Journal of Biosafety

Volume 13, Number 3, Fall 2020

pISSN 2717-0632, eISSN 2716-9804

Biofertilizers, Biopesticides and Integrated Pest Management: Potentials and Challenges in the Islamic Republic of Iran

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Resived Date: 2021/02/6, Accepted Date: 2021/02/16

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Abstract

The Islamic Republic of Iran has a rich agricultural background; agriculture accounts for 10% of the GDP and provides livelihood to about 30% of the population. Efforts to increase farm productivity resulted in importing pesticides with about 3000 tons annually between 2012 and 2014; therefore, there is urgent need for using alternatives such as application of biofertilizers and biopesticides in integrated pest management (IPM) systems. With the rapid development in biotechnology techniques, many scientists in Iran hope to solve the country's food problems more efficiently. The number of companies engaged in the production of biofertilizers and biopesticides in Iran is far from the number of fingers. Fortunately, public health issue and the need for environmental protection are mentioned in the 20-year plan of the government which indicates that main authorities concern on the production of healthy products. The bright side of market development for biofertilizers and biopesticides in the world, the benefits of using them to provide community health and growing awareness of the people of Iran, provide the legal framework and accompaniment of high-level officials in the field of development in this industry. Moreover, the young population of Iran and raising interests in biofertilizers and biopesticides research and commercialization at research institutes and universities can be considered as promising perspective.

Keywords: Biofertilizers, Biopesticides, Integrated Pest Management.

[DOR: 20.1001.1.27170632.1399.13.3.4.8]

Introduction

The Islamic Republic of Iran (I.R.Iran), the largest country in the Middle East has a rich agricultural background; however, 90% of the land classified as arid or semi-arid due to the only 240 mm of annual rainfall (1). The country includes 90 million ha of rangeland, 12 million ha of forests, 14 million ha in agricultural production, and 34 million ha of deserts. Agriculture accounts for 10% of the gross domestic product (GDP) and provides livelihood to about 30% of the population. As Iran's population has doubled in the past four decades, there is a continuous need to intensify agricultural production to meet growing food demands (2).

Food availability shows signs of improvements, due to increased productive capacity in the main food crops along a ten-year period (2005-2015), particularly in wheat, rice, potatoes, soybeans, beans and vegetables. However, production is not sufficient to meet domestic demand, met only through complementary imports (3). Efforts to increase farm productivity resulted in increased pesticide use, with about 3000 tons of formulated pesticides imported annually between 2012 and 2014 comprising 25% acaricides and insecticides, 35% herbicides, and 38% fungicides (4). Consequently, pesticide residues in agricultural products are one of the public health concern in I.R.Iran (5). Moreover, overuse of chemical fertilizers, has no economic and environmental justification.

Environmental hazards of chemical fertilizers, including degradation and compaction of soils and declining soil organic matter, have also an important role in this trend. The idea of green revolution and minimum utilization of chemical fertilizers and pesticides and the increasing social attitude toward consumption of "organic" products have led to increasing interest in biofertilizers (6).

As such, there is urgent need for using consumer's friendly alternatives such as application of biofertilizers and biopesticides in integrated pest management (IPM) systems instead of hazardous chemical derivatives . Over recent decades, application of novel technologies such as genetic engineering, gene expression, and production of transgenic plants, developing more super-foods with attention to the each region climate, and biologically derived pesticides and fertilizers has led to a faster racing world to reach and feed the global market. In such competence, countries which apply these technologies under their biosafety rules will win the future market world-wide. There is no doubt by combining all these technologies together we can reach to more sustainable agricultural goals in IPM systems.

