

Antifungal Properties of Bioactive Compounds from Plants

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1. Introduction

Currently, the consequences derived from application of fungicides in traditional agricultural production systems for control of crop diseases have impacted negatively this activity. Fungicides application, where the indiscriminate use and application frequency high has led to problems and constraints in the control of these diseases by loss in efficiency, increased resistance to active ingredients, ecological damage and a serious negative impact on the human health. For this reason, it is had carried out research to develop new products, methods and strategies for diseases control. The investigation and development of bio-based products is of great interest to subtract the negative effects generated by traditional agricultural production systems. The use and application of bioactive phytochemicals with antifungal properties represent an attractive and efficient alternative to inhibit the growth of several fungal pathogens.

These bioactive compounds are naturally produced in the plants how secondary metabolites, the principal groups with antifungal activity were terpenes, tannins, flavonoids, essential oil, alkaloids, lecithin and polypeptides. These groups of compounds are important for the physiology of plants contributing properties confer resistance against microorganisms, other organisms and help preserve the integrity of the plant with continuous exposure to environmental stressors, such as ultraviolet radiation, high temperatures or dehydration.

2. Bioactive antifungal activity groups

2.1 General

Plants have developed natural defense mechanisms to protect themselves long before the man played an active role in protecting them. It is known that plants synthesize a variety of groups of bioactive compounds in plant tissues as secondary metabolites that have antifungal activity to stop or inhibit the development of mycelia growth, inhibition of germination or reduce sporulation of fungal pathogens, each these groups presented variable mechanisms of action, for example, the toxicity of polyphenols in microorganisms is attributed to enzyme inhibition by oxidation of compounds. For essential oils is

postulated that cause disruption of the membrane by the action of lipophilic compounds, the use or employment as formulations of these compounds is in the form of extracts. The process of extraction of secondary metabolites from plant extracts is variable, can be obtained as aqueous extracts or powders using different solvents used for many different compounds, depending on their polarity. It is considered that these compounds obtained from plants are biodegradable and safe for use as an alternative for disease control in a traditional production system (Sepulveda *et al.*, 2003; Hernandez *et al.*, 2007; Wilson *et al.*, 1997; Bautista *et al.*, 2002; Abou-Jawdah *et al.*, 2002; Cowan, 1999).

These substances known as secondary metabolites, *secondary products*, or *natural products*, have no generally recognized, direct roles in the processes of photosynthesis, respiration, solute transport, translocation, protein synthesis, nutrient assimilation, differentiation or metabolism processes as the formation of carbohydrates, proteins and lipids. That is, particular secondary metabolites are often found in only one plant species or related group of species, whereas primary metabolites are found throughout the plant kingdom. In function to classify to chemically groups the secondary metabolites can be divided into three groups: terpenes, phenolics and nitrogen- containing compounds. This classification is due by the interrelationship with primary metabolism Figure 1.

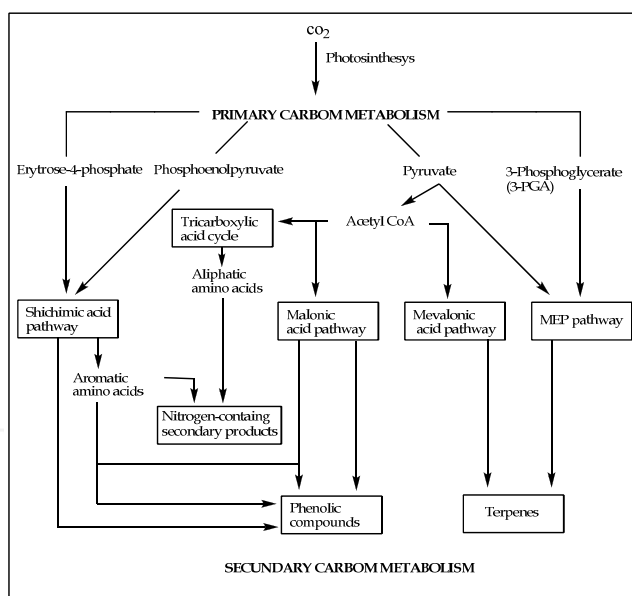


Fig. 1. A simplified view of the major pathways of secondary metabolites biosynthesis and their interrelationship with primary metabolism (Taiz & Zeiger, 2002)

2.2 Polyphenols

Plant phenolics are a chemically heterogeneous group of nearly 10,000 individual compounds: Some are soluble only in organic solvents, some are water-soluble carboxylic acids and glycosides and others are large, insoluble polymers. Present a structure of various

groups replaced by hydroxyl functions benzene and its derivatives are simple phenolic compounds called phenylpropanoids (Figure 2). Allowing them to be highly soluble organic substances in water and are present in extracts of leaves, bark, wood, fruits and galls of certain ferns, gymnosperms and angiosperms (Swain, 1979). These polyphenols are important for the physiology of plants to contribute to resistance to microorganisms, insects and herbivorous animals that can affect (Haslam, 1996), help to preserve the integrity of the plant with continuous exposure to environmental stressors, including radiation ultraviolet, relatively high temperatures and dehydration (Lira *et al.*, 2007). These polyphenol antioxidants are therefore active in biological systems and probably the capacity or biological value explains its abundance in plant tissues (Meckes *et al.*, 2004).

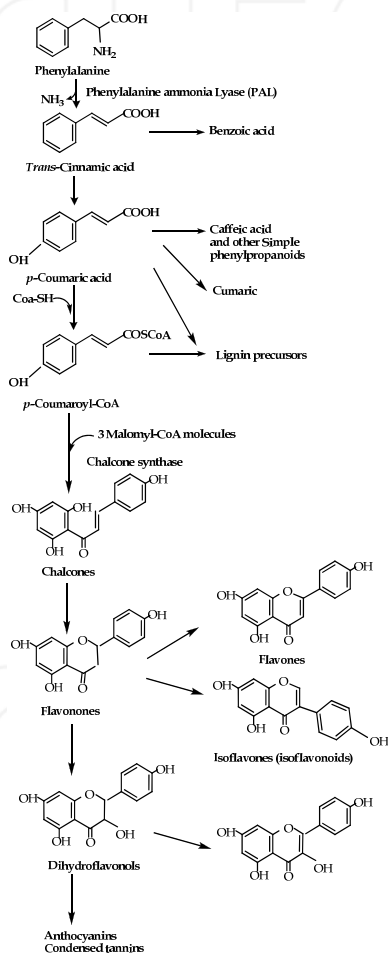


Fig. 2. Outline of the biosynthesis of phenols from phenylalanine. The formation of many plant phenolics, including simple phenylpropanoids, coumarins, benzoic acid derivatives, lignans, anthocyanins, isoflavones, condensed tannins and other flavonoides, begins with phenylalanine (Taiz & Zeiger, 2002)

