Journal of Biological Control, 36(4): 179-186, 2022, DOI: 10.18311/jbc/2023/34091

Status Article

Integration of augmentative biocontrol with synthetic pesticides and other control methods for IPM – Challenges and prospects*

T. M. MANJUNATH
Consultant on Biocontrol, Agri-Biotechnology and IPM, Bengaluru – 560092, Karnataka, India
E-mail: manjunathtm@gmail.com

ABSTRACT: The importance of augmentative biological control and chemical control, and the need and scope for integrating these, rather than dismissing them as incompatible, so as to create a win-win situation for both are highlighted. Besides the judicious use of chemicals and periodical releases of parasitoids/predators, other options such as insect-resistant transgenic crops, host plant resistance, botanical insecticides, sex pheromones, trap crops, pest resistance management, new product development, regulatory measures, etc., should also be exploited, as appropriate to a given situation, so as to develop an Integrated Pest Management (IPM) package. The practicality of such an IPM is explained, citing *Bt* cotton as an example. It is reiterated that IPM is the most prudent approach for sustainable crop production and protection with the major emphasis being laid on biological control and other eco-friendly methods as indicated by the latest global trend.

KEYWORDS: Biocontrol, *Bt* cotton, chemical pesticides, integration, integration, IPM

(Article chronicle: Received: 18-12-2022; Revised: 28-12-2022; Accepted: 30-12-2022)

INTRODUCTION

Biological control is the most desirable and valuable asset in plant protection. It is estimated that there are about 500,000 phytophagous arthropods (Bernays, 2009), mostly insects, and of these about 95% are kept under check by their natural enemies, which consist of the beneficial parasitoids, predators, and pathogens, without any human intervention, as a result the pests generally remain below the Economic Threshold Level (ETL). It should be realized that even with only 5% turning serious pests, we undergo 30-35% crop yield losses despite taking control measures, but imagine what would have been the fate if pests in the remaining 95% had also multiplied unchecked and devoured our crops! Obviously, our problems would have multiplied many folds, and we would have been left with very little food. Such silent contribution of natural biocontrol is seldom realized and acknowledged. No doubt, biological control is nature's gift to mankind, and it is the '*Mother of all plant protection measures*' (Figure 1).

However, when such natural balance is affected due to various factors, both natural and induced, some of the minor pests become serious, and we need to take timely control measures to save our crops. This can be achieved mainly through the restoration of natural balance through augmentative biological control, which involves inoculative or inundative releases of appropriate macrobials (parasitoids/predators), use of entomopathogenic microbials (viruses, fungi, bacteria, nematodes), or by the application of synthetic chemical pesticides. Of these, chemical control has been by far the most predominant choice as these products are readily available in the market, easy to use and the results when successful are dramatic and clearly visible! While both these methods are very important, it has also been increasingly realized that chemical pesticides have caused several undesirable side effects such as destruction of natural enemies and 'RRR', i.e., Resistance, Resurgence and Residues. On a critical introspection, it appears that such ill effects could have been significantly minimized if we had refrained from overuse or abuse of pesticides. On the whole, the general impression is that biological control and chemical control are not compatible or, in other words, they are considered antagonistic or mutually exclusive. However, with the advances made in various areas of science, this need not be entirely so. There is scope to innovate and integrate these methods with a little give-and-take approach and turn it into a useful combination that can be used either sequentially or concurrently, thus creating a win-win situation for both.

Besides biological control (both with microbials and microbials) and chemical control, other methods such as

**Transcript of a keynote address delivered at the 7th National Conference on Biological Control organized by ICAR-NBAIR & Society for Biocontrol Advancement (SBA) on 15-17 December 2022 in Bengaluru. It is not a review, but more of an overview and recommendations.*

