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Review Article

Natural Plant Products as Eco-friendly Fungicides for Plant Diseases Control- A Review

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Abstract

The use of chemical pesticides for controlling various plant diseases is still a common practice especially in developing countries. Although with the application of chemical fungicides, plant diseases can be controlled but the hazardous impacts of such products in human health and environment are well known. Moreover, with their excess applications pest resistance may exist. Natural plant products have been found effective in plant disease managements and could be safely incorporated as suitable alternatives for synthetic fungicides. It is estimated that there are more than 250,000 higher plant species on earth that can be evaluated for their antimicrobial bioactive chemical compounds. During last several decades researchers have evaluated plant extracts and oils against plant pathogens, valuable results have been achieved and some commercially botanical formulations have been prepared and marketed. If we are supposed to move toward production of safer agricultural products, more attention and effort are still needed for production of more commercially botanical fungicides in the near future. The organic agriculture cannot rely on a limited number of commercially pesticides of natural origin, therefore it seems that more researches in formulating more commercially botanical products as fungicides are still needed.

Keywords: Organic agriculture, botanical fungicides, plant disease, management

1. Introduction

Chemical control of most of fungal diseases of plants may be available and could extensively reduce the impact of plant diseases, but field application of synthetic fungicides may not always be desirable. During the last decades there has been a global awareness that excessive and improper use of chemical fungicides is hazardous to the health of humans, animals, and the environment, therefore an extensive research for environmentally safe and easily biodegradable bio-fungicides is being carried out. Furthermore these compounds are natural in origin, have minimum adverse effects on the physiological processes of plants and are easily convertible into common eco-friendly organic materials (Gnanamanickam, 2002).

Plant extracts, essential oils, gums, resins etc. have been shown to exert biological activity against plant fungal pathogens *in vitro* and *in vivo* and can be used as bio-fungicidal products (Fawzi *et al*., 2009; Jalili *et al*., 2010; Romanazzi *et al*., 2012). These products are generally assumed to be more acceptable and less hazardous for the ecosystems and could be used as alternative remedies for treatment of plant diseases (Chuang *et al*., 2007).

Natural plant products have a narrow target range with specific mode of action, therefore are suitable for a specific target, mostly nontoxic for antagonistic microorganisms, show limited field persistence and have a shorter shelf life and no residual threats. They often constitute a part of integrated pest management (IPM) programs, generally safe to humans and environment in comparison to conventional synthetic chemical pesticides. They can easily be adopted by farmers in developing countries who traditionally use plant extracts for the treatment of human diseases (Nuzhat and Vidyasagar, 2013).

It is estimated that there are more than 250,000 higher plant species on the earth offering a vast virtually untapped reservoir of bioactive chemical compounds with many potential uses, including their application as pharmaceuticals and agrochemicals (Cowan, 1999). As in pharmacology, bio-chemicals isolated from higher plants may contribute to the development of natural products for the agricultural industry in three different ways: 1) - by acting as natural pesticides in an unmodified state (crude extracts), 2) - by providing the chemical 'building blocks' necessary to synthesize more complex compounds and 3) - by introducing new modes of pesticidal action that may allow the complete synthesis of novel products in order to counter the problem of resistance to currently used synthetic products by plant pathogenic fungi and bacteria (Cox, 1990).

Many reports approve the efficacy of natural products of plants in controlling fungal growth and mycotoxin production, eg.: cinnamon, clove, oregano, palmarosa and lemongrass oils (Marin *et al*., 2004), tea tree oil (Burgiel and Smaglowski, 2008), common thyme, cinnamon leaf and aniseed oils (Ćosić *et al*., 2010), sweet basil, neem, eucalyptus, datura, garlic and oleander extracts (Nashwa and Abo-Elyousr, 2012).

Thymol and carvacrol are definitely the most effective active constituents against most fungal species tested (Numpaque *et al*., 2011; Shin *et al*., 2014; Villanueva Bermejo *et al*., 2015; Gavaric *et al*., 2015). The mechanism of action of these compounds against fungi is not completely understood but it is supposed to be in relation to their general ability to dissolve or otherwise disrupt the integrity of fungal cell walls and cell membranes (Isman and Machial, 2006). Some more examples regarding antifungal potential of plant products are listed in table 1.

