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Biopesticides - An Alternative for Pest Management

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ABSTRACT: A biopesticide is a biological substance or organism that damages, kills, or repels organisms seen as pests. Biological pest management intervention involves predatory, parasitic, or chemical relationships.

They are obtained from organisms including plants, bacteria and other microbes, fungi, nematodes, *etc*.[1] They are components of integrated pest management (IPM) programmes, and have received much practical attention as substitutes to synthetic chemical plant protection products (PPPs). The U.S. Environmental Protection Agency states that biopesticides "are certain types of pesticides derived from such natural materials as animals, plants, bacteria, and certain minerals, and currently, there are 299 registered biopesticide active ingredients and 1401 active biopesticide product registrations."[3] The EPA also states that biopesticides "include naturally occurring substances that control pests (biochemical pesticides), microorganisms that control pests (microbial pesticides), and pesticidal substances produced by plants containing added genetic material (plant-incorporated protectants) or PIPs".[4]

KEYWORDS: biopesticides, integrated pest ,management, environmental protection, pests, plant incorporated protectants

I.INTRODUCTION

The European Environmental Agency defines a biopesticide as “a pesticide made from biological sources, that is from toxins which occur naturally. - naturally occurring biological agents used to kill pests by causing specific biological effects rather than by inducing chemical poisoning.” Furthermore, the EEA defines a biopesticide as a pesticide in which “the active ingredient is a virus, fungus, or bacteria, or a natural product derived from a plant source. A biopesticide's mechanism of action is based on specific biological effects and not on chemical poisons.” [5] Biopesticides usually have no known function in photosynthesis, growth or other basic aspects of plant physiology. Many chemical compounds produced by plants protect them from pests; they are called antifeedants. These materials are biodegradable and renewable, which can be economical for practical use. Organic farming systems embraces this approach to pest control.[6]

Biopesticides can be classified thusly:

- Microbial pesticides consist of bacteria, entomopathogenic fungi or viruses (and sometimes includes the metabolites that bacteria or fungi produce). Entomopathogenic nematodes may be classed as microbial pesticides, even though they are multicellular.[7][8][9][
- Bio-derived chemicals. Four groups are in commercial use: pyrethrum, rotenone, neem oil, and various essential oils are naturally occurring substances that control (or monitor in the case of pheromones) pests and microbial disease.[10][6]
- Plant-incorporated protectants (PIPs) incorporate genetic material from other species (*i.e.* GM crops). Their use is controversial, especially in European countries.[11]
- RNAi pesticides, some of which are topical and some of which are absorbed by the crop.

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RNA interference is under study for use in spray-on insecticides (RNAi insecticides) by companies including Syngenta and Bayer. Such sprays do not modify the genome of the target plant. The RNA can be modified to maintain its effectiveness as target species evolve to tolerate the original. RNA is a relatively fragile molecule that generally degrades within days or weeks of application. Monsanto estimated costs to be on the order of $5/acre.[12]

RNAi has been used to target weeds that tolerate Roundup. RNAi can be mixed with a silicone surfactant that lets the RNA molecules enter air-exchange holes in the plant's surface. This disrupted the gene for tolerance long enough to let the herbicide work. This strategy would allow the continued use of glyphosate-based herbicides.[12]

They can be made with enough precision to target specific insect species. Monsanto is developing an RNA spray to kill Colorado potato beetles. One challenge is to make it stay on the plant for a week, even if it's raining. The potato beetle has become resistant to more than 60 conventional insecticides.[12]

Monsanto lobbied the U.S. EPA to exempt RNAi pesticide products from any specific regulations (beyond those that apply to all pesticides) and be exempted from rodent toxicity, allergenicity and residual environmental testing. In 2014 an EPA advisory group found little evidence of a risk to people from eating RNA.[12]

However, in 2012, the Australian Safe Food Foundation claimed that the RNA trigger designed to change the starch content of wheat might interfere with the gene for a human liver enzyme. Supporters countered that RNA does not appear to survive human saliva or stomach acids. The US National Honey Bee Advisory Board told EPA that using RNAi would put natural systems at "the epitome of risk". The beekeepers cautioned that pollinators could be hurt by unintended effects and that the genomes of many insects are still undetermined. Other unassessed risks include ecological (given the need for sustained presence for herbicides) and possible RNA drift across species boundaries.[12]