The industrial development of biofertilizers and biopesticides in Iran over the past five years: market information and needs of the industry

With the rapid development in biotechnology techniques, many scientists in Iran hope to solve the country's food problems more rapidly and efficiently (7). Fluctuations in chemical fertilizers and pesticides economy and the necessity of paying attention to soil, crop production and public health have placed biofertilizers and biopesticides in focus. Production of biofertilizers in Iran began around two decades ago. Although the usesz of biofertilizers in Iran is not unknown, unfortunately, the general knowledge of Iranian farmers in this area is low. Most of the national biofertilizer producers are suffering from lack of research and development section and this negatively

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affects the quality of their products. While for many years there was huge governmental subsidy for chemical fertilizers, there was little opportunity for biofertilizers to be adequately introduced in the country. Most of the biofertilizers introduced during those years have faced different problems in spite of passing all steps of research, development and commercialization (6). Approximately 15 microbial pesticides are registered for use in Iran, targeting insects, mites, and several plant diseases (Table 1).

Table 1. List of microbial biopesticides in Iran as of January 2018 (8).

Species (strain)	Trade name(s)	Producer/Importer	Formulation	Target pest(s)*	Manufactured
		Bacteria			
B. thuringiensis subsp *kurstaki*	Biolep	Biorun	SC	Lepidoptera larvae	Iran
			WP		
	Bithurin	Mehr Asia Biotechnology Co.	SL	Lepidoptera larvae	Iran
B. thuringiensis subsp. *kurstaki* (AzLP)	Rouien-2	Green Biotech Co.	WP	Lepidoptera larvae	Iran
B. thuringiensis subsp. *tenebrionis*	BioBeet**	Biorun	SC	Coleoptera larvae	Iran
B. thuringiensis subsp.*morrisoni*	Bithiran**	Mehr Asia Biotechnology Co.	SL	Coleoptera larvae	Iran
B. thuringiensis subsp *isralensis*(MH14)	Bioflash	Biorun	GR/WP	Diptera larvae	Iran
Bacillus subtilis	Biosubtil**	Mehr Asia Biotechnology Co.	SL	Plant pathogenic fungi	Iran
	Probiotect	Biorun	SC	Soil-borne fungi	Iran
	Pistagaurd	Biorun	SC	Psyllid	Iran
B. subtilis (BS106 & BS24)	Rouien-1	Green Biotech Co.	WP	Plant pathogenic fungi	Iran
Pseudomonas fluorescens	Pomeg**	Sadra Biotech Co.	SL	Plant parasitic nematodes	Iran
		Fungi			
Beauveria bassiana (ATCC 74040)	Naturalis	Afrasam Co.	SC	Sucking pests	Spain
		Aryan Teb Parto	L		CBC Italy
Metarhizium anisopliae s.l.	MetaKara**	Kara Industrial Biotechnology Co.	WP	Wide range of insect pests	Iran
Lecanicillium lecanii	Mycotal	Gyah corp.	WP	Whitefly & thrips larvae	Netherlands
Trichoderma harzianum	TrichoKara**	Kara Industrial Biotechnology Co.	WP	Plant pathogenic fungi	Iran
	TricoMix HV	Greenlife Biotech Co.	WP	Plant pathogenic fungi	Iran
	Trichofarm P	Biorun	WP	Soil-borne fungi	Iran
	Trichofarm G	Biorun	GR	Soil-borne fungi	Iran
T. harzianum (strain T22)	Trianum-P	Gyah Corp.	WP	Soil-borne	Netherlands

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	Trianum-G	GR	fungi Soil-borne fungi	Netherlands

*Data based on the Plant Protection Organization of Iran (10) and personal communication of Karimi et al. (8) with A. Ameri and S. Ghasemi. **Indicate the product has pending registration issue.

Growth in this industry will be stimulated by private sector investment in mass production technology for microbial pesticides and concomitant demand for pesticide-residue free and organic food (8). While *Bacillus thuringiensis* remains the primary microbial pesticide registered in Iran, new companies and products are starting to diversify the biopesticide market. Economic growth in agricultural sector is creating a demand for new pest control tools (9).

