

Analysis of Economic Benefits Brought by Industrialization of Natural Enemy Insects

Jie XIE¹, Shoumei WAN^{2*}, Jinyu ZHAO², Lingling XIAO², Haiyan WANG^{2*}, Jian TANG², Xiaolei JI², Jing PENG²

1. Guiyang Customs Logistics Management Center, Guiyang 550081, China; 2. Guizhou Light Industry Technical College, Guiyang 561000, China

Abstract In the field of biological control of agricultural and forestry pests, natural enemy insects play an important role, constituting the core of modern integrated pest management (IPM) strategy, providing solid support for the zero growth goal of chemical pesticide use, and helping the sustainable development of green agriculture. The rise of the natural enemy insect industry has become a key driver of the transformation of green agriculture, injecting vitality into the sustainability and ecological protection of agriculture. With the increasing concern about food safety, environmental protection and ecological balance all over the world, the application scope of natural enemy insects as biological control means is constantly expanding. Its unique ecological adaptability and environmentally friendly characteristics help to reduce dependence on chemical pesticides, ensure the safety of agricultural products and maintain ecological diversity. The purpose of this study is to analyze the current situation of natural enemy insect industry, evaluate its cost and benefit, emphasize its great significance in promoting the transformation of green agriculture, improving production efficiency and promoting ecological protection by drawing lessons from foreign successful experiences, and explore an efficient and sustainable new agricultural development model.

Key words Natural enemy insects, Industrialization, Transformation of green agriculture, Economic benefits

1 Introduction

Crop diseases and pests affect stable and high grain yield. According to the data of the Food and Agriculture Organization of the United Nations, the annual global crop output loss caused by diseases and pests is as high as 40%. At present, the concept of green agriculture development is deeply rooted in people's hearts, and all sectors of society are pursuing to reduce the use of chemical pesticides. This trend emphasizes that reduction should not be at the expense of yield and control effect, and we should focus on eliminating inefficient, highly toxic and high-residue pesticides, improving the use efficiency, and introducing efficient and environmentally friendly green and biological pesticides as substitutes^[1]. Under this background, the biological control strategy centered on the release of natural enemy insects has increasingly highlighted its importance, opening up a new blue ocean for the commercialization of natural enemy insects. With the in-depth exploration of natural enemy insect variety resources, the progress of large-scale feeding technology, and the continuous optimization of ecological regulation and efficiency technology, natural enemy insects are increasingly widely used in agricultural production practice and are favored by practitioners^[2]. In the 21st century, commercial natural enemy insect production and sales enterprises have risen rapidly and become an important force to promote industrial development^[3].

Through commercial channels and integration with other plant protection technologies, these enterprises have achieved non-project-dependent promotion of biological control of natural enemy insects, indicating the mainstream direction of future development in this field. This process not only promotes the transformation of agricultural green production mode, but also contributes positively to ecological environment protection.

2 Industrialization status of natural enemy insects at home and abroad

2.1 Industrialization status of natural enemy insects abroad

In terms of industrial development scale, the industrialization of natural enemy insects has made remarkable achievements. According to relevant data, about 150 kinds of natural enemy insects in the world have been commercialized and sold on the market, mainly covering ladybugs, parasitic wasps, predatory mites, *Orius similis* Zheng, lacewings, etc., as well as some entomopathogenic nematodes and pathogenic microorganisms as supplements^[1]. At the industrial level, nearly a hundred large-scale enterprises have emerged in the field of natural enemy insects, showing the vigorous development and market potential of this industry. These companies are mainly distributed in Europe, North America, Australia, Latin America, Asia and Russia, and European and North American producers occupy the main market share, accounting for about 75%^[1]. In terms of technological maturity, key technologies such as artificial feeding, breeding, storage and quality control of foreign natural enemy insects are relatively mature. For example, breakthroughs have been made in artificial feed technology, storage technology and quality control standards of natural enemy

Received: June 19, 2024 Accepted: September 5, 2024

Jie XIE, bachelor's degree, intermediate title, research fields: integrated pest management and its related economics, modern enterprise economic management.