2.2.1 Hydrolysable tannins (HT)

Are organic compounds, amorphous, taste astringent, weakly acidic, most soluble in water, only a few in organic solvents are yellow, red, or brown and are located in the cytoplasm and cell vacuole of plant tissues. Esters of glucose are partially or fully attached to different polyols such as ellagic acid, say, m-digallic, hexahydroxydiphenic acid or its derivatives (Figure 3). Obtained by hydrolysis with acids, bases and hydrolytic enzymes to break the glycosidic bond to liberate the sugar and phenolic compounds in it. (Gonzalez *et al.*, 2009).

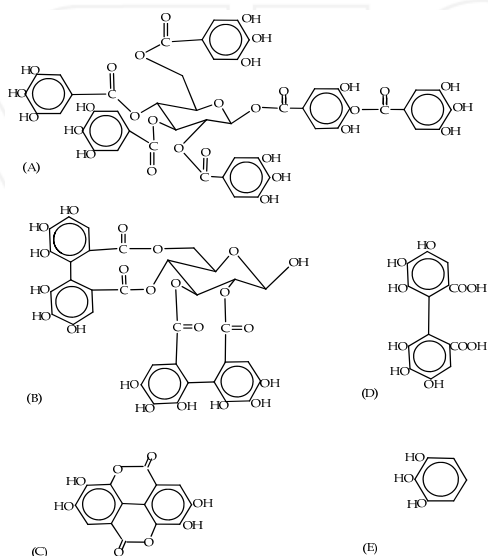


Fig. 3. Hydrolysable tannins and some of its derivatives: A) gallotannins, B) ellagitannins. C) ellagic acid, D) hydroxyphenolic acid, E) gallic acid

The hydrolysable tannins are divided into the following subgroups: The gallotannins, which by enzymatic hydrolysis give more sugar and gallic acid of phenolic compounds that comprise it (Figure 4) and ellagitannins, which give ellagic acid enzymatic hydrolysis more sugar or a derivative as hexahydrophenic acid (Figure 4).

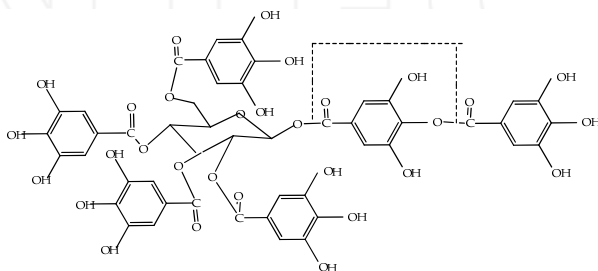


Fig. 4. Chemical structure of a gallotannins

2.2.2 Condensed tannins (CT)

Also called proanthocyanidins (PAS), are derived from the oxidation reaction that produces anthocyanidins (ACS) red in acid-alcohol solution (Figure 5). Are polymers of flavan 3-ol (catechin) and 3-4 flavan diol (leucoanthocyanidins) and have no sugar residues and their carbohydrate content is low or negligible. Are polymers of high molecular weight (1000 to 3000 Daltons), which gives them a relative immobility. Its complexity and easy to form bonds with proteins make them difficult to study. Condensed tannins include flavonoids, which in turn are subdivided into anthocyanidins and leucoanthocyanidins and catechin (Makkar *et al.*, 2007; Taiz & Zeiger, 2002).

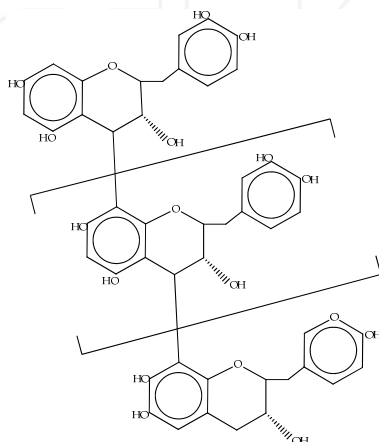


Fig. 5. Condensed tannins or proanthocyanidins

The substituents in the groups R1, R2 and R3, can have an effect on the reactivity of tannin (Figure 6). The group R2 is an OH radical can sometimes be esterified gallic acid (known as Gallo-catechin). For example an increase in the ratio prodelphinidins/procyanidins enhance the ability of condensed tannins to complex proteins.

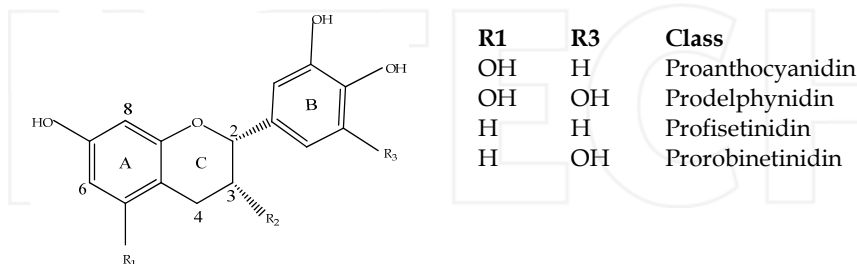


Fig. 6. Structure of some condensed tannins

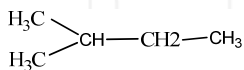
Hydroxyl groups allow the formation of complexes with proteins, metal ions and other molecules such as polysaccharides. In general, polyphenols identified and grouped according to their basic result is a chain of six carbons (Table 1).

