REVIEW ARTICLE

Insecticide Induced Resurgence in Insect pests

Rajna S and Nikhil Raj M

Abstract: Resurgence is an adverse effect of indiscriminate and non-judicious insecticide use in crop production. As more evidences of increase in pest population appear, resurgence is gaining practical significance in agriculture. Insecticides being the key factor responsible for inducing resurgence, can enhance the target or non-target pest number through direct and indirect effects. In some pest populations, insecticide induced hormesis can also cause stimulatory effects in physiological and behavioral processes. The insecticide application, leading to elimination of natural enemies, and inducing biochemical changes in plants such as change in plant defense chemicals triggers indirect mode of resurgence development. Even though not directly related, and do not occur always, with resistance development, the probability of the population to resurge will be higher.

Key words: Insects, pesticides, outbreaks, pests, resistance

Resurgence is a result of indiscriminate and non-judicious use of synthetic pesticides in field conditions. More than 50 cases of resurgence reported, since the commencement of pesticide application in agriculture (Dutcher, 2007), and we have failed in resolving this problem. Globally, many researchers have proposed various definitions for resurgence. One of the oldest definitions is by Bartlett (1964) which stressed on pesticides and natural enemies to explain that resurgence is an anomalous quick come back to economic abundance of a pest, which was initially suppressed by the application of pesticide and had also destroyed its natural enemies. In order to make the definition better acceptable to the scientific community Heinrichs *et al.* (1984) imparted a statistical dimension and described resurgence as 'statistically significant increase in the pest population or pest damage in insecticide treated plots over that of untreated plots. Other researchers suggested an initial decline in the pest population due to pesticide application for resurgence. Conversely, pesticides having sub-lethal effects on a pest will not show an initial decline of the population. The classification of resurgence as primary and secondary brought in more clarity. The increase in target pest population by insecticide treatment to a level at least as high, or higher than the untreated control is attributed as primary pest resurgence, whereas the increase in non-target pest population as an accidental consequence of the insecticide treatment is the secondary pest resurgence (Fig.1) (Hardin et al., 1995).

Pest resurgence, though depends on a multitude of reasons, is however caused primarily by the insecticides (Cutler, 2013). There is no single group of insecticides free from resurgence inducement. Homopteran insects registered the maximum resurgence cases in field condition, followed by phytophagous mites. The resurgence does not require multiple insecticide applications of insecticides and may happen after even a single spray (Dutcher, 2007). The very first report of insect outbreak post-insecticide treatment was the population abundance in the soft scale (*Coccus hesperidium* L.) in citrus after application of parathion, an organophosphate insecticide. The resurgence phenomenon has come to the limelight in Asian countries after the population explosion of brown planthopper in insecticide-treated rice tracts (Chelliah and Heinrichs, 1980). Nutritional factors such as excessive use of nitrogenous fertilizers can also contribute to resurgence. In addition to these, introduction of high yielding varieties, continuous cropping, staggered planting, and use of some insecticides are reported to cause for increased brown plant hopper populations in rice (Chelliah and Heinrichs, 1980).

For an insect population explosion to be called insecticide induced resurgence, an increase in population must follow the insecticide treatment, response of the insecticide application should be showed as an increase in abundance, and the valid resurgence can be compared only with treated and untreated populations (Hardin *et al*., 1995). This indicates, mere crop loss cannot be designated as resurgence phenomenon in the field. The general response of insects to high and low dose of insecticides differs as *lethal dose* (causing mortality) *and sub-lethal dose* (no mortality). Although growers try to apply pesticides evenly at recommended concentrations to kill target pests, many biotic and abiotic processes will spatially and temporally change the dose of insecticide to which an insect is exposed in the field (Cutler and Guedes, 2017).

Lethal dose/Higher dose of insecticide application in the field: Lethal dose always keeps the susceptible population a level lower than the economic threshold level. Spraying insecticides more than the recommended dose can cause deleterious effects to not only the environment but also to the natural enemies and many non-target organisms. Resurgence increases as the frequency of insecticidal spray increases because insecticides eliminates the natural enemy population and may reduce the chances of predation and parasitization and thus providing a safer place for pests to feed and multiply, resulting in population abundance of pests.

Sub-lethal doses of insecticides: Sub lethal dose of insecticides will not cause mortality to a desirable level in field populations. Sub-lethal dose is categorized into two classes, *viz*. deleterious and hormetic. Deleterious sub-lethal effects cause a reduction in reproduction and longevity, poor behavior of the insect species, whereas hormetic response causes stimulatory effects on pest species including reproduction, longevity, and enhanced behavior. In short, the same chemical which is lethal at high doses can bring in certain biological processes of the same insect species at sub-lethal levels (Guedes and Cutler, 2014). This biphasic dose-response characterized by high-dose inhibition and low-dose stimulation during or following exposure to a toxicant is termed hormesis. Hormesis is defined *as a dose–response relationship characterized by a reversal in response between low and high doses of a stressor, thus characterizing a biphasic relationship.* The stressors can be of different kinds *viz*., pesticides, temperature, ionising radiation, heavy metals, calorific restrictions, exercise, *etc*. and are known as hormetic agents.

