РАСТЕНИЕВОДСТВО
CROP PRODUCTION

DOI: 10.22363/2312-797X-2019-14-2-105-113

Review article

DNA insecticides as an emerging tool for plant protection and food security strategies

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Abstract. A large number of plant diseases and damages are caused by insects and insect vectors of plant pathogens, leading to the serious threats facing plant protection and food security. The access to safe and nutritiously high-quality food is essential for human growth and development. This translates to a well-developed society with systematically organized efforts for maintenance and increased food production or supply to meet the continuous growing demand. The effects of environmental, biological, chemical, political and socioeconomic factors have all contributed to the present nature of food dynamics, its availability, supply and security. Hence, the development of safe bio-based substances should be prioritized for precise and effective use in plant protection strategies. This review examines the sequential results of the insecticidal potentials of unmodified short single-stranded DNA fragments used as DNA insecticides, and emerging tool for safe plant protection strategy.

Keywords: plant protection, food production and security, IAP genes, biopesticides, DNA insecticides

Introduction

The outright challenge of the constant flow of a nutritionally balanced diet available for a given population to aid growth, socioeconomic development and productivity at large, calls for a continuous exigent integration of all sectors of research, this coalition will make certain food security at the optimum level.

The increasing demand for safe and quality food is directly proportional to the growing population of the world. Today we have enough food to meet the world's needs. Indeed, we have an extraordinary global food system that brings food from all over the planet, with some countries leading better than others (Fig. 1) for consumers who can afford to buy it [1]. However, a significant amount of the human population still

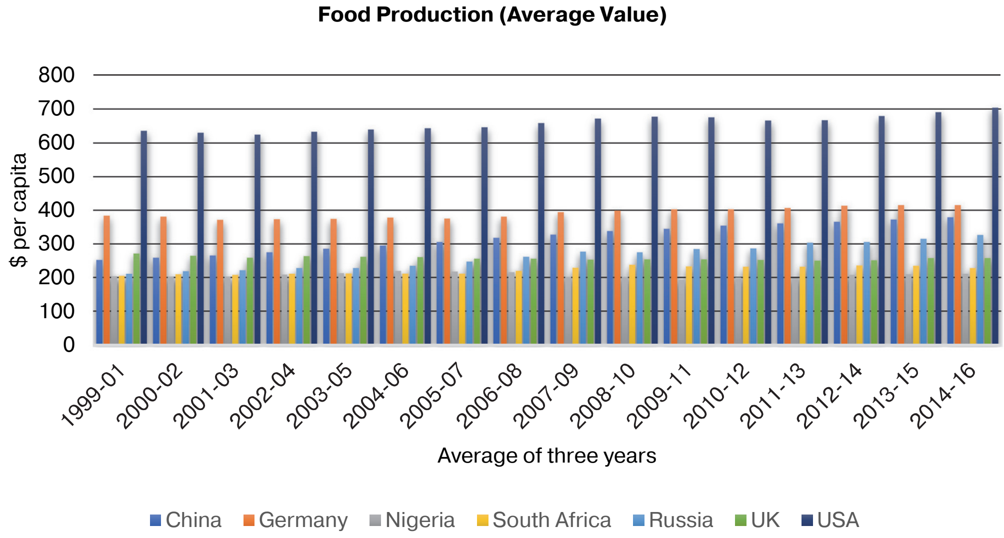

Fig. 1. Food security indicator showing the average value of food production for an individual, using the course of three years as a constant.
The data provides a comparable estimation of food production in different economies of the world (http://www.fao.org/economic/ess/ess-fs/ess-fadata/en).

do not have access to drinking water, food and arable land or environment [2—4]. These results to less intensively grown plants that serves as food source and nutrition requirements in some areas of the globe. Plant protection can be threatened by abiotic and biotic factors. These biotic constraints, such as insect pests, can at times seriously compromise food production and security.

