A REVIEW ON BIOLOGICAL CONTROL AGENTS: EVALUATING THE EFFECTIVENESS OF PARASITOIDS AND PREDATORS

Ritin Kumar*, Deepanshu Kumar, Keshav Raj, K. P. Singh, Ankit Kajla, Ajay Kumar*

Department of Plant Protection,
CCS University Meerut- 250004 (Uttar Pradesh)
(*Corresponding author E-mail: kumarajay.ag.pp@gmail.com)

7

DOI: https://doi.org/10.31995/Book.AB334.A25.Chapter7

ABSTRACT

Biological control is an essential component of sustainable pest management, harnessing natural enemies like predators and parasitoids to suppress pest populations and minimize dependency on chemical pesticides. This review delves into the historical progression, effectiveness, and present challenges associated with using biological control agents, emphasizing their role in agricultural systems. Notable case studies, such as the successful control of *Icerya purchasi* using *Rodolia cardinalis* and the management of *Salvinia molesta* with *Cyrtobagous salviniae*, underscore the potential of these agents to provide significant pest suppression. Factors affecting their effectiveness, including environmental conditions and agricultural practices, are discussed. The review also highlights recent advancements in biotechnological approaches to augment biological control methods. Despite their success, the challenges of economic constraints, limited facilities, and the influence of the pesticide industry persist. The integration of these agents into comprehensive pest management frameworks holds promise for enhancing ecological sustainability and reducing chemical pesticide use.

Keyword: Predators, Parasitoids, Sustainability

Introduction

Biological control has been used for centuries, but the first big wave of activity in the modern era followed the spectacular success of the introduction in the late 1880s of the parasitic fly Cryptochaetum iceryae (Williston) (Diptera: Cryptochaetidae), and the vedalia beetle, Rodolia cardinalis (Mulsant) (Coleoptera: Coccinellidae) to control cottony-cushion scale (Icerya purchasi Maskell) (Hemiptera: Monophlebidae) in California citrus orchards (Caltagirone 1981). Scientists are concerned about the issue of enhancing natural enemies (parasitoids, predators, and weed feeders) through habitat management for the control of insect pests. The class of insects known as invertebrates is a member of the arthropod phylum. The world's bug species are presently divided into about 30 insect orders. There are over 750,000 bug species classified as hexapoda. The worst pest organisms, which comprise around 37 dangerous insects, are categorised. The main agricultural pests that cause significant crop loss are the American oil beetle, aphids, blister beetle, and boll weevil, among others (Oliveira, C.M. et al., 2014). Biological control refers to the employment of living creatures to reduce the damage that pest populations might otherwise cause. All pests, including insects, animals, plant diseases, and weeds, can be controlled using biologicalmeans. For each species of pest, a particular set of techniques and substances are employed. The biological control of insects and similar species is the main topic of this information sheet (S. Kimberly, 1914).

The use of biological control agents, particularly predators and parasitoids, has emerges a vital strategy in sustainable agriculture, aiming to manage pest populations while minimizing the reliance on chemical pesticides. As global agricultural practices face increasing scrutiny due to environmental concerns, the integration of biological control offers a promising alternative that aligns with ecological principles. Predators, such as lady beetles and lacewings, directly consume pests, while parasitoids, including various wasps and flies, exploit pests as hosts, ultimately leading to their demise. This review seeks to evaluate the effectiveness of these biological control agents within agricultural systems, examining their role in pest suppression, ecological interactions, and long-term sustainability. Recent advances in research have enhanced our understanding of the complex dynamics between pests and their natural enemies, highlighting the importance of specificity and adaptability in successful biological control programs. Furthermore, as agricultural landscapes become more complex due to practices like monoculture and the application of agrochemicals, the role of natural enemies becomes even more critical. Through a comprehensive analysis of case studies, field trials, and ecological assessments, this paper will explore the factors that influence the success of predators and parasitoids, including their life history traits, environmental conditions, and interactions with non-target species. By critically examining these elements, we aim to provide insights into the practical applications and challenges of implementing biological control strategies in diverse agricultural contexts. Ultimately, this review will underscore the necessity of integrating biological control into holistic pest management approaches that promote both agricultural productivity and ecological health.