2. Chemical composition and mode of action of plant products

The most commonly plant products used for plant disease management are essential oils and extracts. These two types of plant based products have many similarities but also differ for some characteristics. Essential oils are oily liquids obtained from plants through fermentation, enfleurage and steam distillation (Burt, 2004), whereas plant extracts, in contrast are obtained from dried plant products by filtration and evaporation using various solvents (Wang *et al*., 2004). The major compounds that have been investigated to date include phenols, flavonoids, quinones, terpenens, tannins, alkaloids, lectins, polypeptides, saponins and sterols (Halama and Van Haluwin, 2004). These products may have fungicidal or fungistatic activity on plant pathogens or they can create conditions unfavourable for establishment and multiplication of pathogenic microorganisms on host plants (Scheuerell and Mahaffee, 2002).

Simple phenols and phenolic acids are bioactive phyto-chemicals consisting a single substituted phenolic ring. Phenolic toxicity to microorganisms is due to the site (s) and number of hydroxyl groups present in the phenolic compound. Quinones are characteristically highly reactive, colored compounds with two ketone substitutions in aromatic ring. Flavones, flavonoids and flavonols are phenolic structures with one carbonyl group. They are synthesized by plants in response to microbial infection and are often found effective *in vitro* as antimicrobial substance against a wide array of microorganisms. Tannins are polymeric phenolic substances possessing the astringent property (Figure 1). These compounds are soluble in water, alcohol and acetone (Gurjar *et al*., 2012). The mechanisms of some important natural compounds on plant pathogenic fungi are given in table 2.

Species of some plant families such as Solanaceae for their high alkaloid contents, Mimosaceae for their high tannins contents and Lamiaceae and Meliaceae for their wide diversity of terpenoids may be more feasible for investigations regarding their biofungicidal compounds. For production of active ingredients, there are some factors that determine variability in quality and quantity of metabolites. The concentration of a chemical in different parts of a plant such as roots, leaves, flowers and fruits may differ. It may even be absent in one or more parts, therefore it is convenient to collect integral samples (Montes-Belmont and Carvajal, 1998).

Table 1. Fungicidal properties of some of plant products

Name of plant product /compound	Controlled plant pathogen	Reference
Acacia, sapodilla, datura, eucalyptus, pomegranate and black plum extracts	*Aspergillus candidus, A. flavus, A. fumigatus, A. niger, A. ochraceus*	Satish *et al*. (2007)
Eucalyptus and lavender extracts	*Alternaria alternata*	Zaker and Mosallanejad (2010)
Clove bud, cinnamon, ginger, black pepper, garlic and onion extracts	*Aspergillus niger*	Avasthi *et al*. (2010)
Neem, chinaberry, garlic and turmeric extracts	*Fusarium oxysporum*, *Rhizoctonia solani*	Hadian (2012)
Artemisia, thyme and eucalyptus extracts	*Fusarium solani*	Zaker (2014)
Indian beech, milk weed, oleander and turmeric extracts	*Aspergillus fumigatus, Alternaria solani, Helminthosporium* spp.	Masih *et al*. (2014)
Kokum, wild turmeric and jasmine extracts	*Rhizopus stolonifer*, *Colletotrichum coccodes*	Bhagwat and Datar (2014)
Grape seed, thyme, rosemary, mint, basil and sage essential oils	*Botrytis cinerea*	Mermer-Doğu and Zobar (2014)
Anise, cumin, caraway, ammin, pennyroyal, thyme and cinnamon essential oils	*Aspergillus flavus*, *Phoma sorghina*, *Alternaria alternata*, *Botrytis cinerea*	Behdani *et al*. (2012)
Pepper and cassia extracts, neem, mustard and cinnamon essential oils	*Phytophthora nicotianae*	Bowers and Locke (2004)
Citral, eugenol and geraniol	*Fusarium moniliforme, Curvularia lunata*	Krishna Kishore *et al*. (2007)
Carvacrol, eugenol, citronellol, geraniol, citral, perillyl and menthol	*Monilinia fructicola*, *Botrytis cinerea*	Tsao and Zhou (2000)
Thymol, carvacrol, 1,8 cineole,Y-terpinene, p-cymene and anethole	*Fusarium moniliforme, Rhizoctonia solani, Phytophthora capsici*	Mueller-Riebau *et al*. (1995)

