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Review Article

Impact of Synthetic Agricultural Pesticides on Non-Target Insects

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Abstract: Pesticides are indispensable for safeguarding agricultural production, yet their application presents a multifaceted challenge to ecosystem integrity and sustainable pest management. This review synthesizes current knowledge on the primary ecological and agronomic consequences stemming from pesticide use, with a focus on unintended impacts. A central concern is the disruption of biological control services, as pesticides inflict lethal and sublethal effects on natural enemies, including predators and parasitoids. These effects compromise vital behaviors, physiological functions, and demographic parameters, thereby diminishing their regulatory efficacy and potentially inducing pest resurgence. Furthermore, pollinators face significant risk from systemic and contact exposure, which impairs navigation, learning, colony communication, and reproduction, threatening both biodiversity and crop pollination. Concurrently, the intensive selection pressure exerted by pesticides drives the evolution of resistant pest populations, undermining chemical control and complicating integrated pest management strategies. Compounding these issues, pesticide drift facilitates the off-target deposition of active ingredients, leading to the contamination of adjacent ecosystems and aquatic networks, which in turn affects non-target organisms and broader ecological processes. The evidence underscores that the ecological costs of pesticides extend beyond acute toxicity. Sublethal impairments to beneficial species and the evolution of resistance represent critical, long-term threats to agricultural resilience. Consequently, advancing IPM requires a concerted shift towards selective chemistries, refined application technologies, and the prioritization of non-chemical tactics to mitigate these pervasive impacts and preserve ecosystem functionality.
Keywords: Natural Enemies, Pesticide Drift, Pollinators, Parasitoids, Integrated Pest Management.

1. INTRODUCTION

Pesticides are hazardous biological or chemical substances that are introduced into the environment to prevent, repel, control, and reduce the populations of insects, weeds, rodents, fungus, and other pests. Pests are creatures (plants, animals, and pathogens) that impair food, health, and human comfort while also having a negative economic impact (Soliman *et al*., 2015).

Pesticides are essential tools in integrated pest management programs which can have the great influence if they are used properly. However, the adverse impacts of these compounds on the environment and ecosystem should not be ignored. The ecological effects of pesticides can be discussed from different points of view. Pesticide side effects on non-target creatures, sub-lethal effects on both target and non-target organisms, the formation of resistant populations, pesticide residue, and their entry into the trophic network are some of the major repercussions of using pesticides. One contentious issue in the use of pesticides is their side effects (Castro *et al*., 2021). They disturb the natural balance between the hosts and their natural foes by eliminating the natural enemies that are present in the field and environment. In the absence of natural enemies, pest populations increase rapidly and makes more controlling efforts, usually pesticides, necessary. In spite of pests, pesticide resistance in natural enemies is not common due to lower exposure to pesticides. Sub-lethal deposits of pesticides can change some biological traits of the organisms exposed to low and highly low concentrations of the toxicants.

In agricultural systems, pesticides serve as a critical tool for pest management by mitigating damage to crops and minimizing yield losses both during

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cultivation and post-harvest (Rembiałkowska, 2007; Castro *et al*., 2019). Consequently, they are functionally categorized based on their primary mode of action against pests, including as destructive (e.g., lethal), repellent, or mitigating agents (Sicbaldi *et al*., 1997). Furthermore, a fundamental taxonomic classification for these compounds is derived from the specific group of target organisms they are designed to control pests, these include acaricides, bactericides, fungicides, herbicides, insecticides, molluscicides, nematicides, and rodenticides (Settimi *et al.,* 2016). On the other hand, the different modes of action can be used to classify certain pesticides according to the physiological effects on target organisms. Thus, animals can be targeted by neuroactive substances (DeMicco *et al*., 2010), plants can be affected by substances that regulate their growth (Wagner *et al*., 2017), and microbes, by substances that inhibit colony formation (Montesinos and Bardaji 2008).

The emergence of pesticide resistance is a direct consequence of their misuse. Through selective pressure, populations with high ecological fitness are gradually favored across successive generations, resulting in descendant populations that exhibit significantly reduced or complete insensitivity to the chemical agents. These resistant populations are frequently distinct from susceptible, natural populations in key demographic parameters, such as their fertility and life table characteristics. For any given population, the ecological impact of a pesticide is contingent not only on its toxicity and the duration of exposure, but also on a complex array of interacting factors. These include the life history traits of the target organism, the method and timing of application, the demographic structure of the population, and the broader landscape context in which exposure occurs (Hawkins *et al*., 2019). Pesticide exposure at sublethal levels can impair physiological function across nearly all major biological systems in insects, including the nervous, muscular, integumentary, respiratory, digestive, excretory, reproductive, circulatory, and exocrine systems. Furthermore, such exposure disrupts critical behaviors related to mobility, orientation, feeding, and reproduction. These cumulative sublethal effects can induce significant alterations in overall insect population dynamics (Martínez *et al*., 2021).