History of Bio-control

1. Ancient Practices: The idea of biological management, which regulates pest populations by deploying predators and parasitoids, has a long history. Early attempts to manage pests using natural enemies may be seen in historical documents from ancient civilizations. Examples include the employment of predatory ants by ancient Chinese farmers to manage crop pests and the introduction of cats by the Romans to reduce rodent populations in granaries and agricultural areas.

2. Emergence of Modern Biological Control (Late 19th Century): The modern era of biological control began to take shape during the late 19th century with the recognition of the cottony cushion scale (Icerya purchasi) as a significant pest threatening California's citrus industry. Charles V. Riley, an entomologist, noticed that the vedalia beetle (Rodolia cardinalis) was a natural predator of the cottony cushion scale in Australia. In 1888, he successfully introduced and established the vedalia beetle in California, resulting in a dramatic reduction of the cottony cushion scale population and saving the citrus industry from potential devastation.

3. Systematic Development of Biological Control (Early to Mid-20th Century): During the early to mid-20th century, biological control gained scientific recognition and was integrated into systematic pest management approaches. Research institutions and government agencies, such as the United States Department of Agriculture (USDA), began focusing on the development of biological control programs.

4. Advances in Biological Control Techniques (Mid-20th Century): In the mid-20th century, significant advancements were made in mass rearing and augmentative releases of beneficial organisms. The development of techniques for mass-producing predators and parasitoids in laboratories allowed for large-scale applications of biological control in agricultural systems. The green lacewing (Chrysoperla spp.), ladybugs (Hippodamia convergens), and Trichogramma wasps are examples of commonly mass-reared beneficial insects used for pest control.

5. Integrated Pest Management (IPM) and Ecological Understanding: As the ecological understanding of pests and their natural enemies improved, Integrated Pest Management (IPM) emerged as a comprehensive approach to pest management. IPM emphasizes the integration of various pest control methods, including biological control, cultural practices, and judicious pesticide use. The aim is to manage pest populations effectively while minimizing adverse effects on the environment and non-target organisms.

6. Global Adoption and Expansion (Late 20th Century to Present): Biological control, particularly using predators and parasitoids, has seen widespread adoption and expansion globally. Many countries have established biological control programs and insectaries dedicated to the mass production and distribution of beneficial organisms for pest control. The use of biological control agents has become an integral part of sustainable agriculture, horticulture, and forestry practices.

7. Advances in Biotechnology and Genetic Control: Advancements in biotechnology have also contributed to the field of biological control. Genetic control methods, such as the release of genetically modified insects with self-limiting traits, are being explored as potential tools for pest management in some regions.The concept of biological management, which employs parasitoids and predators to control pest populations, has a long history.

Historical records from past civilizations may reveal early attempts to control pests using natural enemies. Examples include the Roman adoption of cats to control rodent populations in granaries and agricultural regions and the use of predatory ants by ancient Chinese farmers to manage crop pests.

Biological control and their types

Based on ecology as a phase of natural control it can be defined as ―the action of parasitoids, predators or pathogens in maintaining another organism‗s population density at a lower average than would occur in their absence‖ (Paul De Bach, 1964).

1. Classical Biological Control: Classical biological control involves the deliberate introduction of natural enemies, such as predators, parasitoids, or pathogens, from the pest's native region into a new area where the pest has become invasive or destructive. The introduced natural enemies establish themselves and help regulate the pest population, reducing its impact (Hokkanen, H. M., & Lynch, J. M. (Eds.), 1995).

2. Augmentative Biological Control: Augmentative biological control is the practice of releasing large numbers of commercially produced natural enemies, such as predatory insects or parasitoids, into a target area to provide immediate control of a pest population. This approach is often used when natural enemies are insufficient in the area or when pest populations are already established (Van Lenteren, J. C., 2012).

3. Conservation Biological Control: Conservation biological control focuses on enhancing and preserving the existing populations of natural enemies within an ecosystem. This involves creating and maintaining habitats, providing alternative food sources, and minimizing the use of pesticides that could harm beneficial organisms. By promoting a favourable environment for natural enemies, conservation biological control encourages natural pest regulation (Landis et al., 2000).