* Corresponding author. Lingling XIAO, master, intermediate title, research fields: integrated pest management, synthesis of green compounds.

Table 1 Overview of foreign natural enemy insect products

Natural enemy species	Prevention and control objects	Price	Commercial insect state	Notes on release
<i>Amblyseius cucumeris</i>	Thrips	0.01 yuan	Adult mites	Chemical pesticides, <i>Chrysopa carneas</i> and some biological pesticides should not be applied to fields where beneficial mites are released to prevent natural enemies from being killed
Parasitoids of flies	Flies	0.02 yuan	Nematodes in a water-soluble vehicle	Release parasite wasps at dusk; 5 released for 0.03 m ³ compost
Ladybug	Aphids, leafhoppers, aleyrodids and mites	0.06 yuan	Adult worm	Release in the evening or early morning
<i>Encarsia formosa</i>	<i>Bemisia tabaci</i> and <i>trialeurodes vaporariorum</i>	0.08 – 0.13 yuan	Bee card	Higher humidity and more nectar plants are beneficial to ladybug colonization
<i>Chrysopa carnea</i>	Larvae and eggs of many kinds of aphids, scale insects, psyllids, leafhoppers, red spiders, butterflies and moths, etc.	0.1 yuan/egg	Egg or pupa	Hang the bee card on a low shady branch when releasing the bees
<i>Phytoseius chilensis</i> , <i>Neoseius californiensis</i>	tetranychid	0.13 – 0.19 yuan	Adult mites	Preferably released in the morning or evening
<i>Tenodera aridifolia sinensis</i>	Aphids, leafhoppers, Lepidopteran larvae, crickets, etc.	0.19 yuan	Egg	Chemical pesticides and some biological pesticides should not be applied to fields where beneficial mites are released to prevent natural enemies from killing
<i>Aphidoletes aphidimyza</i>	About 60 species of aphids can be controlled	0.30 yuan	Pupa	When hanging mantis eggs, be careful to prevent ants from eating them
<i>Cryptolaemus montrouzieri</i>	Mealybug	2.23 – 12.09 yuan	Adult worm	Moisturizing during pupal stage
<i>Diglyphus isaea</i>	<i>Chromatomyia horticola</i> , <i>Liriomyza huidobrensis</i> , vegetable leafminer, <i>Liriomyza</i> , etc.	2.74 yuan	Adult bee	When the population density of mealybug is high, <i>Cryptolaemus montrouzieri</i> Mulsant can be released, and the control effect is good
<i>Delphastus catalinae</i>	A variety of whiteflies	3.82 – 5.72 yuan	Development phase	Bee release should be done in the morning or evening
Mixed release of <i>Steinernema feltiae</i> and <i>Heterorhabditis bacteriophora</i>	Plant pathogenic nematodes, fruit flies, cutworms, <i>Spodoptera litura</i> , asparagus caterpillar, onion fly, termites, weevil, mole cricket and fleas	5.06 yuan/Mil	Various insect states	It can be used in combination with <i>Encarsia formosa</i>
<i>Steinernema scarabaei</i>	<i>Mycetophilid</i> , Phorid flies, fruit flies, flea beetle, housefly, root-knot nematode, cutworm, white wax insect, <i>Spodoptera litura</i> , noctuid and asparagus caterpillar	15.25 yuan/10 ⁶ ha	Various insect states	Spraying and releasing the nematodes in the water-soluble carrier
Mixed release of <i>Steinernema feltiae</i> and <i>Steinernema carpocapsae</i>	Especially effective against Japanese beetles, waxworm, weevil	20.10 yuan /Mil	Various insect states	Keep the soil moist within 7 d of release of nematodes
Mixed release of <i>Heterorhabditis bacteriophora</i> and <i>Steinernema carpocapsae</i>	Weevil, waxworm, Cosmopolites <i>Sordidus germar</i> , potato beetle, <i>Lepidoptera</i> , flea beetle, fleas and ticks	22.23 yuan /Mil	Various insect states	Spraying and releasing the nematodes in the water-soluble carrier
<i>Trichogramma</i>	<i>Littorina littorea</i> , <i>Mythimna separata</i> , cutworm, cotton bollworm, cabbage caterpillar, <i>Plutella xylostella</i> and <i>Spodoptera litura</i>	18.99 yuan/10 000	Egg card	Keep the soil moist within 7 d of release of nematodes
Scutellary mite	Tangin mosquitoes, thrips and mites, etc.	133.51 – 444.29 yuan/10 000	Adult mites	Spraying and releasing the nematodes in the water-soluble carrier

