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Use of marigold (*Tagetes* sp.) for the successful control of nematodes in agriculture

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Abstract
Control of plant parasitic nematodes through antagonistic plants has some advantages like biodegradability, selective toxicity to target pests, safety to non-target organisms and environment and is renewable in nature. The primary soil borne plant parasitic nematodes having spear like mouth parts used to feed on plant roots cause serious reduction in yield and quality of wide variety of crops. Management of nematodes in agriculture include crops that are not hosts of these plant parasitic nematodes, using resistant available plants, applying chemical nematicides, soil solarization, use of organic amendments, employing trap crops, microbial biocontrol agents and plants that are antagonistic to parasitic nematodes. Wild marigolds *Tagetes* sps are highly toxic to the plant parasitic nematodes and are capable of suppressing wide range nematode pests. The plausible mode by which marigolds suppress plant parasitic nematodes is through the biochemical interaction known as allelopathy. The root exudates of marigold known to contain toxic bioactive chemicals having nematicidal, insecticidal, fungicidal, antiviral and cytotoxic activities. Thus as a method of biocontrol of nematodes, growing of marigolds is not only a comely but also highly economical and helps in environmental amelioration.

Keywords: Allelopathy, biocontrol, marigolds, nematodes, root exudates

1. Introduction
Nematodes are soil-dwelling, microscopic, worm like parasites that feed on plant roots, causing swelling or galls within the roots, obstructing the flow of water, mineral salts and nutrients. They are most active in summer when soil temperature ranges between 29 °C to 35 °C. Cucumber, okra, squash, beans, brinjal and non-resistant tomatoes are highly susceptible crops for nematodes. However, nematodes being highly active at high soil temperature, they are not a serious threat to most cool season plants, the exception being carrots and beets which could show moderate to severe nematode infestation. Now the question as to how could we control nematodes leads to the most comprehensive solution of using eco-friendly approaches of growing trap crops, antagonistic nematode suppressing plants, soil solarization and crop rotation. Marigolds could be effectively grown and could serve as a landscaping element while taking care of nematode problem. French marigolds (*Tagetes patula*) suppresses multiple genera of plant parasitic nematodes which includes *Meloidogyne*, Lesion nematode, *Pratylenchus* spp and Reniform nematodes.

2. Marigold as effective nematode suppressing crop.
Nematodes are minuscule round worms which are subterranean in nature and effect almost all the agricultural crops and cause substantial yield loss. Root knot nematode, *Meloidogyne incognita* is a polyphagous pest which affects all the vegetable crops. This nematodes along with other pathogenic fungi and bacteria increases the disease severity in crops and leads to the crop failure. Root knot nematode infected roots show modified galls in the functional root system imparing the conduction of water and mineral nutrients in plants. The entire root system may be shallow with excessive branching.
Marigold (*Tagetes* spp) is an excellent plant for the management of root knot nematodes, the bioactive chemicals secreted by the root exudates of marigold could effectively control the nematode population. Thus use of marigold in nematode in nematode control is an environmentally safer and economically viable method. Marigold had been reported to contain 5-(3-buten-1-ynyl)-2,2-bithienyl and alpha terthienyl in a synthetic form and acts as nematode suppressant. The roots of marigold was reported to contain flavonoids, Di-hydroflavonoid, flavones and flavonones lacking a free OH group. The roots had also been reported to contain chemicals like amines, amides, phenols and ketones.

Nematode suppression occurs when marigold is grown as an intercrop with nematode susceptible hosts. In pot experiments, marigold plats remain in close proximity to the test host plant thus allowing the root leachate from marigold to reach the root zone of nematode host plant. However, under experimental field condition marigold could be effectively planted along the borders of the planting bed of the main crop to avoid crop competition. Thus, the chances of the marigold root leachate to reach the rhizosphere of the cash crop is comparatively less. On the other hand, intercropping of a biannual or perennial nematode host cash crops with marigold may be a valuable management option as the leaf canopy between the cash crop and marigold will be at different levels, reducing the growth competition between these plants.