2. Impacts of Pesticides on Natural Predators

The concept of Integrated Pest Management (IPM) was first formally articulated as a strategy combining biological control through natural enemies with the judicious application of chemical pesticides (Stern *et al*., 1959). This conceptual framework later evolved to encompass the coordinated use of multiple, complementary tactics for suppressing pest populations below economically damaging thresholds (Ruberson *et al*., 1998). Within contemporary IPM programs, the integration of chemical and biological control primarily operates through three principal mechanisms: the use of selective pesticides or reduced application rates, the temporal separation of pesticide applications from key periods of natural enemy activity, and the spatial separation of treated areas from natural enemy reservoirs (Ruberson *et al*., 1998). Conventional use of insecticides can have deleterious effects on natural enemy populations because beneficial arthropods can have greater susceptibility to low concentrations of insecticides than their prey or host (Ruberson *et al*., 1998; Torres & Ruberson, 2004). Pesticide compatibility with biological control agents is a major concern to practitioners of IPM, and knowledge about the activity of insecticides toward pests, non-target insects and the environment is a necessity (Stark *et al*., 2004). Pesticides exert a wide range of lethal (acute and chronic) and sublethal (often chronic) impacts on natural enemies (Rezaei *et al*., 2007; Ruberson *et al*., 1998; Stark *et al*., 2004). Predatory insects cause pest suppression by natural consumption of prey and are used in biological control (Campos *et al*., 2021; Lima *et al*., 2021). Predators present in nature or introduced by man are exposed to pesticides by direct or indirect contact with the sprayed parts of the plants or the ingestion of contaminated prey (SantosJunior *et al*., 2019). The mass death of predators can affect the agroecosystem and cause an imbalance in favor of pest infestation and resurgence (De Castro *et al*., 2015). Thus, the potential of predators to control pests can be reduced if the pesticide used is toxic to this natural enemy or causes its repellency from the environment, thus inducing the resurgence of pest insect populations (Silva *et al*., 2020). Therefore, a selective pesticide that causes maximum mortality to the pest and minimum damage to the predator is necessary to incorporate compatible strategies in integrated pest management programs. However, some pesticides have sublethal toxic effects that affect predator physiology and behavior by reducing functional and numerical response due to prey consumption (De Castro *et al*., 2015). In physiology, histotoxic and cytotoxic effects caused by spinosad in the salivary glands (Santos-Junior *et al*., 2019) and by imidacloprid (Martínez *et al*., 2019), permethrin (Martínez *et al*., 2018), and spinosad (Santos Junior *et al*., 2020) in the midgut of the predatory bug, *Podisus nigrispinus* Dallas, have been reported.They include reduced predation ability and difficult ingestion and digestion processes. The predatory behavior of ladybug *Coccinella undecimpunctata* Linnaeus is altered by the insecticides pymetrozine and pirimicarb (Cabral *et al*., 2011), while the fungicides azoxystrobin, ferbam, and mefenoxam affect the mobility of ladybird beetle *Harmonia axyridis Pallas*.

A pesticide that causes 50% acute mortality in a predatory insect population may be considered less ecologically disruptive than one that impairs the fitness of survivors. Sublethal effects—such as reduced fecundity, anatomical malformations, and developmental inhibition—can profoundly diminish long-term predatory potential and compromise biological control. For instance, exposure to acetamiprid disrupts embryogenesis and reduces egg hatch in the ladybird beetle *Eriopis connexa* (Fogel *et al*., 2013), while teflubenzuron and deltamethrin sharply decrease nymph hatching in the spined soldier bug, *Podisus maculiventris* (Mohaghegh *et al*., 2000). Insecticides can also inhibit development, as seen in the vedalia beetle, *Rodolia cardinalis*, where larval-to-adult maturation is suppressed (Grafton-Cardwell & Gu, 2003). Furthermore, anatomical malformations have been documented in *P. maculiventris* and *P. nigrispinus* following exposure to azadirachtin and teflubenzuron (Mohaghegh *et al*., 2000). The predatory bug, *Supputius cincticeps Stål* decreases developmental time for females and increases for males when contaminated with permethrin, which negatively affects the reproduction of this natural enemy. Thus, some pesticides alter (extend or shorten) the development time of different predatory insects. Shortening life stages seem to be advantageous, but this kind of pesticide-induced acceleration can have negative effects on adults (Michaud and Grant 2003). Life table analyses can assess the toxic effects of pesticides more accurately than any other estimates and have been used on natural enemies (Stark and Banks 2001; Exposure to sublethal concentrations of pesticides can significantly alter the demographic parameters of predatory insects, directly influencing population growth and stability. For example, imidacloprid adversely affects multiple life-table parameters in the ladybird beetle *Cryptolaemus montrouzieri*, including prolonging the pupal period and reducing adult longevity, gross fecundity rate, net reproductive rate, and the average number of eggs laid per day (Aghabaglou *et al*., 2013). Similarly, indoxacarb compromises population fitness in *Harmonia axyridis* by reducing both adult fertility and first-instar larval survival (Galvan *et al*., 2005). Conversely, certain species exhibit resilience to specific compounds; in the lacewing *Chrysoperla carnea*, key demographic metrics such as the intrinsic rate of increase, net reproductive rate, mean generation time, finite rate of increase, sex ratio, adult longevity, and fertility remained unaffected following exposure to imidacloprid, indoxacarb, or endosulfan.

