CHAPTER-7

7.0 INSECTICIDE RESISTANCE AND MANAGEMENT

7.1 Insecticide Resistance

The insecticides resistance may be defined as: “The inherent ability of individuals in a normal population to survive against lethal doses of certain insecticide” (FAO, 1979).

------OR-----

“The ability of an organism to survive a dose of toxin which is lethal to a susceptible one” (Georghiou & Saito, 1983).

------OR-----

“Any heritable decrease in sensitivity to a chemical within a pest population” (Brent, 1986).

------OR-----

“Any heritable change that reduces susceptibility of pests relative to conspecifics and do not include economic impact as a criterion for resistance” (NRC, 1986).

------OR-----

“Genetically based decrease in the susceptibility to a pesticide” (Tabashnik et al., 2014).

------OR-----

“A heritable change in the sensitivity of a pest population that is reflected in the repeated failure of a product to achieve the expected level of control when used according to the label recommendation for that pest specie” (IRAC, 2016).

In 1914, resistance to lime sulfur was first time reported in San Jose Scale. Resistance to hydrogen cyanide was observed in red scale in California during 1916. In 1946, house flies were discovered resistance to DDT in Sweden. The insecticide resistance was reported in a total of 11 arthropod species such as: citrus thrips to potassium antimonyl tartrate, codling moth to lead arsenate, walnut husk fly to cryolite, since 1946. After this, resistance to every class of commonly available compound was reported in 428 species of arthropods (Georghiou & Mellon, 1983). In the early 1990s, approximately 504 arthropod species were proven resistance to one or more insecticides of the major insecticide groups (Georghiou & Lagunes-Tejeda, 1991). A typical example is Colorado potato beetle in which resistance to 52 chemicals belonging to different insecticide classes has been observed. Thereafter, the cases of resistance development to organochlorine, organophosphate, carbamate, pyrethroid and novel chemistry (neonicotinoids, *B. thuringiensis*, spinosyns, avermectins, diamides and insect growth regulators) insecticides have been increasing day after day in many insect pests. This phenomenon is termed as the ‘pesticide treadmill, and the sequence is familiar (IRAC, 2016). The continued application of insecticides has led the development of resistance and the strains which become resistant are increasingly challenging to control at the label recommended rates. This led the farmers to use high doses of the insecticide that is very dangerous. Both the genetics of resistance and the extensive application of insecticides are responsible for the rapid increase of resistance in insect pests (Abbas et al., 2014b, a; Khan et al., 2014a; Abbas & Shad, 2015; Afzal et al., 2015a). Globally pesticide resistance is documented in 954 pest species with 546 arthropods, 190 plant pathogens, and 218 weeds (Tabashnik et al., 2014). Overall, 14644 cases of resistance to 336 compounds in 597 arthropods species have been reported since 1914 to 2015. Highest cases of resistance to different insecticides against different insect pests have been reported in European Union (3520) following United State of America (2621), China (1923) and Pakistan (1693). Pakistan is the fourth country out of top 20 countries in resistance development to different insecticides (IRAC, 2017).

7.1.1 Field evolved resistance

Genetically based decline in the susceptibility to an insecticide in a field population is called field evolved resistance (Tabashnik et al., 2014). The effect of field evolved resistance might vary from no to very high on pest control. None to very high levels of field-evolved resistance to various insecticides have been documented by many authors in cotton leafworm *Spodoptera litura*

(Fabricius) (Ahmad et al., 2007a; Ahmad et al., 2008; Saleem et al., 2008; Shad et al., 2012; Ahmad & Mehmood, 2015), house fly *Musca domestica* Linnaeus (Khan et al., 2013a; Khan et al., 2013c; Abbas et al., 2015b; Abbas et al., 2015d; Abbas et al., 2015e), beet armyworm *Spodoptera exigua* (Hübner) (Ishtiaq et al., 2012), cotton whitefly *Bemisia tabaci* (Gennadius) (Basit et al., 2013a), cotton mealybug *Phenacoccus solenopsis* Tinsley (Saddiq et al., 2014; Saddiq et al., 2015), citrus psylla *Diaphorina citri* Kuwayama (Naeem et al., 2016) and cotton jassid *Amrasca devastans* (Distant) (Saeed et al., 2017).

7.1.2 Laboratory selected resistance

Genetically based decline in the susceptibility to an insecticide in a population due to continuous exposure in the laboratory is called laboratory selected resistance (Tabashnik et al., 2014). Laboratory-selected resistant strains are used to study the risk assessment, cross-resistance, stability, fitness costs, genetics and biochemical and molecular mechanism of resistance. A lot of laboratory-selected resistance reports to different insecticides in insect pests are available in Pakistan (Basit et al., 2012a; Abbas et al., 2014a, b; Abbas et al., 2014d; Zaka et al., 2014; Afzal et al., 2015a; Afzal et al., 2015b; Shah et al., 2015a; Shah et al., 2015b; Abbas et al., 2016a; Abbas et al., 2016b; Ullah et al., 2016).

7.1.3 Practical resistance

A field evolved resistance which decreases insecticide efficacy and has practical concerns for the control of pests is called practical resistance (Tabashnik et al., 2014). The efficacy of an insecticide can be assessed as a percent decline in the pest density due to exposure of an insecticide (Burkness et al., 2001; Tabashnik et al., 2014), and calculated as:

$$\text{Efficacy} = \frac{\text{Density of pest in control} - \text{ density after exposure to pesticide}}{\text{density of pest in control}}$$

If the pest density is same in the treatment and control, the efficacy of that insecticide is 0% and if the insecticide reduces the pest population to zero, the efficacy of that insecticide is 100%.

7.1.4 Sequential resistance

The growth of resistance to different insecticides at different times in the same population is called sequential resistance (Tabashnik et al., 2014).

Sequestration

The resistance occurred due to increase in the extent to which an insecticide that enters an organism is kept away from the target sites, yet remains inside the organism is known as sequestration (Tabashnik et al., 2014).

7.1.5 Cross resistance

Cross resistance can be defined as:

A population or strain which exhibit resistance due to a single mechanism of one molecule which offers resistance to the other molecules. This phenomenon is known as Cross Resistance (Sparks et al., 2012).

Resistance to an insecticide caused by the exposure of a population to a different insecticide with same mode of action is called cross resistance (Tabashnik et al., 2014).

Cross resistance is assumed a useful tool in assessing the mechanisms of insecticide resistance (Abbas et al., 2014a; Khan et al., 2014b). It is more common for insects that show resistance to an insecticide to be resistant to other insecticide with the same mode of action (Sparks et al., 2012). For example, a acetamiprid selected strain of *P. solenopsis* confirmed high cross-resistance to imidacloprid (62-fold), which have same mode of action (Afzal et al., 2015d). However, no cross-resistance to bifenthrin in the lambda-cyhalothrin selected population of *M. domestica* (114-fold) was also observed (Abbas et al., 2014b). The result of no cross-resistance between lambda-cyhalothrin and bifenthrin having same mode of action is may be due to independent mechanism (Khan et al., 2014b). Such results are interesting in term of control strategy, as the same mode of action insecticides can be used in rotation that reduce the selection pressure of a specific insecticide and ultimately delay the resistance rise to both insecticides but such cases are rare. Cross resistance may occur due to: (1) non-specific enzyme (microsomal oxidases) that attack functional groups of insecticides rather than specific molecule; (2) mutations at target sites that can lower sensitivity to insecticides; (3) delayed cuticular penetration that can affect chemically different insecticides.

7.1.6 Multiple cross resistance

Resistance to an insecticide caused by the exposure of a population to a different insecticide with unlike modes of action is known as multiple cross resistance (Tabashnik et al., 2014). Insects develop this type of resistance by expressing multiple resistance mechanisms (Qian et al., 2008; Afzal et al., 2015d). With multiple resistances, two resistance mechanisms are acquired independently through exposure to two different pesticides. Multiple cross resistance is not very common than cross resistance but has a big concern if occurred because it significantly reduces the number of insecticides that can be used for the control of pests. Cross resistance among insecticides from different group could also be possible when an iso-enzyme from insects act on different insecticides. For example, the MFO iso-enzymes selected by tebufenozide could well detoxify abamectin in *Plutella xylostella* (Linnaeus) (Qian et al., 2008). A acetamiprid selected strain of *P. solenopsis* showed multiple cross-resistance to deltamethrin (30-fold) (Afzal et al., 2015d).

7.1.7 Negative cross resistance

A situation in which an insect strain resistant to one insecticide is hyper-sensitive to other insecticide is known as negative cross resistance. It is a phenomenon in which increasing resistance to one insecticide lead to decrease in resistance to another insecticide (Gorman et al., 2010; Abbas et al., 2012). Negative cross resistance plays an important role in developing insecticide rotation strategies. Negative cross resistance has been reported in many resistant strains. For example, the imidacloprid-selected strain of *S. litura* demonstrated negative cross-resistance to methomyl (Abbas et al., 2012). Another example is the spinosad selected strain of *M. domestica* which showed negative cross-resistance to imidacloprid (Khan et al., 2014b). Negative cross resistance may occur due to fitness costs of resistant strains, allosteric effects at the target site, and increased metabolic processes.

7.2 Resistance Mechanisms

The genetically based alteration in physiology, morphology, or behavior that declines susceptibility to an insecticide is called resistance mechanism (Tabashnik et al., 2014).

7.2.1 Types of resistance mechanisms

7.2.1.1 Behavioral resistance

Resistance occurred due to changes in behavior that reduce exposure to an insecticide is known as behavioral resistance (Tabashnik et al., 2014). Avoidance of chemical baits is an example of behavioral resistance. When an insect no longer response to insecticide bait, it will not come in contact with that insecticide, ultimately limiting the exposure.

Example:

The avoidance of German cockroach *Blattella germanica* Linnaeus resistant strain from harborages treated with cypermethrin and chlorpyrifos and survived is the example of behavioral resistance (Hostetler & Brenner, 1994).

7.2.1.2 Physiological resistance

Reduced cuticular penetration

The resistance occurred due to reduced entry of an insecticide into cuticle of an insect is known as reduced cuticle penetration (Tabashnik et al., 2014). A change in integument structure of insect might affect the amount of chemical that reaches the target site.

Example

A change in cuticle has been documented in a common bed bug, *Cimex lectularius* Linnaeus strain resistant to pyrethroid insecticide (Lilly et al., 2016).

Increased metabolic detoxification
The resistance occurred due to enhanced enzymatic activity of an insecticide to make it less toxic is known as increased metabolic detoxification (Tabashnik et al., 2014). The enzymes such as acetylcholinesterase, cytochrome-P450, glutathione-S-transferase, and carboxylesterase are involved. It is very common resistance mechanism and has been reported in many insect pests (Kristensen, 2005; Abbas et al., 2014a; Afzal et al., 2015b; Afzal et al., 2015c).

