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Editorial

Sustainable Biological Control of Pests: The Way Forward

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1. Introduction

Synthetic pesticides have been and are still the mainstay of pest management. While their use has contributed significantly to the agricultural sector's development, their long-term, widespread, and incorrect use has equally contributed to environmental contamination and degradation and the unsolicited increase in pesticide resistance. Furthermore, many consumers in developing countries cannot afford the high cost of synthetic pesticides. However, increased awareness of the risks posed by synthetic pesticides, scientific and technological advancement in biological control of pests, and increased recognition and benefits of indigenous and organic practices gradually contribute to the move from synthetic pesticides to sustainable alternatives. As the plethora of evidence on the shortcomings of conventional pest control methods and the economic, social, and environmental benefits of biological control methods mount, the shift toward using alternative control strategies for pest management will record sustained growth into the future. The prospects, challenges, and interacting factors that influence the effectiveness and sustainability of biological control are discussed.

2. Body

Living organisms, also referred to as natural enemies or beneficial organisms, are used by humans to manage pest organisms. This is achieved by exploiting their natural traits, such as predation, parasitism, pathogenicity, antagonism, and herbivory. The different biological control methods include classical biological control, conservation biological control, and augmentation biological control. In classical biological control, a foreign organism is introduced into a new locality to control an invasive pest. When the population of a resident or indigenous natural enemy is increased with the same commercially available species or genetically enhanced natural enemy to improve effectiveness in bringing down the level of a targeted pest, it is referred to as augmentation biological control. Conservation biological control involves creating conditions that protect and enable the thriving of natural enemies. Adopting sustainable farming and landscape practices, such as cultural and mechanical pest control methods and organic farming, mixed cropping and resistant cultivars, and maintaining high diversity and refuge habitats, can preserve and increase the effectiveness of resident natural enemies [1].

2.1. Some Successes of Biological Control Agents

2.1.1. Control of Plant Pathogens

Based on promising results from some experiments, biological control agents, including bacteria and fungi obtained from the rhizosphere and phyllosphere, could be deployed to control disease-causing plant pathogens under greenhouse and field conditions. These biocontrol agents fight disease-causing plant pathogens through parasitism, antibiosis, or competition for resources and space [2].

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2.1.2. Bioherbicides

The development of bioherbicides has recorded some successes. Many bacterial (Pseudomonas fluorescens strains D7 and FRG 100), viral (Pepino mosaic virus and Obuda pepper virus), and fungal (e.g., *Colletotrichum truncatum* and *C. orbiculare*) strains are active ingredients in bioherbicides. Some *Collectotrichum* spp. have the genes that enable the fungi to produce plant cell wall-degrading enzymes and secrete disease effectors, including proteins, and the fungi can have the ability to produce the hormone indole acetic acid, which has herbicidal properties [3].

2.1.3. Control of Invasive Plant Species

The use of biological control agents to manage invasive species has been tried in many countries, including South Africa, the USA, Australia, and New Zealand, with mixed results. Seastedt (2015) [4] reviewed three case studies in North America, Australia and New Zealand. In one of the case studies in North America, several species of Diorahabda beetles (Chrysomelidae) obtained from Asia were used as biological control agents against *Tamarix* spp., riparian trees, and shrubs from Eurasia. Although there was evidence of control of the *Tamarix* spp., tamarisk species provide essential ecological services by controlling erosion in the riparian areas and providing habitat for the southwestern willow flycatcher (*Empidonax traillii* extimus), which diminishes the value of the biological control efforts. The author concluded that the criteria for judging the effectiveness of the biological control of invasive plants could vary over space and time. Besides scientific filters, social filters are also important. Following sustained commitment and effort, long-term funding and research programmes spanning over a century, South Africa has developed a solid foundation and protocols for long-term biological control initiatives [5].