Opportunities for development of biofertilizers and biopesticides

It seems that from zero to hundred percent of research is achievable in the field of production and development of biofertilizers and biopesticides in Iran. The reasons are well trained human resources and academic personnel, the establishment of factories equipped well with production, formulation and packaging machines as well as governmental and private sectors support for promoting biofertilizers and biopesticides have been established. The most important factor for the entry this kind of products into the market is to increase the awareness of both farmers and society (or consumers as the last component of the market) and producers' confidence in the investment and profitability of the production process. In the realm of the market, trade and industry, there are significant administrative rules for the commercialization of technical knowledge. Another issue is the promotion of effective inoculations, which unfortunately does not show an acceptable interaction between the research and development department. The issue of monitoring and controlling the quality of commercial inoculants is another aspect of the commercialization and sustainable introduction of biofertilizers and biopesticides in the market, which is one of the tasks of the main authorities and should be considered as an appropriate mechanism for this issue. Sometimes there are biological products in the market that may not have sufficient technical knowledge behind and research support. This will create a sense of farmers' distrust and generalize this issue to such products.

Challenges of biofertilizers and microbial pesticides are as follows:

- Regulatory and legislative issues
- Time-consuming registration process
- Biosafety issues
- Lack of educated farmers and knowledge pitfalls
- Grower needs
- Producer issues
- Research limitations

The most controversial issue is related to the effectiveness of biofertilizers that has affected research, production, government procurement and other policy-making related to this area. In general, one of the known characteristics of biological fertilizers is the inconsistency of the results of their application. Unfortunately, at the moment, the number of companies

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engaged in the production of fertilizers in Iran is far from the number of fingers. Some of these companies produce microorganisms used in biofertilizers from other countries and pack them in Iran after producing and formulation.

The innovative biofertilizers and biopesticides related IPM technologies in Iran

Although there are good microbial resources in the world for production of biofertilizers, a small part of it has been able to stabilize in the market. In Iran, as with other countries in the world, the private sector has entered into the field and has done a good job of producing fertilizers, but the disadvantages are still in place. The question that arises here is whether the research department has failed or other parts involved in the production and development of biofertilizers are not committed to their duties. The study of global and national scientific sources suggests that many studies have been done in this regard. The reason for this claim can be the review of numerous scientific articles published in scientific publications (11-15). So what can be the reason for the slight development? One of the reasons for this is the existence of different reports and contradictions between laboratory, greenhouse and field results and the non-repeatability of these results. These issues are mainly due to variations in plant species and cultivars, soil compositions, the presence of microorganisms, the climate, soil moisture content and insufficient understanding of the mechanisms by which plant growth promoters (PGPRs) are effective in plant growth. The second reason is the low price of chemical fertilizers, which has been another barrier to considering and using PGPRs in crop production. Although farmers are aware of the importance of healthy crops, chemical fertilizers are more cost-effective than biofertilizers. Hence, encouraging programs by government agencies and the private sector producer can be a useful tool for the effective acceptance of biofertilizers by farmers. The third reason is the quality of the formulations, some of which do not effective in the long run, or lose their efficiency in various climates. Another point about formulation is the microbial population found in the final formulation (16).

Biofertilizers

Green Biotech Incorporation was founded in 2002 with the aim of developing novel, world-class and environmentally safe agricultural technologies. PhosphoBARVAR-2 phosphate biofertilizer, nitrogenous biofertilizer AzotoBARVAR-1 and PotaBARVAR-2 are the main products of the company at the present time which are the outcome of a giant research project done by a group of outstanding Iranian researchers for substitution of chemical phosphate, nitrogen and potash fertilizers. Beneficial bacteria of PhosphoBARVAR-2 biofertilizer efficiently hydrolyze both mineral and organic phosphate compounds in the soil to release the soluble phosphate ion which is readily absorbed by plants. AzotoBARVAR-1 nitrogenous biofertilizer contains a kind of bacteria that actively fixes air nitrogen to plant absorbable forms. PotaBARVAR-2 potash biofertilizer contains two types of potassium solubilizing bacteria (11).