Yet another term, ‘hormoligosis’, coined by Thomas D Luckey in 1968, more accurately pointed towards a phenomenon known as insecticide hormoligosis. The term hormoligosis has derived from two Greek words, *hormo* (= to excite) and *oligo* (= small quantities) and defined it as a *phenomenon in* *which sub-harmful quantities of many stress agents may be helpful when presented to organisms in suboptimal environments* (Luckey, 1968). Insecticide hormoligosis is basically a special case of hormesis in which a biphasic dose–response for an insecticidal compound is observed when the organism is already under stress due to another environmental factor or agent (Guedes and Cutler, 2014).

Insecticide induced hormesis in insect pests

One of the earliest studies reported the increased fecundity of females of bean aphid (*Aphis rumicis)* treated with low concentrations of rotenone, while high concentrations were lethal (Sun 1945). The fruit fly (*Drosophila melanogaster*), house fly (*Musca domestica*), granary weevil (*Sitophilus granaries*) and house cricket (*Acheta domesticus)* were early subjects of study, particularly with exposure to sublethal doses of organochlorine insecticides. Insecticide-induced population stimulation in mites has been observed since the 1970s and has sparked concerns of insecticide-induced pest outbreaks among at least two mite species: the citrus red mite (*Panonychus citri)* and the two-spotted spider mite (*Tetranychus urticae)*. Pyrethroid insecticide also reported to cause hormesis of sucking pests at sublethal doses. A list of pests reported to have evidence of insecticide induced hormesis is enclosed in Table 1.

Resurgence through indirect effects of insecticides

The use of insecticides can cause certain indirect effects that trigger the resurgence of a pest population, *viz*., natural enemy destruction, biochemical changes in host plants, physiological and biological changes in insect pests, and insecticide resistance.

Natural Enemy Destruction: In nature, natural enemies are important in regulating a pest population. It is believed that the elimination of natural enemies by insecticide applications is a strong cause for resurgence phenomenon. The toxic and non-specific insecticides are assumed to destruct natural enemies in the ecosystem, so this can be considered as a reasonable factor for insecticide induced pest resurgence. Even before the use of organic insecticides, non-selective insect control agents including sulfur and petroleum oil formulations induced resurgence. Insecticide application cause both direct and indirect effects on natural enemies. The most important direct effect is the increased mortality of the natural enemies, due to the enhanced susceptibility to insecticides than their herbivore host. This dissimilarity in susceptibility may be due to the rapid concentration of insecticides in natural enemies which feed on contaminated prey, increased exposure of the adult natural enemies to insecticide residues due to their increased mobility compared to its host, differences in detoxification enzyme levels in prey and natural enemy, and even the inability of the natural enemies to develop resistance as quickly as their host insect species (Hardin *et al*., 1995). As a result of the difference in the feeding habits of the natural enemy species, the direct toxic effect may vary between species.

Insecticides can interfere with the quality of its prey by indirectly altering the quality of the host plant, where the herbivore feed. Alternate prey of natural enemies can also be eliminated by insecticide applications. Moreover, alternate food source such as honeydew become unavailable in the absence of prey. Even though all these factors exist, natural enemy population destruction can be called responsible for resurgence when there is an increase in pest population abundance in their absence compared to the situation when they exist. However, natural enemies may not always cause mortality of its prey that is proportionate to the prey population density, and certain populations may not be regulated by natural enemies even when they are present (Hardin *et al*., 1995). So, it can be concluded that the complicated phenomenon of resurgence, may not be solely caused by the removal of natural enemies. Moreover, insecticide induced reduction in the natural enemy population can be due to the shift of the prey from density dependent to density-independent response in unsprayed and sprayed field respectively, which can even lead to the extinction of natural enemy species. Apart from these, the physiological effect of the pest and the natural enemy can also contribute to the resurgence. The higher fecundity rate of the pests helps them to escape from the suppression by natural enemies. Voltinism, dispersal ability, feeding habits, *etc*. of both the pest and natural enemy influence the recovery duration after insecticide application, thereby enhancing or reducing the chances of the pest to resurge.