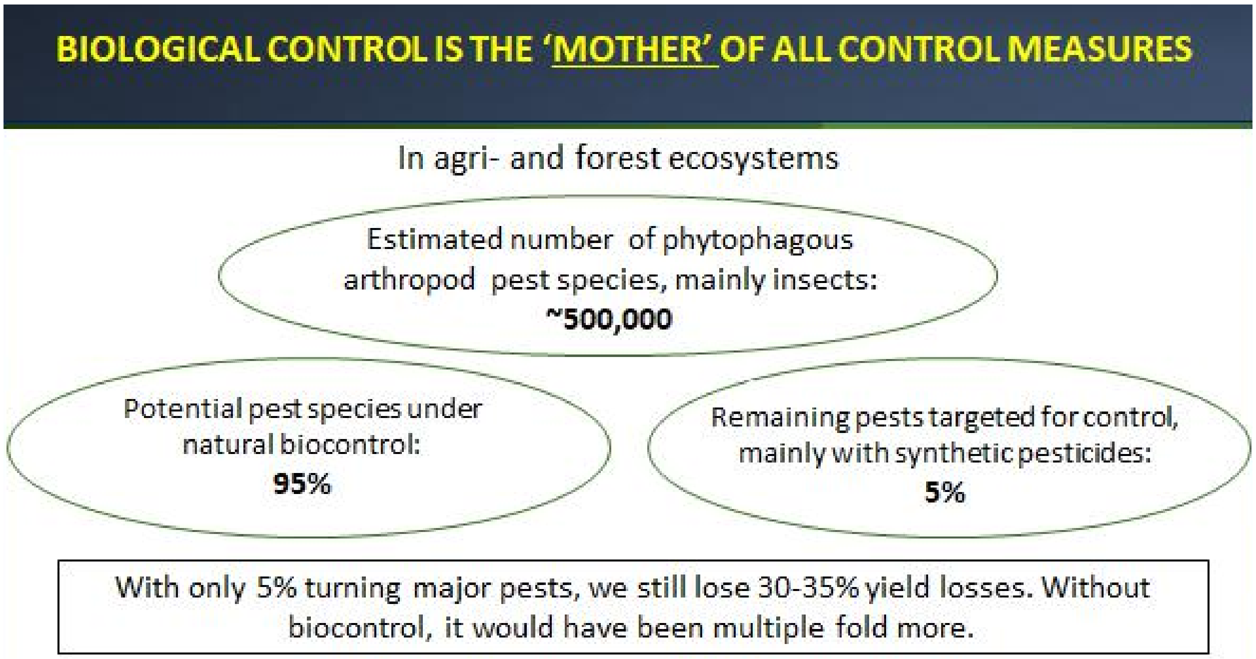


Figure 1. About 95% of phytophagous insect pests are under natural biocontrol.

cultural, botanical insecticides, sex pheromones, host plant resistance, insect-resistant transgenic crops, regulatory measures, etc., can also be exploited and incorporated as appropriate, thereby widening the scope of Integrating Pest Management (IPM). *Bt*-cotton is briefly cited as an example of such IPM. Of late, the importance of IPM has been realized even by large pesticide companies who are coming up with innovations for integration. These aspects are also indicated.

Present trend is leaning towards biocontrol

Despite all the concerns and criticism, the ground reality has been that synthetic pesticides dominate the global market with a share of US$85.0 billion as compared to biopesticides with only US$6.6 billion. However, of late, owing to the increased awareness about the adverse impact and a growing clientele for organic agri-products, there have been stricter regulations for agrochemicals and increasing emphasis on organic farming, resulting in more demand for biopesticides. The recent global trend indicates that the biopesticide market, though remaining small, is growing at a Compounded Annual Growth Rate (CAGR) of 14% as compared to chemical pesticides at only 5%. This trend is projected to increase gradually, and biopesticides would overtake conventional pesticides in the next 3-4 decades (Olson, 2015; Harry, 2021) (Figure 2).

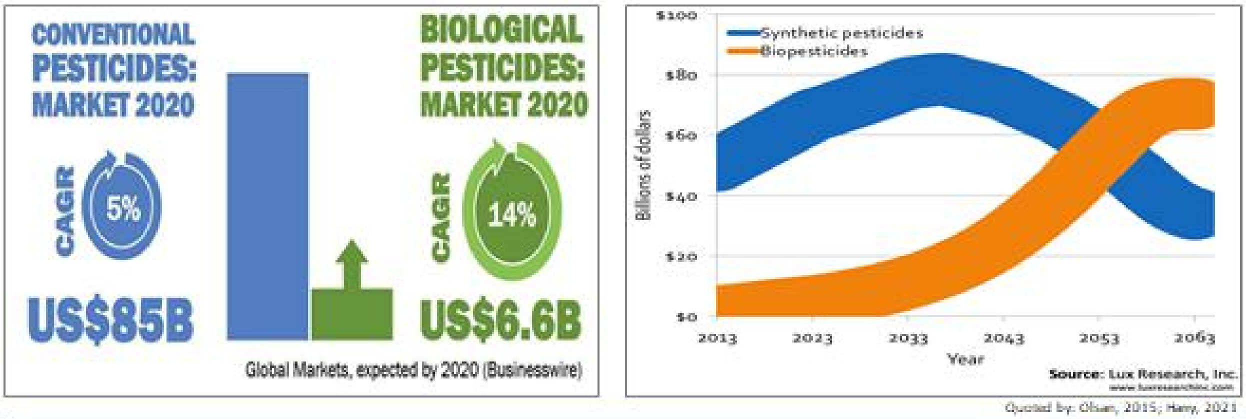
Thus, there is a great opportunity for biopesticide industry to take advantage of this favourable environment and move forward. Presently, the biopesticide market is almost entirely focussed on the production and use of microbials (beneficial microorganisms/entomopathogens) with negligible attention given to commercial production and augmentation of macrobials (parasitoids and predators). It is so because the mass production, storage, transport and marketing of parasitoids and predators are beset with several challenges. These should be overcome with more determined R&D in the interest of promoting this important approach. Emphasis should also be laid on the conservation of natural enemies.