Phosphate biofertilizer Barvar 2

This product is the result of several years' study of phosphate-dissolving bacteria. These bacteria occupy the plant root region and cause release of phosphorous from insoluble minerals and

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organic soil compounds resulting in an increase of available phosphate for the plant. About 80% of chemical phosphate fertilizers convert into an insoluble form in the soil very quickly. This means that more than the necessary amount of phosphorous must be added to the soil resulting in increased cost and environmental contamination due to fertilizer residues. Phosphate biofertilizer can decrease phosphate chemical fertilizer usage by 50% while increasing the yield by 10%–50%, thus eventually doubling the benefit to farmers. The product is formulated and marketed by the private sector and is currently exported to several countries in the region (7, 11).

Nitrogeneous biofertilizer

Economic, health, and environmental problems have resulted from the use of chemical nitrogen fertilizers, demonstrating the importance of alternative plant feeding methods. After seven years of research, Iranian researchers have produced nitrogen fertilizers containing native rhizobacters as a nitrogen fixative. These bacteria can increase N-uptake in native rice cultivars by 69% (7, 11).

A case study: StreptIran, a biofertilizer from discovery to market

Iran is located in a warm and arid region and many of its lands and water resources are saline. Fifteen years ago, a study was carried out to find biocontrol growth-promoting species tolerant to environmental stress. Strain C-2012 isolated from soil and has been well-studied in lab, greenhouse and field. At first, the biocontrol properties of this bacterium was investigated to increase the health and yield of sugar beet (17). The results of these studies showed that the bacteria are capable of controlling fungal diseases and enhancing plant yield under greenhouse and field conditions. In addition, the bacteria tolerated high concentrations of salt and reduced the negative effects of salt stress on wheat (12).

Morphological, physiological and molecular characteristics revealed that this bacterium is a strain of *Streptomyces rimosus*. It was also found that the production of ectoine and hydroxyectoine by this bacterium is one of the mechanisms of its tolerance to salt (18). Interestingly, the antagonistic and growth promoting properties of this bacterium increased in the presence of salt (12).

Optimization of culture conditions and medium composition was conducted and an appropriate combination of inexpensive materials was designed to increase the viability of the bacteria more than three years at room temperature (19). The effect of this formulation on the peppermint was evaluated at both greenhouse and field conditions. Treatment with this bacterium, in addition to increasing plant yield, increased essential oils under normal and water stress conditions (20). Currently, the formulation containing strain C-2012 named StreptIran and is under registration stage as a biofertilizer.

Biopesticides

Pests reduce crop yield worldwide by 10%–20% annually. Because of both the harmful effects of chemical pesticides and the economic cost, biopesticides are considered to be a viable alternative. Bt-derived pesticides are the most conventional and environmentally friendly (Table 1). In Iran, Bt-derived Cry proteins are produced on a large scale as a biopesticide, and have been

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shown to effectively control one of the most important rice pests, the green rice caterpillar (*Naranga aenescens*) (7).

The efficacy of biopesticides application in IPM to combat serious pests over the past 5 years

Iran is one of the only countries in the world which has the complete and diverse four season climate. The temperature difference of two locations in Iran at a specific period of time reaches to 50°C. As such, it is not possible to nominate the most serious pest and disease from the whole country to discuss at this section, hence it is preferred to refer to successful examples of biopesticides application as an effective tool in IPM systems.