4. Inundative Biological Control: Inundative biological control is similar to augmentative control but involves the periodic or repeated releases of natural enemies in large numbers to achieve control of a pest population. These periodic releases aim to maintain the population of natural enemies at sufficient levels to regulate the pest population continuously (De Clercq et al., (2011).

5. Microbial Biological Control: Microbial biological control involves the use of naturally occurring microorganisms, such as bacteria, viruses, fungi, or nematodes, to control pest populations. These pathogens can infect and kill pests or disrupt their reproductive processes (Shapiro-Ilan et al., 2006).

Predators

Natural enemies known as predators are essential for reducing insect populations in agricultural environments. These predators frequently include insects, spiders, birds, and other creatures that actively seek for, catch, and consume pests that might harm plants and crops. Agricultural predators help keep the agro ecosystem in balance by preying on insect species. This reduces the demand for chemical pesticides and encourages the use of more ecologically friendly and sustainable pest control techniques.

Types of Agricultural Predators:

a) Ladybugs (Coccinellidae): Ladybugs are well-known agricultural predators that feed on aphids, mealybugs, scales, and other soft-bodied insects. They are widely used for aphid control in various crops, including vegetables, fruit trees, and ornamental plants.

b) Lacewings (Chrysopidae and Hemerobiidae): Green lacewings are important predators of small insects, such as aphids, thrips, and mites. They are commonly used in greenhouse and field crops for pest management.

c) Predatory Mites (Phytoseiidae): Predatory mites are beneficial arthropods that feed on plant-damaging mites, including spider mites and rust mites. They are used to control mite infestations in crops like strawberries, citrus, and ornamental plants.

d) Predatory Beetles (Carabidae and Staphylinidae): Ground beetles and rove beetles are predatory insects that consume a wide range of pests, including insect larvae, slugs, and snails. They contribute to the suppression of pest populations in various agricultural systems.

e) Parasitoid Wasps (Braconidae and Ichneumonidae): Parasitoid wasps are not only important as parasitoids but also as predators of pest insects. Some species feed on pest larvae or eggs, while others parasitize the larvae of pest insects, leading to their control.

f) Birds: Certain bird species, such as sparrows, swallows, and starlings, are known to be agricultural predators that feed on insects and pests in farmlands, reducing pest pressure.

g) Spiders: Various spider species are natural predators of insects and other pests in agricultural fields, contributing to pest management.

Utilizing of Agricultural Predators:

To effectively utilize agricultural predators for pest control, it is essential to create a habitat that supports their presence and activity. This can involve implementing practices that enhance biodiversity, such as maintaining hedgerows, cover crops, and wildflower strips, which provide shelter, alternative food sources, and nesting sites for beneficial organisms. Additionally, minimizing the use of broad-spectrum pesticides that can harm both pests and natural enemies is essential for preserving agricultural predators' populations and promoting effective biological control. Overall incorporating agricultural predators into integrated pest management (IPM) strategies can lead to more sustainable and economically viable agricultural practices, reducing reliance on chemical pesticides and promoting a healthier agroecosystem.

Insect and Arthropod Predators:

Almost every natural and agricultural ecosystem has insect predators. Each community could have a unique life cycle and set of customs. Even while several common predators' life histories have been extensively investigated, there is a dearth of knowledge on the biology and relative significance of numerous predatory arthropods.

Major characteristics of arthropod predators:

a) They are generally larger than pray

b) They kill or consume many prey (pests)

c) Males, females, immatures, and adults may be predatory

d) Adults and immatures are often generalists rather than specialists

e) They attack immature and adult prey (pests)

Parasitoids

A class of natural enemies known as parasitoids actively participates in biological management by parasitizing particular pest species. These parasitoids are often insects, and as part of their life cycle, they deposit their eggs within or on a host insect. As the parasitoid larvae grow and consume the host's tissues, the host insect eventually perishes.