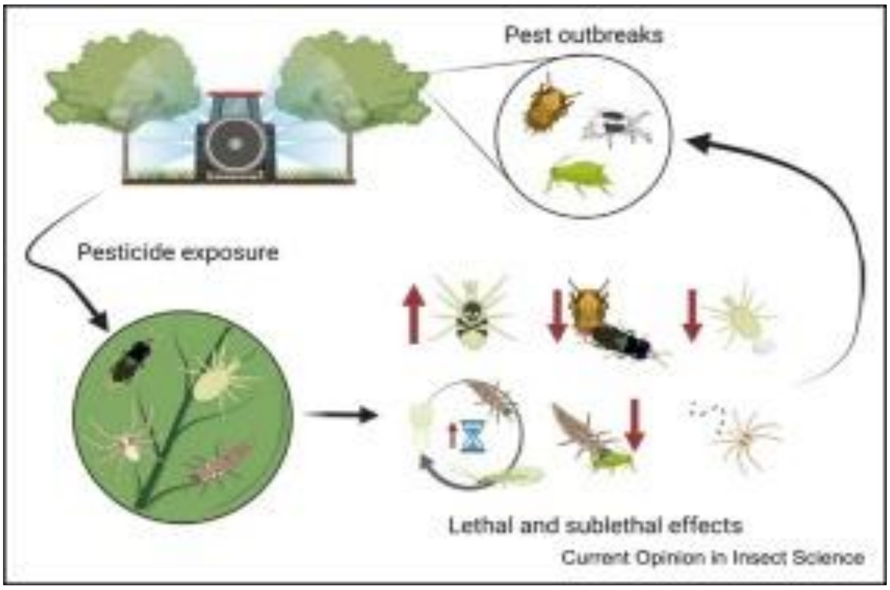

Figure 1: Illustrates the impact of chemical pesticides on natural predators in the ecosystem

3. Effects of Chemical Pesticides on Parasitoid Insects

Parasitoids, which attack various developmental stages of their insect hosts, serve as vital natural enemies that regulate pest populations. Their natural presence within agricultural systems provides a simple, effective, and economical form of biological control (Morais *et al*., 2019). The indiscriminate application of pesticides, however, disrupts this ecosystem service by decimating parasitoid communities, creating imbalances within agroecosystems, and triggering severe disruptions in pest population dynamics (Saber, 2011). Similar to their impacts on pollinators and other predators, pesticides affect parasitoids through multiple exposure pathways. These include direct routes—such as contact with spray droplets, absorption of residues from contaminated surfaces, and ingestion of contaminated food sources as well as indirect, host-mediated exposure. The resulting impacts manifest as acute, lethal toxicity or as long-term sublethal effects on physiology and behavior (Rolim *et al*., 2020). The main sublethal effects evaluated in parasitoids are fertility, fecundity, developmental rate, survival, emergence, and sex ratio. The sublethal effects on behavior include the damaged parasitoid ability to detect host induced plant odors (synomones), since these signals can be disrupted after pesticide contamination. In particular, sublethal effects caused by pesticides on parasitoids alter their biology, with effects on parasitism rate. The fecundity of the parasitoid wasp *Trichogramma pretiosum Riley* is reduced by pyrethroids, regardless of the host lepidopterous species, *Sitotroga cerealella* and *Ephestia kuehniella*, and may continue for several subsequent generations (Bastos *et al*., 2006). Exposure to various pesticide classes demonstrably impairs parasitoid fitness and efficacy. Broad-spectrum insecticides such as fenitrothion and deltamethrin significantly reduce adult emergence in the wasp *Trissolcus grandis* (Saber *et al*., 2005), a pattern mirrored by dimethoate and chlorpyrifos in *Tamarixia radiata*. Sublethal impacts on population growth are also prevalent; pymetrozine adversely affects life-table parameters in *Diaeretiella rapae* (Kheradmand *et al*., 2012), and imidacloprid induces similar alterations in *Trichogramma cacoeciae* (Saber, 2011). Furthermore, insecticides with insect growth regulator activity, including diflubenzuron and methoxyfenozide, suppress the production of immature stages in *Colpoclypeus florus* and *Arrhenophagus chionaspidis*, respectively. Hexaflumuron, profenofos, and spinosad reduce the generation time and alter the sex ratio of Habrobracon hebetor Say (Dastjerdi *et al*., 2009). The male to female ratio is also altered by chlorpyrifos in the parasitoid *Aphytis melinus DeBach*, and higher numbers of males is observed. Abamectin affects the emergence and sex ratio of *T. pretiosum* (Carvalho *et al*., 2003). Deltamethrin exposure has been shown to reduce adult longevity across multiple parasitoid wasp species, including *Telenomus busseolae* (Bayram *et al*., 2010), *Aphidius ervi* and *Habrobracon hebetor*.