Case study 1: *Eucnaemidophorus rhododactylus*, insect pest of damask rose

Among the major products of the Kerman province (located in the South-East of Iran), damask rose (*Rosa damascena* Mill.) has a special importance which is earning high income for the province's farmers. The products obtained from damask rose flowers such as rose water are one of the most important products of the mountainous regions of the province which are of high economic value and high resistance to water shortage condition which has led to its cultivation in Kerman province. In recent years, farmers have introduced infested damask rose seedlings with an insect pest (*Eucnaemidophorus rhododactylus*) which has led to the spread of this pest in flower buds of damask rose in district of Bardsir located in Kerman province. As there was no information about this pest in the province, the biology of *E. rhododactylus* was studied and the effectiveness of some biopesticides such as Bt was investigated in a project. In Iran, this pest has been reported from Kashan as well and damaging up to 75.33%. In 2015, after receiving of damask rose flowers from infested areas, this pest introduced to the Lalehzar region of Kerman province. In 2017, samples collected from the Lalehzar were sent to the Plant Protection Research Institute of Iran and the presence of pest of buds of damask rose in Lalehzar district of Kerman was confirmed. In 2017, the pest damage rate was confirmed as 57% in Lalehzar region. Based on the preliminary results, the Bt application had up to 83% ability to control the pest (personal communication with H. Zohdi, Kerman Agricultural and Natural Resources Research and Education Center, July 2019).

Case study 2: *Heterodera schachtii*, sugar beet cyst nematode

Sugar beet cyst nematode (*H. schachtii*) has been reported from sugar beet farms located in different provinces including Khorasan, West Azarbaijan, Isfahan, Semnan, Fars, Kerman, Hamedan and other provinces as one of the most serious nematode. A valuable and impressive research has been conducted across Iran and particularly in Khorasan, Isfahan, West Azerbaijan and Fars provinces in the fields of identification, biology and management of this nematode (21).

IPM achievements

- Introducing more than 300 fungal isolates in association with sugar beet cyst nematode which few species including *Pochonia chlamydosporia* var. *chlamydosporia* and *Paecilomyces lilacinus* significantly reduce the infestation of sugar beet cyst nematode in soil.

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- Two patents has been registered with regards to two antagonistic fungal species with nematicidal activity: *P. fumosoroseus*, *P. chlamydosporia* var. *chlamydosporia*

- Six-year rotation with plants such as cotton, wheat, barley, corn, sorghum, onions. alfalfa, clover, sunflower, walnut squash, cucumber, tomato, eggplant, peas and beans can increase the yield of sugar beet and reduce the population of nematodes.

- Identification of host weed species such as wild spinach, rapeseed, cabbage, radish, mustard, rhubarb and wild thistle.

- Evaluation of planting date, as early cultivation of sugar beet increases yield, reduces damage of nematodes and delay in cultivation causes severe damage.

- Introducing some resistant cultivars such as white mustard with two months cultivation can lead to reduction of damage to more than 70%.

- Application of green manure from commercial canola cultivars can decrease the population of nematode up to 70% (21).

Outline of the biofertilizers and biopesticides commercialization registration process in Iran

In Iran, two main governmental organizations including the Soil and Water Research Institute of Iran (SWRII) and Plant Protection Organization of Iran (PPOI) (Figure 1), are the main authorities for biofertilizers and biopesticides commercialization registration process, respectively (Figure 2).

Companies that produce biofertilizers and biopesticides in the country must pay attention to the selection of the microorganisms and the processes of production, formulation and packaging so that in the future farmers can trust these biological products (6).

Figure 1. Logos of the main authorities of biofertilizers and biopesticides commercialization registration process in Iran; left: Plant Protection Organization of Iran, right: Soil and Water Research Institute of Iran.