Atoms number	Basic carbon skeleton	Compounds
6	C ₆	Simple Phenols and Benzoquinones
7	C ₆ - C ₁	Phenolic acids
8	C ₆ - C ₂	Acetofenons and fenilacetonics acids
9	C ₆ - C ₃	hidroxicinamics Acids, fenilpropanoids
10	C ₆ - C ₄	Naftoquinones
13	C ₆ - C ₁ - C ₆	Xantones
14	C ₆ - C ₂ - C ₆	Estilbens and anthraquinones
15	C ₆ - C ₃ - C ₆	Flavonoids and isoflavonoids
18	(C ₆ - C ₃) ₂	Lignans and neolingnans
30		Biflavonoids
N	(C ₆ - C ₃) _n	Lignins, Catecol Melanins and flavolans
	(C ₆) ₆ (C ₆ -C ₃ - C ₆) _n	

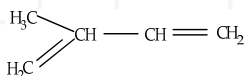
Table 1. Classification of phenolics compounds in carbons atoms to base number (Garcia, 2004)

2.3 Terpenes

The *terpenoids*, constitute the largest class of secondary products, the diverse substances of this class are generally insoluble in water. The terpenes are biosynthesized from primary metabolites by at least two different routes, a route mevalonic acid, where three molecules of acetyl CoA is condensed step by step to form mevalonic acid. This six-carbon molecule is pirofosforilada and dehydrated to form isopentyl diphosphate and this is the basic unit of the terpenes active, the other route is called route metileritritol phosphate that functions in chloroplasts and other plastids. All terpenes are derived from the union of five-carbon elements that have the branched carbon skeleton of isopentane:



The basic structural elements of terpenes are sometimes called **isoprene units** because terpenes can decompose at high temperatures to give isoprene:



The terpenes or *isoprenoids* are classified by the number of five-carbon units they contain, example: Ten-carbon terpenes, which contain two C₅ units, are called *monoterpenes*; 15-carbon terpenes (three C₅ units) are *sesquiterpenes*; and 20-carbon terpenes (four C₅ units) are *diterpenes*. Larger terpenes include *triterpenes* (30 carbons), *tetraterpenes* (40 carbons) and *polyterpenoids* ([C₅]_n carbons, where $n > 8$) (Taiz and Zeiger, 2002).

2.4 Nitrogenous compounds

A large variety of plant secondary metabolites have nitrogen in their structure. Included in this category are such well-known anti-defenses as alkaloids, amines, cyanogenic glycosides, non-protein amino acids, glucosinolates, alkamides and peptides (Wink & Schimmer, 2010). Most nitrogenous secondary metabolites are biosynthesized from common amino acids.

2.5 Plants with antifungal properties

It's has studied the secondary metabolites present in various plant species, one to identify its presence, chemical structure and effect on the plant and on other organisms, so that the number of Identified Substances exceed to 100 000 at present (Wink and Schimmer, 2010) in table 2 shows a relationship of phenolic compounds in other organisms different to the plants with presence of these compounds.

Phylum	Structural patrons
Bacteria	Phenols from polyketides and quinones (occasionally present)
Fungi	Simple phenols, phenylpropanoids, quinones (usually present)
Algae	Oidados and brominated phenols, phloroglucinol derivatives from cell wall
Lichens	Anthraquinones, xanthonones and depsidones
Bryophytes	Phenols in the cell wall, phenylpropanoids, stilbenes and some flavonoids
Ferns, conifers and flowering plants	Lignin in the cell wall and wide range of phenols of all kinds

Table 2. Distribution of polyphenols compounds on different phylum's in comparative to Plant phylum (Garcia, 2004, as cited in Harborne, 1990)

The number of plant species containing one or more of the major groups of compounds with anti-fungal activity is very diverse (Glasby, 1991), in Table 3 lists some of the studied plant with antifungal effect.

Specie	Compounds Identifying	Reference
<i>Simmondsia chinensis</i>	Glucosides	Abbassy <i>et al.</i> , 2007
<i>Thymus zygis</i> subsp. <i>sylvestris</i> ,	Carvacrol	Gonçalves <i>et al.</i> , 2010
<i>A. gypsicola</i> and <i>A. biebersteinii</i>	Camphor , 1,8-cineole, piperitone , borneol and α -terpineol, <i>n</i> -eicosane , <i>n</i> -heneicosane , <i>n</i> -tricosane, linoleic acid	Kordali <i>et al.</i> , 2009
<i>Larrea tridentata</i>	lignans, methyl-nordihydroguaiaretic acid and nordihydroguaiaretic acid	Vargas-Arispuro <i>et al.</i> , 2005

Specie	Compounds Identifying	Reference
<i>Chenopodium quinoa</i>	triterpenoid saponins	Stuardo & Sn Martin, 2008
<i>Aloe vera</i>	Crude extracts	Jasso de Rodríguez <i>et al.</i> , 2005
<i>Drimys winteri</i>	essential oil	Monsálvez <i>et al.</i> , 2010,
<i>Pimenta dioica</i>	Essential oils	Zabka <i>et al.</i> , 2009.
<i>Catharanthus roseus</i>	5-hydroxy flavones	Roy & Chatterjee, 2010
<i>Larrea tridentata</i> , <i>Flourensia cernua</i> , <i>Agave lechuguilla</i> , <i>Opuntia sp.</i> and <i>Yucca sp.</i>	Condensed and hidrolizables Tannins	Castillo <i>et al.</i> , 2010,
<i>Flourensia microphylla</i> , <i>Flourensia cernua</i> and <i>Flourensia retinophylla</i>	Crude extracts	Jasso de Rodríguez <i>et al.</i> , 2007
<i>Salvia officinalis</i>	essential oil	Pinto <i>et al.</i> , 2007
<i>Carya illinoensis</i> shells and <i>Punica granatum</i>	polyphenolic extracts	Osorio <i>et al.</i> , 2010
<i>Bulnesia sarmientoi</i>	bulnesol, hanamyol	Rodilla <i>et al.</i> , 2011
<i>Caesalpinia cacalaco</i>	gallic and tannic acids	Veloz-García <i>et al.</i> , 2010
<i>Clausena anisata</i>	essential oils	Osei-Safo <i>et al.</i> , 2010
<i>Ruta chalepensis</i>	2-undecanone, 2-decanone and 2-dodecanone	Mejri <i>et al.</i> , 2010
<i>Bucida buceras</i> , <i>Breonadia salicina</i> , <i>Harpephyllum caffrum</i> , <i>Olinia ventosa</i> , <i>Vangueria infausta</i> and <i>Xylothea kraussiana</i>	crude plant	Mahlo <i>et al.</i> , 2010
<i>Agapanthus africanus</i>	Crude extracts	Tegegne <i>et al.</i> , 2008
<i>Reynoutria sachalinensis</i>		Pasini <i>et al.</i> , 1997
<i>Laurus nobilis</i>	1.8-cineole, linalool, terpineol acetate, methyl eugenol, linalyl acetate, eugenol, sabinene, β -pinene, α -terpineol.	Corato <i>et al.</i> , 2010
<i>Asarum heterotropoides</i> var. <i>mandshuricum</i>	methyleugenol, eucarvone, 5-allyl-1,2,3-trimethoxybenzene and 3,7,7-trimethylbicyclo(4.1.0)hept-3-ene	Dan <i>et al.</i> , 2010
<i>Rumex crispus</i>	chrysophanol, parietin and nepodin	Choi <i>et al.</i> , 2004; Gyung <i>et al.</i> , 2004