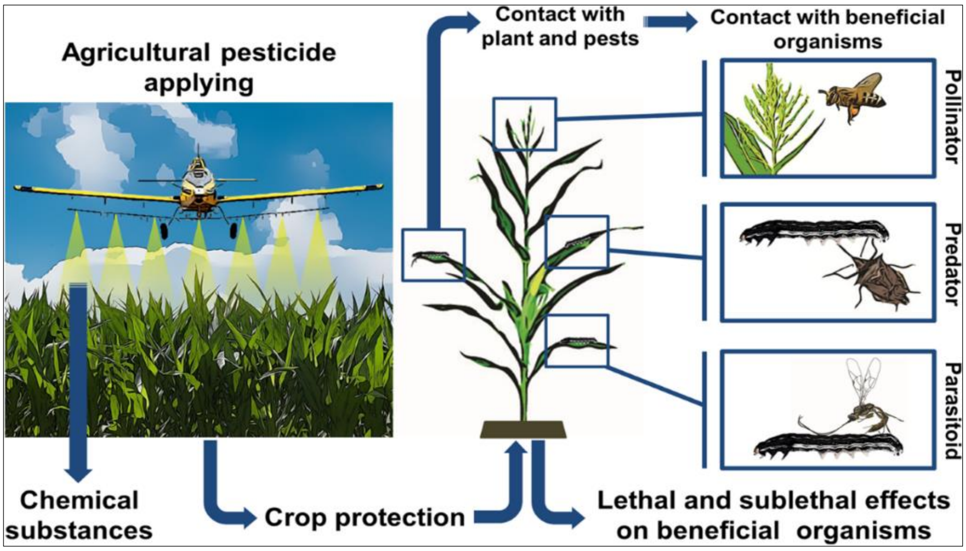

Figure 2: shows the side effect of parasitoids and other beneficial insects

4. Effect of Pesticides on Pollinators

Pollinators are keystone organisms in agroecosystems, enabling the reproduction of self-incompatible, cross-pollinating crops and contributing significantly to biodiversity conservation (Campos, 2014). Their role is economically critical, with insects estimated to pollinate approximately 84% of global crop plants (Saunders, 2018). The widespread use of contact and systemic pesticides poses a major threat, as these compounds translocate to all plant tissues and can accumulate in pollen and nectar (Calatayud-Vernich *et al*., 2018). Consequently, pollinators are chronically exposed to pesticides through their food sources. For social bees like honeybees (*Apis mellifera*), this exposure pathway initiates a complex poisoning process. Foragers collect contaminated nectar and pollen, which are subsequently stored within the hive, leading to the chronic exposure of the entire colony. The resulting toxic effects can manifest as acute mass mortality events (Sponsler *et al*., 2019) or as the gradual population decline and disorder characteristic of Colony Collapse Disorder. Solitary pollinating insects, which do not store food, face primary exposure through direct contact with spray residues or contaminated surfaces. Notably, pesticide exposure is not solely a consequence of environmental contamination; beekeeping practices also involve the direct application of certain compounds, such as bactericides and acaricides, to hives for disease and parasite management, introducing an additional route of exposure (Serra *et al.,* 2021). In this context, the queen and bee larvae are exposed to pesticides when poisoned bees offer contaminated glandular secretions (Kopit and Pitts-Singer, 2018). Several studies on oral toxicity with LC50/LD50 estimations are taken as criteria to demonstrate the lethal effects of pesticides on pollinators (da Costa *et al*., 2015). Sometimes, the values are below or above the recommended commercial dose. While there are molecules with unique modes of action that particularly affect one or one group of insects, many others are broad-spectrum and affect most insects. Thus, sublethal effects caused by pesticides on pollinators have been reported Serra *et al.,* 2021. Pesticides, particularly neurotoxic insecticides, exert severe physiological and behavioral impacts on pollinators, ultimately compromising colony health and viability. These impacts can be categorized as acute (mortality within 72 hours) or chronic (mortality after 72 hours), often with no observed recovery. Specific insecticides, including chlorpyrifos, imidacloprid, and lambda-cyhalothrin, are documented to induce such lethal effects (Arthidoro de Castro *et al*., 2020).

