

Review Article

Avermectins: The promising solution to control plant parasitic nematodes

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Abstract

Abamectin and emamectin are members of avermectin family which categorized as very effective but in the same time are toxic naturally. Most of products in this family are utilized as pharmaceuticals in both humans & animals and for crop protection. Despite avermectins are having complex chemical structures, but they are produced via synthesis in large scales for commercial use. Plant parasitic nematodes (PPNs) cause severe damages in all parts of their host plants, in addition to yield losses. The available strategies to control PPN include use of insecticides/nematicides but these have proved detrimental to environment and human health. Therefore, this scenario gave an opportunity for the utilization of avermectins (abamectin and emamectin) to control plant parasitic nematodes because of their chemical and biological properties, as well as relative safety. Avermectins have short half-lives and their residues can be eliminated easily through different food processing methods. Both abamectin and emamectin were very effective nematicides which proved capability of reducing PPNs significantly in various crops.

Introduction

Plant parasitic nematodes (PPNs) considered a threat to crops production and are responsible for about US \$173 billion annual losses in agriculture world [1]. Sometimes, PPNs are co-operating with other plant pathogens such as bacteria and fungi and cause complex diseases. Nematodes can damage all parts of their host plants, although according to their life style, individual species target the roots, stems, leaves, flowers, or seeds. There are about 31% of known species of nematodes are parasites of vertebrates [2], while 16% are parasites of plants, mostly soil-borne root pathogens [3]. Approximately 2.4% species of those parasites on plants are responsible for economically important phytoparasites of crops.

Globally, farmers are still depending on chemical nematicides to control PPNs, because of their effectiveness, but the environmental aspects of these synthetic pesticides was drastically devastating [4]. Avermectins are one of new alternatives which proved its activity towards different genera of plant parasitic nematodes [5-10]. Avermectins were discovered in 1976 by scientists at Merck & Co. Inc. obtained from isolate by the Kitasato Institute from soil samples collected at Kawana, Ito city, Shizuoka Prefecture, Japan [11]. Avermectins are sub-class of natural products that consisting of a large macrocyclic lactone ring which produced from metabolites of Gram-positive bacterium, *Streptomyces avermectinius* [12].

The residue of avermectins is rapidly decomposed under sunlight, resulting in a relatively low toxicity to beneficial insects [13]. They are rapidly photodegraded in water with a half-life ($t_{1/2}$) of approximately 0.5 days or less in summer. Emamectin benzoate, a novel insecticide with translaminar movement in plant leaf tissue. Emamectin has improved thermal stability, greater water solubility and a broader spectrum of insecticidal activity than abamectin [14]. The half-life of emamectin benzoate may reach 7 days in water, but may reduce to one day if the water contained a natural photosensitizer such as humic acid. However, the half-life of emamectin benzoate under sunlight in water may take 22 days. The half-life of abamectin on water surface was only 4 to 6h [14]. Therefore, this review aimed to clarified the importance of avermectin group especially; abamectin and emamectin to use as a new nematicides which are environmentally safe than other synthetic nematicides.

Abamectin

Abamectin is belonging to the sub-group: Avermectins that follow the macrocyclic lactones group. Avermectins have been obtained from Gram-positive bacterium, *Streptomyces avermitilis* [15]. Newly, the name of bacterium species was changed to *Streptomyces avermectinius* [12].

Avermectins are consisting of eight components which divided to four major components as A1_a, A2_a, B1_a and B2_a

and four minor components as A1_b, A2_b, B1_b and B2_b [16]. The component (A) means that there is a methoxy group at the C₅ - position and component (B) means that there is a hydroxy group at the C₅ - position. While component (a) means that there is a secondary butyl side chain at the C₂₅ - position and component (b) means that there is an isopropyl substituent at the C₂₅ - position. Also, component (1) means that there is double bond between C₂₂ and C₂₃ - position, whereas component (2) means that there is a single bond with a hydroxy group at the C₂₃ - position. Abamectin (avermectin B1) is a blend of avermectin B1_a (≥ 80%) and B1_b (≤ 20%) as mentioned by [15]. Both components B1_a and B1_b of abamectin almost have the same biological and toxicological properties [16].