Target site resistance
Target site is a part of an insect at which the insecticide interacts to kill the insect. It can be a specific molecule or portion of a molecule that interact with target site. Resistance occurred due to changes in the target site that reduce the toxicity of insecticide is known as target site resistance (Tabashnik et al., 2014). Small changes in the interaction of insecticide with the target site can have dramatic effects on the susceptibility which lead the development of resistance. Such mechanisms have been commonly shown for every class of neurotoxic insecticides. Some examples are acetylcholinesterase insensitivity for organophosphates and carbamates, acetylcholine receptors for neonicotinoids and spinosyns, sodium channel sensitivity for pyrethroids and point mutations for fipronil (Matsuda & Sattelle, 2005; Millar & Denholm, 2007; Tian et al., 2011; Zhang et al., 2016).

Example
Mosquito resistance to pyrethroid is due to insensitive of sodium channel.

7.3 Factors for resistance development

- Extensive rise of pesticide use for the control of different pests.
- Resistance to an insecticide occurs when susceptibility of a pest population changes.
- Extensive applications of insecticides and genetics basis of resistance are accountable for the evolution of resistance in insect pests. Due to selection pressure with insecticides, the insects having resistant genes survive and transfer these resistant traits into their progeny. In this way, the quantity of resistant insects increased in a population due to elimination of susceptible ones. Ultimately, resistant ones outnumber susceptible ones and the particular insecticide is no longer effective.
- More persistency of poison and more rapid life cycle of insects are the greater risk for the rapid development of resistance.
- The influx of unexposed migrants dilutes the inbreeding of resistant insects in the field conditions, so that the heterozygotes are often found to develop resistance more rapidly.
- Selection pressure of an insecticide in the laboratory can lead rapid development of resistance.

7.4 Monitoring of Resistance

The development of resistance to insecticides is an expected consequence of insecticide usage for the control of insect pests. The efficacy of chemical control is economically unacceptable when the frequencies of resistant phenotypes increase at certain level in the field populations. However, poor efficacy of insecticides is not always due to resistance under the field conditions. Other factors such as quality of technical grade materials used, formulations, doses of application and method of application may also play a significant role in harming field control. But if resistance is major factor, the field control failure is expected, regardless of above mentioned factors and a major threat to sustainable pest management. Therefore, it is most important to monitor the resistance in field populations so that appropriate measures can be implemented for effective pest management (Abbas et al., 2015d; Jan et al., 2015; Saddiq et al., 2015; Saeed et al., 2017).
Applications of resistance monitoring are as follows:

1. Monitoring of resistance to insecticides helps to know the temporal and geographical changeability in a population response to selection pressure of particular insecticide.
2. Resistance detection helps us to avoid ineffective insecticides and to make proper recommendation of alternate effective insecticides.
3. Resistance monitoring helps to prevents wastage of pesticide applications that would otherwise pollute the environment.

4. Resistance detection confirms the reasons of pest control failure by particular insecticide under the field conditions.
5. Monitoring of resistance helps to assess the influence of implemented resistance management strategies.

7.5 Genetics of Resistance

7.5.1 Gene frequency

In generally, frequency of resistant alleles (R) in natural/field strains would be expected to be low ranged from 0.0001-0.01. For example, the estimated frequency of resistant alleles to Cry1Ab was 0.0023 in sugarcane borer field populations (Huang et al., 2007). However, the frequencies of resistant alleles in some field populations are surprisingly high. For example, a bedbug population contained 0.5% DDT-R genes prior to use of DDT in Taiwan.
In resistant populations, the frequency of resistant alleles can be very high. For example, the frequency of pyrethroid resistance allele ranged from 0.25-0.966 using the real time PCR amplifications of specific allele (rtPASA) method in eleven field population of malarial mosquito *Anopheles sinensis* Wiedemann in Korea (Kim et al., 2007).

7.5.2 Autosomal or sexed linked

1. **Sex linked resistance**
   Alleles controlling resistance to any insecticides are present on sex chromosome is called sex linked resistance.
2. **Autosomal resistance**
   Alleles controlling resistance to any insecticides are not present on sex chromosome is called autosomal resistance.

It can be evaluated by reciprocal crosses between susceptible and resistant homozygotes insects. By comparing the LC_{50} values of reciprocal crosses, if the CI of LC_{50} values are overlapping suggests autosomal inheritance of resistance to insecticides. If CI not overlapped, then there is sex linked inheritance. In mostly studies, the autosomal resistance is reported in many insect pests in *M. domestica* to pyriproxyfen, and *P. solenopsis* to chlorpyrifos (Abbas et al., 2014b; Khan et al., 2014a; Afzal et al., 2015b; Afzal et al., 2015c; Shah et al., 2015c). However, few cases of sexed linked inheritance are documented in insects, for example *P. xylostella* resistance to tebufenozide (Cao & Han, 2013).

7.5.3 Dominance of resistance

The inheritance of resistance in which insects have a resistant phenotype only if they have two resistant alleles at a genetic locus that controls susceptibility is called **recessive resistance** (Tabashnik et al., 2014).
The inheritance of resistance in which insects have a resistant phenotype only if they have either one or two resistant alleles at a genetic locus that controls susceptibility is called **dominant resistance** (Tabashnik et al., 2014).
The degree of dominance can play an important role in expression of the resistance genes (Abbas et al., 2014b). Resistant genes may be completely recessive, incompletely recessive, incompletely dominant, or dominant. Chemical control is very difficult if genes controlling resistance are completely dominant to insecticides. Resistance due to dominant genes can increase quicker than the resistance due to recessive genes, because resistance genotypes increase as R:S = 1:3 for recessive and R:S = 3:1 for dominant (Wang et al., 2009; Khan et al., 2014a). In toxicology, dominance levels were firstly assessed by the comparison of mortality curves of the susceptible, resistant, and hybrid insects. Resistance was categorized as recessive, incompletely recessive, dominant, and incompletely dominant based on whether the mortality curve of hybrids was closer to mortality curve of susceptible or resistant insects, respectively.
There are two formulae used for determination of value of dominance.
(i) A formula was introduced by Stone (1968) to calculate the value of dominance level as:

$$D = \frac{2 \log LCRS - \log LCR - \log LCS}{\log LCR - \log LCS}$$

Where, LC_R, LC_{RS}, and LC_S are the median lethal concentrations for the resistant, hybrid and susceptible insects, respectively. D value varies from -1 (completely recessive) to +1 (completely dominance).

Stone's formula is the most extensively used method to determine the dominance values of resistance to insecticides.

(ii) There is another formulae which was introduced by Bourguet & Raymond (1998) which is given as follows:

$$D_{LC} = (\log LC_{RS} - \log LC_S) / (\log LC_R - \log LC_S)$$

Its value ranged from 0 to 1. Zero means completely recessive and one means completely dominant.

7.5.3.1 Completely dominant resistance

The distribution and expression of dominant resistant genes in the heterozygotes is called completely dominant resistance to insecticides. If resistance is completely dominant, only one parent has to possess the trait for it to be fully expressed in the offspring.

Example

Completely dominant resistance has been reported in house fly resistant to pyriproxyfen (Shah et al., 2015c).

Remedy

The dominant resistance can rapidly become established within the populations and very difficult to manage therefore those insecticides should be withdrawn from resistance management strategies.

7.5.3.2 Incompletely dominant resistance

The distribution and expression of partially dominant resistant genes in the heterozygotes is called incompletely dominant resistance to insecticides. If resistance is incompletely dominant, only one parent has to possess the trait for it to be partially expressed in the offspring.

Example

Incompletely dominant resistance has been reported in house fly resistant to fipronil and lambda-cyhalothrin and cotton mealybug resistant to spinosad (Abbas et al., 2014b, a; Afzal et al., 2015c).

Remedy

This type of resistance can be managed by cautioned and rotational use of insecticides with different mode of action.

7.5.3.3 Completely recessive resistance

The distribution and expression of recessive resistant genes in the heterozygotes is called completely recessive resistance to insecticides. If the resistance is completely recessive, both parents must possess the trait for it to be fully expressed in the offspring.

Example

Completely recessive resistance has been reported in diamondback moth resistant to *Bt* toxin Cry1Ac.

Remedy

The recessive resistance cannot rapidly become established within the populations. It is considered an advantage for resistance management because heterozygotes should be easily killed under field conditions.

7.5.3.4 Incompletely recessive resistance

The distribution and expression of partially recessive resistant genes in the heterozygotes is called incompletely recessive resistance to insecticides. If the resistance is incompletely recessive, both parents must possess the trait for it to be partially expressed in the offspring.

Example

Incompletely recessive resistance has been reported in house fly resistant to imidacloprid and cotton mealybug resistant to chlorpyrifos (Khan et al., 2014a; Afzal et al., 2015b).

Remedy

If the heterozygotes tolerate a higher dose of insecticides compared to the susceptible strain, therefore those insecticides should be used cautiously for the management of pests to retain long term efficacy.

7.5.4 Effective dominance (D_{ML})

Effective dominance measures the relative mortality level for a given insecticide concentration on different concentrations of bioassay. D_{ML} can be quantified as follows according to Bourguet & Raymond (1998).

$$D_{ML} = (ML_{RS} - ML_{SS}) / (ML_{RR} - ML_{SS})$$

Where, ML_{RR}, ML_{RS}, and ML_{SS} are the mortalities on given concentrations for the resistant, hybrid and susceptible insects, respectively. D_{ML} varies between 0 and 1 (0 recessive and 1 dominant). The extent of resistance dominance depends upon the doses of specific insecticide used and is reported in many insect pests (Abbas et al., 2014a, b; Khan et al., 2014a; Afzal et al., 2015c). ~~The recessive resistance gives an advantage for the management of resistance because heterozygotes can be easily killed in the field. However, if the heterozygote insects tolerate a higher dose of insecticide compared with the susceptible insects, then~~ particular insecticide should be used sensibly for the management of insect pests to retain long term efficacy.

7.5.5 Monogenic or polygenic resistance

On the basis of number of genes

1. Monogenic resistance
   Resistance controlled by one gene (major gene effect) is known as monogenic resistance.
2. Polygenic resistance
   Resistance controlled by more than one genes (minor gene effect) is known as polygenic resistance.

To know the resistance is monogenic or polygenic, the reciprocal crosses (F1) of the susceptible and resistant strains are backcrossed with parent strains (either susceptible, resistant or both).

Monogenic or polygenic resistance can be estimated by using a chi-square goodness of fit test according to Sokal & Rohlf (1981) as follows:

$$\chi 2 = (Ni - pni)2 / pqni$$

Here, *Ni* is the observed mortality in backcross strain to a particular dose, *ni* is the number of insects exposed to a particular dose, *p* is the expected mortality calculated following Georghiou (1969) and q is calculated as 1-p. The expected mortality is calculated as 0.5 (number of cross (F1) insects killed + number of resistant insects killed)/number of insects exposed in concentration. If there are significant differences between observed and expected mortalities at more than half of total concentrations (e.i. $P < 0.05$ in 4 concentrations out of 6 concentrations), the null hypothesis of monogenic resistance is rejected.