Specie	Compounds Identifying	Reference
<i>Astronium fraxinifolium</i> , <i>Inga marginata</i> , <i>Malva sylvestris</i> , <i>Matayba elaeagnoides</i> , <i>Miconia argyrophylla</i> , <i>Myrcia fallax</i> , <i>Ocimum gratissimum</i> , <i>Origanum vulgare</i> , <i>Rollinia emarginata</i> , <i>Siparuna arianaeae</i> , <i>Styrax pohlii</i> , <i>Tabebuia serratifolia</i> and <i>Trichilia pallid</i>	Crude extracts	Andrade <i>et al.</i> , 2010
<i>Piper longum</i>	Eugenol, piperine, piperlongumine and piperettine)	Lee <i>et al.</i> , 2001
<i>Datura metel</i>	Enzymes, peroxidase, β -1,3-glucanase and chitinase	Devaiah <i>et al.</i> , 2009
<i>Calotropis procera</i> , <i>Nerium oleander</i> , <i>Eugenia jambolana</i> , <i>Citrullus colocynthis</i> , <i>Ambrosia maritima</i> , <i>Acacia nilotica</i> and <i>Ocimum basilicum</i> and fruit extracts of <i>C. colocynthis</i> , <i>C. procera</i> and <i>E. jambolana</i>	Crude extracts	Abdel-Monaim <i>et al.</i> , 2011
<i>Robinia pseudoacacia</i>	Crude extracts	Zhang <i>et al.</i> , 2008
<i>Cassia</i> sp	cassia oil	Feng <i>et al.</i> , 2008
<i>Reynoutria sachalinensis</i>	Crude extracts	Konstantinidou-Doltsinis and Schmit, 1998
<i>Hypericum perforatum</i> and <i>Hypericum tomentosum</i>	α -pinene, <i>allo</i> -aromadendrene, germacrene-D, <i>n</i> -octane, α -selinene and β -selinene. Menthone, <i>n</i> -octane, β -caryophyllene, α -pinene, lauric acid and β -pinene	Hosni <i>et al.</i> , 2008
<i>Metasequoia glyptostroboides</i>	α -pinene, caryophyllene oxide, α -thujene, bornylene, totarol, β -caryophyllene, δ -3-carene, 2- β -pinene and α -humulene.	Bajpai <i>et al.</i> , 2007
<i>Aegle marmelos</i>	essential oil	Pattnaik <i>et al.</i> , 1996
<i>Allium sativum</i>	essential oil	Pyun and Shin 2006
<i>Bystropogon plumosus</i>	essential oil	Economou & Nahrstedt, 1991
<i>Citrus aurantium</i>	essential oil	Pattnaik <i>et al.</i> , 1996
<i>Cryptomeria japonica</i>	essential oil	Cheng <i>et al.</i> , 2005
<i>Cymbopogon flexuosus</i>	essential oil	Pattnaik <i>et al.</i> , 1996
<i>Cymbopogon martini</i>	essential oil	Pattnaik <i>et al.</i> , 1996

Specie	Compounds Identifying	Reference
<i>Eucalyptus citriodora</i>	essential oil	Pattnaik <i>et al.</i> , 1996
<i>Melaleuca alternifolia</i>	essential oil	Nenoff <i>et al.</i> , 1996
<i>Mentha piperita</i>	essential oil	Pattnaik <i>et al.</i> , 1996
<i>Pelargonium graveolens</i>	essential oil	Pattnaik <i>et al.</i> , (1996
<i>Pimpinella anisum</i>	essential oil	Kosalec <i>et al.</i> , (2005
<i>Piper angustifolium</i>	essential oil	Tirillini <i>et al.</i> , 1996
<i>Salvia officinalis</i>	essential oil	Hili <i>et al.</i> , 1997
<i>Salvia sclarea</i>	essential oil	Pitarokili <i>et al.</i> , 2002
<i>Tagetes patula</i>	essential oil	Romagnoli <i>et al.</i> , 2005
<i>Thymbra capitata</i>	essential oil	Salgueiro <i>et al.</i> , 2004
<i>Thymus pulegioides</i>	essential oil	Pinto <i>et al.</i> , 2006
<i>Lavandula angustifolia</i>	essential oil	D'Auria <i>et al.</i> , 2005
<i>Dictamnus dasycarpus</i>	Dictamnine	Zhao <i>et al.</i> , 1998
<i>Heliotropium bursiferum</i>	9-Angeloylretronecine, Heliotrine, Lasiocarpine, Supinine	Marquina <i>et al.</i> , 1989
<i>Ficus septic</i>	Antofine, Ficuseptine	Baumgartner <i>et al.</i> , 1990
<i>Glycosmis cyanocarpa</i>	Illukumbin B, Methylillukumbin B, Methylillukumbin A, N-Methylsinharine, Sinharine	Greger <i>et al.</i> , 1992, 1993
<i>Olea europaea</i>	Hexanal, E-2-Hexanal, E-2-Heptanal, Nonanal and E-2-Octenal	Battinelli <i>et al.</i> , 2006
<i>Cochlospermum tinctorium</i>	Cochloxanthin, Dihydrocochloxanthin	Diallo <i>et al.</i> , 1991
<i>Eupatorium riparium</i>	Methylripariochromene A	Bandara <i>et al.</i> , 1992
<i>Apium graveolens</i>	Angelicin, Bergapten, Columbianetin, Xanthotoxin	Afek <i>et al.</i> , 1995
<i>Wedelia biflora</i>	3'-Formyl-2',4',6'-trihydroxydihydrochalcone	Miles <i>et al.</i> , 1991
<i>Scutellaria spp</i>	Clerodin, Jodrellin A, Jodrellin B	Cole <i>et al.</i> , 1991
<i>Croton sonderianus</i>	Hardwickic acid, 3,4-Secotrachylobanoic acid	McChesney & Clark, 1991
<i>Gomphrena martiana</i> and <i>Gomphrena boliviana</i>	5-Hydroxy-3-methoxy-6,7-methylenedioxyflavone	Pomilio <i>et al.</i> , (1992
<i>H. nitens</i>	3,5,6,7,8-Pentamethoxyflavone, 3,5,6,7-Tetramethoxyflavone, 5,6,7,8-Tetramethoxyflavone, Dimethylchrysin, Trimethylgalangin	Tomas-Barberan <i>et al.</i> , 1988
<i>H. odoratissimum</i>	3-O-Methylquercetin	Van Puyvelde <i>et al.</i> , 1989
<i>Wedelia biflora</i>	veratrylidenehydrazide, 3,3'-di-O-methylquercetin, 2,7-dihydroxy-3(3'-methoxy-4'-hydroxy)-5-methoxyisoflavone and 3',7-di-O-methylquercetin	Miles <i>et al.</i> , 1993
<i>Podophyllum hexandrum</i>	4'-O-demethyldehydropodophyllotoxin and picropodophyllone	Rahman <i>et al.</i> , 1995