insects, providing strong support for industrialization. In terms of market application, natural enemy insects are more and more widely used in agricultural production, mainly used to control various crop pests. The continuous growth of market demand has promoted the rapid development of natural enemy insect industry. Major producers include Koppert of the Netherlands, Biobest of Belgium,

BCP of the United Kingdom, *etc.* These enterprises have branches or distributors all over the world^[4], forming a relatively complete market sales network. Table 1^[1] lists the basic information of main foreign natural enemy products.

2.2 Industrialization status of natural enemy insects at home

In terms of industrial base, China is rich in natural enemy insect resources, which has great potential for development and application. At present, some scientific research institutions have conducted in-depth exploration in the field of natural enemy insects, and successfully developed a variety of high-quality natural enemy insect products. For example, Beijing Academy of Agricultural and Forestry Sciences has established a large-scale production line of natural enemy insects such as *Trichogramma dendrolimi*, *Trichogramma chilonis*, ladybug, lacewing, *Anastatus* and *Encarsia formosa*. Miyun County, Beijing focuses on the breeding of *Trichogramma*; in Yanqing area of Beijing, predatory natural enemies such as predatory mites and ladybugs are the main production targets; the Forestry Biological Control Station of Xishan Forest Farm in Beijing has set up a special area for the production of natural enemy insects, focusing on the mass production of natural enemy insects against forestry pests, such as *Chouioia cunea* Yang and *Sclerodermus guani*. These measures have effectively promoted the application and development of natural enemy insects in agricultural and forestry biological control. Compared with developed countries, the industrialization of natural enemy insects in China is still in its infancy and faces many challenges^[5]. In terms of technology, the artificial feed technology, storage technology and quality control standards of natural enemy insects are still immature, which restricts the development of industrialization. For example, the artificial feed of natural enemy insects is mostly semi-artificial feed or alternative feed, and the production of full artificial feed cannot be realized yet; in terms of storage technology, although natural enemy products can be stored at low temperature to prolong the storage time, the technology of inducing and releasing diapause is not perfect. In terms of market awareness, for a long time, farmers have been accustomed to using chemical pesticides for pest control, and they have insufficient understanding of the biological control effect of natural enemy insects. This leads to low acceptance of natural enemy insect products in the market, and market awareness needs to be improved. Major producers include Fujian Yanxuan Biological Control Technology Co., Ltd., Henan Jiyuan Baiyun Industrial Co., Ltd., Beijing Yikeman Biotechnology Co., Ltd., *etc.* These enterprises have made some achievements in the raising, breeding, popSclerodermus guaniularization and application of natural enemy insects, but there is still a certain gap compared with the international advanced level. Table 2^[1] lists the general situation of main natural enemy insect products in China.

3 Production and application costs of natural enemy insects

3.1 Production costs (i) Feeding costs: The feeding costs of natural enemy insects are usually high because many of their species require live animals and plants as food sources. This particular feeding requirement increases production costs.

(ii) Storage and transportation costs: Natural enemy insects

are live products, so special conditions and technical support are required during storage and transportation, which also increases costs. In addition, due to the uncertainty of market demand, producers also face the risk of unsalable products.