Polygenic and monogenic resistance to insecticides can happen in the natural strains (Ahmad et al., 2007b; Abbas et al., 2014b). Polygenic resistance is more likely under laboratory selections, due to lack of rare variants in the laboratory selected strains than natural strains

(McKenzie et al., 1992; Abbas et al., 2014b). Polygenic resistance is observed in many laboratory selected insect species to different insecticides; for example, *M. domestica* resistant to imidacloprid, lambda-cyhalothrin, fipronil, pyriproxyfen, and spinosad (Abbas et al., 2014a, b; Khan et al., 2014a; Khan et al., 2014b; Shah et al., 2015c), *P. solenopsis* resistant to chlorpyrifos, spinosad, and acetamiprid (Afzal et al., 2015a; Afzal et al., 2015b; Afzal et al., 2015c). Monogenic resistance is also observed in *M. domestica* resistant to beta-cypermethrin (Zhang et al., 2008). The change in resistance type depends upon the selection history, number of insect exposed and geographical origin of the pest species.

7.6 Fitness Costs

The ability of a certain individual in a population to survive and reproduce compared to other individuals of the same species is called fitness. The development of resistance to an insecticide is complemented with high energetic cost or significant disadvantage that weakens the fitness of insects compared with its susceptible counterparts in the population is called fitness cost (Kliot & Ghanim, 2012).

Relative fitness is a significant tool for evaluating the biological changes in insecticide resistant strains and the adaptability of insects to insecticides. Relative fitness is measured as Ro of resistant strain/Ro of susceptible counterpart strain, where Ro is net reproductive rate calculated as N_{n+1}/N_n, where N_n is the parental population quantity, and N_{n+1} is the number of larvae produced in next generation (Abbas et al., 2012). Moreover, biological parameters such as survival rates, larval durations, pupal durations, pupal weights, development times, growth rates, fecundity, hatchability, female ratio and biotic potential are studied to see the fate of fitness. Fitness costs in resistant insects may delay the development of resistance under certain conditions.

7.6.1 Types of fitness costs

7.6.1.1 Increased fitness costs

When the resistant individuals of a strain showed disadvantageous biological parameters compared with counterpart susceptible / unselected strain are called increased fitness costs. These fitness costs have been observed in pests and chance of the resistance development is low. These traits could increase the impact of insecticide rotations and sustainability of the resistance management strategy for insecticides. In this, value of relative fitness is less than one.

Example

Increased fitness costs have been reported in house fly resistant to fipronil, imidacloprid, methoxyfenozide, pyriproxyfen and lambda-cyhalothrin (Abbas et al., 2015c; Shah et al., 2015d; Abbas et al., 2016a; Abbas et al., 2016b; Shah et al., 2017).

7.6.1.2 Decreased fitness costs

When the resistant individuals of a strain showed advantageous biological parameters compared with counterpart susceptible strain are called decreased fitness costs. Such fitness costs have been observed in natural enemies and chance of the resistance development to insecticides is high which show compatibility of natural enemies with chemical control. In this, value of relative fitness is more than one.

Example

Increased fitness has been observed in spinosad and emamectin benzoate resistant strain of *C. carnea*.(Mansoor et al., 2013; Abbas et al., 2014c) If increased fitness of resistance to insecticides is observed in pests, then those insecticides should be withdrawn from resistance management strategies.

7.6.1.3 No fitness costs

When the resistant individuals of a strain showed neither disadvantageous nor advantageous biological parameters compared with counterpart susceptible strain are called no fitness costs. If there are no fitness costs of resistance, these traits could decrease the impact of insecticide rotations ~~and~~ threaten sustainability of the resistance management strategy for insecticides. In this, value of relative fitness is equal to one.

Example
Lack of fitness costs have been reported in whitefly resistant to pyriproxyfen and acetamiprid (Crowder et al., 2009; Basit et al., 2012b).

7.7 Stability of Resistance

Determination of insecticide resistance stability has practical implication in making effective resistance management strategies (Abbas et al., 2015b; Afzal et al., 2015d). A decline of resistance to insecticides in the resistant strains is determined as R = log final LC_{50}-log initial LC_{50}/number of generations selected with a particular insecticide. If R value comes in negative, the resistance is unstable. The stability of insecticide resistance is also assessed by comparing the LC_{50} values of field strain and laboratory selected strain. If the fiducial limits of LC_{50} of both strains did not overlap, the resistance is unstable. The removal of an insecticide from spray program for some time may bring the resistance level lower if resistance is unstable, and therefore, prolong the efficacy of that particular insecticide. The decline in resistance levels is observed in many insecticides selected populations of different species in the laboratory and might be due to high fitness cost of resistance to insecticides (Abbas et al., 2015c; Afzal et al., 2015d; Shah et al., 2015d; Abbas et al., 2016a; Abbas et al., 2016b; Shah et al., 2017).

7.8 Insecticide Mixtures

Insecticide mixtures work as an important tool for resistance management in many insect pests and are used to delay the development of resistance to insecticides or to increase the efficacy of control (Abbas et al., 2015a). Insecticides mixtures are assessed by using ratios of 1:1, 1:10, 1:20 and LC_{50}:LC_{50} (Khan et al., 2013b; Abbas et al., 2015a). A combination index (CI) is calculated to assess the mixture effects according to Chou & Talalay (1984) as:

$$\mathrm{CIx} = \frac{\mathrm{LCx\ (1m)}}{\mathrm{LCx1}} + \frac{\mathrm{LCx\ (2m)}}{\mathrm{LCx2}} + \left(\frac{\mathrm{LCx\ (1m)}}{\mathrm{LCx1}} \times \frac{\mathrm{LCx\ (2m)}}{\mathrm{LCx2}}\right)$$

$LC_x^{(1m)}$ and $LC_x^{(2m)}$ are the ~~median lethal concentrations of insecticide mixtures~~ and LC_x^1 and LC_x^2.are the median lethal concentration of insecticides alone~~, giving mortality x~~. Combination index values are categorize as a synergistic effect (CI <1), an additive effect (CI = 1), and an antagonistic effect (CI >1).

The insecticide mixtures with different modes of action indicating synergistic effects should be used in insecticide resistance management strategies. For example, synergistic effects of pyrethroid and organophosphate/new chemical and neonicotinoid and insect growth regulator mixtures are observed in *B. tabaci* (Basit et al., 2013b), *S. litura* (Ahmad, 2009), and *M. domestica* (Khan et al., 2013b). Furthermore, the evaluation of newly introduced insecticide mixtures is needed in future for effective resistance management

7.9 Detoxification Mechanisms of Insecticides

Detoxification is the biotransformation of complex/toxic compounds into simple/less toxic compounds is known as detoxification. Detoxification mechanisms occur by the following type of chemical changes:

7.9.1 Phase 1 reactions

Phase 1 reactions are also known as primary reactions. These reactions are:

7.9.1.1 Oxidation

The removal of hydrogen atom or addition of oxygen atom is called oxidation. This detoxification reaction is carried out by the enzyme, cytochrome P450 monooxygenases, microsomal oxidase or mixed function oxidase (MFO). The overall reaction is as follows:
$RH+NADPH+H^++O_2 \rightarrow ROH+NADP+H_2O$
Oxidation reactions are hydroxylation, de-alkylation, dearylation, epoxidation, sulfoxidation and desulforation.

Example

Carbamate insecticide carbaryl (1-naphthyl methylcarbamate) converted into 1-naphthol which is less toxic compound.

7.9.1.2 Reduction

The removal of oxygen atom or addition of hydrogen atom is called reduction. The reductive detoxification of nitro group to amino group is occurred by reductase enzyme.

Example

Parathion is reduced to aminoparathion which is less toxic to parathion.

7.9.1.3 Hydrolysis

Addition of water molecule to esters or amides resulting in the cleavage of ester or amide linkage is called hydrolysis.

$R^1COOR + H2O \rightarrow R^1COOH + ROH$

Organophosphates, carbamates, pyrethroids and juvenoids that contain ester linkages are hydrolyzed by the enzymes, carboxylesterase, phosphatase and amidase etc.

Example

Malathion hydrolyzed into α and β-monoacids and ethanol.

7.9.1.4 Dehydrochlorination

Removal of HCL from the insecticide to convert the toxic substance to none toxic metabolites is known as dehydrochlorination. The enzyme involved is called dehydrochlorinase.

Example

DDT is converted into DDE, resulting in detoxification.

7.9.2. Phase II reactions

7.9.2.1 Conjugation

Conjugation reaction is biosynthesis pathway (production of chemical substance by living organisms) by which foreign compounds and their metabolites containing certain functional groups are linked to endogenous substrate and convert them generally to less toxic compounds.

Example

O-Alkyl conjugation of methyl parathion with GSH produces desmethyl parathion and methyl glutathione.

7.10 Genotoxicity

The property of a chemical that damages the genetic makeup within a cell causing mutations, which may lead to cancer, is known as genotoxicity. Genotoxicity is often confused with mutagenicity; all mutagens are genotoxic but all genotoxic substances are not mutagenic. Pesticides are considered likely chemical mutagens because various agro-chemical ingredients contain mutagenic properties such as chromosomal alterations mutations, or DNA damage (Bolognesi, 2003). For example, cytotoxic and genotoxic effects on human intestinal cells by acetamiprid, DNA damage by low dosage of avermectin in silkworm hemocytes, and cytotoxic, genotoxic, and aneugenic effects by pyrethroid insecticides on human blood lymphocyte are observed (Shen et al., 2011; Çavaş et al., 2012; Muranli, 2013). Genotoxic effects of insecticides can be tested in both in vitro and in vivo systems by Micronucleus Assay, Ames Test, Pig-a Assay, Reconstructed Skin Micromolecule Assay, Comet Assay/Single Gene Electrophoresis.

7.11 Resistance Management

1. Resistance gene frequency can be reduced by using low doses of insecticides, using insecticides with short environmental persistence, providing refugia where susceptible insects reproduce and treating more damaging life stage.

2. Resistance can be delayed by using insecticide mixtures having synergistic interactions and no cross resistance between them.
3. Rotations of insecticides with different mode of action having no cross resistance/multiple cross resistance to each other and unstable resistance should be implemented to delay the development of resistance.
4. By using insecticide synergists such as PBO, DEF and DEM, the efficacy of insecticides can be increased, ultimately delay the resistance.
5. New bio-rational insecticides and bio-pesticides should be integrated for the control of insect pests.
6. By using resistant predators and parasites, the selection pressure of insecticides can be reduced.
7. Monitoring of resistance to insecticides should be done on regularly basis that reduce the frequent use of insecticides in the field.
8. Cultivation of transgenic crops (Bt cotton) may reduce the number of sprays especially for lepidopteran pests which may delay the development of resistance.

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CHAPTER-8

8.0 INSECTICIDE APPLICATION

8.1 Application Equipment

A number of application equipment is available for applying insecticides. But the type of application equipment used depends upon the following factors (Edward, 1975).

- Size of the area (mechanical equipment for large area while hand equipment for small area)
- Availability and the type of carrier (oil, water etc.)
- Availability of the workers
- Cost, availability and durability of equipment
- Type of insect and insecticide formulation
- Time, speed and accuracy of application equipment

8.1.1 Boom sprayer

8.1.1.1 Parts of Boom Sprayer

A number of insecticide formulations are sprayed by the sprayers so the material of sprayers should be such that it can withstand the effects of spraying material. Some of the insecticide formulations like wettable powders exhibited abrasive activity while other may have corrosive effects in contact with the sprayer material. Boom sprayer has following parts (FAO, 1994; Malik, 2012).

