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Review

# Potential of bacterial derived biopesticides in pest management

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ABSTRACT

Biopesticides, key components of integrated pest management programs, are receiving practical attention as a means to reduce the amount of synthetic chemical products being used to control plant pests and diseases and to protect stored products. A large number of bacterial derived products have been released, several of which have already played dominant roles in the market. Bacterial pesticides are used to control pests, pathogens and weeds by a variety of mechanisms. Among them, they might act as competitors or inducers of host resistance in plant. Some act by inhibiting growth, feeding, development or reproduction of a pest or pathogen. The aim of this review is to provide an overview of the use of bacterial derived biopesticides for pest management and to discuss the current development and application of their various types. Detailed classification of *Bacillus thuringiensis*, *Bacillus subtilis* and *Bacillus sphaericus* based biopesticide is provided along with their insecticidal, mosquitocidal, nematicidal and antimicrobial activities. The review revealed great potential for further exploitation of bacterial derived biopesticides in plant protection. *Pseudomonas* sp. derived biopesticides and their potential use as mosquitocide, nematicide, antimicrobial agents and inducer of systemic resistance in plants are also discussed.



## 1. Introduction

Agriculture has been facing the destructive activities of numerous pests including fungi, weeds and insects from time immemorial, sometimes leading to drastic decreases in yields and quantities. Pests are continuously being introduced to new areas either naturally or accidentally, or, in some cases, organisms that are intentionally introduced become pests. Global trade has resulted in increased numbers of aggressive non-native pest species being introduced to new areas. Controlling these aggressive species presents a serious challenge worldwide.

Over years, chemical pesticides had made a great contribution to the battle against pests and diseases. However, their use resulted in the development of insecticide resistance, use-cancellation or deregistration of some insecticides due to human health and environmental concerns, extensive damage to the environment, pest resurgence, pest resistance to insecticides and lethal effects on non-target organisms (Abudulai et al., 2001). Therefore, an eco-friendly alternative is required to generate higher quality and greater quantity of agricultural products. Hence, an urgent need has arise for the development of biopesticides for effective control of agricultural pests without causing serious harm to the ecological chain or worsening environmental pollution. We define a biopesticide as a mass-produced agent manufactured from a living microorganism or a natural product and sold for the control of plant pests (Organisation for Economic Co-operation and Development, 2009). Biopesticides fall into three different types according to the active substance: (i) micro-organisms; (ii) biochemicals; and (iii) semiochemicals (Chandler et al., 2011). Based on the natural resources from which they are derived, biopesticides are classified as microbial pesticides, botanical pesticides, zooid pesticides and genetically modified plants (Chandler et al., 2011). They were swiftly becoming the preferred choice for pest control thanks to the great increase of the number of areas in which they were used moving from one year to another. Biopesticides were usually applied to control rather than to destroy pests. They were also more selective than chemical pesticides. In fact, most biopesticides had the advantage of higher selectivity and non-target biological safety (Cheng et al., 2010). The biopesticides characteristics included low-residue and high-performance, fewer toxic side effects and good compatibility with the environment. The resistance to biopesticides in target organisms was not easily generated, unlike in many cases of their chemical counterparts. They are fast becoming a new trend

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in the global pesticide industry.

Microbial biopesticides derived from bacteria, fungi, oomycetes, viruses and protozoa are all being widely used for the biological control of pestiferous insects, plant pathogens and weeds. For all crop types, bacterial biopesticides claim about 74% of the market; fungal biopesticides, about 10%; viral biopesticides, 5%; predator biopesticides, 8%; and "other" biopesticides, 3% (Thakore, 2006). However, only a few insect pathogenic bacteria have been developed as biocontrol agents. The most commonly used microbial biopesticide is the entomopathogenic bacterium *Bacillus thuringiensis* (Bt) (Berliner), which produces a crystal protein (δ-endotoxin) during bacterial sporulation that is capable of causing lysis of gut cells when consumed by susceptible insects (Jisha et al., 2013). *Bacillus subtilis* (Ehrenberg), *Pseudomonas fluorescens* (Trevisan) and *P. aureofaciens* (Kluyver) are being applied against a variety of plant pathogens including, especially, damping-off and soft rots (Berg, 2009).

In this review, we will discuss a large variety of bacterial derived biopesticides including those derived from Gram positive isolates; *B. thuringiensis*, *B. subtilis*, *Bacillus sphaericus* and *Bacillus* sp. based biopesticides and those derived from Gram negative isolates *Pseudomonas* sp.

## 2. *Bacillus thuringiensis* based biopesticide

The entomopathogenic organism, *B. thuringiensis* is a gram-positive spore-forming bacterium that produces crystalline proteins called δ-endotoxins released to the environment after lysis of the cell wall at the end of sporulation (Jisha et al., 2013). The δ-endotoxin is host specific and can cause death within 48 h (Jisha et al., 2013). It does not harm vertebrates and is safe to the peoples and the environment (Van Driesche et al., 2008). *B. thuringiensis* sprays are an emergent policy for pest management on fruit and vegetable crops where their high level of selectivity and safety are considered desirable, and where resistance to synthetic chemical insecticides is a problem (Van Driesche et al., 2008).