Recently, a new member of avermectins family was registered in china as a patent under number (2012105478044). This new member was Abamectin B2 which produced by Hebei Xingbai Agricultural Technology Co., Ltd., China. This compound was registered to manage the root-knot nematodes in different crops such as tomato, cucumber, celery, watermelon, peanut, soybean, banana, coffee and Chinese herbal medicine plants and applied at little amounts. Abamectin B2 which contains a mixture of B_{2a} and B_{2b} was registered under trade name Xing-Bai® (5.0% EC).

The environmental aspects of abamectin

The toxicity of abamectin is low towards non-target organisms. This aspect nominated abamectin to join into the integrated pest management (IPM) programs, as well as proved its safety to human beings and environmental components [16].

Avermectins have relatively shorter residual activities. The stability of abamectin is moderate in environment. The half-life of abamectin under field conditions was about 31 ± 6 days, while the half-life was ranged between 20 and 47 days

in soils with 5 - 9 pH. The photo-degradation occurs in thin films (6 hours) and water (12 hours), while it was 21 hours in soil [17]. Despite its rapid decomposition in various systems, abamectin still provides a relatively long residual activity against target pests in field conditions due to its translaminar activity [18].

The systemic activity of abamectin is limited and the water solubility is very low because of its binding with soil particles tightly, resulting in poor movement of the product through the soil profile [16,19,20].

The residues of abamectin are very low in treated plants because of it is highly degraded readily by soil microorganisms. Moreover, the most avermectin degradation products have been reported to pose 1-3 times less toxicity than the parent compound. The temperature coefficient of abamectin is positive which mean that the toxicity increased with the increment of temperature till 37 °C [17].

The efficacy of abamectin on plant parasitic nematodes

The avermectin B1 (Abamectin) proved its ability to manage different pests as an acaricide [16,21], insecticides [22], nematocide [10,23] and Molluscicide [24-26]. Meanwhile, abamectin was applied in many different methods such as soil treatment, seed treatment, injection in to plant stem and seedling root dip (Table 1) (Figure 1).

Emamectin benzoate

Emamectin benzoate is a novel avermectin derivative which belongs to the macrocyclic lactones family. Emamectin benzoate was developed as a pesticide by Merck and Company and was classified as a second generation of avermectins which is a derivative of abamectin. Emamectin benzoate is a biological insecticide contains a mixture of the benzoic acid salt of two structurally complex heterocyclic compounds which were emamectin B1_a (> 90%) and emamectin B1_b (<

Table 1: The effect of abamectin on different genera of plant parasitic nematodes on different crops.

Compounds	Nematodes' genera	Crops	Application methods	Reduction parameters (%)				Authors
				Population	Galls	Egg masses	Eggs	
Vertemic® (1.8% EC)	<i>Meloidogyne incognita</i>	Rapeseed	Soil Application	94.2%	61.5%	92.5%	----	Korayem, et al. [42]
Abamectin (1.8% EC)	<i>Meloidogyne incognita</i>	Egg plants	Soil Application	----	61.77%	78.82%	----	Shahid, et al. [43]
Abamectin	<i>Pratylenchus zeae</i>	Maize	seed treatment	80%	---	----	----	Cabrera, et al. [6]
	<i>Heterodera schachtii</i>	Sugar beets		60%	---	----	----	
	<i>Meloidogyne incognita</i>	Cotton		----	80%	----	----	
Vertemic® (1.8% EC)	<i>Meloidogyne incognita</i>	Tomato	Soil Application	74.0%	60.7%	----	----	Khalil, [44]
Vertemic® (1.8% EC)	<i>Meloidogyne incognita</i>	Cabbage	Soil Application	----	40% to 88%	58% to 98%	----	Ibrahim, et al. [7]
	<i>Heterodera schachtii</i>			68% to 92%	----	----	----	
Vertemic® (1.8% EC)	<i>Meloidogyne incognita</i>	Tomato	Soil Application	61.3%	68.0%	41.7%	----	Youssef and Lashein, [45]
Tervigo® (2% SC)	<i>Meloidogyne incognita</i>	Tomato	Soil Application	75.34%	66.69%	66.31%	16.34%	Saad, et al. [46]
Tervigo® (2% SC)	<i>Tylenchulus semipenetrans</i>	orange trees	Soil Application	78% to 87%	----	----	----	El-Tanany, et al. [9]
Tervigo® (2% SC)	<i>Meloidogyne incognita</i>	Tomato	Soil Application	86% to 91%	67% to 71%	70% to 78%	40% to 63%	Radwan, et al. [23]
Tervigo® (2% SC)	<i>Meloidogyne incognita</i>	Tomato	Soil Application	78.88% to 81.07%	71.64% to 72.48%	----	----	Khalil and Alqadasi, [10]