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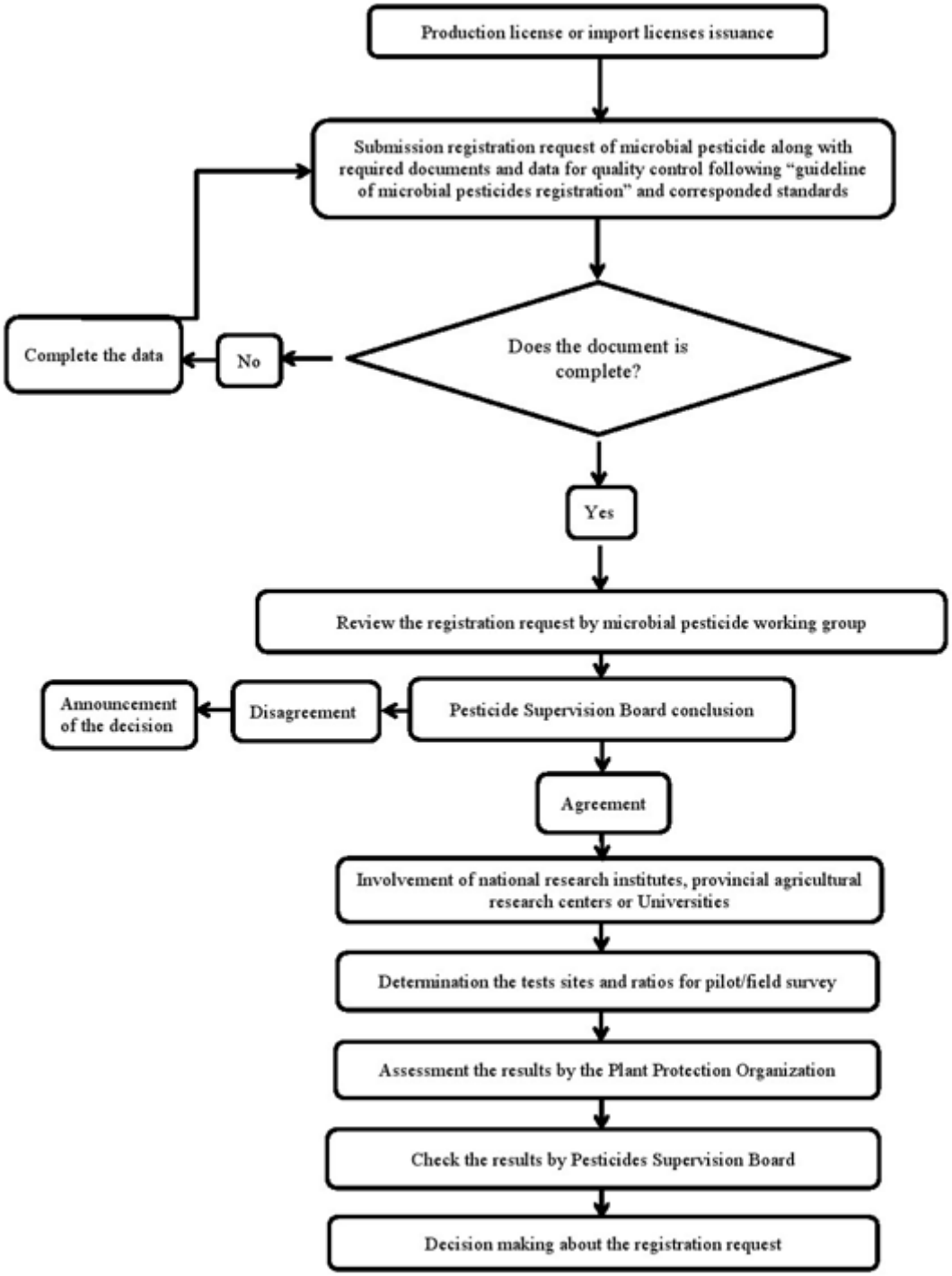

Figure 2. Flowchart showing registration procedures for microbial pesticides implemented by the Plant Protection Organization of Iran (8) and personal communication with S. Mirsardoo, Kerman Agricultural Organization, July 2019**.**