8.1.1.2 Pump

Pump produces the necessary pressure to facilitate the flow and atomization of spray material towards the nozzle. Different types of pumps are available in the market like roller, piston, diaphragm and centrifugal pumps. Piston and diaphragm pumps are more suitable to develop required amount of pressure for thorough plant coverage. Two things must be considered for choosing a good quality pump, one is the gallons per minute supplied by the pump and the other is the pressure range that can handle by it.

Figure 8.1 Pump of boom sprayer

8.1.1.3 Tank

Sprayers used water and other materials as diluents in addition to the insecticides. Spray tank is a necessary component to carry the spray material. The size of the tank should be large enough to avoid the frequent refilling. The size of the tank also depends upon the rate of application and space available for its mounting. Tanks must be equipped with large upper and bottom opening. The large top opening with strainer helps in easy filling, inspecting and cleaning while the lower opening is used for draining. Both openings must be provided with water tight cover to avoid spillage. A good tank must have gauge to indicate the water level of the tank.

Spray tank can be made of different materials including steel, fiberglass, aluminum and polyethylene. Tanks made of fiberglass, polyethylene or stainless steel is more preferred because of their resistance towards corrosion and abrasion. In case of other materials tank should be coated with a protective lining to resistant the above activities.

Figure 8.2 Tank of boom sprayer

8.1.1.4 Spray Lance of boom

It is a horizontal pipe of varies length (1-15m) with two or several nozzles separated by 50cm apart. Usually long boom is used for tractor sprayers. It is more beneficial than spray lance because of its wide swath (Area covered by a single nozzle during spray) it covers in each trip. Width of swath can be adjusted to obtain three types of sprays.

- Directed spray
- Band spray
- Uniform spray

It contains 28-36 nozzles.

Figure 8.3 Spray Lance of Boom

8.1.1.5 Power source

It is the main requirement to operate the sprayer. Different power sources are operated now days including the manual, tractor or tractor with air craft engines, traction and motor.

8.1.1.6 Control Valve and gauge

It is valve which control flow of pesticide solution and gauge depicts pressure of solution which is being flowing.

8.1.1.7 Nozzles

Its main function is to convert the pressurized liquid into small droplets or mist for thorough application on the target site. It also controls the droplet size, amount of liquid and distribution pattern. Size of the droplet and flow rate is also dependent upon the pressure in addition to the design of the nozzle. Under high pressure and with small nozzle tip droplets of smaller size are produced and vice versa. Small droplet size provides thorough and even coverage while bigger size results in the reduction of off-target drift.

Nozzles can be available in different materials including brass, aluminum, stainless steel, ceramic, and plastic. Selection of nozzle material is quite dependent upon the type of formulation. Aluminum or brass can't be used for abrasive formulation (wettable powders and dry flowables). These materials wear down quickly. Selection of nozzle type consider many factor like coverage desired, target pest or area, method of application and potential for drift. A nozzle consists of nozzle body, a strainer, replaceable nozzle tip and a cap to hold it. Nozzles can be classified on the basis of droplet size and spray pattern (UK, 2016). A nozzle performs three important functions.

- Covert the spray able liquid into smaller droplets
- Spray and spread these droplets in a specific pattern
- Nozzles regulate the rate of release of the sprayer

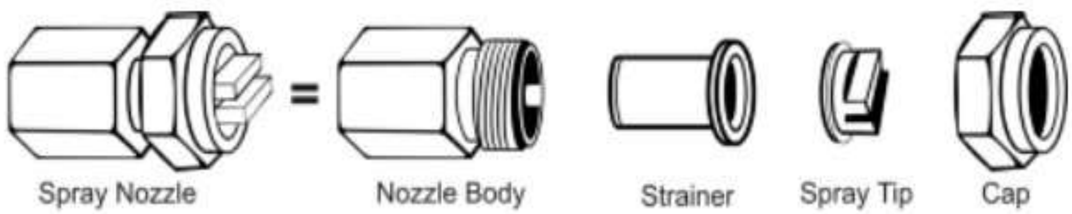

Figure 8.4 Parts of nozzle

8.1.1.7.1 Fan nozzle / Tee jet

These are used for banding sprays and produce a narrow, oval pattern with a sharp cutoff at the edge. These are available in different types like even flat fan, standard flat fan, low pressure, off center, and twin orifice flat fan nozzles. These are mostly used for applying herbicides. Nozzle spray angle and boom height effect the width of the spray. These are available in different colors depending upon the size of the orifice.

Figure 8.5 Fan nozzle

8.1.1.7.2 Hollow cone nozzle

These nozzles release a more uniform and fine spray particles than the solid cone nozzles. These are used for spraying agricultural crops with formulation of wettable powders, suspensions and flowables at higher pressure. These are usually used to apply fungicides or insecticides when complete coverage and foliage penetration is the priority. Spray drift is more than other nozzles. These are available in varying colors with different hole sizes.

Figure 8.6 Hollow cone nozzle

8.1.2 Knapsack sprayer

It is commonly used and small unit of sprayer which is operated by hand or engine. These are also manually operated and carry by operator on its back by a pair of mounting straps during application of insecticides. It is suitable for small lands up to some acres. The lever is used to push the liquid from spray tank to the air cylinder with the help of a piston. Air present in the cylinder creates pressure that releases the water through via cut-off valve. A plastic tank of 14-16 liters capacity is used with the sprayer. Hand level is usually operated at 15-20 strokes/ minute at the pressure of 40psi. However, applicator requires constant pumping to develop pressure. It requires good practice for thorough coverage of the area to be treated (McAuliffe & Gray, 2002).

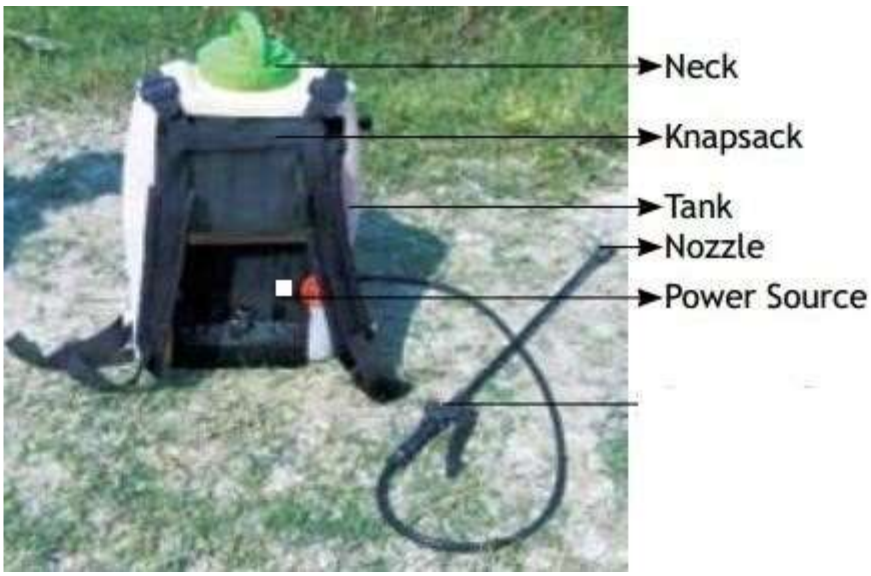

Figure 8.7 A Knapack sprayer

8.1.2.1 Parts of Knapsack Sprayer

8.1.2.1.1 Spray tank

This is main part of sprayer which is filled with pesticide solution being sprayed for control of different pests.

Figure 8.8 Spray tank

8.1.2.2 Spray lance

It is a long rod of 90cm in length made up of steel or brass. On one side it is attached to the delivery pipe and provided with a replaceable nozzle at the other end. At the hose side it is equipped with a trigger mechanism to regulate the flow of liquid and it bents at its nozzle end forming a goose neck. Sometimes a plastic shield is used to fix the spray lance to prevent chemical drifting.

Figure 8.9 Spray Lance

8.1.2.3 Control valves

Additional cutoff valves are provided between the pressure regulators and nozzle to provide the on/off function. These should be easily reachable by the spray person and should large and tight enough that does not hamper (when open) and release the liquid flow (when closed).

Figure 8.10 Control valve

8.1.2.4 Pressure regulators

Pressure regulators and gauges are provided to control and check the rate of pressure, respectively. It helps to maintain the operation at constant pressure. These also protect the sprayer parts to wear down due to excessive pressure. The type of regulators depends upon the type of pump. Likewise the type of pressure gauge depends upon the type of sprayer. High pressure gauge not provides the accurate readings for low pressure sprayer. These functions are sometimes performed by the cut-off valves of the sprayer.

Figure 8.11 Pressure regulator

8.1.2.5 Hose

These are used to deliver insecticides out of tank. These should be strong enough to resist the pressure and the effect of different formulations of insecticides. The inlet diameter of hoses should be greater or at least equal to the diameter of inside parts of the pump. Undersized hoses can reduce the pump capacity that can alter the pump pressure and ultimately results in uneven flow rate. The most effective materials used for the hoses are neoprene, plastic and rubber.

8.1.2.6 Pump

Pump is provided in a automatic sprayer which provide source to throw pesticide solution outside sprayer.

Figure 8.12 Pump of knapsack sprayer

8.1.2.7 Strainers

These are also called filters and are in the form of small mesh screen. These present at different places in the sprayers and help to filter the small particles present in the spray solution that may clog or damage the distribution system. Strainers of different sizes are present in the following places

- In the nozzle body to screen out the small particles to avoid the clogging of nozzle
- At the entrance of pump intake pipe (25-50 mesh size)
- In the way between the pressure regulator and boom (50-100 mesh size)

- For wettable powders all screens should be of 50 mesh size or coarser


Figure 8.13 Both are Strainer

8.1.2.8 Tank agitator

Spray material of an insecticide is a mixture different component (See chapter Formulations) including the insecticide and carrier. Agitator devices help to maintain the homogeneity of the spray material. Constant mixing is necessary for some of the formulations like dry flowables and wettable powders (suspension, emulsion). It will produces the uniform spraying material for even application. Agitation can be achieved by using paddles provided in the tank while jet agitation is another method for constant stirring the spray mixture.

In jet agitation, a nozzle is present inside the tank that continuously throws the stream of spray within the tank to keep it agitated constantly. Jet agitation is controlled by different ways. The amount of stream released depends upon the type of formulation and size of the tank. For the foam forming formulations, flow rate of liquid or agitation is reduced by using the control valve of the agitator.

8.1.3 Granule spreaders

These spreaders are used to apply uniformly coarse sized, dry particles of insecticides to water, soil and foliage. These are mostly used in broadcast and band applications. These are less likely used as a single unit because they are mostly attached with cultivating equipment (planters). It is usually operated by gravity (gravity feed) and has an adjustable opening to control the release of granules.