Types of Parasitoids:

a) Braconid Wasps (Braconidae): Braconid wasps are common agricultural parasitoids that attack a wide range of pest insects, including caterpillars, aphids, and leafhoppers. The female wasp lays eggs directly into the host insect's body, and the developing braconid larvae consume the host's internal tissues, eventually killing it.

b) Ichneumonid Wasps (Ichneumonidae): Ichneumonid wasps are large and diverse parasitoids that target various insect hosts, including caterpillars, beetles, and sawflies. They lay their eggs on or inside the host, and the parasitoid larvae develop within the host, eventually causing its death.

c) Chalcid Wasps (Chalcidoidea): Chalcid wasps are tiny parasitoids that have a remarkable ability to parasitize a wide range of pest insects, such as scales, whiteflies, and leaf miners. They are often used in greenhouse and horticultural settings for pest control.

d) Trichogramma Wasps (Trichogrammatid): Trichogramma wasps are extremely small parasitoids that lay their eggs inside the eggs of various pest insects, including moths and butterflies. The developing trichogramma larvae consume the contents of the host egg, preventing the pest from hatching.

e) Tachinid Flies (Tachinidae): Tachinid flies are parasitoids that lay their eggs on or near the body of their host, typically caterpillars, beetles, or true bugs. The tachinid fly larvae feed on the host's internal tissues, ultimately leading to its death.

Utilizing of Agricultural Parasitoids:

Agricultural parasitoids are essential components of integrated pest management (IPM) programs. To effectively utilize these natural enemies for pest control, it is crucial to provide suitable habitats and conditions that support their survival and reproduction. Conservation biological control, which involves creating and maintaining habitats that favor natural enemies, can be implemented to encourage the presence of parasitoids in agricultural landscapes. Reducing the use of broad-spectrum pesticides that harm parasitoids and other beneficial organisms is also critical for preserving their populations.

Major characteristics of arthropod parasitoids:

a) Specialized in own choice of host

b) Only the female searches for host

c) Adults parasitoids are free living, mobile, and may be predaceous

d) Always smaller then host

e) Parasitoid eggs are usually near or in or on the host

f) Immature parasitoids almost always kill the host

g) Different parasitoid species can attack different life stage of host

SIGNIFICANT SUCCESS STORIES

Singh (2004) has presented a few of the initial and most significant successful case studies in classical biological control from India. Through this publication, the author has divided the significant success stories into three sections a) cases where excellent control was achieved, b) where substantial control was achieved, and c) where partial control was achieved.

A. Examples of excellent control achieved through classical biological control

1. Biological Control of Prickly Pear Opuntia spp.

Prickly pear cacti, Opuntia spp. were originally introduced into India as they were known for their edible fruits, drought resistance, forage value of the spineless forms, attraction as botanical curiosities, and garden ornamentals and as a source of cochineal dye. Opuntia vulgaris, O. stricta and O. elatior, which were introduced to producecochineal dye, later spread and occupied large areas and became serious agricultural pests in India. India's first successful classical biological control report was that of the importation of cochineal insect, Dactylopius ceylonicus (wrongly identified as the true carmine dye producing insect Dactylopius coccus, from Brazil in 1795, which brought about spectacular suppression of O. vulgaris in the north and central India. Since D. ceylonicus could not control the two other species of Opuntia, in 1926, D. opuntiae, a North American species, was imported from Sri Lanka, which successfully suppressed O. stricta and O. elatior. Thus, this is a perfect example of success achieved in suppressing the notorious weed Opuntia spp., through the classical biological control approach.

2. Biological Control of Water Fern, Salvinia molesta D.S. Mitchell

Salvinia molesta, a native of southeastern Brazil was initially recorded in 1955 in Vole Lake in Kerala which later on in 1964 turned into a notorious weed pest, affecting the lives of millions. In the Kuttanad area in Kerala, around 75,000 acres of canals and about 75,000 acres of paddy fields were affected as this weed could choke rivers, canals, lagoons, cover reservoirs, viz. Kakki and Idukki; hinder navigation, irrigation, fishing, shell collection, etc., and even led to paddy cultivation being abandoned. An exotic weevil, Cyrtobagous salviniae, native to Brazil, was imported from Australia. Host range testing indicated that the weevil was safe for non-targets. Initial efficacy tests were conducted in 1983-84 in a lily pond infested by water fern in Bangalore. Within a year, Salvinia collapsed, and lily plants were resurrected. Later, adults of C. salviniae were shipped to Kerala, Jammu & Kashmir, Bhubaneshwar and Hyderabad. The rapid establishment of the exotic weevil was recorded in ponds/tanks / lakes. The thickly clogged waterways could be cleared of Salvinia and turned navigable. In around three years after the release and establishment of C. salviniae, most of the canals which were abandoned due to the weed menace became navigable and large areas of paddy fields were cleared of the weed, leading to significant savings. Before release of the weevil, INR two hundred thirty-five had to be spent per hectare for manual removal of the weed from the paddy fields. Post release, INR 6.8 million annual savings (considering the savings on labour alone) were recorded from this biocontrol initiative. Besides, the aquatic floral diversity was resurrected.