Biochemical Changes in Plants: The ability of the insecticides to change the biochemical constituents of the plants is well described in the literature. These changes can in-turn alter the physiology of the pests including reproductive behavior. The quality changes in plants include enhanced plant growth, increased nutritive value, and increased attractiveness, but reduced plant defense (Heinrichs and Mochida, 1984). The literature shows that field applications of insecticides results in increase accumulation of total sugar and protein and depletes phenol content in plant species. A synthetic pyrethroid, deltamethrin was found to reduce carbohydrates to nitrogen ratio and increase the amino nitrogen content in brown planthopper susceptible varieties. The phenol content in cotton leaves, which has a major role in imparting defense against insects, was found reduced by the application of synthetic pyrethroids, cypermethrin, and deltamethrin which can be assumed as a primary factor for whitefly and aphid resurgence.

Physiological and Behavioural Changes Caused Due to Insecticides: Insecticides can cause alterations in the physiology and behavior of target pests. Increased longevity and fecundity of females, decreased mortality of progeny are some physiological effects due to insecticides. A high female to male ratio of progenies is observed in some mite species when the adult or nymph gets exposed to sub-lethal doses of insecticides which in-turn help in population builds up in the next generation. Direct application of deltamethrin, methyl parathion, and diazinon to the brown planthopper cause enhanced fecundity in females irrespective of any host plant effects. In addition to direct application, contact with treated surfaces can also act as a basis for change in fecundity. Hyper-excitability of male insects in response to pheromones due to the exposure of sub-lethal dose of insecticides is the behavioral change which in-turn affects the more rapid location of calling females. This cannot be considered as common behaviour, still, it has been reported in some major insect pests such as *Pectinophora gossipiella* and *Trichoplusia ni.* Indirect stimulation of fecundity can also occur due to enhanced nutritional contents of the host plant. However, this insecticide induced behavioral changes will not always be responsible for resurgence

Destruction of Non-Target Species: Insecticide may also kill other non-target phytophagous pests that share the same habitat/niche with the target pests. The reduction in competition for resources could be a reason to facilitate resurgence of a pest population. In the absence of competition, in favourable environmental conditions, pest species may reach maximum reproductive potential, which enables the population to rebound to a level higher than that of spraying (Hardin *et al*., 1995).

Insecticide Resistance Development: It is the need of the hour to think about the development of resistance and resurgence together and in the same direction. Even though there is no direct relationship between resistance and resurgence, it can be mentioned that there is a probability that resistance can enhance the resurgence of a population. Nevertheless, for comparing both, an assumption that, when both susceptible and resistant populations receive the same dose of an insecticide, a higher number of survival will be in a resistant population, can be made. If the insecticide can impart any of the above-said characteristics on the pest or the host plant, there is a chance that resurgence happens only in resistant population, not in susceptible one (Hardin *et al*., 1995). Mironidis *et al*. (2012) reported that the resurgence of *Helicoverpa armigera* in cotton is closely associated with the resistance of the pest to the insecticides, chlorpyriphos, and alpha cypermethrin. It can be concluded that although resistance is not required for resurgence to occur, resistance may enhance resurgence (Hardin et al., 1995).

Conclusion

The persistence of resurgence in agriculture over the years is an indication that we need to deal with it more cautiously. It is not an evolutionary process happening naturally in the biosphere and hence can be maneuvered by meticulous scientific research efforts. For successful resurgence management, it is crucial to recognize it as an ecological phenomenon, occurring as a result of insecticide application, coupled with many other biotic and abiotic factors.

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Table 1. Evidence of insecticide induced hormesis in insect pests