Monsanto invested in multiple companies for their RNA expertise, including Beeologics (for RNA that kills a parasitic mite that infests hives and for manufacturing technology) and Preceres (nanoparticle lipidoid coatings) and licensed technology from Alnylam and Tekmira. In 2012 Syngenta acquired Devgen, a European RNA partner. Startup Forest Innovations is investigating RNAi as a solution to citrus greening disease that in 2014 caused 22 percent of oranges in Florida to fall off the trees.[12]

II.DISCUSSION

Mycopesticides include fungi and fungi cell components. Propagules such as conidia, blastospores, chlamydospores, oospores, and zygospores have been evaluated, along with hydrolytic enzyme mixtures. The role of hydrolytic enzymes especially chitinases in the killing process, and the possible use of chitin synthesis inhibitors are the prime research areas.[13]

The encapsulation of some biological compounds in nanoparticulate systems has been shown to improve their effectiveness against pests, reduce their toxicity toward people and the environment, and lessen the losses caused by physical deterioration (such as volatilization and leaching).[14][15][16] Thus, nanotechnology may aid in the creation of less toxic biopesticides with acceptable safety profiles, greater active agent stability, improved efficacy against the intended pests, and higher end-user acceptance.[15][17][18] Neem (*Azadirachta indica*) oil can be effectively protected from quick degradation by the use of nanoparticles, providing a more sustained action on the intended pests. The biodegradable polymers utilised in this type of formulation enable continuous administration of the active ingredient with no damage to the environment. Because there is currently a lack of extensive understanding regarding risk assessment factors and the subsequent toxicity of nanoparticles towards components of agroecosystems after their release into the environment, future research must focus on ways to avoid the risks associated with the use of nanoparticles.[19]

Bacillus thuringiensis is a bacterium capable of causing disease of Lepidoptera, Coleoptera and Diptera. The toxin from *B. thuringiensis* (Bt toxin) has been incorporated directly into plants via genetic engineering. Bt toxin manufacturers claim it has little effect on other organisms, and is more environmentally friendly than synthetic pesticides.

Other microbial control agents include products based on:

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- entomopathogenic fungi (*e.g. Beauveria bassiana*, *Isaria fumosorosea*, *Lecanicillium* and *Metarhizium* spp.),
- plant disease control agents: include *Trichoderma* spp. and *Ampelomyces quisqualis* (a hyperparasite of grape powdery mildew); *Bacillus subtilis* is also used to control plant pathogens.[7]
- beneficial nematodes attacking insects (*e.g. Steinernema feltiae*) or slugs (*e.g. Phasmarhabditis hermaphrodita*)
- entomopathogenic viruses (*e.g.*. *Cydia pomonella* granulovirus).
- weeds and rodents have been controlled with microbial agents.

Various animal, fungal, and plant organisms and extracts have been used as biopesticides. Products in this category include:

- Insect pheromones and other semiochemicals
- Fermentation products such as Spinosad (a macrocyclic lactone)
- Chitosan: a plant in the presence of this product naturally induces systemic resistance (ISR) to allow the plant to defend itself against disease, pathogens and pests.[20]
- Biopesticides may include natural plant-derived products, which include alkaloids, terpenoids, phenolics and other secondary chemicals. Vegetable oils such as canola oil have pesticidal properties[21][Products based on plant extracts such as garlic have now been registered in the EU and elsewhere[22][