3. Biological Control of Cottony Cushion Scale, Icerya purchasi Maskell

Icerya purchasi, which originated from Australia, is suspected of entering India through orchard stock or flowering plants imported from Sri Lanka. In 1928, this pest was first reported from Nilgiris in Tamil Nadu on the cultivated wattle, Acacia decurrens and other Acacia spp. Further, it spread to the states of Karnataka, Kerala and Maharashtra and was recorded on 117 host plants. This pest posed a threat to fruit crops, especially citrus and chemical control methods were totally ineffective. A coccinellid predator Rodolia cardinalis (a native of Australia), was imported into India in 1926 via the USA and South Africa and in 1930 via Egypt. From 1930, this exotic predator was released in the Nilgiris, and upper Palni hills in Tamil Nadu and the infested regions in the states of Maharashtra, Karnataka and Kerala and significant control was obtained.

B. Examples of substantial control achieved through classical biological control

The import and mass production and field releases of the exotic coccinellid predator Cryptolaemus montrouzieri and its establishment in field conditions on different species of mealybugs infesting fruit crops, coffee, ornamentals, etc. in south India are recorded as significant achievements. Further, this predator was commercially produced and utilised to manage several species of mealybugs and some species of scale insects. For the biological control of San Jose scale Quadraspidiotus perniciosus, different geographical (American, Chinese and Russian) strains of the aphelinid parasitoid Encarsia perniciosi were introduced, and field released, which led to the establishment of this parasitoid in several apple orchards, thus bringing down the San Jose scale population. The coccinellid beetle Curinus coeruleus (origin from South America) was imported from Thailand into India to target the Subabul psyllid Heteropsylla cubana. The initial releases were made in Karnataka and later on in the states of Kerala, Andhra Pradesh, Tamil Nadu and Manipur. These beetles established in the areas of release and succeeded in providing efficient, cost-effective and environmentally safe control of H. cubana on a sustainable basis.

The exotic aphelinid parasitoid Aphelinus mali emerged as an important bioagent regulating the population of the apple woolly aphid Eriosoma lanigerum, especially in the valleys. In some cases, exotic natural enemies are accidentally introduced. The spiralling whitefly, Aleurodicus dispersus, a native of the Caribbean region and Central America, was first reported in 1993 from Kerala and later from other parts of peninsular India and the Lakshadweep islands. Two aphelinid parasitoids, Encarsia guadeloupaeand E. sp. nr. meritoria were fortuitously introduced together with the host insect into mainland India. These parasitoids could establish in Kerala, Karnataka and several parts of Andhra Pradesh. These parasitoids, especially E. guadeloupae, were responsible for a significant reduction in the population of the Spiralling Whitefly, which can infest more than 250 species of plants / trees (Ramani et al., 2002).

C. Examples of partial control achieved through classical biological control

Some of the classical biological control initiatives for managing invasive weeds could provide only partial control and hence were not very successful. For, eg. An agromyzid seed fly, Ophiomyia lantanae (origin: Mexico), was imported from Hawaii and released in south India for the suppression of the invasive weed Lantana camara. In spite of its establishment, O. lantanae could not provide satisfactory suppression. A tingid lace bug of Mexican origin, Teleonemia scrupulosa was imported in 1941 from Australia. Though this weed insect was established in several parts of the country, various abiotic and biotic factors impaired its population build-up.