In the 1970s a concept of food security was introduced in the discussions of international and national food trouble during a period of world food crisis, which focused on the attention of structural food supply, and to assure to some degree the provision and stable price index basic foodstuffs at all levels [5]. Analyses of the United Nations projections indicate that the human population will expand from roughly 7.2 billion today to 9.6 billion in 2050 and 10.9 billion by 2100 [6, 7]. This implies that, the more population the higher the food demand and the greater intensity of food security to prevent global food crisis.

One of the major challenges of plant protection and food security in the world today is insect pest management [8—10]. Insects can be found almost everywhere, both in terrestrial habitats as well as every fresh-water habitat, they are the most diverse group of living things in the world [11]. Some insects have coevolved with humans and have been associated with significant roles since the start of modern agriculture, with a large number of them becoming natural rivals and causing damages to plants grown for human food [12—14]. Though some insects can be beneficial in agriculture, a number of them are destructive to plants and their products.

Insects coexist with baculoviruses [15, 16], a pathogenic virus that can be utilized as a control substance [17]. These viruses are insect-host specific, circular and super coiled double-stranded DNA genomes in a range of ca. 80 to180-kbp [18]. There is up to 600 and more baculoviruses originating from insect orders of Lepidoptera, Hymenoptera and Diptera (butterflies and moths, sawflies, and mosquitoes respectively) [15].

Baculoviruses are characteristically rod-shaped like nucleocapsids, known as "*baculum*" in latin, that are as long as 230—385 nanometre (nm) and as wide as 40—60 nanometre (nm) [18]. They have enveloped virions, also having phenotypes that are occlusion derived virus (ODV) and budded virus (BV). These virions share same genome properties but differ in composition and morphogenesis of their functions during the life cycle of the virus. Their environmental stability as well as their infectivity in target insects, are generally different [19]. The nature of baculoviruses have provided a platform for studies and trials on insect pests control [19—21], and maximum positive results of control programs based on baculoviruses will depend upon joint efforts among research institutes, governments, companies and growers' associations [19]. So far, studies on modern insecticides termed DNA insecticides created from unmodified short single-stranded DNA oligonucleotides of IAP genes of baculoviruses are being considered as an emerging tool for plant protection and food security.

DNA Insecticides, current status and future prospects

DNA insecticide is a developing contemporary approach for plant protection and insect pest management [20, 22]. Based on 18—20 nucleotides long unmodified DNA fragments of viral inhibitor of apoptosis (IAP) genes, DNA insecticides can be used to significantly manage its target insect-host. The action of DNA insecticides is attributed to its ability to interfere with target gene expression [23—25]. Recent studies show that topical application of DNA insecticides designed form IAP-2 and IAP-3 genes of LdMNPV (*Lymantria dispar* Multicapsid Nuclear Polyhedrosis Virus), decreases the population of gypsy moth (*Lymantria dispar*) caterpillars, an insect pest with damaging effects on forest trees of economic importance, located mostly in North America and Eurasia [26, 27]. Another study indicated that DNA insecticides from DIAP-2 (*Drosophila* inhibitor of apoptosis) genes used on the larvae of fruit fly (*Drosophila melanogaster*) interfered with DIAP-2 gene expression [23], suppressing the development female fruit flies. This phenomenon was also observed in gypsy moth larvae treated with DNA insecticides from LdMNPV IAP-3 genes where the target IAP-Z gene was interfered with in female gypsy moth larvae [27]. The actions of DNA insecticides majorly from the antisense fragments indicated that it acts as RNase H-dependent oligonucleotides that promote the degradation of target mRNA and can be effectively utilized against target insect pests.

In addition, further studies of DNA insecticides on non-target plant organisms like common wheat *Triticum aestivum*, apple seedlings *Malus domestica* and oak leaves *Quercus robur* showed that DNA insecticides are safe and not harmful to non-target (plants) organisms [28, 29]. This implies that DNA insecticides designed from specific baculovirus affect only its host insect, a characteristic nature of modern insecticides that are insect-specific and engineered for plant protection that will support food security strategies.