Specie	Compounds Identifying	Reference
<i>Piper angustifolium</i>	Camphene	Tirillini <i>et al.</i> , 1996
<i>Cistus incanus</i> subsp. <i>creticus</i>	Geraniol	Chinou <i>et al.</i> , 1994
<i>Bystropogon plumosus</i> , <i>B. organifolius</i> var. <i>palmensis</i> , <i>B. wildpretii</i> , <i>B. maderensis</i> and <i>B. canariensis</i> var. <i>smithianus</i>	Pulegone	Economou & Nahrstedt, 1991;
<i>Zingiber officinale</i>	Gingerenone A	Endo <i>et al.</i> , 1990
<i>Coleonema pulchellum</i>	Precolpuchol	Brader <i>et al.</i> , 1997
<i>P. argentatum</i> × <i>P. tomentosa</i>	8-oxo-Argentone, 8-oxo-15-nor-Argentone, 15-Hydroxyargentone, Argentone and 15-nor-Argentone	Maatooq <i>et al.</i> , 1996
<i>Bidens cernua</i>	Cernuol	Smirnov <i>et al.</i> , 1998
<i>Garcinia mangostana</i>	BR-xanthone A, Garcinone D, Gartanin, Mangostin, γ -Mangostin	Gopalakrishnan <i>et al.</i> , 1997
	(<i>E</i>)-3-Chloro-4-stilbenol, (<i>E</i>)-3,5-Dimethoxy-4- stilbenol, (<i>E</i>)-3,5-Dimethoxystilbene, (<i>E</i>)-3-Methoxy-4-stilbenol, (<i>Z</i>)-4-Methoxy-3-stilbenol, (<i>E</i>)-5-Methoxy-3-stilbenol, (<i>E</i>)-4-Stilbenol, (<i>E</i>)-3-Stilbenol, (<i>Z</i>)-3-Stilbenol, (<i>E</i>)-3,4-Stilbenediol, (<i>E</i>)-3,5-Stilbenediol	Schultz <i>et al.</i> , 1992
	Geraniol, Linalool, 1,8-Cineole, Citral	Pattnaik <i>et al.</i> , 1997
	Isolimonene, Isopulegol, Carvone	Naigre <i>et al.</i> , 1996
	5,7-Dihydroxy-4-hydroxyisoflavan, 6,7-Dihydroxy-4_-methoxyisoflavan, 5,7-Dihydroxy-4_-methoxyisoflavan, Biochanin A	Weidenborner <i>et al.</i> , 1990
<i>Thymus pulegioides</i>	Carvacrol, p-Cymene and γ -Terpinene	Pinto <i>et al.</i> , 2006
	8-Acetylheterophyllisine, Panicutin, Vilmorrianone	Rahman <i>et al.</i> , 1997
	Clausenal	Chakraborty <i>et al.</i> , 1995
	Harman, Harmine, Norharman	Quetin-Leclercq <i>et al.</i> , 1995
<i>Calycodendron milnei</i>	Isopsychotridine E, Hodgkinsine A, Quadrigemine C, Quadrigemine H, Psychotridine E, Vatine, Vatine A, Vatamine, Vatamidine,	Saad <i>et al.</i> , 1995

Specie	Compounds Identifying	Reference
	Dehatrine, Actinodaphnine, Anhydroushinsunine, Methoiodide, N-Methylactinodaphnine	Tsai <i>et al.</i> , 1989
	Anonaine	Tsai <i>et al.</i> , 1989; Simeon <i>et al.</i> , 1990
	Lanuginosine, Lysicamine	Simeon <i>et al.</i> , 1990
	Berberine	Okunade <i>et al.</i> , 1994
	Alkaloids	
	3-Methoxysampangine	Liu <i>et al.</i> , 1990
	Steroidal alkaloids	
	α -Chaconine, α -Solanine	Fewell & Roddick, 1993
	Polygodial	Lee <i>et al.</i> , 1999

Table 3. Chemical compounds identified with antifungal properties derived from species plants

2.6 Effect of compounds in inhibiting mycelia fungi

The most compounds have varied effects on the development of mycelia growth of fungi and the effect on sporulation rate and inhibition of germination ranging from a fungistatic effect to complete inhibition. The answer depends on the arrest of compounds derived from extracts of the species and to inhibit fungus. Table 4 shows the sensitivity of plant pathogen fungi to bioactive coumponds from plants.