MORE RECENT SUCCESS STORIES

1. Biological suppression of the Papaya mealybug Paracoccus marginatus

One of the most significant success stories in the field of classical biological control is that of the excellent control of papaya mealy bug Paracoccus marginatus W & G through the introduction and field releases of exotic natural enemies (Shylesha et al., 2010). The papaya mealybug Paracoccus marginatus, an alien mealy bug native to Mexico, was first recorded on papaya plants in Coimbatore in 2008 and later spread to different states, viz. Kerala, Karnataka, Maharashtra and Tripura. Chemical pesticides could not give permanent relief, and repeated use of chemical pesticides resulted in toxicity hazards, pollution and harmful effects on non-target beneficials. The indigenous natural enemies like Spalgis epius, Cryptolaemus montrouzieri and Scymnus coccivora could not keep the papaya mealy bug population under check. Three species of exotic parasitoids,Acerophagus papayae, Pseudleptomastix mexicana and Anagyrus loecki, which were known to effectively suppress the papaya mealy bug in its native range, were imported from USDA-APHIS in Puerto Rico. The parasitoids were successfully multiplied and distributed to different states, where the infestation was recorded. The parasitoids could successfully establish in all the areas of release and suppress the papaya mealybug infestation on different crops. Within a year of the release of the parasitoids, the pest was brought below the Economic Threshold Level. Over five years, the total economic benefit was estimated to be the USD 1,340 million, besides the ecological benefits accrued through the non-use of chemical insecticides. It is estimated that annual savings of INR 1,623 crores were accrued to the farmers in Tamil Nadu, Karnataka and Maharashtra.

2. Biological control of the Eucalyptus gall wasp Leptocybe invasa Fisher and La

Salle: Leptocybe invasa was first reported in the Middle East in 2000 and later caused severe damage to eucalypt plantations throughout the world. In India, the first confirmed report was during 2004 from Tamil Nadu and further on, the pest spread to the states of Andhra Pradesh, Karnataka, Kerala, Maharashtra, Goa, Gujarat and Madhya Pradesh and even to the north Indian states of Punjab, Haryana, Uttarakhand and Uttar Pradesh. The exotic parasitoid Quadrastichus mendeli (origin Australia) imported from Israel was released, leading to savings of several thousand crores of rupees for the Indian paper industry. A complex of indigenous parasitoids viz., Aprostocetus gala Walker and Aprostocetus sp., Megastigmus spp., Parallelaptera sp. contributed to a combined parasitization ranging from 49 to 74 per cent on severely infested early-stage galls. However, Megastigmus sp. was the most dominant indigenous parasitoid providing around 90.74% parasitism. Repeated releases of indigenous parasitoids A. gala and Megastigmus dharwadicus were made in the infested sites of West Coast Paper Mills, Dandeli. Karnataka. There was no resurgence of the pest even after one year after the last field release. This clearly indicated that some of the native parasitoids could succeed in halting the ravages of an invasive pest (Vastrad et al., 2010).

3. Biological control of Cassava mealybug (CMB) Phenacoccus manihoti Matile-

Ferrero: In the early 1970s, the Cassava mealy bug was introduced from S America into Africa,causing 65% yield losses in 1983 and the economic costs of the losses were valued at $58 to $106 million. Search for an effective natural enemy resulted in identifying Apoanagyrus lopezi (DeSantis) – a parasite and host feeder on CMB as the ideal bioagent for field releases. IITA, Benin developed mass rearing and release techniques in the early 1980s for this parasitoid, which was introduced into sub-Saharan Africa to tackle the cassava mealybug. By 1987, A.

lopezi was established in 90% of the cassava growing regions. The benefits of this programme for a period of 40 years for 27 African countries was estimated as $9 billion (Zeddies et al., 2001). CMB was recorded in Thailand in 2009 and in 2011 A. lopezi was introduced from IITA. While in 2009, CMB infested area was 176 m ha, post release in 2013 it was reduced to 11 ha. In 2020, the cassava mealybug entered India and is currently creating havoc in the states of Kerala and Tamil Nadu. Based on the African success story, it was realised that the solution could only be through importation and release of the exotic parasitoid A. lopezi (Joshi et al., 2020). Accordingly, the parasitoid was imported in 2021 by ICAR-NBAIR, Bangalore from IITA, Benin, quarantine tested, mass rearing protocol developed and is now being evaluated against CMB in different parts of the country. A success akin to the experiences of Africa and Thailand is expected from India too. There are some striking examples clearly depicting the importance of conservation strategies in pest management through biological control.