Judicious use of chemicals to reduce risks to biocontrol agents

In the past, indiscriminate use of chemical pesticides caused wholesale destruction of natural enemies. This should be avoided or minimized as far as possible. There is considerable scope for conserving naturally occurring parasitoids and predators and also to reduce risks for their augmentative releases through the judicious use of synthetic pesticides. Some of the 'Dos' and 'Don'ts' include:

Don'ts:

- Avoid or significantly reduce the use of contact insecticides as these directly harm biocontrol agents, i.e., they kill pests as well as natural enemies without any discrimination.



Present pesticide market is huge. However, the biopestsicide market is projected to grow steadily, though slowly, and overtake traditional pesticide market in another 3-4 decades. This favourable trend should be exploited.

Figure 2. Projected market trend for synthetic pesticides and biopesticides.

- Refrain from spraying when natural enemy populations are high or pest population is below ETL.

<u>Dos</u>:

- Use systemic insecticides and their metabolites as these are absorbed by the plants and relatively safe to natural enemies as they do not directly come in contact them.

- Use translaminar insecticides as these are quickly absorbed by the leaves and do not leave much surface residues.

- Adopt spot application of insecticides only in highly infested areas (with aphids, mealybugs, whiteflies, BPH, etc.) instead of the entire field so as to reduce the quantity of insecticides and, moreover, to avoid destruction of natural enemies in the entire field.

- Use remote sensing devise to detect and monitor pest infestation so as to initiate control measures only when needed.

- Use latest equipment that is designed to deliver precise quantity of insecticides in targeted area.

- Deploy agricultural drone spraying as it is fast (about 40 times more than the traditional sprayer), can save up to 90% water and 30-40% pesticides, and reduce drift with better coverage of the target crop.

- Seed coating with systemic insecticides offers protection from sucking pests right from the early stage of the crop up to 30-40 days without disrupting the activities of parasitoids and predators. This will help the natural enemies to build up their natural populations and exert control later on.

- Use granular insecticides which will be absorbed by the plants. They can kill only the pests without harming natural enemies.

These approaches are different from the earlier indiscriminate spraying of synthetic pesticides without considering the status of pests and their natural enemies. These help to reduce risks to parasitoids and predators.

Promising biocontrol agents

A large number of parasitoids and predators of various crop pests has been recorded and studied in India as well as in other countries. Although, globally, more than 230 natural enemies are listed as commercially available, only about 25 species are considered as being often used on a large scale, especially for control of sucking pests in greenhouses, while others are produced only on a very small scale (van Lenteren, 2012). However, on further review, hardly 12 to 15 species may be considered as commercially viable in terms of professional production technologies and growers' demand and, therefore, only these are regularly mass-produced and used in any significant numbers in augmentative biological control. Such natural enemies are listed in Figure 3.

