

Journal of Biological Control, 38(4): 371-377, 2024, DOI: 10.18311/jbc/2024/46321

Review Article

Advancing biocontrol: An Indian perspective on the production and status of biocontrol agents

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ABSTRACT: Biological control plays an important role in ecosystem services. Globally, 350 species of invertebrate natural enemies (macrobials) are produced to tackle 100 insect pests. Besides invertebrate natural enemies, 209 microbial strains from 94 different species are commercially available in many countries for control of pests. In India, more than 13 insect predators and parasitoids are being multiplied in many states on a small scale. Among them, trichogrammatids are produced by more than 25 states and supplied to the farmers. A total of 104 biopesticide formulations have been officially registered in India under the Insecticide Act of 1968, encompassing 19 distinct types of biopesticides. A database was prepared to comprise information on biocontrol production units in all the states/UTs with details which are engaged in the production of biocontrol agents including both microbials and invertebrate natural enemies. According to the database, 86 government-funded units are engaged in the production of macrobials and 141 units are producing microbial biopesticides. As demand for biocontrol agents is increasing, government-funded laboratories for the production of macrobials and microbials are not sufficient to cater to the needs of farmers. Therefore, it is important to create a suitable environment and funding for start-ups to produce macrobials. There are private firms that produce microbial biopesticides, but it could be further enhanced by providing good infrastructure, ease in biopesticides regulation policies etc.

KEYWORDS: Biocontrol production units, macrobials, microbials, trichogrammatids

(Article chronicle: Received: 12-10-2024; Revised: 28-12-2024; Accepted: 30-12-2024)

INTRODUCTION

Biological control refers to the management of insect pests using specific agents such as insect predators, parasitoids, and microbial biopesticides. This is a significant ecological service that plays a crucial part in integrated pest management within sustainable agriculture. The estimated value offered by natural and inoculative biological management is tenfold greater than the resources allocated to chemical pest control (Crop Life International, 2008, van Lenteren, 2012). Conversely, in Augmentative Biological Control (ABC), natural enemies viz. predators, parasitoids and microorganisms are systematically bred and released into the field to reduce insect populations. Nevertheless, the implementation of augmentative biocontrol methods is limited to a mere 30 million hectares (van Lenteren, *et al.*, 2018), which is far smaller than the extent of natural and inoculative biological control processes.

GLOBAL SCENARIO

Between 1970 and 2010, the number of commercially produced species rose from 11 to 170. Presently, over 350 species of insect natural enemies are employed globally to combat insect pests, with over 500 commercial manufacturers actively involved in the manufacturing of biological control agents (van Lenteren *et al*., 2018). This figure could be higher if government-owned operations were also included. Prior to 2005-06, hymenopteran parasitoids were primarily used in augmentative biological control. However, since then, predatory mites and hemipteran predators have dominated the market for protected and high-value crops in open field conditions, accounting for 80-90% of the invertebrate biocontrol market. The market for natural enemies employed in the control of greenhouse pests was valued at €150–200 million in 2008 (Bolckmans, 2008, Cock *et al.*, 2010) and then grew to US$400 to US$600 million in 2014 (van Lenteren 2012, van Lenteren *et al.*, 2018, Knapp *et al*., 2018). The Global Biocontrol market, comprising microorganisms, biochemicals and invertebrate biocontrol agents, has a valuation of USD 6.6 billion in 2022 and is projected to expand at a Compound Annual Growth Rate (CAGR) of 15.8% until 2027 (Marketsandmarkets, 2024). The use of invertebrate bioagents for insect pest control is most prevalent in Europe, followed by North America, Asia, Latin America, Africa, and the Middle East (van Lenteren, *et*

al., 2018). Some 90% of invertebrate bioagents are utilised in greenhouses throughout Europe. Furthermore, microbial biocontrol agents play a crucial part in enhancing biological control. In 2018, van Lenteren and colleagues compiled a comprehensive inventory of 209 microbial strains derived from 94 distinct species that are commercially accessible in Australia, Brazil, Canada, the European Union, Japan, New Zealand, and the United States of America. These strains are specifically designed for pest control purposes. Europe is the second largest market for biopesticides worldwide, after North America.

