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Invited Article

Success Stories in Biological Control: Lessons Learnt

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ABSTRACT

Globally, several success stories have been documented on classical, augmentative and conservation biological control strategies for managing insect pests and weeds. India too has had its share of successes in the field of biological control. Some examples include the management of the papaya mealy bug through classical biological control, suppression of the sugarcane woolly aphid through conservation biological control, and management of rice pests through augmentation biological control. However, it is a sad state of affairs that biocontrol practices have not been either universally accepted or optimally utilised as per the expectations. There are several hurdles to the uptake of biological control, which include unwieldy regulatory procedures to be followed for international exchange of biocontrol agents and registration of microbial biopesticides; hesitation amongst the commercial units to take up production of biocontrol agents (macrobials and microbials) and lack of active interactions between biocontrol researchers and all other stake-holders including farmers, public, extension workers, regulators and politicians. In this paper, an attempt has been made to compile information on some of the significant success stories in the field of biological control. Based on the lessons learnt from the older biological control success stories, proactive steps have been taken in India to tackle some of the recent invasive pests. The need of the hour is for biocontrol researchers and practitioners to network with economists, social scientists and other relevant stakeholders so that the social, economic and financial value of biological control (primarily based on the success stories) can be clearly defined and accurately quantified and communicated to farmers, commercial units and policymakers, which can lead to increased uptake of this sustainable method of pest management.

Keywords: Augmentation, classical biological control, conservation, invasive pests

INTRODUCTION

The most enchanting factor about natural biological control by predators, parasites, and pathogens of agricultural pests is that this happens regardless of whether humans are aware of it or not. At the same time, it is essential to make humans aware of the services provided by biological control agents so that they allow these agents to perform. After the second world war, when the public understood how rapidly insect pests could be controlled with chemical insecticides, there was no way to halt their extensive use in agriculture. It is evident that temporarily they were blinded to the fact that these chemical insecticides could equally or even more rapidly kill the beneficial insects. However, Rachel Carson's "Silent Spring", published in 1962, triggered a change in the public perception regarding the pernicious effects of pesticides in agriculture. Besides natural biological control, biological control initiatives were also purposefully taken up, wherein populations of natural enemies such as predatory and parasitic insects, weed insects, and microbials were manipulated by human beings to manage undesirable insects, weeds, and diseases. The three modules coming under biological control are conservation, augmentation, and classical. Classical biological control involves the importation and field release of an effective natural enemy(ies) from the homeland of an exotic, invasive pest species. Augmentation biological control involves the utilisation of biological control organisms (macrobials or microbials, generally indigenous) by releasing them into the field to target outbreak pests. Conservation biological control aims to modify pesticide application practices to favour the populations of natural enemies or modify the environmental conditions, viz., habitat manipulations to build up the populations of natural enemies or improve their performances. Biological control has been widely accepted as a pest management strategy, which is sustainable, environment-friendly, economically viable and socially acceptable. Still, there is a large population in the society which looks at the science of biological control with scepticism. Hence, this publication aims to elucidate the information on the success stories documented on biological control, with a more significant focus on Indian examples. This may not succeed in convincing scepticism; however, it could definitely create awareness amongst the student community, who as torch bearers could spread the message of biological control, thus encouraging adoption of this pest management system for both indigenous and exotic pests.

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 produce cochineal 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 guadeloupae* and *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).

6. Biological control of the Fall Army Worm *Spodoptera frugiperda* (J. E. Smith)

There are instances where attempts to tackle invasive pests using indigenous natural enemies have also been successful. One example is that of the recent invasive fall army worm (FAW) (*Spodoptera frugiperda*) (J. E. Smith), which after spreading across sub-Saharan Africa, has entered South Asia, creating total distress to the smallholder farmers. In India, the occurrence of FAW was first reported by ICAR-NBAIR as a PEST ALERT on its website in July 2018. The damage was first noticed in Karnataka, where the incidence ranged from 9.0 to 62.5% and by 2019 August, it had been reported in almost all the states except J&K and Himachal Pradesh. A search for indigenous natural enemies resulted in a report of an indigenous natural enemy complex comprising of egg parasitoids *viz.*, *Telenomus* sp. and *Trichogramma* sp.; egg larval parasitoid *Chelonus* sp., gregarious larval parasitoid *Glyptapanteles creatonoti*, solitary larval parasitoid *Campoletis chlorideae;* a solitary indeterminate ichneumonid larval-pupal parasitoid and a larval-pupal(?) pteromalid parasitoid *Trichomalopsis* sp. Several predators were also found associated with the pest viz. earwig *Forficula* sp., predatory bugs *Andrallus spinidens* and *Eocanthecona furcellata.* Epizootics of entomopathogenic fungus *Metarhizium* (*Nomuraea*) *rileyi* (Farl.) Samson was also recorded in Chikballalpur, Shivamogga and Bangalore, causing considerable mortality of the pest in the larval stage. Through a very intensive search in several infested fields, virus infected FAW larvae were also collected. ICAR-NBAIR evaluated all the promising bioagents from its natural enemy repository, including egg parasitoids, entomofungal pathogens, *Bt*, NPV and entomopathogenic nematodes. The initial laboratory testing and small plot trials led to the identification of the following bioagents which could form an integral part of an IPM module viz., Egg parasitoids *Trichogramma chilonis, Trichogramma pretiosum* and/or *Telenomus remus,* microbials *Metarhizium anisopliae* (NBAIR Ma-35), *Beauveria bassiana* (Bb-45), *Bacillus thuringiensis* (NBAIR Bt-25) and EPN (NBAII Hi-38 or NBAII Hi-101). These bioagents developed by NBAIR are now being widely tested and validated in the different states through farmer field trials and also through the AICRP Biocontrol centres and KVKs. The results of the biological control trials are highly promising, thus encouraging the researchers and farmers (Ballal et al., 2021a, b).