This list remained more or less the same for the last several decades. Among these, several species of *Trichogramma* continue to be the most dominantly produced and used parasitoids in several countries. One of the major reasons for it is that these accept the factitious hosts like *Sitotroga, Corcyra*, etc., which are readily amenable for

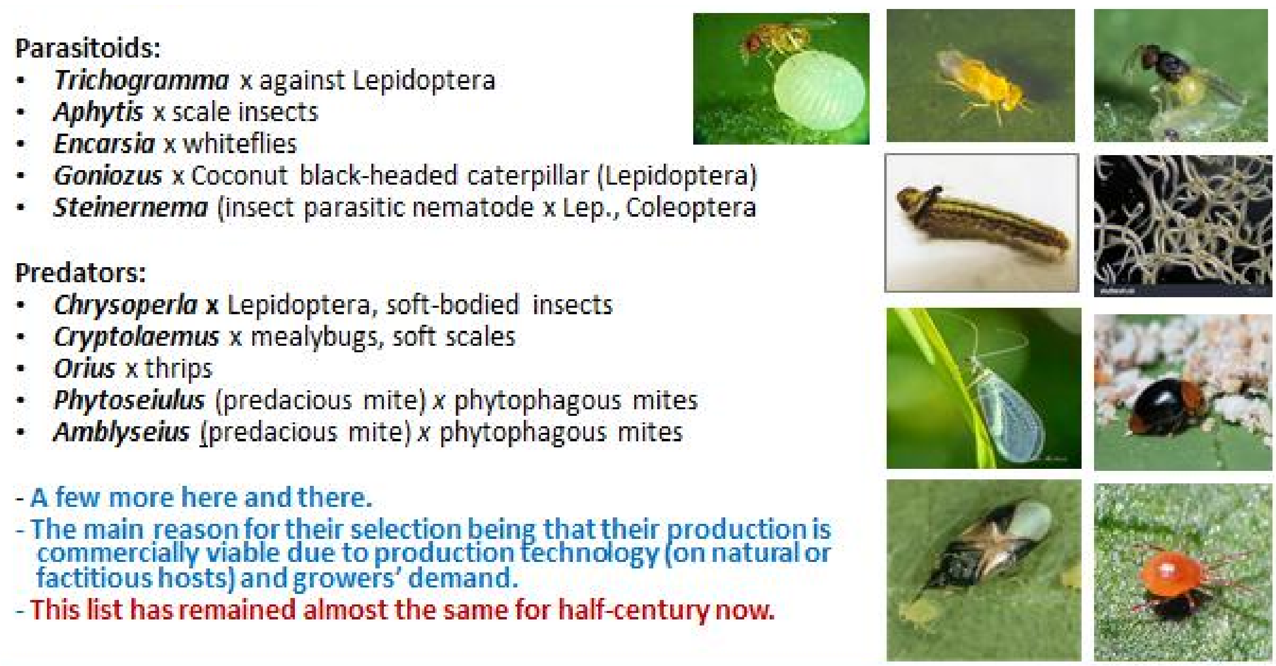


Figure 3. The most common commercially produced parastoids and predators.

Parasitoids:

- *Tetrastichus schoenobii* (Eulophidae) x Rice yellow stem borer
- *Adelencyrtus mayurai* (Encytidae) x *Melanaspis* (Scale insect)
- *Anagyrus dactylopii* (Encyrtidae) x *Maconellicoccus* (soft scale)
- *Campoletis chlorideae* (Ichnuemonidae) x *Helocoverpa armigera*
- *Cotesia vestalis* (Braconidae) x Diamond-back moth
- *Epiricania melanoleuca* (Epipyropidae) x Sugarcane Pyrilla
- *Rhogas aligarhensis* (Braconidae) x *Earias vittella*

Predators:

- Lycaenids (Lepidoptera) x Mealybugs
- Syrphids (Diptera) x Aphids

These are not easily amenable for commercial production, especially on factitious hosts. Should be taken up as a challenge to provide breakthrough.

Figure 4. Promising natural enemies that deserve breakthrough in mass-production.

mass production in insectaries. There is a need to break this stagnation and develop efficient mass production technologies for some more natural enemies. A few of such promising natural enemies requiring attention from the Indian perspective are indicated in Figure 4.

The parasitoids mentioned above are mostly host specific and do not accept *Sitotroga* or *Corcyra* as laboratory host. Scientists should come out of their comfort zone and develop technology for multiplying these promising biocontrol agents (Manjunath, 2020). One of the possibilities is to develop artificial diets for mass production of their natural hosts or for natural enemies themselves. Some progress has been made in other countries, but not adequate and dependable. It may take a few to several years to develop a production technology and also standardise a diet that meets with all the nutritional requirement of the concerned insect. It is a pity that, in general, long-term research is losing its priority, and most of the scientists are eager to carry out short-term studies and publish as many papers as possible. In biocontrol, the paradox is that greater challenge lies in the mass production of host insects rather than the parasitoids or predators in the laboratory. A breakthrough is a long-felt need, and qualified scientists in research institutions should take it up as a challenge. It is better to undertake such long-term studies as a team work, involving interdisciplinary collaboration if required, under institutional goals rather than individual goals. This helps to ensure continuity of research even if there is a change in the staff for any reason (Manjunath, 2020).