Owing a wide spectrum of bioactivity, *B. thuringiensis* based biopesticide presented approximately 95% of microorganisms used for pest control. Table 1 presents a wide array of *B. thuringiensis* based biopesticides along with their nature and the antagonist strain. As suggested by Schünemann et al. (2014), there are different commercial *B. thuringiensis* products developed for control of agricultural insect pests and also against mosquito species. Most of the spore-crystal formulations are obtained from different strains including *B. thuringiensis* var. *kurstaki* (*Btk*)-isolate HD1 (contains Cry1Aa, Cry1Ab, Cry1Ac, and Cry2Aa proteins); *B. thuringiensis* var. *kurstaki* (*Btk*)-isolate HD73 (contains Cry1Ac); *B. thuringiensis* var. *aizawai*-isolate HD137 (contains Cry1Aa, Cry1B, Cry1Ca, and Cry1Da); *B. thuringiensis* var. San Diego and *B. thuringiensis* var. *tenebrionis* (contains Cry3Aa) and *B. thuringiensis* var. *israelensis* (contains Cry4A, Cry4B, Cry11A, and Cyt1Aa) toxins (Schünemann et al., 2014).

In a study conducted by Raddadi et al. (2009), 16 *B. thuringiensis* strains were investigated for their polyvalent biocontrol potential mediated by a screening of their capacity to protect plants against phytopathogenic insects, fungi and bacteria. They have shown that two strains *B. thuringiensis* subsp. *entomocidus* HD9 and *B. thuringiensis* subsp. *tochigiensis* HD868 have several activities among them chitinolytic activity, fungal inhibition, β-1,3-glucanase and autolysin and bacteriocin activities suggesting their potential feasibility as biological control agents (Raddadi et al., 2009).

### 2.1. Insecticidal activity of B. thuringiensis derived biopesticides

The mode of action of *B. thuringiensis* proteins involves numerous events which would be achieved several hours after ingestion leading to insect death. After ingestion, the crystals are solubilized by the alkaline conditions in the insect midgut and are, afterwards, proteolytically transformed into a toxic core fragment (Jisha et al., 2013). During proteolytic activation, peptides from the N terminus and C terminus are cleaved from the full protein. Activated toxin binds to receptors located on the apical microvillus membranes of epithelial midgut cells. After binding, toxin changes conformation, allowing its insertion into the cell membrane. Subsequently, oligomerization occurs, and this oligomer forms a pore or ion channel within the functional receptors contained on the brush borders membranes, causing disruption of membrane transport and cell lysis and leading to insect death (Jisha et al., 2013; Schünemann et al., 2014).

*B. thuringiensis* derived biopesticide can act either on Lepidoptera, Dipterans and Coleopterans insects. Lepidoptera encompasses the majority of susceptible species belonging to agriculturally important families such as Cossidae, Gelechiidae, Lymantriidae, Noctuidae, Pieridae, Pyralidae, Thaumetopoetidae, Tortricidae and Yponomeutidae (Gathmann and Priesnitz, 2014). Dipterans are also important target pests and many of them are highly susceptible to *B. thuringiensis*. This order includes the families Tephritidae, Culicidae, Muscidae, Simuliidae and Tipulidae (Lysyk, 2006). Coleopterans are important pests in agriculture and forestry. Several families such as Chrysomelidae, Curculionidae, Tenebrionidae and Scarabeidae have recently been found to be susceptible to toxic activity of the crystals (Gathmann and Priesnitz, 2014). Zhong et al. (2000) characterized a *B. thuringiensis* delta-endotoxin which is toxic to the three orders of insects (Diptera, Coleoptera and Lepidoptera).

It's well documented that the encoded products of cry genes of certain *B. thuringiensis* are toxic against diverse insect order such as Hymenoptera, Hemiptera, Orthptera, Acaria and Phthiraptera (Mallophaga) (Eswarapriya et al., 2010). Wu et al. (2011) described the toxic effect of a novel *B. thuringiensis* δ-endotoxin against Locusts (Orthoptera: Acrididae): *Locusta migratoria manilensis*; pests that cause extensive destruction of crops. Also, previous studies reported the entomocidal activity of novel *B. thuringiensis*-endotoxins to *Lygus Hesperus* Knight (Hemiptera: Miridae) (Wellman-Desbiens and Côté, 2005), the cotton aphids *Aphis gossypii* (Hemiptera: Aphididae) and whiteflies *Bemisia tabaci* (Hemiptera: Aleyrodidae) (Malik and Riazuddin, 2006). Craveiro et al. (2010) reported the efficient biological control of sugarcane giant borer caused by the Lepidopteran larvae *Telchin licus licus* (Castniidae) by variants of Cry1Ia toxins. Other studies reported the high toxicity of *B. thuringiensis* Cry protein towards *Anthonomus grandis* Boheman (Coleoptera: Curculionidae) (de Souza Aguiar et al., 2012) and towards *Cylas puncticollis* and *Cylas brunneus* (Coleoptera: Brentidae) (Ekobu et al., 2010).

Another interesting protein derived from a *B. thuringiensis* strain is the Vegetative Insecticidal Proteins (Vip) (Yu et al., 2011). It includes the binary toxin Vip1 and Vip2 with Coleopteran specificity and Vip3 with a wide activity spectrum against Lepidoptera (Yu et al., 2011). Shingote et al. (2013) reported the insecticidal potency of derived Vip1/Vip2 against the Coleopteran store grain pest, *Sitophilus zeamais* (Curculionidae family) with 60% mortality. As presented by Fang et al. (2007), Vip3Ac1 showed high insecticidal activity against the Lepidoptera larvae, the fall armyworm *Spodoptera frugiperda* (Noctuidae) and the cotton bollworm *Helicoverpa zea* (Noctuidae) but very low activity against the silk worm *Bombyx mori* (Bombycidae). Moreover, Beard et al. (2008) reported the insecticidal activity of *B. thuringiensis* Vip 3Bb2 towards the cotton bollworm *Helicoverpa armigera* (Noctuidae).

Similarly, Schünemann et al. (2014) reported the effectiveness of *B. thuringiensis* toxins in the control of velvetbean Caterpillar;