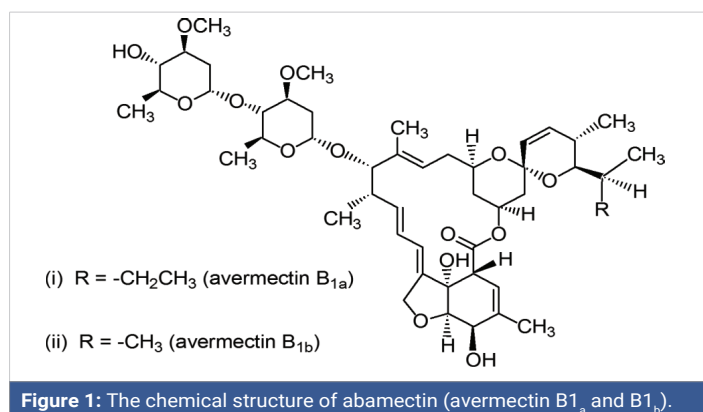


Figure 1: The chemical structure of abamectin (avermectin B_{1a} and B_{1b}).

10%). The only difference between emamectin B_{1a} & emamectin B_{1b} is the presence of an additional methylene unit on the side chain at C-25 [27].

However, emamectin benzoate is consisting of a 16-membered ring macrolide and a di-saccharide via substitution of an epi-methylamino (-NHCH₃) group for a hydroxyl (-OH) group at the 4''-position on the di-saccharide. The limited potentiality of abamectin towards the most of Lepidoptera pushes the scientists to focus and try many prompts to get an alternative compound (s). According to these prompts they discovered of 4''-epi-methylamino-4''-deoxyavermectin B_{1a&b} (emamectin) in 1984. Emamectin was derived from abamectin via a five step synthesis [28].

Many investigations clarified that emamectin benzoate were applied as soil drench to control underground nematodes [23,29,30] and as injection in to the plant trunk/stem [31].

Environmental aspects of emamectin benzoate

Because of that emamectin was derived from soil microbes it offers a promising solution to inhibit environmental pollution and crop losses due to the invasion of pests and diseases. The diversity in structure, activity, biodegradability and the eco-friendly properties make these proposed microbial derivatives, agricultural active agents of the future generation [32]. Also, emamectin benzoate is safe towards non target organisms, as well as it has low residue and environmental pollution [33-36]. The both components of emamectin have similar structure; thus, their physicochemical properties, fate, and toxicity profiles are almost to be similar.

Emamectin benzoate showed thermal stability and greater water solubility, which then resulted in a broader spectrum of insecticidal activity than abamectin [31]. The half-life of emamectin benzoate in water may reach to 7 days, but would be reduced to as short as one day if the water contained a natural photosensitizer such as humic acid. Meanwhile, the stability of emamectin benzoate's characteristics is depending on pH levels. For example, the solubility of emamectin in water reach to 320mg/L at pH 5, 93mg/L at pH 7, and 0.1mg/L at pH 9. Similarly, its log K_{ow} is 5.0 at pH 7 and 5.9 at pH 9.