Availability of natural enemies – A big challenge

Augmentative biological control involves periodical releases of natural enemies, which may be inoculative (in small numbers to supplement the prevailing natural enemy populations so that together they can build up their populations) or inundative (in large numbers to overwhelm the pest population and to have direct impact) depending upon the circumstances. The availability of required parasitoids and predators in adequate quantities for timely releases constitutes the most important factor for implementing augmentative biocontrol. Therefore, these need to be mass produced in laboratories or commercial units. Insect production is beset with numerous challenges. There is a vast difference between culturing them in small numbers for academic studies and producing them in thousands and millions on a regular basis for practical releases. More we try to produce; more challenges may be encountered. It requires years of experience and commitment to take preventive steps or to solve such problems as and when these arise. Being live, sensitive and short-lived, not only production, but also storage, transport and marketing of biocontrol agents are associated with unique challenges. Having established Bio-Control Research Laboratories (BCRL) of Pest Control India Ltd., India's first-ever commercial insectary, way back in 1981 (Manjunath, 1984) and managed it successfully for 16 years until 1997, I have experienced the practical difficulties and tension associated with such mass production at every step. But, when you succeed, it gives a lot of satisfaction. Never before the biocontrol agents and pheromones were produced in such large quantities in India. These were supplied for direct field applications in crops such as sugarcane, cotton, coconut, grapevine, etc., for IPM all over the country. I have personally visited, interacted with the growers and managed to obtain confirmed orders one or two months in advance so as to confidently take up the production. In recognition, BCRL received the National Award for its unique contribution in the Agricultural Sector from the Council of Scientific and Industrial Research (CSIR), Govt. of India, in 1993. It is a pity that after I left BCRL in January 1998, the production of parasitoids and predators gradually declined and was finally given up. There is a need to revive commercial production of parasitoids and predators for promotion of IPM.

Farmers are ready, but what about the products?

The experience at BCRL for over 16 years proved that our farmers are ready to purchase biocontrol agents and pheromones and use these in their fields as they would do chemical pesticides. As mentioned, the production of parasitoids and predators as well as their marketing require enormous efforts and coordination. These are laced with uncertainty, and also the profit margin is not very high, and therefore there are not many takers. After BCRL, there have been no commercial producers of parasitoids and predators of any significance since 1998. Most of the government labs maintain small stocks sufficient for demonstrations. They spend a lot of resources on training programs, conferences, publications, etc. While these are important, but will not serve any practical purpose if the products are not available for actual use. The situation today is that the farmers are ready to adopt biocontrol, but are the products readily available? The answer is a very disappointing 'No'. It requires serious attention.

Governments can play a supportive role

The government of India and also the state governments have been spending a lot of money and resources on promoting organic agriculture. They should support biological control also as it falls within the purview of organic farming.

One of the uncertainties faced by the producers, more so with parasitoids and predators, is that there is no assured demand. Being live and short-lived, one cannot risk their huge production lest it may go waste and cause financial losses. Last minute cancellation of confirmed orders will add to the misery. Here, the governments can play a supportive role. As a part of the promotion of organic farming and environmental safety, they can identify certain geographical areas and crops and prescribe that these should be treated with the recommended biocontrol agents and pheromones. They may notify the total seasonal requirement of biocontrol agents for a given crop/pest a few months in advance with the assurance that these would be procured from identified producers of quality bioagents. The governments may buy these products and make them available to farmers at a subsidized rate or free of cost in an effort to popularize this practice. Strong growers' cooperatives of certain crops like sugarcane, cotton, grapevine, coconut, etc. can also come up with such offers. With this kind of assured market, several entrepreneurs or industries may come forward to set up commercial insectaries/bio-factories. The subsidies may be gradually withdrawn after a few years after the farmers have gained confidence in this approach. With my long experience at BCRL, I can vouch that our farmers are willing to adopt biocontrol/IPM provided the products are readily available (Manjunath, 2020). This would create a win-win situation for the producers, farmers and governments, and would be the most realistic way of promoting eco-friendly farming and a model for Public-Private-Partnership (PPP).