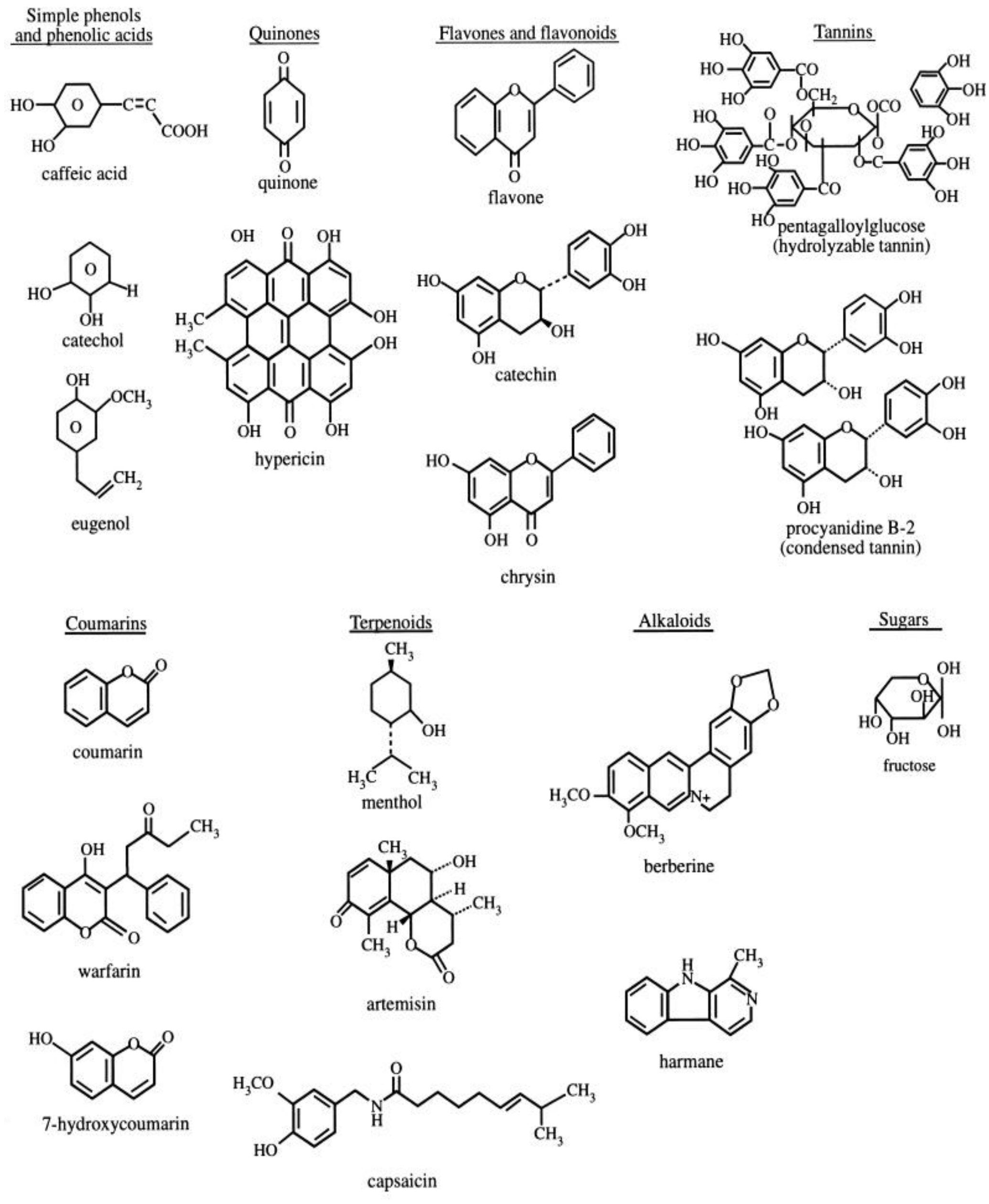

Figure 1. Chemical structures of main groups of natural compounds (Cowan, 1999)