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Concluding remarks

The increasing population and demand for food have highlighted the overuse of chemical fertilizers and pesticides as a tool to achieve maximum production per unit area. Disadvantages of over-utilization of these are water and soil pollution, change of the nutrient balance in the soil, the reduction of agricultural yields due to the lack of or toxicity of certain elements and the accumulation of pollutants (such as nitrates) in agricultural products. Although the use of biofertilizers in Iran is known, unfortunately, the general knowledge of Iranian farmers in this area is low. One of the most important practical and safe factors to reduce the use of chemicals are biofertilizers and biopesticides application. The use of microorganisms in the industry requires full knowledge and the use of microbial biotechnology. Obviously, both approaches i.e. neglecting biofertizers or biopesticides or excessive promotion and attention are not wise and may not lead to a sustainable production. It seems that the best approach is to gradually increase the use of proper types of biofertilizers and biopesticides. Fortunately, importance of producing a healthy product and the need for environmental protection are mentioned in the 20-year vision of the I.R.Iran. This kind of planning and management perspective in the fourth plan, and reiterating it in the fifth program, indicates the emphasis of the authorities on the production of healthy products. The bright side of development of the market for biofertilizers and biopesticides in the world, the benefits of using them in order to produce a healthy product and provide community health and the growing awareness of the people of I.R.Iran, provide the legal framework and accompaniment of high-level officials in the field of development in this industry.

Moreover, the young population of I.R.Iran and raising interests in biofertilizers and biopesticides research and commercialization at research institutes and universities can be considered as promising perspective. Over the recent decades, there are tremendous efforts in terms of research towards a safer and efficient way to satisfy high demanding markets and also safeguard the food production security in parallel with biosafety and environmental issues. For instance, advances gained in application of genetic engineering, gene expression, and production of transgenic plants, developing more super-foods with attention to the each region climate, and biologically based pesticides and fertilizers (13-15, 22). With such fast racing world, those countries which apply these technologies under their biosafety rules will win the future market not only nationally but world-wide. Hence, by combining all these technologies together we can reach to more sustainable agricultural goals in Integrated Pest Management systems.

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مجله ایمنی زیستی

دوره ۱۳، شماره ۳، پائیز ۱۳۹۹

ISSN 2716-9804 الکترونیکی، ISSN 2717-0632 چاپی

کودهای زیستی، سموم زیستی و مدیریت تلفیقی آفات: پتانسیل‌ها و چالش‌ها در کشور جمهوری اسلامی ایران

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تاریخ دریافت: ۹۹/۱۱/۱۸، تاریخ پذیرش: ۹۹/۱۱/۲۸

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چکیده

کشور ایران دارای زمینه‌های غنی کشاورزی است. ۱۰٪ از تولید ناخالص داخلی را کشاورزی تشکیل می‌دهد و معیشت حدود ۳۰٪ از جمعیت را تأمین می‌کند. تلاش برای افزایش بهره‌وری مزرعه منجر به واردات سموم دفع آفات با حدود ۳۰۰۰ تن سالانه بین سال‌های ۲۰۱۲ و ۲۰۱۴ شد. بنابراین، نیاز فوری به گزینه‌هایی مانند استفاده از کودها و سموم زیستی در سیستم‌های مدیریت تلفیقی آفات وجود دارد. با پیشرفت سریع در بیوتکنولوژی، بسیاری از دانشمندان امیدوارند که مشکلات غذایی را به‌طور موثرتری حل کنند. خوشبختانه، مسئله نیاز به حفاظت از محیط زیست در برنامه ۲۰ ساله دولت ذکر شده است که نشان می‌دهد نگرانی در خصوص تولید محصولات سالم وجود دارد. جنبه روشن توسعه بازار کودهای زیستی و سموم زیستی در دنیا، مزایای استفاده از آنها برای تأمین سلامت جامعه و افزایش آگاهی مردم ایران، فراهم‌آوردن چارچوب قانونی و همراهی مقامات عالی‌رتبه در زمینه توسعه در این زمینه است. علاوه‌براین، جمعیت جوان ایران و افزایش علاقه به تحقیق و تجاری‌سازی کودهای بیولوژیکی و سموم زیستی در موسسات تحقیقاتی و دانشگاه ها می‌تواند چشم‌انداز امیدوارکننده‌ای باشد.

واژه‌های کلیدی: کودهای زیستی، سموم زیستی، مدیریت تلفیقی آفات.

[DOR: 20.1001.1.27170632.1399.13.3.4.8]