Empowering biocontrol agents and their improved use

Several improvements can be made with regard to the mass production and use of parasitoids and predators so as to enhance their performances and the scope for augmentative biocontrol. These include:

- **Technologies:** Develop efficient and economic mass production, storage, packing and release technologies.

- **Decentralized production:** Establish more production units (i.e., decentralized production units), preferably in all major districts in each State, as this would reduce the problems associated with storage and transport. These may undertake production of selected natural enemies to tackle the local pest problems. Perhaps such responsibilities are best left to private sector while the government can concentrate on R&D and keep a watch on quality parameters.

- **Local strains:** To give preference to local strains of natural enemies as they are already acclimatized. Further, the strains adopted to particular crops may be used on the same crops.

- **Proactive marketing** (i.e., advance booking) and production strategies to match the seasonal demands and also to avoid wastage. In fact, biocontrol agents should be presold even before they are produced!

- **Pesticide tolerance:** i) A few natural enemies have developed field resistance to several commonly used insecticides owing to constant exposure (Bielza, 2016). Such examples include the predators like *Cryptolaemus*, *Chrysoperla* and predatory mites, and parasitoids like *Trichogrmma*, *Leptomastix*, *Cotesia*, etc. ii) There are several examples where resistance in these natural enemies has also been induced through selective breeding for several generations in laboratories. iii) Resistance can also be imparted in parasitoids and predators through genetic engineering or gene editing (CRISPR). It is a very promising area for further exploitation. Such insecticide tolerant natural enemies may be mass produced in laboratories and used in fields along with pesticides, if need be, so as to have double benefits and also sustained effect.

- Genetic option may also be utilized to develop **climate resilient** natural enemies (i.e., temperature tolerance, cold tolerance, etc.), to induce or break diapause, etc. These may be mass produced and utilized.

- Use **sex pheromone** traps to detect and monitor the pests so as to time the releases of natural enemies.

- Use **kairomones** to attract and retain natural enemies in the desired fields.

- **Habitat management** to favour the activities of natural enemies (flowering plants, trap crops, etc.).

- Release natural enemies when pest populations are low so as to supplement the natural populations, resulting in more efficient control from the beginning of the season itself with minimum releases.

Thus, through strengthening or empowering biocontrol agents and judicious use of chemicals, these two methods can be integrated so as to create a win-win situation for both.

***Bt* cotton as an example for IPM**

There are several examples for successful IPM. *Bt* cotton is provided as an example to highlight how various methods can be integrated.

- *Bt* cotton was legally commercialized in India in March 2002. Farmers have readily adopted this technology, and now it occupies 90 to 95% of the total cotton area (11 to 12 m ha) in the country. The following IPM strategy can be exploited for *Bt* cotton:

- *Bt* cotton is incorporated with the Lepidopteron specific *Bt* gene(s) (Cry-1Ac/Cry-2Ab) derived from the soil bacterium, *Bacillus thuringiensis*, through genetic engineering. The technology is made available in the seed itself. The insecticidal *Bt* protein(s) is expressed in all parts of the plant, and it provides control of the notorious cotton bollworms, which have defied chemical and other methods. It has no adverse effect on natural enemies or the environment and is compatible with all other control measures, be it chemical or any other. Since its control effect is limited only to bollworms, other non-Lepidopteron pests will have to be controlled with suitable other methods.

- *Bt* seeds are coated with a systemic insecticide like Imidachloprid, which offers protection against the sucking pests like aphids, thrips, whiteflies, etc., right from the early stage of the crop up to 30-40 days without disrupting the activities of parasitoids/ predators.

- Since no contact insecticides are sprayed during the early crop stage, the parasitoids and predators are not affected, thus allowing them to build up their natural populations and exert sustained control.

- In case the natural populations are not adequate to control the sucking pests, augmentative releases of recommended parasitoids/predators may be made to strengthen biological control.

- Grow trap crops like marigold around the *Bt*-cotton fields which attract *Helicoverpa armigera* for egg laying. This reduces the pest load on cotton. Moreover, such eggs are heavily parasitized by *Trichogramma chilonis,* which profusely multiplies and contributes to biocontrol in cotton and other crops.

- Set up pheromone traps with lures to mass trap the male moths and also to monitor the activities of pests so as to time the releases of natural enemies or to initiate any other suitable control measure. Pheromones are available for all cotton bollworms.