SUCCESSES IN AUGMENTATION BIOLOGICAL CONTROL

In the rice ecosystem, conservation and inundative releases of the egg parasitoids *T. japonicum,* and *T. chilonis* have provided promising results. The biological control of rice pests in Kerala – the Adat Panchayat model, has been documented as one of the success stories, where the biocontrol-based integrated pest management module was adopted in 2500/3000 ha in a year and the bio-agents utilized were *Trichogramma* (as Tricho-cards) and *Pseudomonas.* In this model system, active collaboration existed between the farmers, NBAIR (then PDBC), Kerala Agricultural University, State Biocontrol Lab-Mannuthy and input management by Farmer's cooperative bank. Besides conserving the bio-diversity, a high yield of 6.5 MT/ha could be obtained (Ballal & Verghese, 2015). Though *Trichogramma* spp. are proved to be effective against several lepidopteran pests, the availability of Tricho-cards is a major constraint. The lack of technology for long term storage of Tricho-cards has posed a hurdle to the commercial uptake of production of Tricho cards. A technology developed at ICAR-NBAIR on long term storage of Tricho-cards through diapause induction has provided an answer to this major issue (Ghosh & Ballal, 2017, 2018).

Notable success has been achieved in the bio-suppression of the hopper *Pyrilla perpusilla* in some states by the colonization / redistribution of the lepidopteran parasitoid, *Epiricania melanoleuca*. Misra and Pawar (1984) reported that this parasitoid when released @ 400,000 – 500,000 eggs or 2000 – 3000 cocoons / ha in eastern UP, West Bengal, Orissa, Karnataka, Kerala, Maharashtra, Rajasthan, Andhra Pradesh and Madhya Pradesh gave complete control of the pest. Pawar (1979) reported that in July – September if 20 – 60% parasitism of nymphs and adults is recorded there is no need to panic even if outbreak like situation is noticed.

Indigenous parasitoids play a major role in the management of the coconut black-headed caterpillar in the coconut ecosystem. Field release of the three stage-specific *Opisina arenosella* parasitoids *viz Goniozus nephantidis, Elasmus nephantidis* and *Brachymeria nosatoi* at fixed norms and intervals in a heavily infested coconut garden (2.8 ha) for a period of five years resulted in highly significant reduction in *Opisina* population (Sathiamma et al., 2000). Follow up observations revealed that even after three years no build-up of the pest was noted in the released site.

Biological control scientists are expected to provide farmers and extension personnel with sustainable, environment friendly and effective tools to manage the relentless pressure of invasive species and indigenous pest outbreaks on natural and agricultural ecosystems. Based on the above challenges and previous successes and failures faced by global and Indian biocontrol workers, the following thrust areas have been identified:

FUTURE THRUSTS BASED ON THE LESSONS LEARNT

- Research thrust should be on
  - the precise mechanisms through which a natural enemy performs in nature
  - the reason for the success or failure of a natural enemy in specific situations
  - the effect of climate change on pests, their natural enemies and their interactions
  - interactions between transgenic crops and biocontrol agents
  - In classical biocontrol, identification of the appropriate species (or biotype) or combination of species (and/or biotypes) to release for control of a target pest in a given situation
  - the environmental impact resulting from the introduction of an exotic enemy.
  - Nontarget impacts of introduced bioagents on indigenous plants and insects
  - The effect of intrinsic and extrinsic ecological factors on the diversity and performance of natural enemies.
  - Standardisation of general methodologies for release and evaluation of natural enemies.
  - Development of sound ecological theories concerning pest population dynamics, natural –enemy-prey interactions and the genetics of colonization in biocontrol.
- For the popularization of biocontrol, the following should be the focus areas
  - Extensive research (including student research) should be taken up on identifying simple and feasible conservation strategies for the effective natural enemies on specific crops.
  - The validated conservation strategies should be demonstrated to farmers in a net-work mode by SAUs and ICAR Institutes through large scale demonstration trials in farmers' fields.
  - Strong research thrust on augmentation of biocontrol-based technologies, which should lead to the commercial uptake of mass production of macrobials and microbials and thus assure availability of bioagents for farmers

- When an invasive pest enters our country, the first option should be to search for effective indigenous bioagents before opting for the introduction of exotic bioagents.
- Need-based modifications in the tox data requirements for biopesticide registration by not considering biopesticides on par with chemical insecticides are the need of the hour. This is of great relevance, especially during emergency situations due to invasive pest attacks. In situations where the promising isolates have been identified and validated by Government research organisations, streamlining the procedures for time-bound registrations would be very important. This would go a long way in effective biopestides reaching the farmers, leading to a significant reduction in the number of chemical pesticide sprays.
- It is important for all the older stakeholders to realise that classical biological control can be very successful only through multilateral exchanges of biocontrol agents. Hence, it is essential to finetune national biodiversity regulations to facilitate such exchanges meant specifically for biological control to benefit the global farming community.
- Emphasis should be on improved and effective communication by biocontrol researchers and practitioners with farmers, other researchers, pesticide companies, policymakers, and other stakeholders.

CONFLICT OF INTEREST

The author hereby declares that there are no conflicts of interest to disclose.

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