Commercial insectaries refer to bio-production facilities managed by growers, entrepreneurs, cooperative groups, and other entities. Globally, there were 85 commercial insectaries reported in 2003, with the highest number in Europe. This number increased to 530 commercial insectaries in 2018 according to van Lenteren *et al.* (2018). Among them, roughly 20-30 are major manufacturers, with the majority being in Europe (Bolckmans, 2008), while around 500 are small-scale commercial producers. While the majority of these commercial insectaries focus on breeding predators and parasitoids, a small number also cultivate entomopathogenic nematodes. A significant number of insectaries were established in Latin America between 1970 and 2002 to fulfil the need for expanded biological control. During the 2000s, Brazil had 44 insectaries providing extensive coverage to combat borers. Twenty-two insectaries in North America were involved in the production of 38 natural enemy species, generating a wholesale turnover of $25-30 million (Warner & Getz, 2008). Yet, in contrast to Europe, just 10% of greenhouse users implemented commercial biocontrol strategies. This phenomenon may be attributed to the fluctuation in prices and the unavailability of bioagents when needed.

INDIAN SCENARIO

Establishing the Commonwealth Institute for Biological Control (CIBC) station at Bangalore in 1957 was pivotal in enhancing knowledge of biological control. Later, All India Coordinated Research Project (AICRP) on Biological Control of Crop Pests and Weeds (AICRP-BC&W) initiated by the Indian Council for Agricultural Research in 1977 continued the activities at the India station of CIBC on its closure. Over time, the Bio-control and Integrated Pest Management (IPM) Programme has received assistance from many government agencies including the Department of Science and Technology, Department of Biotechnology (DBT), Department of Agriculture and Cooperation (DAC), Ministry of Agriculture, and Indian Council of Agricultural Research.

While a small number of state government-funded biocontrol laboratories were operational in the 1980s to generate parasitoids for sugarcane borers and black-headed caterpillars in coconut, they were unable to satisfy the demand. Hence, the establishment of India's inaugural commercial biocontrol insectary Biocontrol Research Laboratory (BCRL) in 1981 addressed the needs of farmers (Manjunath, 1984).

Many indigenous natural enemies have been documented in India to combat insect pests. Many natural enemies such as Trichogrammatids, chrysopids, egg-larval larval parasitoids, hemipteran bugs, and predatory mites have been mass breed and assessed their feasibility against insect pests. Farmers, growers, and extension workers are acutely aware of the effectiveness of biological control, but, the availability of these bioagents is a significant issue. ICAR-NBAIR receives

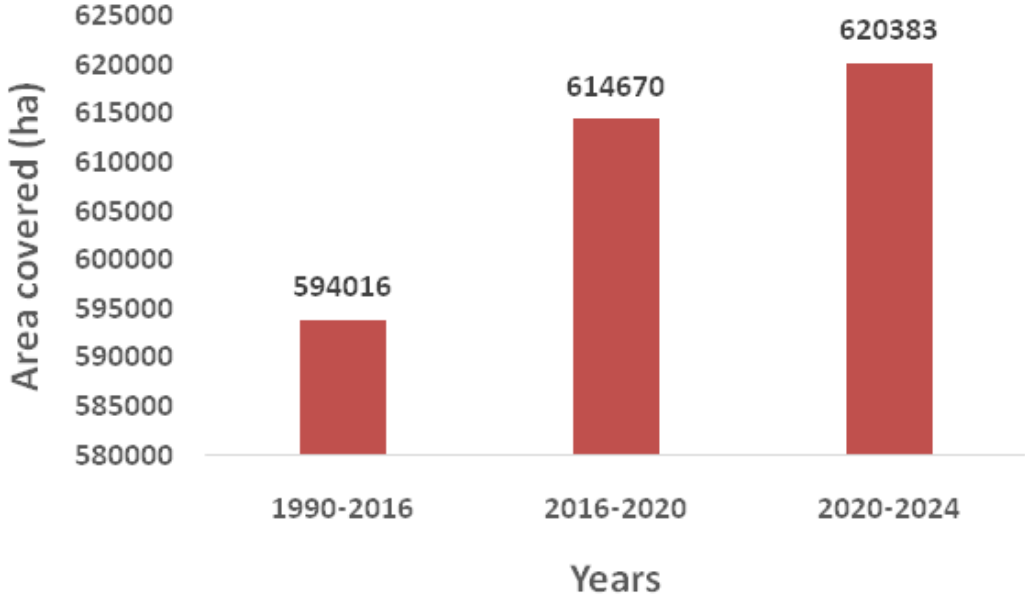


Figure 1. Area covered (ha) under biocontrol agents including macrobials and microbials under the All India Coordinated Research Project (AICRP) on Biological Control of Crop Pests during 1990-2024.