2.1.4. Control of Arthropod Pests

Many biological control agents from a wide range of taxa are effective against many arthropod pests. BCAs, especially microbial, bacterial, and viral agents, have been successfully deployed to control major agricultural and medically important pests such as ticks, mosquitoes, and tsetse flies. Over the last 20 years, significant progress has been made toward improving their performance. New delivery systems, formulations, and the application of genetic manipulation of biological control agents, habitat manipulation techniques, and correct timing have contributed to the development of commercial biocontrol products. An increasing number of mycoinsecticides and mycoacaricides, mostly based on the *Beauveria bassiana* and *Metarhizium* spp., are being developed and marketed to control ticks or insects, especially those in the orders Coleoptera, Hemiptera, Thysanoptera, Lepidoptera, and Orthoptera [6,7]. Different strains of *Bacillus thuringiensis* (Bt) are effective against moths, and there are commercial formulations of Bt [8]. Many species of parasitoids and predators are effective against insect pests. Parasitoids and predators have been mass-reared and released to control agricultural pests. Parasitic wasps have been successfully used to control insects, such as aphids, moths, and stored grain weevils. Parasitoids and predators are commercially available to control pests in many countries, including the USA and South Africa.

2.1.5. Constraints to the Development and Widespread Use of Biological Control Agents

Biological control organisms need conducive environmental conditions to thrive and be effective. For example, microbial agents, parasitoids, and predators need refrigerating, some for a limited period, to remain viable. Generally, specialised infrastructure and expert knowledge are needed to produce and implement successful biological control programmes. The legislative frameworks on using and importing biological control agents are often not well-developed in many countries or harmonised between countries. Moreover, there is a paucity of research on the economic and social benefits of biological control initiatives. Given these challenges, strategies to improve the effectiveness of biological agents are discussed below.

2.2. Legislation and Enabling Environment

The demand for biological control agents (microbial and invertebrate organisms) has continuously increased globally in the last two decades, with over 440 species being developed as control agents by hundreds of companies [9]. However, most of the growth is concentrated in Europe and North America, with the highest number of commercially available biocontrol agents, followed by Asia and Latin America. In Africa, the availability and use of biocontrol agents are generally relatively low; however, the South African and Kenyan markets are growing. Less than 50 microbial agents have been registered in Africa to control arthropods compared to more than 542 microbial pesticide products registered in China in 2021. As of 2019, only 31 products, 7 manufactured locally, are registered under the Fertilizers, Farm Feeds, Agricultural Remedies and Stock Remedies Act 36 of 1947 in South Africa [10]. Nevertheless, the prospects for the growth of the biopesticide market in Africa are positive. The continent has high biodiversity and immense potential for conservation and biological control. Africa also has a growing middle class, and an increasing number of consumers are choosing organic fresh produce. Furthermore, the African Continental Free Trade Area (AfCFTA) agreement will open new markets. These factors incentivise the adoption of a favourable legislative environment and policies that promote biopesticide research and innovation, registration, and use. Recent guidelines for registering biopesticides have supported this endeavour in South Africa. Overall, the market for biological control agents will grow from USD 3.73 billion in 2024 to USD 5.25 billion by 2029 [11].

2.3. Integrated Pest Management

Integrated pest management (IPM) is an ecologically friendly strategy that combines biological, chemical, physical, and cultural management strategies and practices. IPM minimises the use of synthetic pesticides and the risks to the environment but strengthens ecosystem functioning and plant health. Besides conserving ecosystem functions, services and natural resources and enhancing food safety, IPM increases crop productivity, profitability, and farmers' knowledge and strengthens indigenous knowledge systems [12]. Biological control agents work well when they are incorporated into the IPM approach. Organic farming practises, such as the use of organic fertilisers, plant-based pesticides, intercropping, crop rotation, resistant cultivars, the timing of planting and harvesting, and companion planting, are compatible with conservation biological control because they cause minimal disruptions to the ecosystems [9].

2.4. Advancement in Genetics

Genetic engineering and breeding advancements have strengthened IPM programmes by providing tolerance against pests (insects and diseases) and herbicides [13,14]. DNA barcode sequencing-based identification has enabled the accurate and rapid identification of pest species and biological control agents, especially morphologically indistinguishable samples. Reliable and quick identification of pests and biological control agents improves the effective surveillance and monitoring of pests and collection of biological control agents, respectively, which are crucial for the success of IPM.

2.5. Semiochemicals

Semiochemicals are message-carrying chemical substances or mixtures produced by organisms that elicit behavioural responses in individuals of the same or another species. Semiochemicals have been used as pest repellents. They are also used to lure targeted pests to a trap for monitoring or to bring them into contact with the biocontrol agent. Combining semiochemical and biological agents can successfully control arthropod pests [6]. Hence, semiochemicals can be exploited to enhance the dissemination and effectiveness of biological control agents.