Two types of spreaders are commonly used including the rotary and drop spreader. Rotary spreader distributes the granules at the sides and front by using the rotating fan or disk while the drop spreaders differs by an opening at the bottom side which opens by means of a sliding gate that controls the flow of granules by gravity feed. Moat often drop spreaders are preferred over rotary spreaders when precise application is required (Roberson, 2017).

Advantages

These are simple, light weight and easy to calibrate and require no carrier.

Fig 8.14 Granular applicator

8.1.4 Pressurized cans (Aerosols)

These are in the form of pressurized disposable packaging or cans with the capacity of ≤ 1L. These are manually operated sprayers and mostly used for small land holdings such as green houses or for small land holdings. It consists of an air pump that develops pressure in the spray tank that slowly release the liquid droplets form nozzle. It provides less uniform coverage of the treated area.

Figure 8.15 Pressurized cans

8.1.5 Trigger pump sprayers (Gun)

These are non-pressurized sprayers because they do not use separate pressurized air source. The insecticide force through the nozzle under pressure created by the squeezing the trigger. These sprayers give an even application. They are mostly used for small areas.

Figure 8.16 Triger pump sprayer

8.1.6 Motorized / Power operated / Mechanical sprayers

Power driven sprayers have many advantages over conventional sprayers. These provide power and high pressure to operate the different parts of the sprayer. Power is provided by electric motors or engines. The sprayer under this heading may require high to low pressure depending upon the requirements of the pump or other components of the sprayers. These can be mounted on trucks, tractors and aircrafts. These are good for the large scale application in orchards and other crops (Edward, 1975; Malik, 2012; Anonymous, 2017).

8.1.6.1 Boom Sprayer

These are also mounted on trucks, trailers or tractors. These are also designed to apply the insecticides over large field areas in swaths. The application rate may vary from 50-500L/ha at the pressure of 50-500Kpa. The length of boom may be 6-10 meter long with the nozzle distance of 50100cm. these sprayers provide uniform and full coverage of large areas but they may not penetrate the dense foliage. These sprayers mostly use hydraulic sprayers that may cause problem with the wettable formulations.

Figure 8.17 Boom sprayer front and rear view

8.1.6.2 High-pressure / Hydraulic Sprayers

These sprayers are used for thick foliage, to the top of the trees and for the areas where high pressure is a necessary requirement for complete and uniform coverage. The sprayers work at a pressure of 7000Kpa. The design of the high-pressure sprayers is similar with the low pressure sprayers except the components are designed to withstand high pressure. The sprayer may be equipped with a boom, a hose, multiple nozzles or a handgun nozzle for spraying, shade trees, orchards, building, ornamentals, livestock and commercial crops. They are also used mechanical agitators that well mix the wettable powders.

8.1.6.3 Air blast sprayers

These sprayers use a combination of water and air to deliver the insecticide to the target site. Insecticide is pushed through a nozzle or series of nozzle. A high speed fan or blower blows away the insecticide through nozzle in the form of an air blast. The high pressure air converts the insecticide solution into small droplets that moved away by an air blast. The pressure and volume of these sprayers can be adjustable according to the needs. The air blast may be carried 10-40 feet away from the sprayers. Capacity of tank is 500Ltr. These sprayers are used for tree spraying and spraying of agricultural crops (Malik, 2012).

Figure 8.18 Air blast sprayer front and rear view

8.1.6.4 Jeeto sprayer

It is of aluminum three-way valve enabled high efficiency sprayer. Its tank is made up of fiber glass with the capacity of 400 Liters. Its each disc of three stage turbine atomizes the chemical in small droplets (mist). It is mostly used for spraying orchard trees. Flow rate varies from 0.3 to 1.6L/ Min with the speed of 3-45KM/hr.

Figure 8.19 Jeeto Sprayer

8.1.7 Aerosol generators/ Foggers

These have a metallic container to withstand the pressure of liquefied propellant. The droplet size is very small (1-50µm) and these are suspended in the air for long period of time. These are mostly used to control the flying insects like mosquitoes and flies. Dispenser is fitted with a delivery tube and a propeller. The propeller forces the spray to leave through the delivery tube in the form of fine droplets. These are mostly available with the capacity of 300-400g of insecticide while 2-5kg sizes are also available. These are used at the rate of 7-14g per 100m^3 of the area to be sprayed. On the other way compressed air, centrifugal energy and hot velocity air is also a source of energy (Malik, 2012; UK, 2016).

Figure 8.20 Aerosol generator

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CHAPTER-9

9.0 INSECTICIDE LEGISLATIONS IN PAKISTAN

AGRICULTURAL PESTICIDE ORDINANCE 1971 AMENDED 1997 AND AGRICULTURAL PESTICIDES RULES 1973 PAKISTAN

Main points of pesticide ordinance are

1. Short title, range and commencing.

(1) This Ordinance should be pronounced as the Agricultural Pesticides Ordinance, 1971.

(2). It is applicable to whole of Pakistan.

(3). This ordinance will be effective immediately.

2. Other laws for the time being in force will not be interrupted by this ordinance.

3. Definitions– In this Ordinance include different definitions of terminology which is used in rest of ordinance.

(a) “Adulterated” is a pesticide that is not of the standard quality or fulfills the values written on the label. It is either mixed with a material and is not effective against the target pests];

(b) “Advertise” referred to awareness of the community through publication, notice or circular.

(d) “Committee” is meant for Agriculture Pesticide Technical Advisory Committee

(e) “Formulation” is a preparation of a pesticide by mixing an active ingredient with an inert material to make it readily usable to overcome the pest problem.

(f) “Fungi” indicates all kinds of diseases causing mildews, moulds, yeasts, rusts, smuts, and similar other fungi effecting plant life.

(g) “Government analyst” is person who works as a Government Analyst in the Pesticide laboratory under.

(h) “Guarantee” means written statement by an applicant about the quality of pesticide required to submit under the rules when applying for registration of the pesticide.

(i) “inspector” is any Government officer exercising powers under this Ordinance;

(j) “ingredient” means chemicals used to prepare pesticides;

(k) “insect” indicates invertebrate animals

(l) “label” is the wrapper of the pesticide container containing the information regarding its usage, handling, quantity, and retail price etc.;

(m) “package” is a container of pesticide;

(n) “pesticide” is any material or mixture of matter (not a drug according to the definition of drug in the [(Drugs Act 1976 (XXXI of 1976)] applied to repel, mitigate, prevent, destroy, or control an insect, weed, virus, bacterial organisms, fungus, nematodes, rodent, or other plant or animal pests; but does not under comes within the meaning of drug.

(o) “prescribed” according to the Ordinance;

(p) “registered” according to the Ordinance;

(q) “registration number” is a code assigned to each registered pesticide product

(r) “rules” are made under this ordinance (rr) “sub-standard” pesticide does not fulfill the criteria of purity or strength mentioned on the label of the container. Its ingredients are partially or wholly destroyed]

(s) “weed” a plant grown on an unwanted place.

4. **Pesticides to be registered**– No one is allowed to manufacture, formulate, sell, distribute or stock any pesticide until unless it is registered according to this ordinance. A pesticide, notified by the Government in an official gazette that a pesticide without trade will be imported by particular firms. It is also possible that a registration process but notification by the Government for that particular pesticide will be issued.

5. **Application for registration of Pesticide.**

(1) Registration of the name of the pesticide is required by the person (by submitting application to the Government), who is intended to import, manufacture, import, sale or stock for sale.

(2) Following sub-section (1) of the ordinance an application for the registration along with the fee should be submitted.

(3) A person who is not Pakistani and is intended to apply for the registration of pesticide under subsection (1) must have a representative in Pakistan to sign the application.

(4) A pesticide should be registered with name mentioned in the application submitted for this purpose.

(a) A name of pesticide should be chosen keeping in mind that it will not deceive or mislead the public about its quality, ingredients or other criteria written on its label.

(b) The guarantee of one pesticide is such that it will never confuse with the similar product launched or registered by another firm.

(c) A pesticide shall be effective against the pest for which it is meant.

(d) A pesticide applied at label recommended dose is not detrimental to non-target organisms including vegetation except weeds, human beings and wild life etc.

(5) After the successful registration of a pesticide, Government shall issue a certificate of registration to a person who will apply for a particular pesticide.

6. Registration shall be effective for three years and needs to be renewed before the fifteenth day of June of the third year.

7. Cancellation of registration shall be done by Government for a pesticide that violates any provisions of the ordinance or rules or observed to have negative effect on the non-targets like humans, animals or plants other than weeds. However, the Government shall provide an opportunity of clearance to the person who owned its registration by hearing his opinion.

8. (1) Registration of a registered pesticide is renewed for the period of three years on the application to the Government. Meanwhile, the applicant has to assure the guarantee that ingredients are same as that to date of its registration.

(2) The application for the renewal of a registration of shall be submitted under sub-section (1) of this ordinance.

9. Importation of a pesticide that is found adulterated, ineffective or contravenes any rule of ordinance may be prohibited into Pakistan by Government through notification in the official Gazette.

10. **(**1) Proper labelling of packages (pesticide containers) is required in the form of a printed material before it is presented for sale or stocked for such purpose. Advertisements should also follow this format.

(2) Black-listing of a dealer, wholesaler, retailer or an agent who has been convicted two offences under this ordinance shall be done for a specific pesticide.

11. A person can only store or use the pesticide as per requirements of this ordinance or its rules specified.

12. The Agriculture Pesticide Technical Advisory Committee.

(1) The committee should be devised on first priority basis after the commencement of this ordinance. The advice and guidance about the technical matters and hindrances arisen as a result of the administration of this ordinance should be provided to the Government by the Agriculture Pesticide Technical Advisory Committee.

(2) Government may appoint the officers (Government servants) as the chairman, vice chairman and members of the committee and persons indulged in the pesticide business could also be selected as its members.

(3) The names of the Chairman, the Vice-Chairman and the other members of the Committee shall be published in the official Gazette.

(4) The Government should select one of the members of this committee who is officer as the secretary of the committee for the period he owns the membership.

(5) The non-official members of the Committee shall hold office for a term of three years and shall be eligible for re-appointment.

(6) A member of this committee reserves the right to resign from the membership of the committee by writing his resignation to the chairman of the committee. But the seat of that member would be considered vacant only at the conditions that resign is accepted.

(7) An appointment made on a post due to death of or resign of member will remain effective only for residue period of that specified post.

(8) The functions of the Committee may be exercised notwithstanding any vacancy in the membership thereof.

(9) The procedures of working of committee are regulateable by the prior approval of the Government.

(10) The committee has power to appoint the sub-committee consists of specialists to perform the special tasks.

13. Pesticide Laboratory

(1) The Government should set up a pesticide laboratory at provincial level to fulfill the tasks assigned by this ordinance.

(2) Submission of the sample for analysis to the pesticide laboratory and functions of the laboratory may be as such prescribed.

(3) The information regarding the formula or other aspects of the pesticides should be duly safeguarded as may be prescribed.

14. Government Analyst. – The Government shall appoint one or more than one persons as the Government analysts of pesticides by a notification that may also describe the local limits to perform their duties.