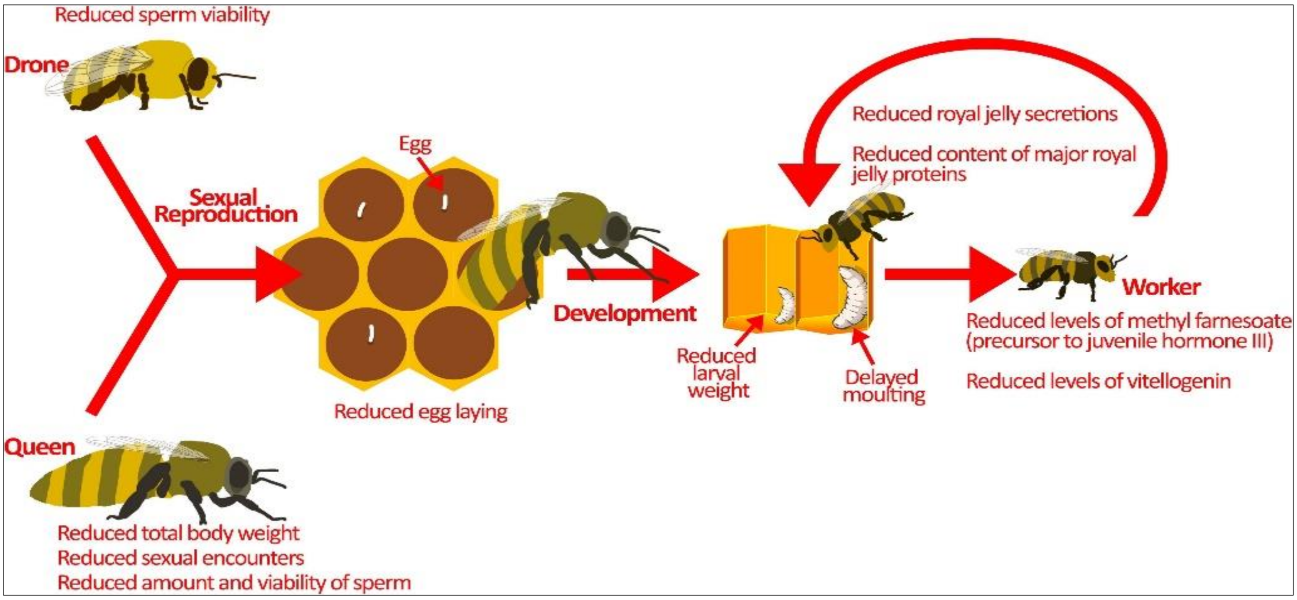

Figure 3: shows the impact of agricultural pesticides on bees

At sublethal concentrations, pesticides disrupt critical behaviors through neurotoxic intoxication, manifesting as hypoactivity, hyperactivity, or involuntary tremors that impair essential activities like walking, flying, and feeding (Lunardi *et al*., 2017). Furthermore, certain pesticide formulations can act as repellents, either through the emission of irritant volatile compounds (Stejskalová *et al*., 2021) or by impairing the olfactory system. Since odor perception and response to pheromones—glandular compounds that coordinate colony behavior—are fundamental to colony survival (Christen *et al*., 2018), this disruption is profound. Chronic exposure to such compounds adversely affects associative learning and memory, extending the time required for young bees to be trained for successful foraging (Palmer *et al*., 2013; Stanley *et al*., 2016). Communication within the colony is also impaired, leading to deviations in the precision of the waggle dance and orientation relative to gravity (Siviter *et al*., 2018).

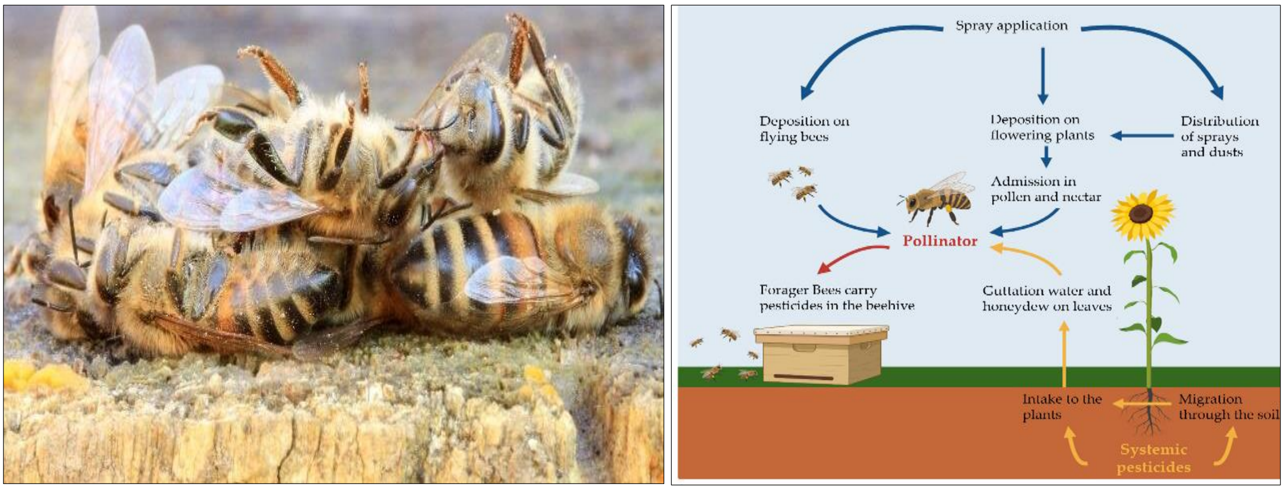

Figure 4: Illustrates the mortality of bees resulting from pesticide spray application