2.6. Economic Evaluation of Biological Control Agents

Few studies have comprehensively investigated the benefit–cost analysis of pest control programmes. It is difficult to accurately measure the cost–benefit ratio associated with the impacts (harmful or beneficial) on the environment and society [9]. In a South African study which estimated the benefit–cost of the biocontrol of six weed species, van Wilgen et al. (2004) [15] showed that investment in biological control has a positive return on investment; however, estimating the market value for biodiversity and ecosystem services is difficult. To mitigate the reluctance to depend on natural control agents, more studies are needed on the valuation of conservation, augmentative, and classical biocontrol control programmes.

3. Sustainable Biological Control Programme

Based on the arguments presented above, a simple model was developed, inspired by the disease triangle, which shows the relationship between the various interacting factors that influence the effectiveness and sustainability of biological control programmes (Figure 1). For example, sustainable biocontrol can be achieved if a virulent entomopathogenic fungal agent is used to manage a susceptible arthropod pest under favourable environmental conditions (positive socio-economic returns, effective delivery technology and formulation, and suitable biophysical environmental conditions for the pathogen).

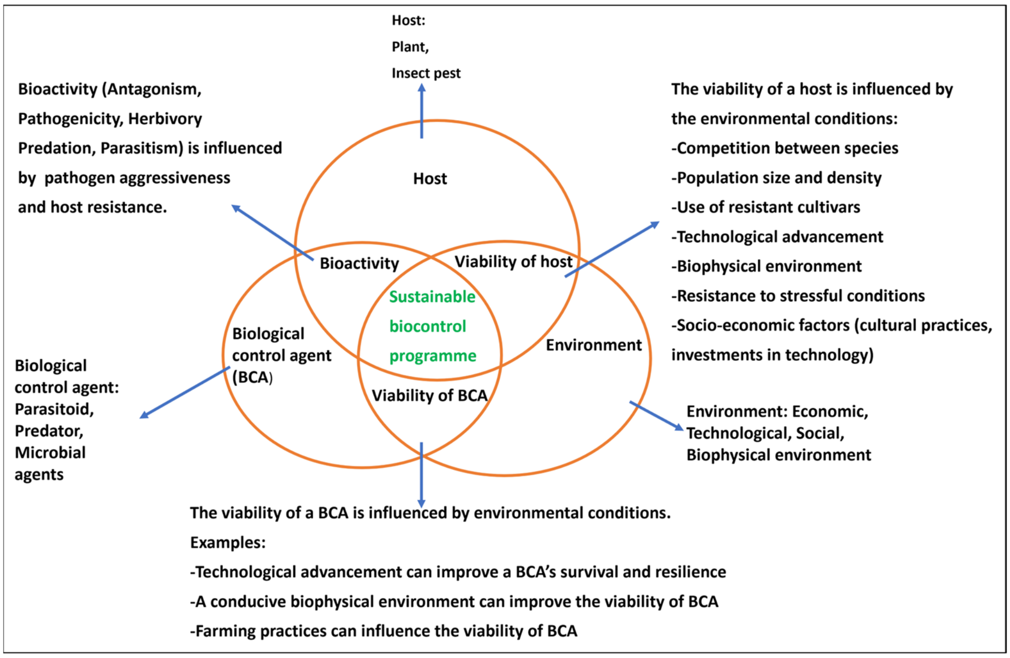

Figure 1. A diagrammatical representation of a model showing the relationships among factors (host, biological control agent [BCA], and environment) in influencing a sustainable biocontrol programme.

The factors influencing sustainable biological control are as follows:

- Social–environmental–economic–technology;
- Biocontrol agent;
- Pest.

4. Conclusions

Thus, sustainable biological control is achievable under a favourable environment. This means that sustained investments in scientific research and innovation, socio-economic and ecological studies, and influencing consumers' value systems are imperative.