15. Inspectors. – The Government notify the officers working related to plant protection as the inspectors in their local limits.

16. Powers exercisable by the Inspectors. – An Inspector may enter into the premises holding the pesticide in bulk or storage, could also took samples and no compensation will be paid for this purpose.

17. Procedure of Sampling. –

(1) An inspector taking sample under section 16 shall intimate in writing to the owner (Unless he is willfully absent), properly seal the sample, mark it and divide it into three portions. The owner should also be allowed to add his signature and stamp on the challan forms. Provided that the containers are of small size, chances of the deterioration of the pesticides by disturbing its container, three containers shall be marked with the same sign and sealed if necessary.

(2) Out of three portions of the pesticide samples drawn by an inspector, one portion should be given to the dealer or the person from whom sample of pesticide is drawn and remaining should be disposed of as follows:

(i) Second portion of the sample should be sent to the Govt Analyst for analysis.

(ii) Third portion of the sample should be sent to the Reference Laboratory (One at Provincial laboratory).

18. Report of Government Analyst. –

(1) After the analysis of the pesticide samples received from the inspector under subsection 2 of the section 17. The Government Analyst delivers his signed report to the inspector in triplicate form. (If the sample is fit the analysis report will be in duplicate form which include one copy for whom from where the sample is taken and second for the office record of inspector. While in case of unfit sample, analysis report is in triplicate form to deliver one copy to whom from where the sample is taken, second to the Director, Reference Laboratory and third to be submitted as evidence in police station to lodge FIR against the accused).

(2) The Inspector shall forward one copy to whom from where the sample was taken and other copy to the Director of reference laboratory.

(3) Anyone who wants to challenge the result of the Government Analyst shall put an application to the Government (Competent authority) with solid evidence that is assumed to be enough to contravene the correctness of results.

(4) If the filer of the applicant under sub-section (3) has evidence of strong nature and convincing, 2nd portion of the sample sent to the reference laboratory shall be analyzed to confirm the results.

(5) After the receipt of the sample in a pesticide laboratory (Reference laboratory), results of analysis are recorded and forwarded to the Government.

(6) The report of the results of the analysis shall be considered as the final evidence.

19. The Government Analyst or pesticide laboratory shall publish the results of the analysis and related information thereto.

20. Purchaser of Pesticide may have it tested or analyzed. –

(1) The purchaser of the pesticide could apply for analysis of the pesticide to the Government analyst or pesticide laboratory.

(2) Fees should also be paid along with the sample submitted for the analysis under sub-section 1 of section 20.

(3) The Government Analyst should issue a report to the applicant duly signed by him after the analysis of the sample received under sub-section-1.

21. Offences and Penalties.

(1) It is an offence to deal an adulterated or sub-standard pesticide in any way the for import, manufacture, formulate, sell, or advertises for sale.

(2) Offences made under sub-section (1) are punishable

(a) In the case of an adulterated pesticide, accused shall be punished for imprisonment not less than one year or more than two years and with fine that may extend to five hundred thousand rupees. In all consequent offenses, punishment of two years with a fine that may extend to one million rupees and punishment shall not be less than charged in first offence.

(b) For a substandard pesticide, accused shall be punished for imprisonment not less than six months or more than two years and with fine that may extend to five hundred thousand rupees. In all consequent offenses, punishment shall extend for three years with a fine not less than charged in previous conviction.

(c) 21A. All the offences under this ordinance for whom the punishment is not defined are punishable with a fine that may extend to the one hundred thousand rupees.

22. Manufacturer's Warranty to dealers. –

Warranty by the manufacturer to the purchaser about the fitness of a substandard or adulterated pesticide is same offence and deserves the same punishment as described under section 21.

23. Any person who–

(a) Unlawful use of registration number either not assigned by or assigned by this Ordinance

(b) Intentionally alters the mix something or alters the composition of the pesticides after it is offered in market by a formulator or distributor.

(c) Intentional interference in performing the duties of Inspectors is offence

(i) A person accused of the sub-section (a) or (b) shall be punished with imprisonment of two or more years along with fine that is extendable to one hundred thousand rupees.

(ii) A person accused of the sub-section (c) with imprisonment for a term which may extend to six months and with fine which may extend to one hundred thousand rupees.

24. Entry and seizure. –

(1) An Inspector may enter a place where any provision of this ordinance is believed to be violated and seize an article or pesticide that believes to commit an offence according to this ordinance.

(2) Material seized under sub-section (1) shall be handled following the decision of the court.

(3) An Inspector may take the assistance of the police party in pesticide sampling by applying to the magistrate who can direct an executive magistrate to accompany the inspector.

25. Court has power to order for penalty. – if a person is convicted under this ordinance, court may further order the person to forfeiture the thing, pesticide or article.

26. Cognizance of Offence etc.–

(1) Offences made under this ordinance shall not be punished in a court inferior to that of the first-class magistrate.

(2) The first-class magistrate can pass any sentence of this ordinance following section 32 of the Code of Criminal Procedure, 1898 (V of 1898).

26A. Cognizance and prosecution of offences. – Offences under this Ordinance are cognizance and non-bail able, only be registered on the complaint by the Inspector. Prosecution of offences under this Ordinance is the responsibility of Public Prosecutor.

27. Power to try offences summarily– Any Magistrate of the first class or any bench of Magistrates has power to try any offence summarily that is punishable under section 21 of this ordinance.

28. Indemnity. –Under this ordinance or rules any suit, complaint or prosecution shall lie against anything or person done or intended to be done in good faith (Inspector will not be punished by the court in case of weak/incomplete evidence for a case put by him against an accused).

29. Power to make rules. –

(1) The Government makes rules to make the provisions of this ordinance into effect.

(2) Rules provide guidance for all or any of the below mentioned matters and will not prejudice to any of the foregoing power.

(a) Names of the animals and plants. (effects of pesticide to be registered on target and non- target organisms)

(b) Form in which an application for the renewal or registration of pesticide should be made containing the necessary information and fee.

(c) The procedure for the grant of certificate of registration or renewal of registration of a pesticide not having a trade name.

(d) The language of tags/labels and character and location of printing.

(e) Following are the functions of the Pesticides Laboratory including

(i) To make sure the secrecy of the formulae of a pesticide known to him.

(ii) Collection of pesticide samples for test or analysis; and

(iii) the form to write down the reports of analysis

(f) Criteria of variability for a tested pesticide product keeping in view the label information and method to be followed for analysis.

(g) Nature of Job and academic requirement for the Government Analyst;

(h) Form that contains information like intimation to the whom from where sample is to be taken and other relevant information including batch no, quantity, manner of preservation and way of sending to the Government Analyst.

(i) Form used to file an application by the purchaser of a pesticide for the analysis of a pesticide that shall send to the Government Analyst. Complete Application along with the necessary fees should be sent.

(j) Generally detrimental poisons (pesticides) which are deleterious to human health even when applied according to the recommended dose.

(k) Labeled contains the words the poison and their antidotes should be mentioned

(l) Storage requirements

(m) The requirements and conditions for the premises where the pesticide is stored and quantity of the pesticide that a person can stock.

(n) Precautionary measures regarding pesticide poisoning of the agriculture workers.
   (i) Spraying pesticides in agriculture
   (ii) on health of agricultural land being sprayed with pesticides

(o) The restrictions, purpose, terms and conditions and circumstances in which the pesticides are being used.

(p) Prohibition of the use of a pesticide in agriculture due to some reasons.

(q) The availability of the materials for cleaning and washing of the body parts or clothes impregnated with the pesticides.

(r) The observation of the precaution measures to avoid the pesticide poisoning that is defined in the rules and abstentions form eating, circumstances and drinking.

(s) Limitations/interval between the consequent exposures of the workers to the pesticide poisoning.

(t) Prohibitions or restrictions on employment of workers to the person who is poisoned by the pesticide

(u) The measure about the exploration of the pesticide poisoning cases by investigation or detection

(v) The provision of the first aid in case of pesticide poisoning and also taking effective efforts to avoid such disturbances

(w) Impart training related to the use of the instruments provided.

30. Delegation of powers. – The Government may delegate power to any of its sub-ordinate officer on its own terms and conditions.

CHAPTER-10

10.0 INSECTICIDE DISPOSAL AND ENVIRONMENTAL SAFETY

The use of insecticide is unavoidable by farming community in the whole world for better crop production to satisfy the human food needs. The agricultural production consumes large amount of pesticides which are not free from many hazards such as development of resistance in insects, accumulation of insecticide residues in food, animal tissues and environment (water bodies, air and soil) (Aktar et al., 2009). Proper training regarding safe handling and use is pre-requisite for the people who work with pesticides. Therefore, safe use of insecticides is necessary at every step such as insecticide formulation, storage, distribution in market, application in field by farmers and disposal of empty bottles (Ogg et al., 2013).

10.1 Pesticide Safety Measures

10.1.1 Safety measures during insecticide formulation

Labeling and packaging of pesticides should be done according to recommendations of World Health Organization (WHO). All the information i.e. active and inert ingredients, instructions for safe use of pesticide and first-aid measures in cases of contamination or swallowing of pesticide must be given on the label in English and/or local language. Pesticides should always be kept in their original containers. Persons working in the pesticide formulation plant must wear the protective clothing and adopt safety measures at every step (WHO, 1990).

10.1.2 Safety measure during insecticide transportation

Transporting pesticides safely is a key responsibility of all workers who supervise, transport, use or apply pesticides in any agriculture related business. Certain safety measures should be taken during transport of pesticides to avoid accidents and any damage. We must also make sure to have the technical data sheets, proper labels and material safety data sheets (MSDS) or safety data sheets for the pesticides being transported in the vehicle. The pesticide label and MSDS contain important information about storage and handling. Transport vehicles should be in good mechanical condition. During transport, improper loading of pesticides may lead to falling and leakage of containers in vehicles and significant loses occur. Avoid transportation of pesticide with minerals, any food item for human consumption, grains, seeds and livestock feed. Pesticides should be transported in trucks or back of pickup and never in passenger vehicles. It should be ensured that vehicles must be in good operating condition. While loading pesticide on the vehicle, always use the protective clothing and equipment. Inspect all the pesticide containers for possible leakages before loading. See if the labels are firmly attached to the containers. Leaked containers must be rejected for loading. Load all containers in a manner that will minimize the risk of puncturing or tearing the containers. Protect containers made of paper, card-board, or similar materials from rain or moisture. After reaching the storage site, unload the pesticide containers with great care. Inspect the vehicle completely to determine the possibility of any pesticide leakage from containers (Ross & Bartok, 1995).