Plant Specie	Plant pathogen	Fungicidal activity concentrations	References
<i>Achillea gypsicola</i> and <i>A. biebersteinii</i>	<i>Fusarium equiseti</i> and <i>F. graminearum</i>		Kordali <i>et al.</i> , 2009
<i>Agapanthus africanus</i>	<i>Pythium ultimum</i> , <i>F. oxysporum</i> , <i>Alternaria alternata</i> , <i>Mycosphaerella pinodes</i> and <i>Ascochyta</i>		Tegegne <i>et al.</i> , 2008
<i>Aloe vera</i>	<i>Rhizoctonia solani</i> , <i>F. oxysporum</i> and <i>Colletotrichum coccodes</i>	$10^5 \mu\text{l L}^{-1}$	Jasso de Rodríguez <i>et al.</i> , 2005
<i>Asarum heterotropoides</i> var. <i>mandshuricum</i>	<i>Alternaria humicola</i> , <i>Colletotrichum gloeosporioides</i> , <i>Rhizoctonia solani</i> , <i>Phytophthora cactorum</i> and <i>Fusarium solani</i>	$<0.42 \mu\text{g mL}^{-1}$	Dan <i>et al.</i> , 2010

Plant Specie	Plant pathogen	Fungicidal activity concentrations	References
<i>Astronium fraxinifolium</i> , <i>Inga marginata</i> , <i>Malva sylvestris</i> , <i>Matayba elaeagnoides</i> , <i>Miconia argyrophylla</i> , <i>Myrcia fallax</i> , <i>Ocimum gratissimum</i> , <i>Origanum vulgare</i> , <i>Rollinia emarginata</i> , <i>Siparuna arianaeae</i> , <i>Styrax pohlii</i> , <i>Tabebuia serratifolia</i> and <i>Trichilia pallida</i>	<i>Colletotrichum lindemuthianum</i>	inhibition of conidial germination	Andrade <i>et al.</i> , 2010
<i>Bucida buceras</i> , <i>Breonadia salicina</i> , <i>Harpephyllum caffrum</i> , <i>Olinia ventosa</i> , <i>Vangueria infausta</i> and <i>Xylothea kraussiana</i>	<i>Aspergillus niger</i> , <i>Aspergillus parasiticus</i> , <i>Colletotrichum gloeosporioides</i> , <i>Penicillium janthinellum</i> , <i>Penicillium expansum</i> , <i>Trichoderma harzianum</i> and <i>Fusarium oxysporum</i>	0.02-0.08 mg mL ⁻¹	Mahlo <i>et al.</i> , 2010
<i>Carya illinoensis</i> shells and <i>Punica granatum</i>	<i>Pythium</i> sp., <i>Colletotrichum truncatum</i> , <i>Colletotrichum coccodes</i> , <i>Alternaria alternata</i> , <i>Fusarium verticillioides</i> , <i>Fusarium solani</i> , <i>Fusarium sambucinum</i> and <i>Rhizoctonia solani</i>	0.2 mgL ⁻¹	Osorio <i>et al.</i> , 2010
<i>Cassia</i> sp.	<i>Alternaria alternate</i>	500 µl L ⁻¹	Feng <i>et al.</i> , 2008
<i>Chenopodium quinoa</i>	<i>Botrytis cinerea</i>	5 mg saponins ml ⁻¹ , 100% of conidial germination inhibition	Stuardo <i>et al.</i> , 2008
<i>Drimys winteri</i>	<i>Gaeumannomyces graminis</i> var <i>tritici</i>	932- 30.37mg L ⁻¹	Monsálvez <i>et al.</i> , 2010,
<i>Flourensia microphylla</i> , <i>Flourensia cernua</i> and <i>Flourensia retinophylla</i>	<i>Alternaria</i> sp., <i>Rhizoctonia solani</i> and <i>Fusarium oxysporum</i>	10 to 1500µl L ⁻¹	Jasso de Rodríguez <i>et al.</i> , 2007
<i>Larrea tridentata</i> , <i>Flourensia cernua</i> , <i>Agave lechuguilla</i> , <i>Opuntia</i> sp. and <i>Yucca</i> sp.,	<i>Rhizoctonia solani</i>	2000 ppm of totals polyphenols	Castillo <i>et al.</i> , 2010,

Plant Specie	Plant pathogen	Fungicidal activity concentrations	References
<i>Larrea tridentata</i>	<i>Aspergillus flavus</i> and <i>Aspergillus parasiticus</i>	300-500 $\mu\text{g mL}^{-1}$ of NDGA	Vargas-Arispuro <i>et al.</i> , 2005
<i>Laurus nobilis</i>	<i>Botrytis cinerea</i> , <i>Monilinia laxa</i> and <i>Penicillium digitatum</i>	1, 2 and 3 mg mL^{-1}	Corato <i>et al.</i> , 2010
<i>Metasequoia glyptostroboides</i>	<i>Fusarium oxysporum</i> , <i>Fusarium solani</i> , <i>Sclerotonia sclerotiorum</i> , <i>Rhizoctonia solani</i> , <i>Colletotricum capsici</i> , <i>Botrytis cinerea</i> and <i>Phytophthora capsici</i> ,	Inhibition range of 49–70% and minimum inhibitory concentration ranging from 500 to 1000 $\mu\text{g mL}^{-1}$.	Bajpai <i>et al.</i> , 2007
<i>Piper longum</i>	<i>Pyricularia oryzae</i> , <i>Rhizoctonia solani</i> , <i>Botrytis cineria</i> , <i>Phytophthora infestans</i> , <i>Puccinia recondite</i> and <i>Erysiphe graminis</i>	1mg mL^{-1}	Lee <i>et al.</i> , 2001
<i>Reynoutria sachalinensis</i>	<i>Sphaerotheca pannosa</i> var. <i>rosae</i>		Pasini <i>et al.</i> , 1997; Konstantinidou-Doltsinis & Schmit, 1998
<i>Robinia pseudoacacia</i>	<i>Sphaerotheca fuliginea</i> ,	80 mg mL^{-1}	Zhang <i>et al.</i> , 2008
<i>Rumex crispus</i>	<i>Blumeria graminis</i> f. sp. <i>hordei</i>	30 $\mu\text{g mL}^{-1}$	Choi <i>et al.</i> , 2004
<i>Salvia officinalis</i>	<i>Penicillium</i> , <i>Aspergillus</i> , <i>Cladosporium</i> and <i>Fusarium</i>	0.63 $\mu\text{l ml}^{-1}$	Pinto <i>et al.</i> , 2007
<i>Thymus zygis</i> subsp. <i>sylvestris</i>	<i>Aspergillus</i> strains	0.08- 0.16 $\mu\text{L mL}^{-1}$	Gonçalves <i>et al.</i> , 2010
<i>Cryptomeria japonica</i>	<i>Rhizoctonia solani</i> , <i>Collectotrichum gloeosporioides</i> , <i>Fusarium solani</i> and <i>Ganoderma australe</i>	MIC(50) values of 65, 80, 80 and 110 mg mL^{-1}	Cheng <i>et al.</i> , 2005
<i>Melaleuca alternifolia</i>	<i>Candida albicans</i> and <i>Candida</i> sp.	500–6000	Nenoff <i>et al.</i> , 1996
<i>Pimpinella anisum</i>	<i>Trichophyton rubrum</i> , <i>T. mentagrophytes</i> , <i>Microsporium canis</i> and <i>M. gypseum</i>	MIC to 1.5 and 9.0% (V/V).	Kosalec <i>et al.</i> , 2005
<i>Piper angustifolium</i>	<i>Candida albicans</i> , <i>Cryptococcus neoformans</i> , <i>Aspergillus flavus</i> , <i>Aspergillus fumigatus</i> ,	10–100	Tirillini <i>et al.</i> , 1996