Mechanical functions are not spared; pesticides like imidacloprid can cause flight muscle discoordination, resulting in partial or total loss of flight ability during foraging (Kenna *et al*., 2019). Ultimately, these cumulative stressors directly impact reproductive success. Documented effects include reduced queen oviposition and loss, decreased mating rates, and male sexual incompetence (Dai *et al*., 2010; Kairo *et al*., 2016), thereby inhibiting the establishment of new colonies and threatening population sustainability.

5. Effect of Pesticides on Beneficial Decomposers

Pesticides can affect decomposer insects through both direct toxic pathways and indirect ecological mechanisms. Direct exposure occurs via contact with contaminated soil, plant litter, or dung, or through the ingestion of contaminated organic substrates. The acute lethal effects are readily apparent; for instance, broad-spectrum insecticides like organophosphates (e.g., chlorpyrifos) and pyrethroids (e.g., cypermethrin) have been shown to cause high mortality in dung beetle and collembolan populations following field applications (Floate, 1998; Jensen *et al.*, 2003). These compounds, designed to target insect nervous systems, do not discriminate between pest and beneficial arthropods. The consequences are immediate reductions in decomposer abundance and local species richness, which can be particularly severe for specialist coprophagous beetles reliant on freshly deposited dung that may contain veterinary anthelmintics or pasture-applied insecticides (Beynon *et al*., 2015). Perhaps more insidious and pervasive are the sublethal effects that impair insect physiology and behavior without causing immediate death. Sublethal doses of neurotoxic insecticides can disrupt essential behaviors such as locomotion, burrowing, and brood ball formation in dung beetles, compromising their reproductive success and soil bioturbation activities (Verdú *et al*., 2018). Similarly, fungicides, often perceived as less harmful to fauna, can have profound indirect effects. By suppressing fungal communities in soil and litter—a primary food source for many Collembola and mites—fungicides can induce starvation and population declines in these micro-decomposers (Morse *et al*., 2018). Furthermore, pesticides can induce physiological stress, altering metabolic rates, reducing fecundity, and increasing susceptibility to pathogens, thereby diminishing population growth rates and long-term viability (Zortéa *et al*., 2021).

The indirect, cascading effects of pesticide-induced decomposer decline can fundamentally alter ecosystem processes. The most documented cascade involves the disruption of dung degradation in pastoral systems. Veterinary anthelmintics like ivermectin, excreted in livestock dung, are highly toxic to dung-breeding insects. Their use has been linked to the collapse of dung beetle communities, resulting in the accumulation of undegraded dung pats, pasture fouling, reduced soil nutrient recycling, and the proliferation of pestiferous dung-breeding flies (Floate, 1998; Manning *et al*., 2017). In arable systems, the loss of microarthropods like Collembola slows the fragmentation and microbial conditioning of crop residues. This decelerates the release of immobilized nutrients (e.g., nitrogen and phosphorus), potentially creating a negative feedback loop where reduced soil fertility prompts increased fertiliser application (Wardle *et al*., 2004).

The impact on soil structure is another critical concern. The tunneling and nesting activities of larger decomposers like dung beetles and termites are vital for creating macropores, which enhance water infiltration, root penetration, and gas exchange. Pesticides that eliminate these "ecosystem engineers" can lead to soil compaction, increased surface runoff, and elevated risks of erosion and nutrient leaching (Brown *et al*., 2010). This degradation of soil physical health represents a direct threat to sustainable land management. Finally, pesticides can disrupt the complex trophic interactions within the soil food web. Decomposers are prey for a wide range of predators, including spiders, carabid beetles, and birds. A decline in decomposer abundance can therefore have bottom-up effects, reducing the resources available for these higher trophic levels (Fountain & Hopkin, 2005). Moreover, by altering the competitive balance between different decomposer species, pesticides can lead to homogenized communities dominated by a few pesticide-tolerant, generalist species, resulting in a loss of functional diversity and resilience (Bunemann *et al*., 2006).