Year	Pest class	Common Name	Insecticide	Author
1	*Aphis rumicis* Linnaeus	Bean aphid, Aphididae; Homoptera	Rotenone	Sun (1945)
2	*Drosophila melanogaster* Meigen	Fruit fly, Drosophilidae; Diptera	Dieldrin	Knutson (1955)
3	*Sitophilus granaries* (Linnaeus)	Stored product weevil, Curculionidae; Coleoptera	DDT	Keunen (1958)
4	*Acheta domesticus* (Linnaeus)	House cricket, Gryllidae; Orthoptera	12 Different insecticides	Lucky (1968)
5	*Spodoptera littoralis* (Boisduval)	Egyptian cotton leafworm, Noctuidae; Lepidoptera	Carbaryl, Methyl Parathion, Deltamethrin	Esaac *et al.* (1972)
6	*Nilaparvata lugens Stal.*	Brown planthopper, Delphacidae; Homoptera	Decamethrin, Methyl parathion	Chielliah *et al.* (1980) Chelliah and Heinrichs (1980)
7	*Choristoneura fumiferana (Clemens)*	Spruce budworm, Tortricidae; Lepidoptera	Fenitrothion, Phosphamidon	Smirnoff (1983)
8	*Myzus persicae* (Sulzer)	Green peach aphid, Aphididae; Homoptera	Azinphosmethyl	Gordon and McEwen (1984)
9	*Tribolium castaneum* (Herbst)	Red flour beetle, Tenebrionidae; Coleoptera	Azadirachtin	Ramachandran *et al*. (1988)
10	*Scirtothrips citri* (Moulton)	Citrus thrips, Thripidae; Thysanoptera	Malathion	Morse and Zareh (1991)
11	*Zabrotes subfasciatus* (Boheman)	Mexican bean weevil, Chrysomelidae; Coleoptera	*Tetradenia riparia* Extract	Weaver *et al.* (1992)
12	*Plutella xylostella* (Linnaeus)	Diamondback moth, Plutellidae; Lepidoptera	Methomyl	Nemoto (1993)
13	*Dysdercus koenigii* (Fabricius)	Red cotton bug, Pyrrhocoridae; Heteroptera	Eucalyptus Oil Volatiles	Srivastava *et al*. (1995)
14	*Blaberus craniifer (*Burmeister)	Death's head cockroach, Blaberidae; Blattaria	Charybdotoxin	Goudey-Perribre *et al*. (1997)
15	*Plutella xylostella* (Linnaeus)	Diamondback moth, Plutellidae; Lepidoptera	Fenvalerate, Methomyl	Sota *et al.* (1998)
16	*Cydia pomonella* (Linnaeus)	Codling moth, Tortricidae; Lepidoptera	Azinphos-Methyl	Abivardi *et al.* (1998)
17	*Myzus persicae* (Sulzer)	Green peach aphid, Aphididae; Homoptera	Bifenthrin	Kerns and Stewart (2000)
18	*Plutella xylostella* (Linnaeus)	Diamondback moth, Plutellidae; Lepidoptera	Fenvalerate	Fujiwara *et al*. (2002)

19	*Bemisia tabaci* (Gennadius)	Whitefly, Aleyrodidae; Homoptera	Fenvalerate, Acephate	Abdullah and Joginder (2004)
20	*Plutella xylostella* (Linnaeus)	Diamondback moth, Plutellidae; Lepidoptera	Spinosad	Yin *et al.* (2009)
21	*Sitophilus zeamais* Motchulsky	Maize weevil, Curculionidae; Coleoptera	Deltamethrin	Guedes *et al*. (2010)
22	*Ceratitis capitate* (Wiedemann)	Mediterranean fruit fly, Tephritidae; Diptera	*Metarhizium anisopliae* Crude Extract	Ortiz-Urquiza *et al*. (2010)
23	*Plutella xylostella* (Linnaeus)	Diamondback moth, Plutellidae; Lepidoptera	Hexaflumuron	Mahmoudvand *et al.* (2011)
24	*Agrotis ipsilon* (Hufnagel)	Black cutworm, Noctuidae; Lepidoptera	Clothianidin	Kullik *et al*. (2011)
25	*Oligonychus ilicis* (McGregor)	Southern red mite, Tetranychidae; Acarina	Deltamethrin	Cordeiro *et al*. (2013)
26	*Zabrotes subfasciatus* (Boheman)	Mexican bean weevil, Curculionidae; Coleoptera	Azadirachtin	Mallqui *et al*. (2014)
27	*Myzu spersicae* (Sulzer)	Green peach aphid, Aphididae; Homoptera	Sulfoxaflor	Tang *et al*. (2015)
28	*Plutella xylostella* (Linnaeus)	Diamondback moth, Plutellidae; Lepidoptera	Chlorpyrifos	Deng *et al*. (2016)
29	*Tetranychus turkestani* (Ugarov&Nikolskii)	Strawberry spider mite, Tetranychidae; Acarina	Biomite®	Mohammadi *et al.* (2016)
30	*Panonychus ulmi* (Koch)	European red mite, Tetranychidae; Acarina	Four Different insecticides	Saritas *et al*. (2016)
31	*Aphis glycines* Matsumura	Soybean aphid, Aphididae; Homoptera	Beta-cypermethrin	Qu *et al*. (2017)
32	*Mythimna separate* (Walker)	Oriental armyworm, Noctuidae; Lepidoptera	Lambda-cyhalothrin	Li *et al.* (2019)
33	*Myzus persicae* (Sulzer)	Green peach aphid, Aphididae; Homoptera	Flupyradifurone	Tang *et al.* (2019)
34	*Rhopalosiphum padi* (Linnaeus)	Wheat aphid, Aphididae; Homoptera	Dinotefuran	Deng *et al*. (2019)
35	*Phenacoccus solenopsis* (Tinsley)	Solenopsis mealybug, Pseudococcidae; Homoptera	Pyriproxyfen, Lufenuron	Idrees *et al.* (2020)
36	*Aphis gossypii* (Glover)	Cotton aphid, Aphididae; Homoptera	Thiamethoxam	Ullah *et al.* (2020)