10.1.3 Safety measures at insecticide storage

Storage area for Pesticide products should be secured one and only trained people such as dealers, distributors and applicators should be given permission to enter there. They must not be placed with drink or food as they may be consumed by anyone mistakenly. Awareness on pesticide storage practices among homeowners is important to create. Pesticides should always be kept dry and must be protected from fire and direct sunlight. A vehicle carrying food should not be used to carry and transport pesticides. Humans especially children may get harm due to accidental exposure to pesticides in storage area therefore safe storage should be ensured. Safe storage prevents environment and property from any damage and also increases the shelf-life of chemicals. It is also important to display warning signs on windows and doors of the pesticide storage area to keep everyone alert and cautious. The storage area should be well-ventilated and well insulated against the extremes in temperatures. The storage structure should be fire-resistant. Floor of storage should be non-permeable such as sealed concrete that will not allow fluids pass through it. Always consult the pesticide product label and MSDS for specific storage information. Storage facilities for fertilizers, pesticides and other similar products should be separate one although existing buildings are often used for pesticide storage. Pesticides should always be stored in their original containers along with label. The labels must contain information on ingredients, directions for use and first-aid measures for accidental poisoning. Pesticides should not be stored with/or near animal feed, human food and medicines. Containers should not be placed directly on the floor. In order to avoid caking of different formulations such as granules, dusts and wettable powders, these must be placed inside the cartons while concentrated formulations in the glass bottles must also be stored inside the cartons to prevent breakage. The height of storage shelves must not be more than 2m; this will prevent the use of ladders. At every pellet, the height of pesticide containers must not be greater than 107 cm. Stability of cartons and containers during stacking can be ensured by placing them at safe heights. The safe height depends on container material. There should be a proper space called aisle space between rows of pesticide stacks for the movement of free air (Dean & Bucklin, 1995).

10.1.4. Safety measures during pesticide application

As pesticides are toxic materials, therefore too much care and caution is needed regarding the indoor or outdoor use of these chemicals. Following safety measures should be adopted for safe application of pesticides (Momanyi, 2017):

- Prior to opening a pesticide container always read the label.
- All directions and precautions as well as requirements for protective equipment should be followed according to label.
- The crops recommended on pesticide label should be sprayed only.

Apply pesticides in the situations listed on the label.

- Dose of pesticide application must be used according to label recommendations.
- During insecticide application, it must be ensured that non-target organisms will remain protected and contamination due to runoff, residues or drift will not occur. The animals that eat the poisoned rodents may experience special hazard due to application of rodenticides.
- For the protection of field workers, *restricted entry intervals* are established after the application of some materials. After application workers are kept out of the field for the specific time and display the signs of safe re-entry date as required by regulations in treated areas.
- Certain chemicals under certain conditions may cause injury to crop (phytotoxicity). Therefore, always see the label for limitations.
- Before the application of pesticides, it is important to consider developmental stage of plant, the soil condition and type, moisture status, temperature and wind. Incompatible materials must not be used as it may result in injury.
- Abstain from smoking, eating and drinking during use of insecticides.
- Proper equipment should be used for calibration, transfer and mixing of insecticide.
- Avoid stirring or scooping insecticides while you are bare-handed.
- For effective removal of blockages in nozzle, prefer using pressure release valve or a soft probe.
- After re-filling the pump, rinse the hands and face with soap and water.
- Make sure to wash the hands and face before eating.
- At the end of the day, take a shower.
- Pesticide applicator must wear shirts with long sleeves or overalls and trousers and sturdy shoes or boots.
- Facial area must be completely covered with washable mask or disposable paper mask and eye protection or goggles be worn.
- It is important not to touch any area of the body with gloves while using pesticides.
- Equipment and protective clothing must be washed everyday but separately from other clothing.
- Replace the gloves with any sign of wear and tear.

- The discharge from the sprayer should be directed away from the body.

In case of any accidental contamination, wash the skin and consult doctor if problem is serious.

- Equipment must be monitored time to time for possible leakage and repair if necessary.
- Pesticide ingestion or extensive skin contact may lead to acute poisoning. First aid is the immediate solution for pesticide poisoning and medical advice and help must be sought at the earliest opportunity. Patient should be taken to the nearest hospital if possible.

10.1.5 Safe disposal of used pesticide bottles or containers and excess waste

It is the sole responsibility of all pesticide users to dispose of pesticide wastes properly. These wastes include pesticide containers and unused chemicals. Pesticide wastes that are not disposed in recommended ways can be a source of serious hazards for environment, the humans and animals (GFIAP, 1987; Ross & Bartok, 1995).

Pesticide wastes that are necessary to dispose of properly come under three types:

1. Empty pesticide containers
2. Unused pesticides that remain in the original container
3. Pesticide mixtures that are left unused after an application
4. Disposal of pesticides should be done according to the directions of label.
5. Statement related to "Storage and Disposal" should be read from pesticide label.
6. Left over pesticide in the container should be disposed of as household hazardous waste.
7. Rinsing of empty pesticide container is essential for recycling and disposal.
8. Triple-rinsing of empty pesticide container, bottles, drums and/or cans should be practiced after complete use of pesticide. Duration between each rinse should be 30 seconds.
9. Don’t forget to make holes in the pesticide containers/bottles to make sure that they cannot be reused for any other purpose.
10. To be recycled, containers must be free of any pesticide residue inside and outside.
11. Pesticide container must never be re-used for any purpose.
12. Children must not be allowed to play with empty containers.
13. Break the containers if possible, before disposal.
14. Paper containers must not be burnt.
15. Protective clothing (apron, gloves, and goggles) are also important to wear while rinsing pesticide containers.
16. Water for rinsing should also be applied according to instructions on the label.
17. Rinsing water should not be drained into any site not mentioned on the label, as it can contaminate environment.
18. Excessive insecticide suspensions should be disposed of either into a specifically dug hole. Hole for disposing off this suspension must be away from homes, streams and wells, by 100 meters minimum. The hole should be dug in a low-lying area if the area is hilly. This hole should also be utilized to bury the empty bottles, boxes and containers. The hole must be closed as soon as the suspension and containers are buried into it. If legally permitted, paper, cardboards or simple plastics should be burnt at a place that is away from residential area and drinking water. Pyrethroids suspensions can be disposed of by pouring them on dry ground because they are promptly absorbed by the ground, degraded and pose no environmental hazards.

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CHAPTER-11

11.0 SUITABILITY OF CHEMICAL CONTROL IN INSECT PEST MANAGEMENT

Insects are the largest and more diverse group of animals and found almost everywhere in the environment ranging from high tropical forests to pools, glaciers and below the soil surface. The number of insect species are greatest than all other known species of organisms. These are adapted to all environments (except marine) but the maximum numbers are found in the warm climate due to the suitable environmental conditions and high availability of food sources. These insects exhibit the phenomena of varying life span, high fertility, long diet breadth (from wood to blood) and efficient body constriction. Various developmental stages like larvae and adults of insect pests attack economically important plant parts resulting in the death or lower yield of the plant.

Control of insect pest and other arthropods is a complex phenomenon and involves a number of insect control tactics including chemical control. Now day's pest control emphasis on the most potential pest control tactics which consider both the ecological and economic consequences. The decisions based on the economic injury level and economic threshold level. Chemical control should become the most important component for the insect management. Despite of the high overall cost, use of insecticides is increasing day by day for intensive agriculture production and vector control. Use and commercialization of synthetic insecticides is due to their high efficacy, ease of use, low cost relative to their benefits and widespread adaptation.

Insecticides are being the most power tool for the insect management. These are adoptable to almost all situations, highly effective exhibited knock down effective and flexible in relation to various ecological and agronomic measures. Moreover, these are the economical, most reliable and dependable tool when pest populations exceeding form the economic threshold and emergency control is needed. There are many pest problems when chemical control is the only solution e.g. secondary pest problems and resurgence of primary insect pests.

11.1 Integrated Pest Management

The implementation and growth of the word IPM in the agricultural system is a new phenomenon with the expression of numerous concerns about the over reliance on the chemical control and its negative impact on agro-ecosystem. The term IPM is synthesized and published by Stern et al. (1959) which was previously used by a number of authors who were gaining the awareness about the negative role of insecticides. So, the new strategy was originated a formalized strategy to address the consequences of excessive insecticidal use and a plan to integrated the all the possible pest control methods and use of insecticides when needed.

The increasing population of Asia and increasing demands for food and for other agricultural products forced the farmers for the increased use of insecticides. Some famers are adapted to use the available control methods in combination. It involves the number of compatible pest management tactics to overcome the pest out break and potential damage to the environment.

11.1.1 Why to use IPM?

The question arises that why to practice IPM when chemical control often succeeded to control the insect pests. There are various reasons to broaden the pest management tactics instead of using the only one.

1. It helps to balance and sustain the ecosystem
2. Insecticides can be ineffective
3. It promotes a healthy environment
4. It can save money

11.1.2. Components of IPM

Planning is the key component of the IPM. Every crop has its own pest which should be considered accordingly. The following components help to set up a successful IPM plan.

11.1.2.1 Monitoring and identify the pest problems

Knowing the field condition is the key component for taking the best management decisions. For this purpose, crops should be regularly monitored to identify the pest problem and their damage pattern, potential for the future damage, crop growth, field and environmental conditions. Scouting helps to take the early actions for the management of the problem and provide a chance to avoid the potential economic losses. Models for different pests have been developed to early forecast the need of the pest management tactics. Scouting enables to know and identify the problem and allow determining and mapping the problematic areas by using the right scouting method.

Identification is the most important for applying the better suited management tactics. Identification also involves the correlation of the damage symptoms or signs that either the observed injury is due to the identified pest or not. Lack of information and improper identification of the pests results in the wrong choice of control method or application time that lead to the pest control failure. Identification can be done by different types of reference materials like books, field guides and keys having pictures and other biological information about pests. Another way is to send the specimen to professionals.

11.1.2.2 Selecting the best and compatible management tactics

Correct identification of a pest aids to select the suitable control methods that are effective, economically, environmental friendly and practical for the particular pest situations. The choice of the control method depends upon the understanding the life cycle and damaging stage of the pest, economic levels of the infestation and comparisons of the cost/benefit ratio of the control methods applied. Various economic concepts are useful in determining the point at which control measures should be triggered.

11.1.2.3 Record keeping and evaluation

It is very essential to evaluate the results of the control methods regularly. Keeping records is easier with different booklets, factsheets and software programs. This will help to determine the impact of management strategies on environment, their success to IPM before implementing them again.

11.2 Goals of IPM

A number of pest control methods that are effective in controlling pest are adopted for achieving the specific goal. Prevention, suppression and eradication are the approaches to maintain the pest status below the economic threshold.

11.2.1 Prevention

This strategy prevents the infestation of pest to the crops. A number of pest management tactics such as resistant varieties, sanitation, cultural control, sowing and planting times are useful for reducing the pest problem.

11.2.2 Suppression

These are used to control the pest population levels below the economic threshold. These methods not completely eliminate the pest infestation but reduce the infestation to tolerable levels. Additional suppressive measures may also require to if the first treatment does not achievement the goal.

11.2.3 Eradication

Eradication aimed at the total elimination of the pest population form the designated area. It is quite expensive for the large area and success is limited. Eradication programs are adopted over wide areas posing economic or health threats of introduced or exotic pests.

11.3 Tools of IPM

11.3.1 Natural control

These are the factors that destroy or check the pest population continuously irrespective of the human activities. It involves the climatic factors like temperature, rain, wind, sunshine etc., topographical features like lakes, mountains, rivers etc. and naturally occurring beneficial insects for the control of insect pests like predators, parasitoids and pathogens. Other control measures

should be applied in the field when natural control is not operative or unable to check the pest population.
Consideration of natural measures should be the part of IPM programs.