daily requests from farmers and producers to supply natural enemies, as they are aware that biocontrol is effective in minimizing the use of pesticides.

Under All India Coordinated Research Project (AICRP) on Biological Control of Crop Pests, research was carried out on evaluating different biocontrol agents including macrobials and microbials against different insect pests in different locations. Several technologies were validated through this project and are popular among the farmers. Farmers are not only saving their money by reducing the application of insecticides on their crops, but, the technologies are safe to the environment and non-target organisms. Under this project, till 2024 a total of 6,20,383 ha area has been covered under biocontrol (Figure 1) (AICRP-BC Review Report, 2016; AICRP-BC Annual Report 2024).

Now protected cultivation in India has been growing and is facing a lot of challenges from insect pests as insect pests thrive well in this conducive environment without natural enemies. Therefore, there is a lot of scope for augmentative biological control with commercial biocontrol agents particularly in protected cultivation. The area coverage reported under protected cultivation in India is 1,10,000 hectares. The maximum area under protected cultivation in Maharashtra and Gujarat covers 5,730.23 hectares and 4,720.72 hectares area, respectively (Singh *et al.*, 2020). In protected cultivation, a major threat is imposed by thrips, aphids, whitefly and mites. Indigenous predators like chrysopids, anthocorids, mirid, predatory mites and geocorid bugs exhibited tremendous potential in curtailing the menace of these sucking pests in protected cultivation. Their use in combination with microbial biopesticides could be a breakthrough in managing these insect pests in Indian conditions. Mass rearing protocols of these predators have been standardized and stakeholders are very keen to use these bioagents to get pesticide residue-free produce. This could be one area which could be explored by entrepreneurs to start a venture.

The ICAR-National Bureau of Agricultural Insect Resources, Bengaluru, is a nodal agency in India that is responsible for the maintenance and supply of insect germplasms. The bureau is currently maintaining more than 100 live insects (90 geographical and evolved strains and species of insect parasitoids, 20 predators species and evolved strains, 20 host insects, 4 pollinators and 1 insect species used for waste conversion) and 711 strains of entomopathogenic microbes. Besides ICAR-NBAIR, state biocontrol laboratories and Central Integrated pest management centres across India are also involved in bioagent production. To fulfil the country's needs and to expand the area under biological control, in line with the Government of India's policy to reduce pesticide usage, it is crucial to understand the production capacity of government-funded laboratories. A survey was undertaken to collect data on biocontrol units that received funding from the state and federal governments, which are involved in the manufacture of bioagents, including both macrobials and microorganisms. State agricultural universities, the State Agriculture and Horticulture Department, the Indian Council of Agricultural Research, Central Integrated Pest Management Centre of the Directorate of Plant Protection, Quarantine, and Storage were consulted to obtain information on the monthly production capacity of bioagents, contact details, and other relevant details of active bioagents production units on a state's basis. This database, accessible at https://databases.nbair.res.in/biocontrol/index.php, has comprehensive information on the availability and contact details for acquiring bioagents on a state-wise basis. This will, therefore, facilitate the prompt availability of bioagents to farmers and other relevant parties.

In India, the production of invertebrate biocontrol agents is restricted to small production units and government-funded units. There is no major player in the production of macrobials so far. Later, a few growers, and FPOs are coming forward to produce macrobials depending upon their needs. The major hurdle in running a macrobial production unit is the gap between demand and supply. Many units which started producing macrobials had to shut off because of the gap in demand and supply. Macrobials have to be produced and supplied immediately without delay as their shelf life is short. Therefore, it is important to create demand and fill the gap by developing networking with KVKS, FPOs, progressive farmers and the state biocontrol department. It will not only help to ensure availability but also create business opportunities and thus avoid shutting down the unit in the absence of demand. However, for microbial biopesticides, many private firms are actively engaged and contribute 70% of production (Chakraborty *et al.*, 2023).