(iii) Cost in non-production season: In non-production season, in order to maintain the stability of natural enemy insect population, producers need to continue to invest costs in feeding and management^[6].

3.2 Application cost Release cost: In practical applications, the release of natural enemy insects requires certain technical and human support, which will also increase the cost. However, the release costs of natural enemy insects may be more economic in the long run compared to chemical pesticides because they can reduce the quantity of pesticides used.

4 Economic benefits of final target agricultural products

4.1 Improving the quality of agricultural products Using natural enemy insects to control pests can reduce the quantity of chemical pesticides used, thus reducing pesticide residues and improving the quality of agricultural products^[7]. This helps agricultural products get higher selling prices and better reputation in the market.

4.2 Increasing production Effective control of pests by natural enemy insects can reduce the damage caused by pests to crops, thus increasing crop yields. This means higher economic benefits for farmers.

4.3 Reducing the cost of pest control Compared with traditional chemical pesticide control, natural enemy insect control has long-term benefits. Although the release cost of natural enemy insects may be higher in the short term, the total cost of pest control may be reduced in the long run due to the reduction in the amount of pesticides used.

4.4 Promoting sustainable agricultural development The application of natural enemy insects can help reduce the pollution and damage of chemical pesticides to the environment, and promote the balance and sustainable development of agricultural ecosystems. This is important for the long-term stability and prosperity of agriculture.

5 Specific cases and data

Taking vegetable production as an example, using natural enemy insects to control pests can significantly improve economic benefits. For example, when controlling Bemisia tabaci on tomatoes, the use of plant-derived pyrethrins requires multiple applications and costs a lot (about 1 200 yuan/120 d), while releasing natural enemy insects such as Encarsia formosa also requires a certain cost (about 1 400 yuan/120 d), but it can reduce the number of applications and improve tomato quality. In the market, tomatoes that do not use pesticides are more popular among consumers and sell at a higher price^[8]. In addition, through the large-scale production and application of natural enemy insects, more employment opportunities and economic benefits can be created. For example, the breeding, collection, packaging, storage and transpor-

tation of natural enemy insects all need the support of professional technicians and labor force; at the same time, the production and sales of natural enemy insect products can also contribute to the local economy.

Although the production and application of natural enemy insects have a certain cost input, its economic benefits to the final

target agricultural products are significantly improved. By reducing the use of pesticides, improving the quality and yield of agricultural products, and promoting the sustainable development of agriculture, the application of natural enemy insects will bring more long-term economic and social benefits to agricultural production.