Table 2. Mechanisms of action of phytochemicals (Cowan, 1999)

Name of compound	Mode of action
Simple Phenols	Membrane disruption, substrate deprivation
Phenolic acids	Bind to adhesins, complex with cell wall, inactivate enzymes
Terpenoids	Membrane disruption
Essential oils	Membrane disruption
Alkaloids	Intercalate into cell wall
Tannins	Bind to proteins, enzyme inhibition, substrate deprivation
Flavonoids	Bind to adhesins, complex with cell wall, Inactivate enzymes
Coumarins	Interaction with eucaryotic DNA
Lectins	Form disulfide bridges
Polypeptides	Form disulfide bridges

3. Current aspects of commercially available natural products

Although considerable research efforts throughout the world have been conducted and an ever-increasing volume of scientific literature on the pesticidal properties of plant products and their constituents are available, but some pest control products based on plant essential oils/extracts have been appearing in the market which seems not enough for substituting with current synthetic pesticides.

In the United States, commercial development of insecticides based on plant essential oils/extracts has been greatly facilitated by exemption from registration for certain oils commonly used in processed foods (Quarles, 1996). This opportunity has encouraged the development of some essential oil-based pesticides using rosemary oil, clove oil, and thyme oil as active ingredients for agricultural and industrial applications. Application of these products has been interesting, particularly for control of greenhouse pests and diseases.

The natural plant product Milsana®, extracted from the giant knotweed (*Reynoutria sacchalinensis*) is probably the best known natural fungicide. This product has been reported to control powdery mildew, caused by *Sphaerotheca fuliginea*, in the long English cucumber under greenhouse conditions, and also showed broad spectrum activity against powdery mildew of tomato, apple and begonia as well as downy mildew of grapevine and rust of bean (Daayf *et al*., 1995). A product based on rosemary oil is available fungicide sold under the trade name 'Sporan™'. A volatile natural product, Carvone™, derived from dill and caraway seed, has been developed to inhibit the growth of storage pathogens (Moezelaar *et al*., 1999). Carvone™ is currently marketed as Talent® in the Netherlands. Additionally, Fungastop™ and Armorex™ II, are two natural products developed in the USA by Soil Technologies Corp., and are commercially available for the control of various plant diseases in agriculture. TimorexGold® manufactured by Stockton group (Switzerland) is the new generation of bio-fungicides based on a plant extract of *Melaleuca alternifolia* for the control of powdery mildews, downy mildews, rust and early and late blight diseases in vegetables, grapevines and orchards and is harmless to beneficial insects and bees. For organic farming also some plant essential oils are marketed as fungicides. These include E-Rase™ from jojoba (*Simmondsia californica*) oil, Sporan™ from rosemary (*Rosemarinus officianalis*) oil, Promax™ from thyme (*Thymus vulgaris*) oil, Trilogy™ from neem (*Azadirakhta indica*) oil and GC-3™ being a mixture of cottonseed (*Gossypium hirsutum*) oil and garlic (*Allium* *sativum*) extract. Bla-S™ is used against rice blast disease in eastern Asia, Kasugamin™, against rice blast and other crop diseases in Japan, Mildiomycin™, for controlling powdery mildews mainly in Japan, Delvolan™, against fungal diseases of ornamental plants and Validacin™, for controlling Rhizoctonia root rot of a variety of crops (Dayan *et al*., 2009).

4. Conclusions

Due to hazardous impact of most of synthetic fungicides, in the near future the use of such chemicals must be strictly regulated by governments which may lead to a growing demand for biologically plant protection materials such as plant origin products. Based on approved data and scientific publications it seems evident that plant essential oils/extracts are biodegradable and do not cause similar environmental risks like widely used synthetic chemicals. The option of replacing fossil oil-based chemicals with plant product formulations fits well with food and agriculture policies directed to the future. Sustainable agriculture and food security cannot rely on the use of fossil oil as has been the case for a long time in the developing countries. Local resources should be utilized and thus production of more bio-pesticides should become a common practice.

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