The term "biological control" was first used by Harry Scott Smith at the 1919 meeting of the Pacific Slope Branch of the American Association of Economic Entomologists, in Riverside, California.[3] It was brought into more widespread use by the entomologist Paul H. DeBach (1914–1993) who worked on citrus crop pests throughout his life.[4][5] However, the practice has previously been used for centuries. The first report of the use of an insect species to control an insect pest comes from "Nanfang Caomu Zhuang" (南方草木狀 *Plants of the Southern Regions*) (c. 304 AD), attributed to Western Jin dynasty botanist *Ji Han* (嵇含, 263–307), in which it is mentioned that "*Jiaozhi people sell ants and their nests attached to twigs looking like thin cotton envelopes, the reddish-yellow ant being larger than normal. Without such ants, southern citrus fruits will be severely insect-damaged*".[6] The ants used are known as *huang gan* (*huang* = yellow, *gan* = citrus) ants (*Oecophylla smaragdina*). The practice was later reported by Ling Biao Lu Yi (late Tang Dynasty or Early Five Dynasties), in *Ji Le Pian* by *Zhuang Jisu* (Southern Song Dynasty), in the *Book of Tree Planting* by Yu Zhen Mu (Ming Dynasty), in the book *Guangdong Xing Yu* (17th century), *Lingnan* by Wu Zhen Fang (Qing Dynasty), in *Nanyue Miscellanies* by Li Diao Yuan, and others.[6]

Biological control techniques as we know them today started to emerge in the 1870s. During this decade, in the US, the Missouri State Entomologist C. V. Riley and the Illinois State Entomologist W. LeBaron began within-state redistribution of parasitoids to control crop pests. The first international shipment of an insect as a biological control agent was made by Charles V. Riley in 1873, shipping to France the predatory mites *Tyroglyphus phylloxera* to help fight the grapevine phylloxera (*Daktulosphaira vitifoliae*) that was destroying grapevines in France. The United States Department of Agriculture (USDA) initiated research in classical biological control following the establishment of the Division of Entomology in 1881, with C. V. Riley as Chief. The first importation of a parasitoidal wasp into the United States was that of the braconid *Cotesia glomerata* in 1883–1884, imported from Europe to control the invasive cabbage white butterfly, *Pieris rapae*. In 1888–1889 the vedalia beetle, *Novius cardinalis*, a lady beetle, was introduced from Australia to California to control the cottony cushion scale, *Icerya purchasi*. This had become a major problem for the newly developed citrus industry in California, but by the end of 1889, the cottony cushion scale population had already declined. This great success led to further introductions of beneficial insects into the US.[7][8]

In 1905 the USDA initiated its first large-scale biological control program, sending entomologists to Europe and Japan to look for natural enemies of the spongy moth, *Lymantria dispar dispar*, and the brown-tail moth, *Euproctis chrysorrhoea*, invasive pests of trees and shrubs. As a result, nine parasitoids (solitary wasps) of the spongy moth, seven of the brown-tail moth, and two predators of both moths became established in the US. Although the spongy moth was not fully controlled by these natural enemies, the frequency, duration, and severity of its outbreaks were reduced and the program was regarded as successful. This program also led to the development of many concepts, principles, and procedures for the implementation of biological control programs.[7][8][9]

Biological control agents

Predators are mainly free-living species that directly consume a large number of prey during their whole lifetime. Given that many major crop pests are insects, many of the predators used in biological control are insectivorous species. Lady beetles, and in particular their larvae which are active between May and July in the northern hemisphere, are voracious predators of aphids, and also consume mites, scale insects and small caterpillars. The spotted lady beetle (*Coleomegilla maculata*) is also able to feed on the eggs and larvae of the Colorado potato beetle (*Leptinotarsa decemlineata*).[34]

The larvae of many hoverfly species principally feed upon aphids, one larva devouring up to 400 in its lifetime. Their effectiveness in commercial crops has not been studied.[35]

The running crab spider *Philodromus cespitum* also prey heavily on aphids, and act as a biological control agent in European fruit orchards.[36]

Several species of entomopathogenic nematode are important predators of insect and other invertebrate pests.[37][38] Entomopathogenic nematodes form a stress–resistant stage known as the infective juvenile. These spread in the soil and infect suitable insect hosts. Upon entering the insect they move to the hemolymph where they recover from their stagnated state of development and release their bacterial symbionts. The bacterial symbionts reproduce and release toxins, which then kill the host insect.[38][39] *Phasmarhabditis hermaphrodita* is a microscopic nematode that kills slugs. Its complex life cycle includes a free-living, infective stage in the soil where it becomes associated with a pathogenic bacteria such as *Moraxella osloensis*. The nematode enters the slug through the posterior mantle region, thereafter feeding and reproducing inside, but it is the bacteria that kill the slug. The nematode is available commercially in Europe and is applied by watering onto moist soil.[40] Entomopathogenic nematodes have a limited shelf life because of their limited resistance to high temperature and dry conditions.[39] The type of soil they are applied to may also limit their effectiveness.[38]