- If notable infestation of aphids/whiteflies, etc., is noticed in certain patches in the field which is most common initially, the recommended insecticide may be applied only in those particular areas (spot application) instead of the entire field. This saves natural enemies in other areas and helps them to build up their population. It also saves insecticides and money.

- The regulatory authorities have made it mandatory that at least 5% of non-*Bt* cotton should be grown as 'refuge' in *Bt*-cotton fields as a step towards pest resistance management as far as possible.

- As a proactive measure against the potential resistance development, new products are developed to replace the old one. For example, the first transgenic *Bt*-cotton, Bollgard, has only one *Bt* gene, Cry-1Ac. The second one, Bollgard II, is incorporated with two genes, Cry-1Ac and Cry-2Ab and the third one, Bollgard III, with three genes, including a VIP (vegetative insecticide protein). Even if the pest develops resistance to one gene, it would succumb to the other. Such product development is a continuous process as the insects have shown an inherent ability to develop resistance to any technology that we develop.

- In the case of a pest like pink bollworm, which has developed resistance to *Bt* cotton, make use of sex pheromone for mating disruption for a few years to overcome the *Bt* resistance in the population.

- Efforts are being made by plant breeders to develop varieties/hybrids that are resistant/tolerant to major pests, especially pink bollworm and sucking pests.

Thus, host-plant resistance, insect-resistant transgenic technology, biological control, chemical control, resistance management, pheromone technology, trap crop, new product development, etc., can be integrated, as per need, for IPM of cotton pest complex. This approach, with modifications as appropriate, may be utilized in crops also.

CONCLUSION

It has been realized through decades of experience that no technology, however powerful, can last forever and no single technology can solve all pest problems. Every technology has its own importance and limitations. Therefore, the most prudent approach is to make use of any technology appropriate to a given situation, and wherever possible opt for a judicious combination of various technologies with the final objective of solving the problems and benefitting the farmers. Although biological control and chemical control are the major options, it has been increasingly realized that neither of these alone can provide satisfactory control of all pest complexes. The latest trend is to integrate biocontrol and chemical control so as to create a win-win situation for both. Such possibilities are indicated in this paper. It is not a review, but more of an overview.

Large chemical companies are showing interest in integrating both insecticides and biologicals. They have come out with improved formulations and equipment for the purpose. Similarly, efforts are being made to improve the mass production, storage, transport and application technologies for biological control agents. Research is also underway to develop pesticide tolerant and climate-resilient natural enemies so that such empowered populations can fit in better for integration with other methods.

Insect-resistant transgenic crops (*Bt* cotton, *Bt* maize, *Bt* brinjal, etc.) are highly effective against the targeted pests and have the unique advantage of being compatible with all other control measures, be it chemical, biological, pheromones, etc. This has been explained by citing *Bt* cotton as an example. Field knowledge is essential to make appropriate choices of control measures. Future efforts should focus on integrating all technologies as appropriate. This is the philosophy of IPM. The acronym IPM stands as much for **Intelligent Pest**