Indian agricultural cultivation in 2022-23 amounted to 207.56 million hectares (https://ppqs.gov.in/statistical-database). Among this, 15.63 million hectares were covered with biopesticides alone, while 21.27 million hectares were treated with biopesticides and pesticides. The consumption of biopesticides in India has had a 29.4% growth from 2018-19 to 2021-22. Over the past five years, from 2018 to 2023, West Bengal reported the highest usage of biopesticides, followed by Maharashtra, Tamil Nadu, Kerala, and Rajasthan (Figure 2).

The registration and regulation of biopesticides is governed by the Insecticides Act of 1968. A total of 104 biopesticide formulations have been officially registered in India under the Insecticide Act of 1968, encompassing

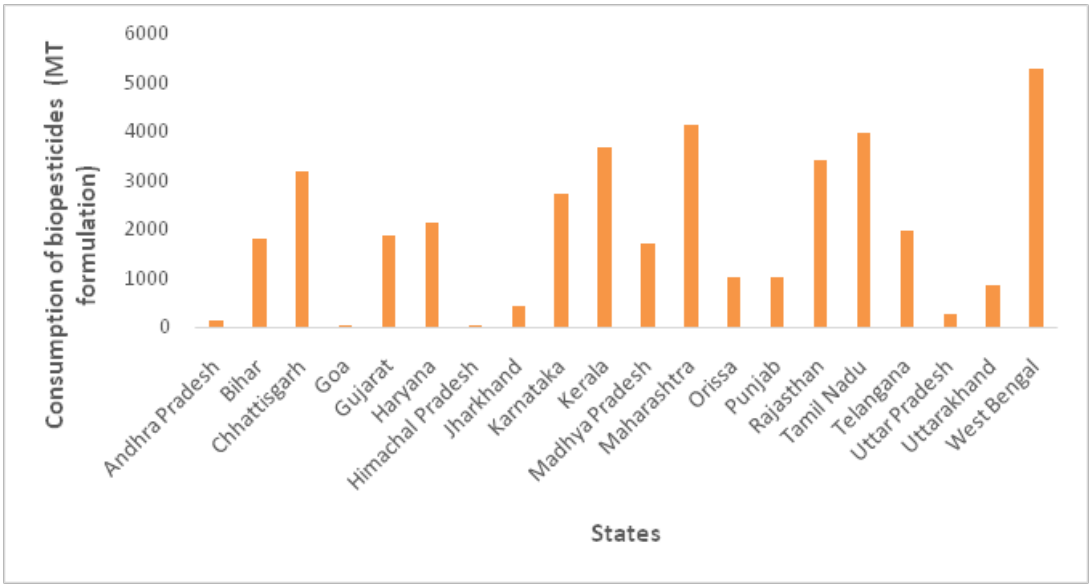


Figure 2. State-wise biopesticides formulation consumption (MT) during 2018-23**.**

19 distinct types of biopesticides including neem based pesticides (DPPQS data, 2024; https://ppqs.gov.in/divisions/cib-rc/registered-products).

They are:

1. Neem-based pesticides (8)
2. *Bacillus thuringiensis* var. galleriae (1)
3. *Bacillus thuringiensis* var. kurstaki (9)
4. *Bacillus thuringiensis* var. israelensis (10)
5. *Bacillus thuringiensis* var. sphaericus (1)
6. *Bacillus sphaericus*; (1)
7. *Beauveria bassiana* (16)
8. *Metarhizium anisopliae* (4)
9. NPV of *Helicoverpa armigera*; (9)
10. NPV of *Spodoptera litura*; (1)
11. *Paecilomyces lilacinus*(1)
12. *Pseudomonas fluorescens* (9)
13. *Trichoderma viride*; (10)
14. *Trichoderma harzianum*;(9)
15. *Trichoderma ressei* (1)
16. *Verticillium lecanii* (5)
17. *Verticillium chlamydosporium* (1)
18. *Bacillus subtilis* (6)
19. *Ampelomyces quisqualis* (1)