Species used to control spider mites include the predatory mites *Phytoseiulus persimilis*,[41] *Neoseilus californicus*,[42] and *Amblyseius cucumeris*, the predatory midge *Feltiella acarisuga*,[42] and a ladybird *Stethorus punctillum*.[42] The bug *Orius insidiosus* has been successfully used against the two-spotted spider mite and the western flower thrips (*Frankliniella occidentalis*).[43]

Predators including *Cactoblastis cactorum* (mentioned above) can also be used to destroy invasive plant species. As another example, the poison hemlock moth (*Agonopterix alstroemeriana)* can be used to control poison hemlock (*Conium maculatum*). During its larval stage, the moth strictly consumes its host plant, poison hemlock, and can exist at hundreds of larvae per individual host plant, destroying large swathes of the hemlock.[44]

For rodent pests, cats are effective biological control when used in conjunction with reduction of "harborage"/hiding locations.[46][47][48] While cats are effective at preventing rodent "population explosions", they are not effective for eliminating pre-existing severe infestations.[48] Barn owls are also sometimes used as biological rodent control.[49] Although there are no quantitative studies of the effectiveness of barn owls for this purpose,[50] they are known rodent predators that can be used in addition to or instead of cats;[51][52] they can be encouraged into an area with nest boxes.[53][54]

In Honduras, where the mosquito *Aedes aegypti* was transmitting dengue fever and other infectious diseases, biological control was attempted by a community action plan; copepods, baby turtles, and juvenile tilapia were added to the wells and tanks where the mosquito breeds and the mosquito larvae were eliminated.[55]

Even amongst arthropods usually thought of as obligate predators of animals (especially other arthropods), floral food sources (nectar and to a lesser degree pollen) are often useful adjunct sources.[56] It had been noticed in one study[57] that adult *Adalia bipunctata* (predator and common biocontrol of *Ephestia kuehniella*) could survive on flowers but never completed its life cycle, so a meta-analysis[56] was done to find such an overall trend in previously published data, if it existed. In some cases floral resources are outright necessary.[56] Overall, floral resources (and an imitation, i.e. sugar water) increase longevity and fecundity, meaning even predatory population numbers can depend on non-prey food abundance.[56] Thus biocontrol population maintenance - and success - may depend on nearby flowers.[56]

Parasitoids lay their eggs on or in the body of an insect host, which is then used as a food for developing larvae. The host is ultimately killed. Most insect parasitoids are wasps or flies, and many have a very narrow host range. The most important groups are the ichneumonid wasps, which mainly use caterpillars as hosts; braconid wasps, which attack caterpillars and a wide range of other insects including aphids; chalcidoid wasps, which parasitize eggs and larvae of many insect species; and tachinid flies, which parasitize a wide range of insects including caterpillars, beetle adults and larvae, and true bugs.[58] Parasitoids are most effective at reducing pest populations when their host organisms have limited refuges to hide from them.[59] Parasitoids are among the most widely used biological control agents. Commercially, there are two types of rearing systems: short-term daily output with high production of parasitoids per day, and long-term, low daily output systems.[60] In most instances, production will need to be matched with the appropriate release dates when susceptible host species at a suitable phase of development will be available.[61] Larger production facilities produce on a yearlong basis, whereas some facilities produce only seasonally. Rearing facilities are usually a significant distance from where the agents are to be used in the field, and transporting the parasitoids from the point of production to the point of use can pose problems.[62] Shipping conditions can be too hot, and even vibrations from planes or trucks can adversely affect parasitoids.[60]