4. Biological control of the sugarcane woolly aphid Ceratovacuna lanigera Zehntner

There are several benefits of conserving the diversity of natural enemies and also the effects of combinations of natural enemies on pest suppression. A classic example of conservation biological control is that of the suppression of the sugarcane woolly aphid Ceratovacuna lanigera Zehntner through conservation of the indigenous predators Dipha aphidivora (Meyrick) and Micromus igorotus Banks and the parasitoid Encarsia flavoscutellum Zehntner. This was enabled through a recommendation to farmers to refrain from applying chemical insecticides. This is also an example to indicate that some of the invasive pests can also be managed through utilization of indigenous natural enemies (Joshi & Viraktamath, 2004).

5. Biological control of the Rugose Spiralling Whitefly (RSW) Aleurodicus

rugioperculatus Martin

Invasive rugose spiraling whitefly (RSW) Aleurodicus rugioperculatus Martin (Hemiptera: Aleyrodidae) was reported infesting coconut, banana, custard apple and several ornamental plants in Tamil Nadu, Andhra Pradesh and Kerala. Several natural enemies were recorded on this pest and maximum parasitism was recorded by E. guadeloupae Viggiani (which was fortuitously introduced from Lakshadweep islands during the 1990s). Thus, conservation biological control strategy was adopted through recommendations on a totally non-chemical pesticidal approach. This enabled build-up of the parasitoid population and the RSW population could be brought under control in most of the areas (Selvaraj et al., 2017).

Factors affecting effectiveness

The effectiveness of biological control agents can be influenced by a number of factors, including environmental conditions, the availability of alternative food sources, and the genetic variability of the target pest population. For example, biological control agents may be less effective in highly disturbed or degraded habitats, where natural enemy populations may be reduced. Additionally, the effectiveness of biological control agents can be influenced by the spatial scale at which they are deployed, as well as the timing of their release.

Challenges to biological pest control:

There are many and different constrains on the way of biological control, these can be summarized in:

a) Less numbers of laboratories, equipments, tools and facilities required for biological pest studies.

b) Lack of professional extension services in biological control.

c) Economic constrains.

d) Institutional constrains.

e) Insufficient supported regulations and legislations.

f) Strong influence of pesticide industry and trading.

g) Absence of proper incent

Present scenario and future projections

Presently, biopesticides cover only 2% of the plant protectants used globally; however its growth rate shows an increasing trend in past two decades. Agricultural biologicals have recorded double-digit sales growth and have accrued around US $2.3 billion in annual sales over the past few years (Cuddeford and Kabaluk, 2010). Around two-thirds of US $2.3 billion is contributed by microbial formulations alone (Cuddeford and Kabaluk 2010).

The global market of bioagents is expected to reach $4 billion by 2024 from $2 billion in 2016, growing at a CAGR of 8.8% from 2016 to 2024 (Fig. 1). Similarly, global investment in biopesticides was US$1.3 billion in 2011and is estimated to reach US $ 3.2 billion by 2017, with at 15.8 % compound annual growth rate from 2012 to 2017 (www. markets and markets.com). These formulations include live microbial cells and microbial active ingredients for seed treatment and foliar applications (www. naasindia.org). There are about 1400 biopesticides currently sold globally, and is estimated that the annual growth rate of the biopesticide sector is greater than that of synthetic pesticides (16% versus 3%) (www. naasindia.org). The USA accounts for 40% of the global biopesticide use, followed by Europe (20%) and Oceania (20%) (www.naasindia.org). However, the usage of bioagents is only about 20% of that of synthetic fertilizers (www.fao. org). In India, biopesticide industry is projected to grow at a CAGR of 20.2 % since 2010 -2020. Scope of Current market for pesticides was US$ 23.92 million in 2015 which represent only 4.2 % of the overall pesticide market. Currently, 34 microorganism have been included in the schedule of Gazette of India for registration as biopesticide with Central Insecticide Board, Faridabad, under section 9 (3B) and 9(3) of the insecticide act 1968 (Keswani et al., 2015). Over 150 Bio pesticide producing companies, 15 types of bio pesticides out of 227 pesticides are registered. Highest demand for bio pesticides was observed from West India - Maharashtra followed by South India. Microbial pesticides sale are dominated by Trichoderma viride, Pseudomonas fluorescens and Bacillus thuringensis, (Ken research Report 2015). Central insecticide Board and registration Committee, Government of India have registered more than 970 Bio pesticide product. More than 63 Indian Private Companies with Registered Products. Some Major Indian Companies for Bio pesticides: Pest Control (Pvt) Ltd; Multiplex Biotech Ltd., International Panacea, Biotech International Ltd; T. Stanes; etc.