Plant Specie	Plant pathogen	Fungicidal activity concentrations	References
<i>Salvia officinalis</i>	<i>Torulopsis utilis</i> , <i>Schizosaccharomyces pombe</i> , <i>Candida albicans</i> and <i>Saccharomyces cerevisiae</i>		Hili <i>et al.</i> , 1997
<i>Salvia sclarea</i>	Soil-borne pathogens	EC50: 493–584 $\mu\text{L L}^{-1}$	Pitarokili <i>et al.</i> , 2002
<i>Tagetes patula</i>	<i>Penicillium digitatum</i> and <i>Botrytis cinerea</i>	1.25–10.0 $\mu\text{L mL}^{-1}$	Romagnoli <i>et al.</i> , 2005
<i>Thymbra capitata</i>	<i>Candida sp.</i> , <i>Aspergillus sp</i>	0.08–0.32 $\mu\text{L mL}^{-1}$	Salgueiro <i>et al.</i> , 2004
<i>Thymus pulegioides</i>	<i>Candida</i> , <i>Aspergillus</i> and dermatophyte species	0.16–0.64 $\mu\text{L mL}^{-1}$	Pinto <i>et al.</i> , 2006
<i>Lavandula angustifolia</i>	<i>Candida albicans</i>	0.69%	D'Auria <i>et al.</i> , 2005
3-Methoxysampangine	<i>Candida albicans</i> , <i>Aspergillus fumigatus</i> and <i>Cryptococcus neoformans</i>	0.2–3.1	Liu <i>et al.</i> , 1990
Steroidal alkaloids			
α -Chaconine	<i>Ascobolus crenulatus</i> , <i>Alternaria brassicicola</i> , <i>Phoma medicaginis</i> and <i>Rhizoctonia solani</i>	60–100 μM	Fewell & Roddick 1993
α -Solanine	<i>Ascobolus crenulatus</i> , <i>Alternaria brassicicola</i> , <i>Phoma medicaginis</i> and <i>Rhizoctonia solani</i>	80–100 μM	Fewell & Roddick 1993
<i>Dictamnus dasycarpus</i>	<i>Cladosporium cucumerinum</i>	25	Zhao <i>et al.</i> , 1998
<i>Olea europaea</i>	<i>Tricophyton mentagrophytes</i> , <i>Microsporum canis</i> and <i>Candida spp</i>	1.9 -250	Battinelli <i>et al.</i> , 2006
<i>Eupatorium riparium</i>	<i>Colletotrichum gloeosporioides</i>		Bandara <i>et al.</i> , 1992
<i>Wedelia biflora</i>	<i>Rhizoctonia solani</i> ; <i>Pythium ultimum</i> ;		Miles <i>et al.</i> , 1991
<i>Scutellaria spp</i>	<i>Fusarium oxysporum f. sp. lycopersici</i> and <i>Verticillium tricorpus</i>		Cole <i>et al.</i> , 1991
<i>Wedelia biflora</i>	<i>Rhizoctonia solani</i> ; <i>Pythium ultimum</i> ;		Miles <i>et al.</i> , 1993
<i>Podophyllum hexandrum</i>	<i>Epidermophyton floccosum</i> , <i>Curvularia lunata</i> , <i>Nigrospora oryzae</i> ,		Rahman <i>et al.</i> , 1995