6. Resistance of Pests to Pesticides

Pesticide resistance describes the decreased susceptibility of a pest population to a pesticide that was previously effective at controlling the pest. Pest species evolve pesticide resistance via natural selection: the most resistant specimens survive and pass on their acquired heritable changes traits to their offspring. If a pest has resistance then that will reduce the pesticide's efficacy – efficacy and resistance are inversely related. Pesticides are applied extensively to control a broad spectrum of agricultural and veterinary pests, including invertebrate insects, plant pathogens, weeds, rodents, and microbial agents (Gould *et al*., 2018) However, their repeated and widespread use has engendered two significant and interrelated challenges: the evolution of resistance within target pest populations and the collateral toxicity to non-target natural enemies. Resistance to pesticides has evolved across diverse taxa, including insects, mites, fungi, weeds, bacteria, and rodents. The repeated application of synthetic pesticides exerts intense selective pressure, eliminating susceptible individuals and allowing those with heritable resistance traits to survive and reproduce. The offspring of these survivors, whether homozygous or heterozygous for resistance genes depending on the selection history and pesticide mode of action, inherit this enhanced survival ability. In the subsequent absence of significant natural enemy pressure, these resistant individuals proliferate, eventually displacing the susceptible population. Thus, pesticide resistance constitutes a clear Darwinian evolutionary process, wherein rare resistance alleles are rapidly selected for in response to intensive chemical use ((Desneux *et al*., 2007). The historical trajectory of this issue is well-documented. Following the commercialization of organochlorine and other synthetic insecticides in the 1940s, resistance to DDT in the housefly (*Musca domestica*) was reported within a few years. This pattern has persisted with each new class of insecticide—including cyclodienes, organophosphates, carbamates, pyrethroids, formamidines, *Bacillus thuringiensis* toxins, avermectins, spinosyns, insect growth regulators, and neonicotinoids—with resistance cases emerging shortly after their widespread deployment (Hollomon, 2016) Consequently, resistance has become a paramount concern in modern pest management. Currently, over 504 key arthropod pest species are documented as resistant to one or more pesticides, representing a major global obstacle to effective Integrated Pest Management and Insecticide Resistance Management programs (Gould *et al*., 2018).

7. Pesticide Drifts & Deposition

Pesticide drift, defined as the off-target aerial movement and deposition of pesticide particles during or after application, represents a significant non-point source of environmental contamination (Booij & van der Werf, 2021). Pesticide drift occurs due to evaporation or improper spraying followed by wind carrying of the drifted particles. The drifted particles can travel through the air over distances of hundreds of kilometers, and in some cases, exceed a thousand kilometers (Kassianov *et al*., 2017; Mayer *et al*., 2024).

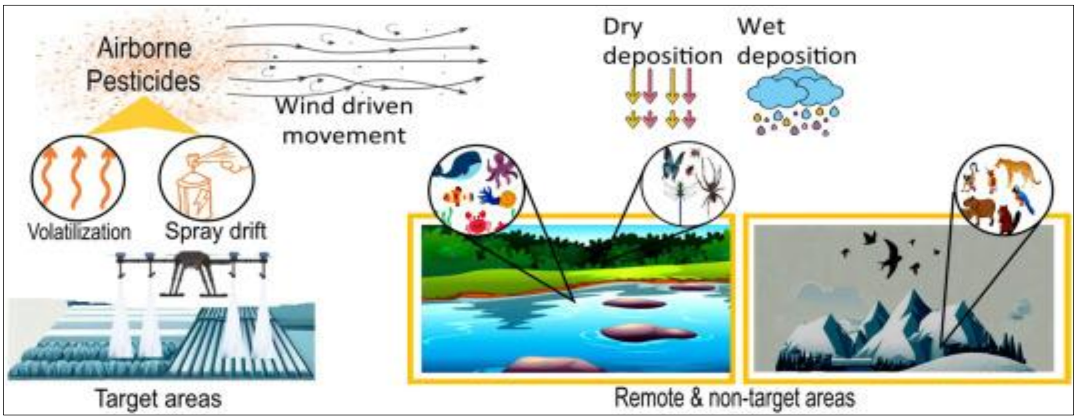

Figure 5: demonstrates how pesticide drift and deposition affect the environment

It is estimated that a quarter of the pesticide sprayed end up being drifted (Aktar *et al*., 2009). More than 100 airborne pesticides were detected in a biosphere reserve in Germany, of which 28 were not approved for use in the country, captured pendimethalin concentrations ranging up to 18.3 ng/m3 (Kruse-Plab *et al*., 2021). This phenomenon results from a complex interplay of physicochemical properties, application technology, and micrometeorological conditions. Factors such as droplet size spectrum, formulation volatility, wind speed and direction, temperature inversions, and relative humidity critically influence the spatial extent and magnitude of drift (Gil & Sinfort, 2005). The resultant deposition contaminates adjacent ecosystems, including non-target terrestrial habitats, surface water bodies, and groundwater resources. The ecological ramifications of pesticide drift are profound and multifaceted. Sub-lethal and lethal exposure to non-target organisms disrupts community structure and ecosystem function. Sensitive taxa, such as pollinators (e.g., bees and butterflies) and beneficial arthropods (e.g., parasitoid wasps and predatory beetles), are particularly vulnerable to drift events, which can impair their reproduction, navigation, foraging efficiency, and survival (Krupke *et al*., 2017). This collateral damage undermines biological control services and pollination, essential pillars of agroecological stability. Furthermore, drift deposition onto surface waters introduces potent toxicants into aquatic food webs, where they can bioaccumulate and affect organisms across multiple trophic levels, from plankton to fish, potentially leading to local biodiversity loss and compromised water quality (Schulz, 2004). From a regulatory and risk assessment perspective, managing drift is a persistent challenge. While mitigation strategies—such as the use of low-drift nozzles, spray adjuvants, buffer zones, and restrictions on application during adverse meteorological conditions—are advocated, their efficacy is variable and often inadequately enforced (Felsot *et al*., 2010). Consequently, pesticide drift remains a critical issue at the interface of agricultural productivity and environmental health, necessitating improved predictive models, real-time monitoring technologies, and policy frameworks that prioritize the protection of susceptible ecosystems and human populations residing near treated areas.