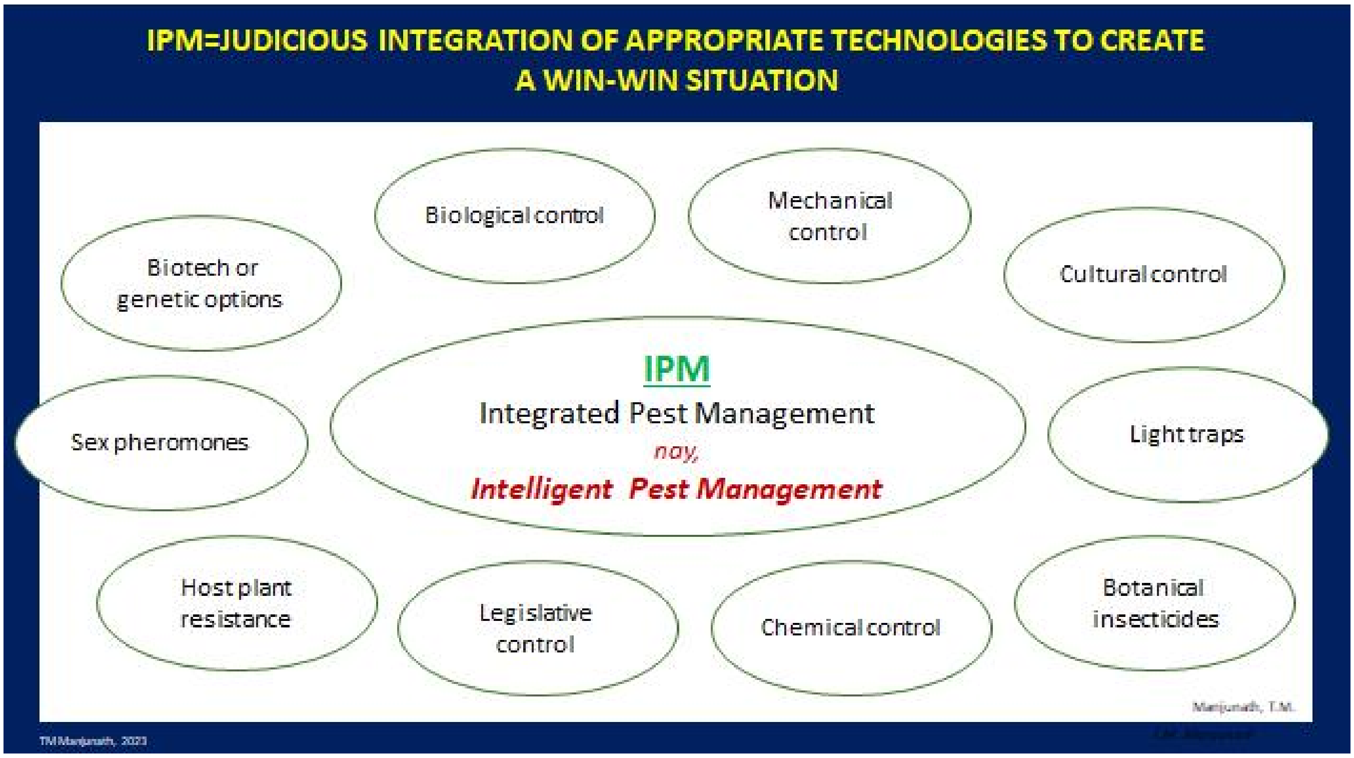


Figure 5. IPM = Integrated Pest Management, nay Intelligent Pest Management.

Management as it is for **Integrated Pest Management** (Figure 5).

The final objective of IPM is to create a win-win situation for all technologies for the benefit of agriculture.

ACKNOWLEDGEMENTS

I thank Dr. S. N. Sushil, Director, ICAR-NBAIR, and Dr. G. Sivakumar, Principal Scientist, ICAR-NBAIR and Chief Organizing Secretary, 7th NCBC, Bengaluru, for inviting me to deliver this talk. I am thankful to Dr. Chandish R. Ballal, former Director, NBAIR, for going through the manuscript and offering valuable suggestions.

REFERENCES

Bernays, A. E. 2009. Phytophagous insects. Chapter 201. In: Encyclopedia of Insects (Second Edition), Academic Press. pp. 798-800. https://doi.org/10.1016/B978-0-12-374144-8.00210-1

Bielza, P. 2016. Insecticide resistance in natural enemies. In: Advances in Insect Control and Resistance Management. (Eds. Horowitz, A. R. and Ishaaya, I. Springer Publications. pp. 313-329. https://doi.org/10.1007/978-3-319-31800-4_16

Teicher, H. 2021. Is there a future for the crop protection industry? Perspectives for a new generation. Outlooks Pest Manag. pp. 18-22.

Manjunath, T. M. 1984. Role of commercial insectaries in promoting biological control., pp. 287-294. In: Biological Control in the Tropics. (Eds. Hussain, M. Y. and Ibrahim, A. *G.), Proc. First Regional Symp. on Biol. Control.* Univ. Pertanian Malaysia, Serdang, Selenger, Kuala Lumpur, Sept. 3-5. pp. 516.

Manjunath, T. M. 2020. Progress of biological control research in India: A walk down the memory lane of legacy - from CIBC to ICAR-NBAIR and the way forward. *J Biol. Control*., **34**(4):231–240. https://doi.org/10.18311/jbc/2020/27124

Olson, S. 2015. An analysis of the biopesticide market now and where it is going. Outlooks Pest Manag. pp. 203-206. https://doi.org/10.1564/v26_oct_04

van Lenteren, J. C. 2012. The state of commercial augmentative biological control: Plenty of natural enemies, but a frustrating lack of uptake. *J Biol. Control*. **1**(1). https://doi.org/10.1007/s10526-011-9395-1