BIOCONTROL AGENTS PRODUCTION UNITS IN INDIA

As per data collected from various government agencies, 86 units are engaged in the production of macrobials (predators and parasitoids) and 141 units are producing microbials (Figure 3). 25 private labs and sugar mills (data provided by a few government organizations) are engaged in the production of microbials and a few macrobials. Maximum biocontrol agents' production units engaged in the production of both macrobials and microbial biopesticides funded by the government are in southern states of India. Tamil Nadu has the maximum number of units (37) followed by Kerala (21), Andhra Pradesh (14), Karnataka (13) and Telangana (10). Other states have 0-5 bioagent production units with 8 numbers in Maharashtra. However, we did not get a response from some of the north-eastern states of India. There are few private bioagent production units engaged in the production of macrobial though their number is insignificant compared to microbial production units. Here, private lab data is received from the government. However, many private firms are engaged in the country for the production of microbials

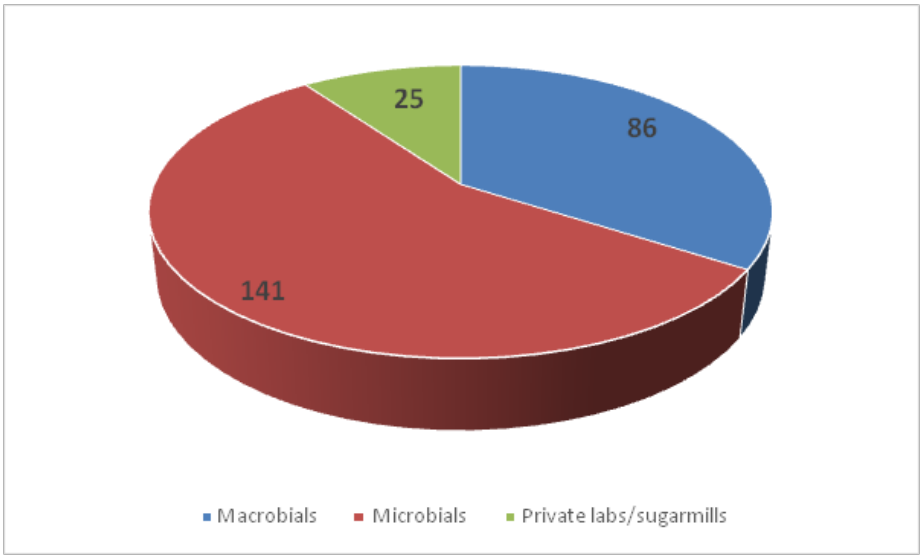


Figure 3. Several bioagent production laboratories engaged in the production of microbials and macrobials.

Table 1. Major macrobials produced by government-funded units

S. No.	Macrobials	No. of states involved in production	Monthly capacity (number)
	Parasitoids		
1	Trichogrammatids (*Trichogramma chilonis, T. japonicum, T. pretiosum* and *Trichogrammatoidea bactrae)*	25	1-14 million insects
2	*Chelonus blackburni*	7	50,000
3	*Goniozus nephantidis*	7	50,000
4	*Bracon* spp.	4	50,000
5	*Acerophagus papayae*	1	-
6	*Anagyrus lopezi*	4	-
	Predator		
7	*Chrysoperla zastrowi sillemi*	9	10,000-2,00,000 grubs
8	Reduviid bugs (*Rhynocoris marginatus; R. fuscipes*)	6	10,000-15,000
9	*Blaptostethus pallescens*	3	10,000-15,000
10	*Apertochrysa astur*	3	10,000-2,00,000 grubs
11	*Cryptolaemus montrouzieri*	3	1000-5000
12	*Sycanus collaris*	2	Minimum quantity
13	*Neoseiulus longispinosus*	2	-

(Approx. 2606 as per KYC data).