Encarsia formosa is a small parasitoid wasp attacking whiteflies, sap-feeding insects which can cause wilting and black sooty moulds in glasshouse vegetable and ornamental crops. It is most effective when dealing with low level infestations, giving protection over a long period of time. The wasp lays its eggs in young whitefly 'scales', turning them black as the parasite larvae pupate.[25] *Gonatocerus ashmeadi* (Hymenoptera: Mymaridae) has been introduced to control the glassy-winged sharpshooter *Homalodisca vitripennis* (Hemiptera: Cicadellidae) in French Polynesia and has successfully controlled ~95% of the pest density.[63]

The eastern spruce budworm is an example of a destructive insect in fir and spruce forests. Birds are a natural form of biological control, but the *Trichogramma minutum*, a species of parasitic wasp, has been investigated as an alternative to more controversial chemical controls.[64]

There are a number of recent studies pursuing sustainable methods for controlling urban cockroaches using parasitic wasps.[65][66] Since most cockroaches remain in the sewer system and sheltered areas which are inaccessible to insecticides, employing active-hunter wasps is a strategy to try and reduce their populations.

Pathogenic micro-organisms include bacteria, fungi, and viruses. They kill or debilitate their host and are relatively host-specific. Various microbial insect diseases occur naturally, but may also be used as biological pesticides.[67] When naturally occurring, these outbreaks are density-dependent in that they generally only occur as insect populations become denser.[68]

The use of pathogens against aquatic weeds was unknown until a groundbreaking 1972 proposal by Zettler and Freeman. Up to that point biocontrol of any kind had not been used against any water weeds. In their review of the possibilities, they noted the lack of interest and information thus far, and listed what was known of pests-of-pests - whether pathogens or not. They proposed that this should be relatively straightfoward to apply in the same way as other biocontrols.[69] And indeed in the decades since, the same biocontrol methods that are routine on land have become common in the water.

III.RESULTS

Microbial agents, effective control requires appropriate formulation[23] and application.[24][25]

Biopesticides have established themselves on a variety of crops for use against crop disease. For example, biopesticides help control downy mildew diseases. Their benefits include: a 0-day pre-harvest interval (see: maximum residue limit), success under moderate to severe disease pressure, and the ability to use as a tank mix or in a rotational program with other fungicides. Because some market studies estimate that as much as 20% of global fungicide sales are directed at downy

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mildew diseases, the integration of biofungicides into grape production has substantial benefits by extending the useful life of other fungicides, especially those in the reduced-risk category.

A major growth area for biopesticides is in the area of seed treatments and soil amendments. Fungicidal and biofungicidal seed treatments are used to control soil-borne fungal pathogens that cause seed rot, damping-off, root rot and seedling blights. They can also be used to control internal seed-borne fungal pathogens as well as fungal pathogens on the seed surface. Many biofungicidal products show capacities to stimulate plant host defense and other physiological processes that can make treated crops more resistant to stresses.

- High specificity: which may require an exact identification of the pest/pathogen and the use of multiple products used; although this can also be an advantage in that the biopesticide is less likely to harm non-target species
- Slow action speed (thus making them unsuitable if a pest outbreak is an immediate threat)
- Variable efficacy due to the influences of various factors (since some biopesticides are living organisms, which bring about pest/pathogen control by multiplying within or nearby the target pest/pathogen)
- Living organisms evolve and increase their tolerance to control. If the target population is not exterminated or rendered incapable of reintroduction, the surviving population can acquire tolerance of whatever pressures are brought to bear, resulting in an evolutionary arms race.
- Unintended consequences: Studies have found broad spectrum biopesticides have lethal and nonlethal risks for non-target native pollinators such as *Melipona quadrifasciata* in Brazil.[26]

The market for agricultural biologicals was forecast to reach $19.5 billion by future.[27]

Prickly pear cacti were introduced into Queensland, Australia as ornamental plants, starting in 1788. They quickly spread to cover over 25 million hectares of Australia by 1920, increasing by 1 million hectares per year. Digging, burning, and crushing all proved ineffective. Two control agents were introduced to help control the spread of the plant, the cactus moth *Cactoblastis cactorum*, and the scale insect *Dactylopius*. Between 1926 and 1931, tens of millions of cactus moth eggs were distributed around Queensland with great success, and by 1932, most areas of prickly pear had been destroyed.[10]