Also, the photo-degradation of emamectin benzoate in soils may reach to 22 days under sunlight. While in darkness the degradation process of emamectin is stable in soils [27,37]. Previous studies revealed that photo-degradation may produces many byproducts under UV light [27,38-40]. The vapor pressure and Henry's constant of emamectin benzoate are low, therefore these suggest that volatility from soil and water will be low.

Table 2: The effect of emamectin benzoate on various genera of plant parasitic nematodes.

Compounds	Nematodes' genera	Crops	Application methods	Reduced parameters (%)				Author (s)
				Population	Galls	Egg masses	Eggs	
Emamectin benzoate (5% SG)	<i>Meloidogyne javanica</i>	Banana	Stem injection	----	46.67% to 86.67%	----	----	Jansson and Rabatin, [5]
Emamectin benzoate (5% SG)	<i>Radopholus similis</i>	Banana	Stem injection	64.29% to 76.62%	----	----	----	Jansson and Rabatin, [5]
			Root dip	81.73%				
Emamectin benzoate	<i>Meloidogyne incognita</i>	Tomato	Soil Application	----	----	49.50% to 58.10%	22.90% to 26.80%	Rehman, et al. [47]
Emamectin benzoate	<i>Meloidogyne spp.</i>	Egg plants	Soil Application	----	43.75%	56.41%	----	Shahid, et al. [43]
Emamectin benzoate	<i>Bursaphelenchus xylophilus</i>	Pinewood trees	Soil Application	98.03%	----	----	85.61%	Bi, et al. [8]
Emamectin benzoate	<i>Meloidogyne incognita</i>	Tomato	Soil Application	----	73.4% to 87.7%	----	----	Cheng, et al. [48]
Emamectin benzoate	<i>Meloidogyne incognita</i>	Egg Plant	Soil Application	46.8% (females)	----	----	----	Atif, et al. [29]
Emamectin benzoate (Proclaim® 5% WG)	<i>Meloidogyne incognita</i>	Tomato	Soil Application	91.81%	71.65%	76.28%	61.71%	Khalil, [30]
Emamectin benzoate (Proclaim® 5% WG)	<i>Meloidogyne incognita</i>	Tomato	Soil Application	60% to 63%	75% to 77%	60% to 62%	90% to 93%	Radwan, et al. [23]

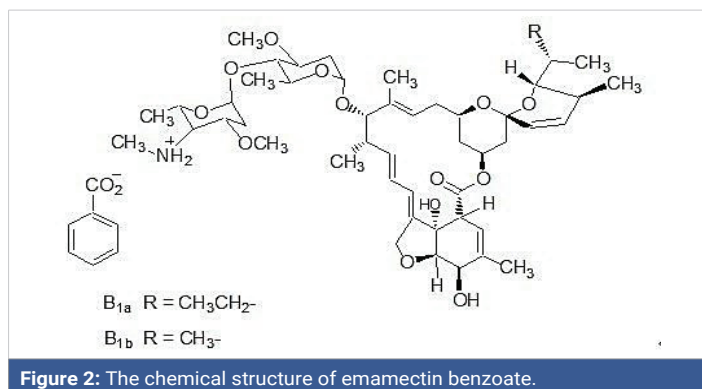


Figure 2: The chemical structure of emamectin benzoate.

The effect of emamectin on plant parasitic nematodes

Emamectin benzoate is a novel semi-synthetic derivative antibiotic which has a wide spectrum activity against insects [33,34]. However, certain reports indicated that emamectin benzoate was effective against different genera of plant parasitic nematodes according to the received information from [41], [8,12] but emamectin was less effective than abamectin. Until now there is no registered compound of emamectin benzoate to manage PPNs. The obtained data in the following (Table 2) showed the impact of emamectin benzoate on different plant parasitic nematodes genera in various crops (Figure 2).

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