The practical advantage in the use of 18—20 nucleotides long insect-specific DNA insecticides is in its cost-efficiency, which implies the ease of synthesis with minimal hands-on participation. However, the development of DNA insecticides is still at an early state, even though there are ongoing studies to expand this idea. The ease of creating DNA insecticides will be advantageous especially for mainstream production, for large scale plant protection.

Additionally, the application of DNA insecticides by contact or oral means is convenient to control and maintain insect pest control of crops as well as economic plants. In the situation were DNA insecticides may be used against feeding insects such as adult beetles, their chitinous covering could protect them from contact with the insecticide [25], Nevertheless, DNA insecticides have demonstrated strong potency for the management of the larval stage of lepidopteran pest such as gypsy moth (*Lymantria dispar*), especially during early larval instars, in their unprotected exoskeleton form. The use of unmodified short single-stranded DNA fragments from conservative IAP genes as insecticides could reduce insect resistance because of the low potential of mutation in the conservative regions of the host insect. The approach of DNA insecticides is of immense value, and elaborations in this field may lead to a very safe and cheap bioinsecticides with high potency for sustained plant protection and food security.

Conclusions

Insect pests have significantly contributed to food shortage by destroying crops and affecting their produce, leading to food insecurity both in developing and industrialized parts of the world. Hence, for effective food security strategies, there is need for integrated methods and tools for plant protection. DNA insecticides are presented as a developing tool for plant protection, and the potency recorded for insect-specific action especially against *Lymantria dispar* implies that insecticides based on short single stranded DNA oligonucleotides from conservative genes of insect baculovirus have the potential to pave a way for the creation of new forms of biological substances to control insect pests. The use of insect viral inhibitor of apoptosis gene fragments is relatively new as a modern tool that is eco-friendly, fast-acting, target-specific, and safe for non-target organisms. DNA insecticides encodes traits that are favourable for plant protection and food security.

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Article history:
Received: 15 April 2019
Accepted: 16 May 2019

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For citation:
Nyadar PM, Razo Sh. DNA insecticides as an emerging tool for plant protection and food security strategies. *RUDN Journal of Agronomy and Animal Industries*, 2019; 14(2): 105—113. doi: 10.22363/2312-797X-2019-14-2-105-113.

DOI: 10.22363/2312-797X-2019-14-2-105-113

Обзорная статья

ДНК-инсектициды как новое направление в защите растений и обеспечении продовольственной безопасности

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Большое число повреждений растений вызывается насекомыми, которые могут одновременно являться как вредителями, так и переносчиками болезней, что создает серьезные проблемы продовольственной безопасности. Крайне важным для человеческого роста и развития является доступ к безопасным и высококачественным продуктам питания. Это становится залогом развития общества потребителей с высокими требованиями к качеству продуктов питания и, в конечном итоге, приводит к постоянно растущему спросу на подобную продукцию. Влияние экологических, биологических, химических, политических и социально-экономических факторов способствовало формированию современного продовольственного рынка, его доступности и безопасности. Именно поэтому разработка безопасных биологических препаратов становится сегодня приоритетом в современной системе защитных мероприятий. Данная работа систематизирует отдельные результаты по исследованию защитных свойств немодифицированных коротких одноцепочечных фрагментов ДНК, используемых в качестве инсектицидов, как новый инструмент в системе защиты растений.

Ключевые слова: защита растений, продовольственная безопасность, IAP гены, биопестициды, ДНК-инсектициды

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История статьи:
Поступила в редакцию: 15 апреля 2019 г.
Принята к публикации: 16 мая 2019 г.

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Для цитирования:
Nyadar P.M., Vvedensky V.V., Pakina E.N., Razo Sh. DNA insecticides as an emerging tool for plant protection and food security strategies // Вестник Российского университета дружбы народов. Серия: Агрономия и животноводство. 2019. Т. 14. № 2. С. 105—113. doi: 10.22363/2312-797X-2019-14-2-105-113.