Table 2 Overview of domestic natural enemy insect products

Company name	Natural enemy species	Prevention and control objects	Packaging specifications	Scope of application
Beijing Yikeman Biotechnology Co. , Ltd.	Predator mites	Whiteflies, thrips, and tetranychids	1 500/bag or 16 000/bottle	Vegetables and fruit trees
	<i>Sclerodermus guani</i>	Longicorn beetles: <i>Monochamus alternatus</i> , <i>Semanotus bifasciatus</i> , <i>Apriona germari</i> , <i>anoplophora malasiaca</i> , etc.	100 tubes/box	× Forestry
		Bark beetles: <i>Ptilineurus marmoratus</i> Reitter, <i>Sinoxylon japonicum</i> Lesne, <i>Phloeosinus aubei</i> Perris, etc.	30 adult bees/tube	
		Other boring pests: <i>Cryptorrhynchus lapathi</i> Linnaeus, <i>Lepyrus japonicus</i> Roelof, <i>Chrysobothris succedanea</i> Saunders, etc.		
Fujian Yanxuan Biological Control Technology Co. , Ltd.	Predator mites	Red spider, rust tick, thrips and other pests and mites	>1 500/bag	Vegetables and fruit trees
	<i>Phytoseiulus peosimieis</i>	<i>Tetranychus cinnabarinus</i>	2 000/bottle	
	<i>Hypoaspis miles</i>	Thrips eggs and larvae	10 000/bottle	
	<i>Amblyseius swirskii</i>	Larvae of various thrips, eggs and larvae of <i>bemisia tabaci</i> and whiteflies	50 000/bottle	
	<i>Macrocheles</i>	Thrips of various species; eggs, larvae, and pupae and especially small larvae of sciarid flies	50 000/bottle	
	Predator mites	Various thrips	12 500/bottle	
	<i>Tetrastichus incertus</i> (Ratzeburg)	Aphids	500/bottle	
Koppert (Beijing) , Netherlands	<i>Aphidius colemani</i>	Black peach aphid, cotton aphid and <i>myzus persicae</i>		Fruit trees, cotton and tobacco
	<i>Anagyrus dactylopii</i> (Howard)	Citrus mealy bug and <i>Mirococcus inermis</i> Hall	500/bottle	Citrus
	<i>Encarsia formosa</i> , <i>Eretmoceris eremicus</i>	<i>Trialeurodes vaporariorum</i> and <i>bemisia tabaci</i>	10/ ×5 cards/box	Greenhouse vegetables, tobacco
	<i>Adalia bipunctata</i>	Various aphids	250/bottle	Greenhouse vegetables
	<i>Cryptolaemus montrouzieri</i> Mulsant	Various mealybugs	25/bottle	Fruit trees
	<i>Delphastus catalinae</i>	<i>Trialeurodes vaporariorum</i> and cotton whitefly	1 000 adults/bottle	Greenhouse vegetables
	<i>Orius similis</i> Zheng	Various thrips	2 000/bottle	Vegetables
	<i>Orius insidiosus</i>		1 000/bottle	
	<i>Orius sauteri</i>		500/bottle	
Henan Jiyuan Baiyun Industrial Co. , Ltd.	<i>Entomopathogenic nematode</i>	<i>Bradysua idiruogaga</i> Yang et Zhang, phorid fly larvae, etc.	Powder 100 g/box	Leeks, edible fungi, peanuts, lawn, garden trees, etc.
	<i>Harmonia axyridis</i>	Aphids	100 adults/cup; 500 egg cards/box	Green organic fruit and vegetable base, flowers, gardens, home gardening, etc.

6 Suggestions on the industrialization development of natural enemy insects

6.1 Increasing policy support and fund and technology investment China is rich in natural enemy insect species resources and has a solid foundation for development and utilization. However, at present, the production and application of natural enemy in-

sect products mostly depend on scientific research institutes and agricultural technology extension institutions, which are faced with the problems of insufficient investment in industrialization research and short time, so it is difficult to effectively promote its industrialization process. In addition, the in-depth exploration of natural enemy insect resources has not received enough attention, resulting

in limited industrial scale, single product category, and easy influence by regional and seasonal changes, and the technical service system needs to be improved. These challenges limit the wide application and industrial development of natural enemy insects in agricultural biological control. Therefore, the government should introduce more preferential policies to encourage the research and development, production, popularization and application of natural enemy insects. At the same time, we will increase financial support for scientific research on natural enemy insects, support the research and development and innovation of key technologies, improve the scientific and technological conversion rate of research results, and promote the industrialization of natural enemy insects to develop in depth.

6.2 Strengthening technology research and development and innovation and improving quality control standards It is necessary to strengthen the research and development of artificial feed technology, storage technology and quality control standards of natural enemy insects, and improve the production efficiency and product quality of natural enemy insects. Selecting natural enemy insect products that meet strict quality control standards and have been inspected by authoritative organizations can enhance consumer confidence and promote the standardized development of natural enemy insect industry. Compared with developed countries, there is a significant gap in quality standard control, detection and identification of natural enemy insect products in China, and a comprehensive and systematic quality control standard system has not been established, which has become an important factor restricting the industrialization process of natural enemy insects.