The biopesticides market has been segmented in different ways. On the basis of type, the biopesticides market is led by the bioinsecticides segment, followed by the bioherbicides, biofungicides, and bionematicides segments and others (sulfur, oil, insect repellent, moth control, and other biochemicals) respectively. The bioinsecticides segment is projected to be the fastest-growing type in the biopesticides market, due to the high crop loss by pests and diseases.

On the basis of crop type, classified as Grains & oilseeds, Fruits & vegetables, Others (turf, plantation, sugar crops, cotton, and ornamental crops). The market for fruit & vegetable crops accounted for the largest share and is also projected to be the fastest growing. This is mainly due to a high demand for fruits & vegetables by the growing population across the world. Biopesticides market share from fruits & vegetables accounted for over 70% of the overall industry revenue (www. markets and markets.com). As many fruits & vegetables are eaten without proper processing, consumers demand for better crop safety processing. Pesticide residue is generally a concern among consumers in these crops than in row crops that are not consumed in raw form. This practice leads to a high increase in pressure on grocery stores and good marketers to offer pesticide-free fruits & vegetables. Grains & oil seeds will observe gains over 6% up to 2024 (www.naasindia.org). Oats, vegetables, grains, and oilseeds are majorly contributing crops. The products prevent the generation of pathogens in the yield and enhance crop productivity. Other segment includes pulses, turfs, forage, and greenhouse crops.

Conclusion

Biological control agents are an important tool for management of pest populations and promotion of biodiversity conservation and ecosystem functioning. However, the effectiveness of biological control agents can bevariable, and their use can have some challenges. Further research is required to increase our understanding of the ecological importance of biological control agents and to develop effective strategies for their application.There might be opportunitiesto create remarkable profits in the field of agriculture by reducing the use of agrochemicals and thereby increasing the use of several biocontrol agents.

Reference

Chandish R. Ballal , Success Stories in Biological Control: Lessons Learnt. Former Director ICAR – National Bureau Of Agricultural Insect Resources & Former Project Co-ordinator, AICRP on Biological Control, correspondence: ballalchandish@gmail.com

Nandini Shukla, Erayya Archana Negi, Akanksha Singh, B.C Kabadwa, Roopali Sharma and Jatinder Kumar, Present Status and Future Prospects Of Bio-agents In Agriculture, Department of Plant Pathology, College Of Agriculture, Govind Ballabh Pant University Of Agriculture and Technology, Pantnagar, Uttrakhand, India.

Abhishek Shukla, Biological Pest Control: Advantages and Challenges, Department Of Entomology, N.M College Of Agriculture, Navsari Agriculture University, Navsari, Gujarat, India

Brajraj Sharan Tiwari, P.hD Scholar, Shailendra Kumar Mishra, P.hD Scholar, Ankit Kumar Mishra, P.hD Scholar, Saurabh Singh, P.hD Scholar, Department Of Entomology, Banda University Of Agriculture and Technology, Banda, Uttar Pradesh, India Mohd. Danish, P.hD Reasearch Scholar, SHUATS, Prayagraj, Pradeep Kumar, P.hD Reasearch Scholar, Maharana Pratap University of Agriculture and Technology, Udaipur, Rajasthan, Biological Control Predators and Parasitoids: An overview.

Muley E.D, Department of Zoology, Shivchhatrapati College, Aurangabad, Chavan A.S Department of Zoology, Dr. B. A. M. University, Aurangabad, A Review On Ecological Importance Of Biocontrol Agents.