of insect resurgence.

By natural enemy conservation: This refers to use of selective chemicals that have stronger depressive influence on the pest population than on its natural enemies.

By physiological selectivity: Some of the more important examples of physiological selectivity are found with non-conventional materials like microbial insecticides and some insect growth regulators.

By ecological selectivity: These include Monitoring of pest population and following recommended economic thresholds, Leaving a pest residue which results in natural enemy conservation and provide hosts for population recovery, avoid treating some areas which can serve as refugia for natural enemies and use of agronomic practices like date of sowing, judicious use of fertilizers and water which are helpful in reducing resurgence.

2.7 Biotype development

This refers to new population capable of damaging and surviving on plants previously resistant to the populations of same species. Certain physiological and behaviour changes in the new populations of insect make it easy to feed and develop on resistant varieties. More specifically, biotype refers to the populations within a species which can survive on and destroy varieties that have genes for resistance (Heinrichs *et al.*, 1985) [24]. Broadly speaking, the term biotype is an intraspecific category referring to insect population of similar genetic composition for a biological attribute. The development of insect biotypes has posed a serious threat to the success of plant resistance for management of insect pests. Biotypes are known to occur in more than 36 arthropod species belonging to 17 families of six orders. Aphids constitute about 50 per cent of these species with known biotypes (Table-7).

Table 7: Biotypes of insect pests of agricultural crops.

Insect species	Common name	Number of biotypes	Crop
Acyrthosiphon pisum	Pea aphid	9	Alfalfa
Amphorophora rubi	Raspberry aphid	6	Raspberry
Eriosoma lanigerum	Wooly apple aphid	3	Apple
Mayetiola destructor	Hessian fly	14	Wheat
Nephotettix virescens	Green leafhopper	3	Rice
Nilaparvata lugens	Brocon planthoppa	5	Rice
Orseolia oryzae	Gallmidge	6	Rice
Rhopalosiphum maidis	Corn leaf aphid	5	Maize
Schizaphis graminum	Green bug	11	Wheat
Therioaphis trifolii	Spotted alfalfa aphid	6	Alfalfa

[**Source:** Dhaliwal and Singh, 2004] [25]

2.8 Remedial measures

Sequential release: When a variety with a major gene becomes susceptible due to selection for a new biotype, another variety with a new major gene for resistance is released.

Gene pyramiding: Two or more major genes for vertical resistance are incorporated into a variety to impart resistance to more biotypes and also increase the stability of resistance.

Horizontal resistance: The level of horizontal resistance and its stability may be enhanced by increasing the number of minor genes in variety.

Gene combination: By combination of minor genes with major genes.

Gene rotation: The major genes may be rotated by seasonally alternating varietal groups having different major genes so that the selective pressure of the resistant variety on insect population may be reduced.

Geographical deployment: The planting of varieties with different resistant genes in adjacent cropping areas.

Breeding: Breeding tolerant varieties with combination of major genes will decrease the insect population and provide a high level of resistance.

3. Conclusion

There is an emerging consensus that modern chemical based farming is unsustainable and there is a need to develop and promote ecological approaches to food production. Recent advances in the science of ecology and environment have paved the way for restricting the use of harmful chemicals in agriculture and going for alternative farming methods which are more sustainable. Farmers generally opt for quick results and apply most toxic chemicals, even while the safer ones are technically suitable. Insect pest resistance to pesticides remain a problem globally, every effort must be made to reduce the risk of pesticide resistance. A thorough understanding of the mode of action, chemical groups/classes, chemical activities and codes will enable to decide which chemicals to use in sound rotations. It is possible to minimize the environmental load of pesticide by selecting suitable compounds which are applied at low dosages, which are biodegradable, have high mammalian safety, have low residual life and are compatible with non-target organisms. If insect resistance to transgenic plants is detected, "soft" options such as increasing the refugia size or refraining from planting transgenic crops must be delayed to the next planting season although the "harder" responses of massive chemical control could be implemented immediately.

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