3. Different marigold species in suppressing nematode population

Marigold plants suppress plant parasitic nematodes through the process of biochemical interaction known as Allelopathy, which is defined as the release of compounds from plants that are toxic to other plants, micro-organisms or other organisms such as nematodes. Marigold plants produce a number of potentially bioactive compounds among which alpha terthienyl is recognized as one of the most toxic chemical. The sulfur- containing bioactive compounds is abundant in marigold tissues, including roots. The nematicidal activity of marigold has been detected in roots of growing plants but not in root or leaf extracts. The sequence of various events in marigold roots is triggered by the penetration and movement of plant parasitic nematodes through root vascular tissue and the end products of these reactions have a nematicidal effect. The nematicidal bioactive compounds apparently permeate from marigolds' root tissues into nematode attached to the roots. However, they are also believed to inhibit oviposition and hatching of nematode eggs found in the rhizosphere.

It has been reported by Khan et al., 1971 that *Tagetes erecta* when grown as intercrop with different varieties of tomato during winter and different varieties of okra during summer brought reduction in species population of *Meloidogyne*, *Hoplolaimus*, *Rotylenchulus* and *Pratylenchus* [1]. The two nematode genera consistently suppressed by marigold are *Meloidogyne* and *Pratylenchus*, but the mechanism responsible for this suppression is still incomprehensible. *Tagetes patula* was reported to inhibit *Pratylenchulus penetrans* and *Pratylenchulus pratensis* by Oostrenbrink, 1960 and the 4 Meloidogyne species *Meloidogyne arenaria*, *Meloidogyne incognita*, *Meloidogyne javanica* and *Meloidogyne hapla* (Sualmadji, 1969) while *Tagetes erecta* could not inhibit the population of *Meloidogyne hapla* [8]. However, other mechanisms of resistance may operate as well. For example, Siddiqui and Alam (1988) had proposed that root exudates of *Tagetes minuta* inhibited the egg hatching of nematodes. Even though *Tagetes patula* was reported to be antagonistic to *Pratylenchulus penetrans*. This suggested that marigold may act as a "dead end " trap crop for *Pratylenchulus penetrans* and consequently significantly reduce population densities of *Pratylenchulus penetrans* in the field [9, 10]. The allelopathic effect of marigold is contributed due to the several compounds includingessential oils that are extremely bioactive and thus potentially active against nematodes and other plant pathogens like *Alternaria solani*.

It has been reported that alpha terthienyl was a major bioactive compound secreted by marigold roots. These types of compounds along with bithienyl compounds from aerial parts of *Tagetes* sps are extremely bioactive in nature. More recently El-Gengaihi et al., (2001) isolated three nematicidal compounds using chloroform from *Tagetes erecta*, *Tagetes patula* and *Tagetes minuta*. These compounds included 5(-ent-1-ol)-2,2-bithienyl, sigma-4, 22-dien-3-beta-ol, and 5-(4-acetoxy-1-butenyl)-2,2-bithienyl. Alpha- terthienyl is a heterocyclic sulfur containing compound usually abundant in Tagetes tissue [6]. The biological activity is greatly enhanced by photoactivation with the near U-V light, resulting in the production of singlet active oxygen molecule which is biocidal in nature. Gommers and Bakker (1988) proposed that in the absence of light, alpha-therthienyl is activated by root peroxidases synthesized when the plant parasitic nematodes puncture and penetrate the roots [3]. Rotating the cash crop with marigold has been found to have similar effects as growing a non-host crop in reducing plant parasitic nematode population and thus may provide better efficiency than soil fumigant use to suppress nematodes.

4. Conclusion

Although much of the research has been conducted to evaluate marigolds to manage plant parasitic nematodes. There are other potential pest suppressive efficiencies of marigolds. Roots of *Tagetes* sps are highly toxic when applied topically to common housefly (*Musca domestica*), lesser grain borer (*Rhyzopertha dominica*) and red flour beetle (*Tribolium castaneum*). Furthermore, Morallo-Rejesus and Decena (1982) also discovered that *Tagetes erecta* root extract was more toxic to the lesser grain borer and the red flour beetle than a standard insecticide (Malathion 0.05 mg/mL) [7]. Welles et al (1992) depicted that the insecticidal volatiles from *Tagetes erecta*, *Tagetes patula* and *Tagetes minuta* were highly effective against the mosquitoes *Aedes aegypti* and *Anopheles stephensi* and the volatile chemicals from *Tagetes minuta* were highly effective against larvae and adults of mosquitoes [12]. Marigold can be grown ahead of time as a cover crop to suppress nematodes before planting a susceptible crop such as a vegetable crop. It is clear that marigold could be successfully used as a substitute for synthetic nematicides. Nevertheless, marigold could reduce nematode population at greater soild depths than soil fumigation. In addition, marigold is more environmentally friendly than chemical nematicides because it does not suppress other beneficial soil-microorganisms.

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