The majority of macrobial production units are engaged in the production of different species of Trichogrammatids viz. *Trichogramma chilonis, T. japonicum, T. pretiosum* and *Trichogrammatoidea bactrae* with a capacity of producing 1-14 million insects per month. 25 Indian states are producing *Trichgramma* spp. 9 states are producing *Chrysoperla zastrowi sillemi* with a capacity of 10,000-2,00,000 grubs/ month. 7 states produce *Chelonus blackburni*, and Reduvid bugs are produced by 6 states. *Goniozus nephantidis*, *Bracon* spp. and *Blaptostethus pallescens* are produced by 7, 4 and 3 states, respectively. Except for trichogrammatids and *C. zastrowi sillemi*, other bioagents are produced in limited numbers and are need-based (Table 1).

Among microbial biopesticides, *Trichoderma viridae* is produced by 22 states; *Metarhizium anisopliae* and *Beauveria bassiana* are produced by 14 states; 12 states are producing *Pseudomonas fluorescence* and *Bacillus thuringiensis* is produced by 4 states (Table 2).

Table 2. Major microbial produced by government-funded units

S. No.	Microbials	No. of states involved in production	Monthly capacity
1	*Trichoderma viridae*	22	1.5-8 MT
2	*T. harzianum*	10	1.5-8 MT
3	*T. asperellum*	3	50 kg
4	*Pseudomonas fluorescence*	12	2-10 MT
5	*Metarhizium anisopliae*	14	1 -2 MT
6	*Beauveria bassiana*	14	10 kg-10 MT
7	*Beauveria brongniartii*	3	10-120 kg
8	*Isaria fumosorosea*	5	20 kg
9	*Bacillus thuringiensis*	4	10 kg-1 MT
10	*B. cereus*	2	
11	*B. subtilis*	6	200 kg
12	*Lecanicillium lecanii*	6	5 MT
13	*Helicoverpa armigera* NPV *(HaNPV)*	4	
14	*Spodoptera litura* NPV *(SlNPV)*	3	
15	*Purpureocillium lilacinum*	5	6-200 Kg
16	*Pochonia chlamydpsporia*	4	400 l

CONCLUSION

There are many success stories where macrobials and microbials played an important role in managing insect pests. The regular releases of Tricho-cards by the IPM farmers have reduced the incidence of sugarcane borers by 53.5-59.0 per cent. Outstanding success was attained in the control of the papaya mealybug. This insect significantly damaged the papaya harvest in Maharashtra. The spread of this insect in Karnataka and Tamil Nadu was effectively controlled by the deployment of Bio Control agents, resulting in significant cost savings of several crores of rupees for the farmers (AICRP-BC Review report, 2016). Inundative release of the egg parasitoids *Trichogramma chilonis* and *T. japonicum* has become one of the most popular practices in rice IPM across Kerala, ensuring the protection of rice without the use of insecticides since 2006. The reduction in consumption of insecticides is calculated at about 1000 litres a year.

In protected cultivation also, spider mites on roses and carnation were managed with the help of an anthocorid predator, *Blaptostethus pallescens*. Besides this, several other predators have been explored, identified and evaluated to manage thrips and mites menace in protected cultivation and are ready to be deployed in the system. Macrobials and microbials could be used in compatible modes to curtail pesticide use but the availability of these biocontrol agents to farmers poses a challenge. Emphasis should be given to research on compatibility between microbial biopesticides and commonly used macrobials, especially in protected cultivation where tailored strategies are required to tackle thrips and mites.

Though there are government-funded laboratories for the production of macrobials and microbials but they are not sufficient to cater for the needs of farmers. To address this problem, both private and government sectors will have to come together and work in this line. To promote macrobials, it is important to fund new start-ups, particularly for entrepreneurs who are interested in producing indigenous macrobials. Therefore, the Government's policy and support in ease of biopesticides regulations, providing better infrastructure, and assuring availability to farmers for using biocontrol agents will also be important.

ACKNOWLEDGEMENTS

The authors are grateful and extend their gratitude to all the State Agricultural Universities, State Agriculture Departments, State Horticulture Departments, Krishi Vigyan Kendras (KVKs), Directorate of Plant Protection, Quarantine and Storage (DPPQ&S), Central Integrated Pest Management Centres (CIPMCs), Institutes under Indian Council of Agricultural Research (ICAR), for providing information on production and monthly capacity of macrobials and microbials.

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