The first reported case of a classical biological control attempt in Canada involves the parasitoidal wasp *Trichogramma minutum*. Individuals were caught in New York State and released in Ontario gardens in 1882 by William Saunders, a trained chemist and first Director of the Dominion Experimental Farms, for controlling the invasive currantworm *Nematus ribesii*. Between 1884 and 1908, the first Dominion Entomologist, James Fletcher, continued introductions of other parasitoids and pathogens for the control of pests in Canada.[11]

There are three basic biological pest control strategies: importation (classical biological control), augmentation and conservation.[12]

Importation

Importation or classical biological control involves the introduction of a pest's natural enemies to a new locale where they do not occur naturally. Early instances were often unofficial and not based on research, and some introduced species became serious pests themselves.[13]

To be most effective at controlling a pest, a biological control agent requires a colonizing ability which allows it to keep pace with changes to the habitat in space and time. Control is greatest if the agent has temporal persistence so that it can maintain its population even in the temporary absence of the target species, and if it is an opportunistic forager, enabling it to rapidly exploit a pest population.[14]

One of the earliest successes was in controlling *Icerya purchasi* (cottony cushion scale) in Australia, using a predatory insect *Rodolia cardinalis* (the vedalia beetle). This success was repeated in California using the beetle and a parasitoidal fly, *Cryptochaetum iceryae*.[15] Other successful cases include the control of *Antonina graminis* in Texas by *Neodusmetia sangwani* in the 1960s.[16]

Damage from *Hypera postica*, the alfalfa weevil, a serious introduced pest of forage, was substantially reduced by the introduction of natural enemies. 20 years after their introduction the population of weevils in the alfalfa area treated for alfalfa weevil in the Northeastern United States remained 75 percent down.[17]

Alligator weed was introduced to the United States from South America. It takes root in shallow water, interfering with navigation, irrigation, and flood control. The alligator weed flea beetle and two other biological controls were released in Florida, greatly reducing the amount of land covered by the plant.[18] Another aquatic weed, the giant salvinia (*Salvinia molesta*) is a serious pest, covering waterways, reducing water flow and harming native species. Control with the salvinia weevil (*Cyrtobagous salviniae*) and the salvinia stem-borer moth (*Samea multiplicalis)* is effective in warm climates,[19][20] and in Zimbabwe, a 99% control of the weed was obtained over a two-year period.[21]

Small commercially reared parasitoidal wasps,[12] *Trichogramma ostriniae*, provide limited and erratic control of the European corn borer (*Ostrinia nubilalis*), a serious pest. Careful formulations of the bacterium *Bacillus thuringiensis* are more effective. The O. nubilalis integrated control releasing *Tricogramma brassicae* (egg parasitoid) and later *Bacillus thuringiensis subs. kurstaki* (larvicide effect) reduce pest damages as better than insecticide treatments [22]

The population of *Levuana iridescens*, the Levuana moth, a serious coconut pest in Fiji, was brought under control by a classical biological control program in the 1920s.[23]

Augmentation

Augmentation involves the supplemental release of natural enemies that occur in a particular area, boosting the naturally occurring populations there. In inoculative release, small numbers of the control agents are released at intervals to allow them to reproduce, in the hope of setting up longer-term control and thus keeping the pest down to a low level, constituting prevention rather than cure. In inundative release, in contrast, large numbers are released in the hope of rapidly reducing a damaging pest population, correcting a problem that has already arisen. Augmentation can be effective, but is not guaranteed to work, and depends on the precise details of the interactions between each pest and control agent.[24]

An example of inoculative release occurs in the horticultural production of several crops in greenhouses. Periodic releases of the parasitoidal wasp, *Encarsia formosa*, are used to control greenhouse whitefly,[25] while the predatory mite *Phytoseiulus persimilis* is used for control of the two-spotted spider mite.[26]