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References

1. Stenberg, J.A.; Sundh, I.; Becher, P.G.; Björkman, C.; Dubey, M.; Egan, P.A.; Friberg, H.; Gil, J.F.; Jensen, D.F.; Jonsson, M.; et al. When is it biological control? A framework of definitions, mechanisms, and classifications. *J. Pest Sci.* **2021**, *94*, 665–676. [CrossRef]
2. Pandit, M.A.; Kumar, J.; Gulati, S.; Bhandari, N.; Mehta, P.; Katyal, R.; Rawat, C.D.; Mishra, V.; Kaur, J. Major Biological Control Strategies for Plant Pathogens. *Pathogens* **2022**, *19*, 273. [CrossRef]
3. Harding, D.P.; Raizada, M.N. Controlling weeds with fungi, bacteria and viruses: A review. *Front. Plant Sci.* **2015**, *6*, 659. [CrossRef]
4. Seastedt, T.R. Biological control of invasive plant species: A reassessment for the Anthropocene. *New Phytol.* **2015**, *205*, 490–502. [CrossRef] [PubMed]
5. Hill, M.P.; Moran, V.C.; Hoffmann, J.H.; Neser, S.; Zimmermann, H.G.; Simelane, D.O.; Klein, H.; Zachariades, C.; Wood, A.R.; Byrne, M.J.; et al. More than a Century of Biological Control Against Invasive Alien Plants in South Africa: A Synoptic View of what has been Accomplished. In *Biological Invasions in South Africa*; van Wilgen, B., Measey, J., Richardson, D., Wilson, J., Zengeya, T., Eds.; Invading Nature Springer—Series in Invasion Ecology; Springer: Cham, Germany, 2020; p. 14. [CrossRef]
6. Sullivan, C.F.; Parker, B.L.; Skinner, M. A review of commercial *Metarhizium*- and *Beauveria*-based biopesticides for the biological control of ticks in the USA. *Insects* **2022**, *13*, 260. [CrossRef] [PubMed]
7. Sandhu, S.S.; Sharma, A.K.; Beniwal, V.; Goel, G.; Batra, P.; Kumar, A.; Jaglan, S.; Sharma, A.K.; Malhotra, S. Myco-biocontrol of insect pests: Factors involved, mechanism, and regulation. *J. Pathog.* **2012**, *2012*, 126819. [CrossRef] [PubMed]
8. Flinn, P.W.; Schölle, M. Biological Control: Insect Pathogens, Parasitoids, and Predators. Management: Monitoring-Based Methods. Kansas State University Agricultural Experiment Station and Cooperative Extension Service. S156–17. 2012. Available online: https://entomology.k-state.edu/doc/finished-chapters/s156-c-17-biological-control-mar2.pdf (accessed on 23 February 2024).
9. van Lenteren, J.C.; Bolckmans, K.; Köhl, J.; Ravensberg, W.J.; Urbaneja, A. Biological control using invertebrates and microorganisms: Plenty of new opportunities. *BioControl* **2018**, *63*, 39–59. [CrossRef]
10. Hatting, J.L.; Moore, S.D.; Malan, A.P. Microbial control of phytophagous invertebrate pests in South Africa: Current status and future prospects. *J. Invertebr. Pathol.* **2018**, *165*, 54–66. [CrossRef]
11. Mordor Intelligence Report 2024. Biological Control Market Size and Share Analysis–Growth Trends and Forecasts (2024–2029). Available online: https://www.mordorintelligence.com/industry-reports/biological-control-market (accessed on 23 February 2024).
12. FAO. Pest and Pesticide Management. 2024. Available online: https://www.fao.org/pest-and-pesticide-management/ipm/integrated-pest-management/en/ (accessed on 23 February 2024).
13. Anderson, J.A.; Ellsworth, P.C.; Faria, J.C.; Head, G.P.; Owen, M.D.K.; Pilcher, C.D.; Shelton, A.M.; Meissle, M. Genetically Engineered Crops: Importance of Diversified Integrated Pest Management for Agricultural Sustainability. *Front. Bioeng. Biotechnol.* **2019**, *7*, 24. [CrossRef] [PubMed]
14. Bielza, P.; Balanza, V.; Cifuentes, D.; Mendoza, J.E. Challenges facing arthropod biological control: Identifying traits for genetic improvement of predators in protected crops. *Pest Manag. Sci.* **2020**, *76*, 3517–3526. [CrossRef]
15. van Wilgen, B.W.; de Wit, M.P.; Anderson, H.J.; Le Maitre, D.C.; Kotze, I.M.; Ndala, S.; Brown, B.; Rapholo, M.B. Costs and benefits of biological control of invasive alien plants: Case studies from South Africa. *S. Afr. J. Sci.* **2004**, *100*, 113–122. [CrossRef]