RECOMMENDATIONS

Pesticide resistance in insects is a complex phenomenon that involves a range of metabolic processes that enable the insects to detoxify or eliminate the pesticide. These metabolic processes are regulated by various genes and enzymes, and their activity can be affected by genetic mutations, changes in gene expression, and other environmental factors. In this overview, we will explore some of the key metabolic processes involved in pesticide resistance development.

Detoxification enzymes: One of the primary mechanisms by which insects develop resistance to pesticides is through the increased production or activity of detoxification enzymes, which enable them to break down and eliminate the pesticide from their system. The three major classes of detoxification enzymes are esterases, glutathione S-transferases, and cytochrome P450s.

Target-site mutations: Another mechanism of pesticide resistance is through mutations in the target site of the pesticide. For example, resistance to pyrethroids, a commonly used class of insecticides, can be conferred by mutations in the sodium channel gene, which reduces the binding affinity of the pesticide to the target site.

Reduced penetration: Insects can also develop resistance to pesticides by reducing the ability of the pesticide to penetrate their cuticle or cell membranes. This can be achieved through structural changes in the cuticle or by upregulating efflux pumps that pump the pesticide out of the cell.

Reduced metabolic rate: Some insects can develop resistance to pesticides by reducing their metabolic rate, which can slow down the detoxification of the pesticide. This can be achieved through the downregulation of genes involved in energy metabolism or through the activation of hibernation-like states.

Increased excretion: Insects can also develop resistance to pesticides by increasing their ability to excrete the pesticide. This can be achieved through the upregulation of transporters involved in the elimination of the pesticide from the body.

Overall, pesticide resistance development is a multifaceted process that involves a range of metabolic processes. Understanding these metabolic processes is critical for developing effective strategies to combat pesticide resistance and preserve the efficacy of existing pesticides. These strategies may include the development of new pesticides that target different metabolic pathways, the use of combination insecticides, or the use of genetic technologies such as CRISPR-Cas9 to target specific genes involved in pesticide resistance.

USE OF CRISPR-CAS9 TOOL

CRISPR-Cas9 is a powerful gene-editing tool that has been revolutionizing various fields of science, including agriculture. Recently, researchers have been exploring the potential use of CRISPR-Cas9 to combat pesticide resistance in insect populations.

The CRISPR-Cas9 technique involves using a guide RNA molecule to target a specific gene of interest and a Cas9 enzyme to cut and modify the gene sequence. By doing so, researchers can selectively edit the genome of an organism, including insects, and induce changes that can combat pesticide resistance.

One potential use of CRISPR-Cas9 in pest control is to target the genes that are responsible for the development of pesticide resistance in insects. Researchers have identified several genes that play a role in insecticide resistance, including detoxification enzymes, target-site mutations, and transporters. By using CRISPR-Cas9 to modify these genes, researchers could create insects that are less likely to develop resistance to certain insecticides.

Another potential application of CRISPR-Cas9 in pest control is to create genetically modified insects that can be used to control pest populations. For example, researchers have proposed using CRISPR-Cas9 to create male insects that are sterile or only produce male offspring. By releasing these insects into a pest population, researchers could reduce the reproductive capacity of the population and ultimately control their numbers.

CRISPR-Cas9 can also be used to create genetically modified crops that are more resistant to pests, reducing the need for pesticides. For example, researchers could use CRISPR-Cas9 to introduce genes from pest-resistant plants into crop plants or modify existing genes to enhance resistance.

Despite the potential benefits of CRISPR-Cas9 in pest control, there are also potential risks and ethical considerations. The technology could be misused for unintended purposes, such as creating genetically modified organisms that have unintended ecological consequences. There is also the risk of disrupting natural ecosystems and biodiversity if genetically modified organisms are released into the environment.

In conclusion, CRISPR-Cas9 holds great promise as a tool for combating pesticide resistance in insects and controlling pest populations. However, further research is needed to fully understand the potential risks and benefits of using this technology in the agricultural sector. Regulatory bodies and policymakers will need to carefully evaluate the ethical and ecological implications of using CRISPR-Cas9 in pest control before it is widely implemented **(Kaduskar et al., 2022)**.

USE OF COMBINATION INSECTICIDES

When insect populations are repeatedly exposed to a single insecticide, they can develop genetic changes that make them resistant to the pesticide. This resistance can then be passed on to future generations of insects, making control of pest populations difficult. To address this issue, researchers and farmers have been exploring the use of combination insecticides as a strategy to combat resistance.

Combination insecticides involve the use of two or more different insecticides with distinct modes of action, applied simultaneously or sequentially, to control pests **(IRAC, 2022)**. By using multiple insecticides with different modes of action, the selection pressure on the pest population is reduced, making it less likely that they will develop resistance to either of the insecticides.

There are several benefits to using combination insecticides to combat pesticide resistance development. Firstly, they offer a more effective means of pest control. By combining different insecticides, the likelihood of pests developing resistance to any one of the insecticides is reduced, which helps to prevent infestations and preserve crop yields.

Secondly, combination insecticides can help to extend the lifespan of existing insecticides. By reducing the rate at which insects develop resistance, combination insecticides can help to prolong the usefulness of currently available insecticides, which is critical as new insecticides take time to develop and bring to market.

Thirdly, combination insecticides can help to reduce the overall use of insecticides, which can be beneficial for the environment. By using multiple insecticides with different modes of action, the amount of each insecticide needed can be reduced, which can help to mitigate the risk of environmental contamination and reduce the exposure of non-target organisms to insecticides.

Finally, combination insecticides can be an economically viable option for farmers. Although the cost of using two or more insecticides may be higher than using a single insecticide, the benefits of increased pest control and reduced resistance development can outweigh the costs in the long run, leading to increased crop yields and profits.

In conclusion, combination insecticides offer an effective means of controlling pest populations and combating pesticide resistance development. By reducing the selection pressure on pest populations, combination insecticides can help to extend the lifespan of existing insecticides, reduce overall insecticide use, and be a viable option for farmers economically. As such, combination insecticides should be considered an important tool in the fight against pesticide resistance.

Lastly, on the basis of resistance knowledge, various tools for control other than insecticides (chemical control) can also be designed. The lepidoptera pest management methods with an integrated approach comprising biological control can be tested as well as implemented in case of *Spodoptera litura* **(Divya, 2016)**. Further work on related species from the noctuidae family, such as other caterpillars (*S. litura, S. exigua*, etc.), which are pests on various crops of importance, can be carried out. Our important findings from the field survey, lab rearing, testing, gene expression can aid in such research works.