The egg parasite *Trichogramma* is frequently released inundatively to control harmful moths. New way for inundative releases are now introduced i.e. use of drones. Egg parasitoids are able to find the eggs of the target host by means of several cues. Kairomones were found on moth scales. Similarly, *Bacillus thuringiensis* and other microbial insecticides are used in large enough quantities for a rapid effect.[24] Recommended release rates for *Trichogramma* in vegetable or field crops range from 5,000 to 200,000 per acre (1 to 50 per square metre) per week according to the level of pest infestation.[27] Similarly, nematodes that kill insects (that are entomopathogenic) are released at rates of millions and even billions per acre for control of certain soil-dwelling insect pests.[28]

Conservation

The conservation of existing natural enemies in an environment is the third method of biological pest control.[29] Natural enemies are already adapted to the habitat and to the target pest, and their conservation can be simple and cost-effective, as when nectar-producing crop plants are grown in the borders of rice fields. These provide nectar to support parasitoids and predators of planthopper pests and have been demonstrated to be so effective (reducing pest densities by 10- or even 100-fold) that farmers sprayed 70% less insecticides and enjoyed yields boosted by 5%.[30] Predators of aphids were similarly found to be present in tussock grasses by field boundary hedges in England, but they spread too slowly to reach the centers of fields. Control was improved by planting a meter-wide strip of tussock grasses in field centers, enabling aphid predators to overwinter there.[29]

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Cropping systems can be modified to favor natural enemies, a practice sometimes referred to as habitat manipulation. Providing a suitable habitat, such as a shelterbelt, hedgerow, or beetle bank where beneficial insects such as parasitoidal wasps can live and reproduce, can help ensure the survival of populations of natural enemies. Things as simple as leaving a layer of fallen leaves or mulch in place provides a suitable food source for worms and provides a shelter for insects, in turn being a food source for such beneficial mammals as hedgehogs and shrews. Compost piles and stacks of wood can provide shelter for invertebrates and small mammals. Long grass and ponds support amphibians. Not removing dead annuals and non-hardy plants in the autumn allow insects to make use of their hollow stems during winter.[31] In California, prune trees are sometimes planted in grape vineyards to provide an improved overwintering habitat or refuge for a key grape pest parasitoid.[32] The providing of artificial shelters in the form of wooden caskets, boxes or flowerpots is also sometimes undertaken, particularly in gardens, to make a cropped area more attractive to natural enemies. For example, earwigs are natural predators that can be encouraged in gardens by hanging upside-down flowerpots filled with straw or wood wool. Green lacewings can be encouraged by using plastic bottles with an open bottom and a roll of cardboard inside. Birdhouses enable insectivorous birds to nest; the most useful birds can be attracted by choosing an opening just large enough for the desired species.[31]

In cotton production, the replacement of broad-spectrum insecticides with selective control measures such as Bt cotton can create a more favorable environment for natural enemies of cotton pests due to reduced insecticide exposure risk. Such predators or parasitoids can control pests not affected by the Bt protein. Reduced prey quality and abundance associated with increased control from Bt cotton can also indirectly decrease natural enemy populations in some cases, but the percentage of pests eaten or parasitized in Bt and non-Bt cotton are often similar.[33]

IV.CONCLUSIONS

Biological control or biocontrol is a method of controlling pests, whether pest animals such as insects and mites, weeds, or pathogens affecting animals or plants by using other organisms.[1] It relies on predation, parasitism, herbivory, or other natural mechanisms, but typically also involves an active human management role. It can be an important component of integrated pest management (IPM) programs.

There are three basic strategies for biological control: classical (importation), where a natural enemy of a pest is introduced in the hope of achieving control; inductive (augmentation), in which a large population of natural enemies are administered for quick pest control; and inoculative (conservation), in which measures are taken to maintain natural enemies through regular reestablishment.[2]

Natural enemies of insects play an important part in limiting the densities of potential pests. Biological control agents such as these include predators, parasitoids, pathogens, and competitors. Biological control agents of plant diseases are most often referred to as antagonists. Biological control agents of weeds include seed predators, herbivores, and plant pathogens.

Biological control can have side-effects on biodiversity through attacks on non-target species by any of the above mechanisms, especially when a species is introduced without a thorough understanding of the possible consequences.

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