6.3 Improving market awareness and improving the industrial chain Through popular science publicity and technical training, farmers' awareness of the biological control effect of natural enemy insects can be improved, and market acceptance can be enhanced. It is necessary to establish a perfect industrial chain of natural enemy insects, including production, processing, sales, service links, and form a large-scale and standardized production mode. At the same time, it is necessary to strengthen cooperation and exchanges with international advanced enterprises, introduce advanced technology and management experience, and promote the rapid development of the industrialization of natural enemy insects in China. This includes establishing a complete after-sales service system, which is a necessary condition to attract consumers to buy products again. Suppliers of natural enemy insects need to be committed to providing excellent after-sales service, including concise and easy-to-understand operation guides and timely scientific guidance, to ensure that users can personally experience the positive effects of natural enemy insects. In addition, we should actively build an interactive communication platform covering developers, producers, promoters and users, so as to quickly capture users' needs and promote users to quickly master correct usage skills, so as to maximize the practical application value of natural enemy insects in agricultural biological control.

6.4 Focusing on medium and long-term comprehensive benefits Compared with traditional chemical methods, natural enemy

insects, as a biological control method of crop pests, are characterized by paying equal attention to medium and long-term ecological and economic benefits. Through the introduction of natural enemy insects, it not only effectively avoids the "3R"^[6] problems that may be caused by chemical control (*i. e.* resistance, residue and re-rampant), but also promotes the recovery of species diversity and reduces the risk of large-scale pest outbreak. Although biological control may increase production costs in the initial stage, its high added value and compliance with green production make this strategy have long-term value. In order to promote the wide application of natural enemy insect control technology, government departments, developers, promoters and producers need to work together to increase popular science publicity and education, and enhance public awareness and acceptance of biological control. Through policy guidance, project support and technical guidance, more agricultural producers are encouraged to adopt natural enemy insects as the first choice for pest control, and jointly contribute to the production of green and safe agricultural products.

All in all, the industrialization development of natural enemy insects is of great significance to promoting the green development of modern agriculture. Through the implementation of policy support, technological innovation and market promotion, it is believed that the industrialization of natural enemy insects in China will usher in a broader development prospect.

References

- [1] SONG SX, YU ZG, WANG L. Analysis of industrialization of natural enemy insects at home and abroad[J]. *Agricultural Science and Technology and Equipment*, 2022(4): 15–18. (in Chinese).
- [2] ZHANG JH, GUO L, MIAO L, *et al.* Evaluation of the effectiveness, environmental benefit and cost-effectiveness, of using *Trichogramma dendrolimi* as a bioyoujiological control for sorghum pests[J]. *Chinese Journal of Applied Entomology*, 2022, 59(3): 689–696.
- [3] HODDLE MS. Arthropod biological control in support of conservation: A prescient approach for invasive species management[J]. Berlin: Springer Berlin Heidelberg, 2015: 125.
- [4] LIU YS. Biological control technology needs to be industrialized urgently [EB/OL]. 2017. <https://www.toutiao.com/article/6415739661415219457/wid=1723776452157>. (in Chinese).
- [5] Farmers Daily. Natural enemy insects build an alliance to control insects and reduce pesticides to become active[J]. *Heilongjiang Grain*, 2016(9): 49–50. (in Chinese).
- [6] CHENG SD, WANG XJ, GUO R, *et al.* Evaluation of economic benefits from the application of natural enemy insects in organic vegetable production[J]. *Journal of Applied Entomology*, 2023, 60(3): 956–963. (in Chinese).
- [7] XIONG LY. Marketing prospects and main problems of natural enemy insects in China[J]. *Modern Agricultural Science and Technology*, 2008(16): 150–151, 153. (in Chinese).
- [8] KE YN, QIU YN. For thirty years, focusing on the research of natural enemies of vegetable pests, the scientific research project led by Professor Chen Xuexin of Zhejiang University won the second prize of the National Science and Technology Progress Award[EB/OL]. 2021. <https://new.qq.com/rain/a/20211103A04CNS00>. (in Chinese).