11.3.2 Biological control

Biological control includes the use of 3P (predator, parasitoids and pathogens) for the control of insect pest population. It provides partial solution to insect pest problem and integrated with other insect control methods. Use of natural enemies provides long term control for many of the key pests.

Predator: an organism which feed upon on another organism having body size or equal to the predator e.g. ladybird beetle, green lacewing.
Parasitoid: an organism which feed internally or externally upon the body of another insects e.g. egg parasitoid *Trichogramma chilonis* Ishii (Hymenoptera: Trichogrammatidae), larval parasitoid (Bracon spp.), pupal parasitoid, adult parasitoid *Epiricania melanoleuca* (Fletcher) (Lepidoptera: Epipyropidae).
Pathogen: organisms that develop diseases in insects to complete their development and kill the insects e.g. bacteria (*Bacillus thuringiensis* Berliner), fungi *Beauveria bassiana* (Bals.) Vuill. (Hypocreales Clavicipitaceae), virus (nuclear polyhedrosis virus), protozoa *Nosema bombysis* Nägeli (Dissociodihaplophasida: Nosematidae) and nematodes.
Biological control if often used for the insect pests that is not native to the specific geographical area. Newly introduced pests always cause problem because they lack natural enemies. It also includes the mass rearing and release of natural enemies into fields, greenhouse and orchards to control the pest population but in many cases their failure is also reported.

Conservation practices

- Provide nectar source and flowering plants
- Provide shelter in landscape
- Protection of habitat
- Reduce the use of insecticides

11.3.3 Cultural control

These control methods make the environment and conditions less conducive for the pest feeding, reproduction and survival or sometimes more favorable for the natural enemies of the pests. This technique includes the cultivation, crop rotation, sanitation, selection of varieties, time of planting and harvesting, irrigation and fertilizer management, use of trap crops etc. Cultivation reduces the pest population by starvation, desiccation, injury and exposure. Sanitation involves the clean cultivation and removal of breeding and overwintering resources. Crop rotation involves the sowing of non-host crop for the particular insect pest.

11.3.4 Mechanical and physical control

This control method uses the physical techniques such as use of machines, devices or other manual techniques to control the insect pest species or to alter their environment. These methods are used to exclude or to trap the particular pest specie. Some of the examples include the use of cultivation devices like disks, mowers and cultivators for the destruction of soil inhabiting stages/pests. Some barriers like screens and patching or cracks or crevices is also another phenomenon to prevent the entry of flying insect pest species into an area like mosquitoes, aphid, flies etc. use of sticky materials or wires around the tree trunk is also a physical control method (e.g. mealybug). Manual picking of insect pest larvae is also practiced under physical control methods.

11.3.5 Genetic control

Sometimes plants and insects are genetically modified to reduce the pest problem in an area. Many host plants are naturally resistant form the attack of insect pests. Researchers also take advantage of this character by selecting or hybridizing the more resistant plants. Control of European corn borer, wheat stem saw fly and alfalfa aphid is well reported. Sometimes the genetic material from a source is transferred to a certain plant species to make it repellent or toxic e.g. Bt. containing varieties.

11.3.6 Chemical control

Chemical control is an important part of IPM despite of the availability of the other effective control methods. The reason may be the other control methods are quite expensive or not very effective for particular conditions and all these control methods cannot assess by every farmer. In fact, it is not possible to obtain the potential yield without prescribed use of chemicals. However, use of the chemicals with particular characteristics is recommended; selective toxicity to the target pest, high efficacy at low application rates, less persistency and good biodegradability, low toxicity to non-target organisms, less mobility to the ground and safe for the environment. Furthermore, treatments should be made at proper timing (when and where they needed) following the label directions.

11.3.6.1Particular of effective chemical control

Insecticides are one of the most important tools in the IPM programs. This control method can be integrated with other control methods but sometimes it cannot provide the control as expected. So, the following points should be kept in mind to attain an effective treatment.

11.3.6.2Pest identification

Wrong identification of a pest can fail the insecticide treatment. Correct identification of a pest requires both experience and practice. For example, knowing the difference between a sawfly larvae and caterpillar is necessary for the success of Bt. insecticides because it is recommended for the caterpillars but not for sawfly. Moreover, misidentification may fail the non-chemical tactics if susceptible cannot be identified.

11.3.6.3Dosage

Make sure to apply the correct insecticide at proper dosage according to the label directions and pest status.

11.3.6.4 Correct use

Always apply the insecticides for the pests for which they are recommended. For example, some insecticides are only recommended for the particular sucking or chewing insects and not for others.
Always follow the label directions for this purpose.

11.3.6.5 Application timing

Improper application time sometimes leads to the failure of the pest control. The pest may not be in the area to be treated or it may not in its susceptible stage. Insects are mostly vulnerable to insecticides when they are immature. Already present insects are also a source of infestation that developed to pest status long after the chemical application.

11.3.6.6 Application equipment

Knowing the right habitat is essential for an effective treatment. Sometimes concealed pests are difficult to detect. For this using, the best equipment is very necessary. For example, air blast sprayer should be used for the insects hiding under tree leaves but a granular applicator should be used for subterranean insects.

11.3.6.7 Environmental conditions

Application of an insecticide must consider the environmental conditions. Mostly treatments are not made just before a rainstorm, at temperature extremes and in windy conditions. All these conditions may wash off the plants or move away the insecticide from the treated area.

11.3.6.8 Insecticide degradation

In storage conditions insecticides may degrade or change into an ineffective form. This may also due to the age of the product. For example, most of the solid formulation can become ineffective under high moisture conditions due to formation of clumps.

11.3.6.9 Insecticide resistance

Knowing the resistance level of the insects is very necessary for reducing the pest population below the injurious levels. Resistant insects initially require frequent applications and higher application rates of specified insecticides. This will sometimes result in the complete failure of the control methods or development of resistance in other insects. So, choosing the better suited form and mode of action is very important for successful control.

11.3.6.10 Insecticides should be the part of IPM programs in the following ways

1. Consider the socioeconomic effects and use of selective insecticides
2. Insecticides should be used to avoid the predictable damage losses using most effective techniques at optimum dosage and appropriate time.
3. Insecticides should be integrated to other control methods and applied when other control methods fail to check the pest population.

11.3.7 Other techniques supporting the use of insecticides in IPM

11.3.7.1 Precision and application

New application equipment and methods increased the efficacy and reduces the potential for environmental contamination. These equipment releases precise application rates regardless of the speed and environmental conditions. Conventional equipment changes their release rate as the speed decreases thus more quantity is being applied than needed. Modern equipment also reduces the extra amount deposited at various areas (end row) by the shut off valve. Such precise application rates enhance the effective use of insecticides in IPM.

11.3.7.2 Remote sensing

It is a satellite or aircraft based system that capture high resolution images to assess the crop health and to take future decisions. This system has the potential to improve the precisions of the damage assessment methods and to transfer the information to the farmers and extension workers in a useable manner within short period of time. These images combined with geographic information system exhibiting many benefits in IPM programs.

11.3.7.3 Controlled released formulations

Newer insecticide formulation also supports the use of insecticides in the IPM programs. Use of controlled released formulation has many benefits. The controlled release rate increased the stability of active ingredients, exhibited prolonged residual activity and improved penetration power. Moreover, lower application rates reduced the losses of insecticides to the environment. However, this area is under progress and need more attentions but it would be a preferred option for an IPM developer.

11.3.8 Changing role of chemical control in IPM

Chemical control is now considered as a part of solutions for pest control but not the only solution for it. However, it becomes the only vital part when all other methods fail to control the pest population. According to a study complete elimination of chemicals from the IPM would not allow the presence levels of productivity of many crops. Changing approach for the chemical control is rather than excluding chemicals, it is better to increase the beneficial use by lowering the risk to environment and non-target organisms. The chemicals should be used to enhance the efficiency of other control methods whenever they are required.

Other advances include the development newer and selective mode of actions with increased efficacy at lower rates. High biodegradable and non-persistence chemicals along with lower application rates also improve the environmental situations. Alternate use of newer mode of actions now becomes a source to break the evolution of resistance. Another important point is the consideration of realistic threshold.

The main goal of the insecticide research is to discover and develop new products and application methods for safer and effective pest management in order to maximize the crop production and to reduce the public health concerns. Although, insecticide research has made significant victories but insects always remain a competitor for food and shelter.

11.3.9 Insecticides and resistant cultivars

Some rice varieties are resistant to some rice insect pests while other insects may require compensatory insecticidal treatments. For example, Philippines IR26 is resistant to brown plant hopper (BPH) but insecticides protect the rice varieties against whorl maggot. Moderately resistant varieties usually support small and less vigorously with low fecundity and may withstand more insecticidal treatments. For example, stem borer infestations received one or two treatments of insecticides are similar to the double received on susceptible varieties. Even the use of moderately resistant varieties along with insecticidal treatments can be an important strategy for the management of many insect pest species.

11.3.10 Insecticides and biological control

Biological control involves the use of biological organisms like predators, parasitoids and parasites to lowers the pest status. The success of biological agents is not well reported and many failures have been reported. However, the integration of chemical control along with biological control agents revolutionized the thoughts of pest management. For example, the use of *T. chilonis* and green lacewing *Chrysoperla carnea* (Stephens) for the control of various sucking insect pests of cotton and bollworm proved more economical than the insecticides alone. This integration also reduced the application of chemicals from eight to two only. Similarly, use of pink bollworm ropes in combination with *T. chilonis* proved quite effective to check the bollworm population. In another study use of insecticides like chlorpyriphos, amitraz and chlorfamaniphos along with *C. carnea* exhibited significant results for the reduction of whitefly. Similar integration was also devised and reported by many authors. Integration of biological and chemical control is possible in the following conditions

- Suitable low density natural enemy is available
- Selective insecticides available which control the insect pests but not lowers the density dependent population of natural enemies
- Presence of maximum insect pest density which do not produce economic damage is not lower than the population needed to retain the population of natural enemies
- Relative stability of the ecosystem that favors the relationship of host and natural enemy.

11.3.11 Insecticides and cultural methods

Integration of cultural and chemical control is an important for the management of various pests. It has been used successful for the control of white stem borer in Java and yellow stem borer in Japan in rice. Management of cultural practices like planting distance, use of fertilizers and drainage of water proved quite effective for the control of rice insect pests like close planting not only increase the hopper population but also prevents the penetration of foliar sprays to lower canopy. Similarly, high use of nitrogenous fertilizer also increases the pest population.

Successful complementation of cultural and chemical control in rice ecosystem can play significant role in IPM. For example, application of insecticides enhanced the effect of water drainage on brown plant hopper population. For the control of other insects spraying of susceptible trap crop has also proved beneficial. These cases indicated that cultural practices that increase in pest population could be integrated with chemical control. In such circumstances, cultural practices could be used for the control of key pest while insecticides could be applied to control the economically less important insect pests.