Plant Specie	Plant pathogen	Fungicidal activity concentrations	References
	<i>Microsporium canis</i> , <i>Allescheria boydii</i> and <i>Pleurotus ostreatus</i> , <i>Drechslera rostrata</i>		
<i>Piper angustifolium</i>	<i>Candida albicans</i> , <i>Aspergillus flavus</i> , <i>Aspergillus fumigatus</i>	1.0–5.0 mM; 0.016–0.13% of oil;	Tirillini <i>et al.</i> , 1996
<i>Cistus incanus</i> subsp. <i>creticus</i>	<i>Candida albicans</i>	125–375	Chinou <i>et al.</i> , 1996
<i>Thymus pulegioides</i>	<i>Candida</i> , <i>Aspergillus</i>	1.25–20.0 μL mL^{-1}	Pinto <i>et al.</i> , 2006
<i>Zingiber officinale</i>	<i>Pyricularia oryzae</i>	10.0 ppm	Endo <i>et al.</i> , 1990
<i>Coleonema pulchellum</i>	<i>Cladosporium herbarum</i>		Brader <i>et al.</i> , 1997
<i>Parthenium argentatum</i> \times <i>P. tomentosa</i>	<i>Aspergillus fumigatus</i> and <i>A. niger</i>	0.25 mg mL^{-1} 1.0 mg mL^{-1}	Maatooq <i>et al.</i> , 1996
<i>Garcinia mangostana</i>	<i>Fusarium oxysporum</i> <i>vasinfectum</i> , <i>Alternaria</i> <i>tenuis</i> and <i>Drechslera</i> <i>oryzae</i>		Gopalakrishnan <i>et al.</i> , 1997
	<i>Aspergillus repens</i> ; <i>A.</i> <i>amstelodami</i> ; <i>A. chevalieri</i> ; <i>A. flavus</i> ; <i>A. petrakii</i> ;		Weidenböcker <i>et al.</i> , 1990a, b
	<i>Coriolus versicolor</i> , <i>Gloeophyllum trabeum</i> and <i>Poria placenta</i>	8–140	Schultz <i>et al.</i> , 1992
	<i>Aspergillus niger</i>	0.78–100 μL mL^{-1}	Naigre <i>et al.</i> , 1996
	<i>Candida albicans</i> , <i>Trichophyton</i> <i>mentagrophytes</i> , <i>T.</i> <i>rubrum</i> , <i>Penicillium</i> <i>marneffei</i> , <i>Aspergillus</i> <i>fumigatus</i> , <i>A. flavus</i> , <i>P.</i> <i>chrysogenum</i> , <i>C. lipolytica</i> and <i>C. tropicalis</i>	0.78–100.0	Lee <i>et al.</i> , 1999
<i>Cymbopogon flexuosus</i>		0.16–11.6	Pattnaik <i>et al.</i> , 1996
<i>Cymbopogon martini</i>		0.5–8.3	Pattnaik <i>et al.</i> , 1996
<i>Eucalyptus citriodora</i>		0.16–10.0	Pattnaik <i>et al.</i> , 1996
<i>Bidens cernua</i>		5.0–200	Smirnov <i>et al.</i> , 1998
<i>Gomphrena martiana</i> and <i>G. boliviana</i>		75	Pomilio <i>et al.</i> , 1992

Plant Specie	Plant pathogen	Fungicidal activity concentrations	References
<i>Helichrysum nitens</i>		1- 20 µg	Tomas-Barberan <i>et al.</i> , 1988
<i>Allium sativum</i>		64	Pyun and Shin 2006
<i>Psidium acutangulum</i>			Miles <i>et al.</i> , 1993
<i>Croton sonderianus</i>			McChesney & Clark, 1991
<i>Bystropogon plumosus</i> , <i>B. organifolius</i> var. <i>palmensis</i> , <i>B. wildpretii</i> , <i>B. maderensis</i> and <i>B. canariensis</i> var. <i>Smithianus</i>		0.4-85.0% of oil	Economou & Nahrstedt, 1991; Kalodera <i>et al.</i> , 1994
<i>Mentha piperita</i>		0.27-10.0	Pattnaik <i>et al.</i> , 1996
<i>Pelargonium graveolens</i>			Pattnaik <i>et al.</i> , 1996

Table 4. Bioactive compounds from plants on fungal species.

2.7 Commercial use of natural fungicides

Currently, the commercial use of natural fungicides on the market is low, the 5th Annual Meeting of the biological control industry (Loison, 2010) reports a total of 55 biological fungicides registered in the U.S. market and in the EU the registered biopesticides are much fewer: 21 fungicides for be used in Pome fruit, vines and tomato (Table 5).

Commercial name	Active Ingredient	Company	Plant pathogen
BC 1000™	Bioflavonoid of Seed extracts and orange pulp	Chemie S.A.	<i>Botrytis cinérea</i>
Bio save™	Seed extracts and orange pulp	Bioland SA	<i>Ascochyta</i> , <i>Pullullaria</i> , <i>Fusarium</i> , <i>Cercospora</i> , <i>Botrytis</i> , <i>Septoria</i> , <i>Alternaria</i> , <i>Stemphylium</i> , <i>Rhizoctonia</i> , <i>Peronospora</i> , <i>Pythium</i> , <i>Penicilium</i> , <i>Sigatoka</i> , <i>Aspergillus</i> .
Agrispon™	Plant and mineral extracts.	Agric. Sci Dallas	<i>Cercospora beticola</i>
Sincocin™	Plant extracts	Agric. Sci Dallas	<i>Cercospora beticola</i>

Commercial name	Active Ingredient	Company	Plant pathogen
Timorex ^{Gold}	Plant extracts of <i>Melaleuca alternifolia</i>	Stockton Group	<i>Mycosphaerella fijiensis</i>
Evergreen TM	Plant extracts	Aashab bio industries	
Gloves Off TM	Thymol, Carvacrol	Organozoid and Such	<i>Trichophyton mentagrophytes</i>
Garden Fungicide TM	Rosemary, thyme and clove oil	EcoSmart	
Eco Safe TM	Pongamia and Tulsi oil, Recines communis	S. K. Bio Extracts & Applications	Root rot, Damping off, Steam rot, leaf spot
Gloss TM	Natural Alkaloids	S. K. Bio Extracts & Applications	fungal diseases in all field crops, vegetables and horticultural crops

Table 5. Some commercial product in the market with active ingredients from plants

3. Conclusions

The plant extracts applied in as crude state or as a fraction affect the development of fungal colonies to inhibit partially and totally in laboratory tests at low concentrations of bioactive compounds, besides affecting the incidence and severity when applied as a treatment to increase the shelf life of products with excellent results. However, more research is needed to determine its effect on molecular changes, morphological and biochemical these compounds cause the pathogen and host.

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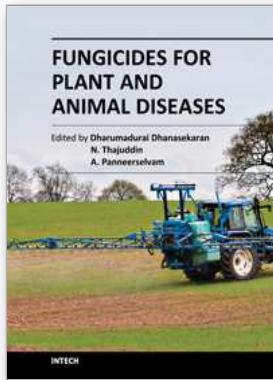
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A fungicide is a chemical pesticide compound that kills or inhibits the growth of fungi. In agriculture, fungicide is used to control fungi that threaten to destroy or compromise crops. Fungicides for Plant and Animal Diseases is a book that has been written to present the most significant advances in disciplines related to fungicides. This book comprises of 14 chapters considering the application of fungicides in the control and management of fungal diseases, which will be very helpful to the undergraduate and postgraduate students, researchers, teachers of microbiology, biotechnology, agriculture and horticulture.

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