8. Recommendations for Proper Pesticide Management in Agriculture

In agricultural systems, sublethal pesticide exposure—whether acute or chronic—elicits a broad spectrum of physiological and behavioral impairments in beneficial insects. These detrimental effects, documented across numerous species, can compromise essential functions such as reproduction, navigation, foraging, and immune response. Consequently, sustained sublethal exposure may drive severe declines in populations highly susceptible to these chemical compounds. When considered as multifaceted stressors, pesticides pose significant ecological risks that propagate across hierarchical levels of biological organization, from molecular and cellular processes to community and ecosystem dynamics.There are few pesticide management options that can considerably minimize pesticide potential hazards. Some examples include monitoring insect populations in the field before applying pesticides and experimenting with various techniques of treatment. To control pests, it's important to limit pesticide applications over time and space, avoid unnecessary persistence, target vulnerable stages of the pest life cycle, and use synergists to increase toxicity. The use of natural control can be a safe option. Natural predators such as lady beetles, mantises, spiders, and parasitic wasps can be purchased/reared and released in the field. Another option can be the use of pheromones that disturb the natural mating cycles of the pests. Sometimes insect trapping methods can also be employed to reduce pest impacts on crops. Bio-pesticides which are frequently regarded as preferable to conventional synthetic pesticides due to their favorable environmental and toxicological profiles should be used. Because they typically exhibit lower non-target toxicity and possess a narrower spectrum of activity, enhancing their specificity for target pests. Bio-pesticides can often be applied in smaller doses and decompose faster than conventional pesticides. This can lower toxic exposure levels, environmental degradation and pollution. In the existing situation, optimized use of pesticides is important to reduce environmental adulteration while increasing their effectiveness against target pest. This has led to the consideration of rational use of pesticides, and the physiological and ecological selectivity of pesticides. Farmers should focus on using insecticides that are more toxic to target species than their natural enemies and other beneficial insects which could help to reduce resurgence to some extent. Growers should use Integrated Pest Management (IPM) to control pests with little environmental impact and replace dangerous chemicals with safer alternatives.

9. CONCLUSION

Pesticide is important for the increase of food production, but the improper use of pesticide is detrimental to all creatures. Different adverse effects, such as, increasing number of resistant pest population, decline in the beneficial organisms such as predators, pollinators and earthworms, change in soil microbial diversity, and contamination of water and air ecosystem are increasing day by day. Insects play crucial roles in agricultural systems as pollinators, predators, parasitoids, and decomposers, which are vital for the stability and productivity of agroecosystems. However, many beneficial insect taxa are sensitive to pesticide exposure, raising significant ecological concerns due to the broader impacts on agroecosystem biodiversity. Recent studies have highlighted sublethal effects on these beneficial insects. Such sublethal exposures manifest through detrimental alterations in fundamental biological parameters. These include reductions in fecundity (egg number and oviposition period), impairments in development (larval and pupal weight, developmental duration, adult emergence), and diminished fitness (adult longevity and fertility). Concurrently, behavioral modifications are frequently observed, affecting critical processes such as foraging efficiency, olfactory-mediated host location, reproductive behaviors, oviposition site selection, and locomotor activity. At the physiological level, pesticides can impair immune function and disrupt nutritional balance. Evaluating sublethal effects is essential for developing evidence-based Integrated Pest Management strategies. This understanding aids in choosing pesticides that are selective and pose lower risks for non-target beneficial insects, fostering their conservation in ecosystems. A thorough grasp of sublethal toxicity is crucial for environmental risk assessments and the registration of new agrochemicals. Global warming exacerbates chemical management challenges by affecting insect pest dynamics, leading to range expansion, altered migration, and increased population growth rates. This situation heightens pest pressure and reliance on chemical controls. It is crucial to understand the interactions between climate change, chemical pollution, and their environmental impacts to promote sustainable agricultural practices. Finally, pesticides can disrupt the complex trophic interactions within the soil food web. Decomposers are prey for a wide range of predators, including spiders, carabid beetles, and birds. A decline in decomposer abundance can therefore have bottom-up effects, reducing the resources available for these higher trophic levels (Fountain & Hopkin, 2005).

Conflict of Interest: The authors declare that they have no relevant conflicts of interest concerning the content of this review.

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