Review of agricultural and medicinal applications of basidiomycete mushrooms

Abstract
Basidiomycetes are characterized in part because they produce their basidiospores on a basidium and many but not all have clamp connections that no other group of fungi has. Basidiomycetes are divided into four classes, Gasteromycetes, Ustilaginomycetes, Urediniomycetes and Hymenomycetes. The class Hymenomycetes is characterized by the formation of basidia in a hymenium. Members of this class form visible macroscopic basidiocarps of different shapes, such as mushrooms, puffballs, shelf fungi, jelly fungi, and bird’s nest fungi. Mushrooms have many unique properties that have played major roles in human history, religion, and culture. Of all the fungi, these organisms are the most visible and the most colorful. The purpose of this work was to review the potential of basidiomycete mushrooms as producers of metabolites with agricultural and medicinal applications. Medicinal mushrooms offer an advantage in that their active ingredients are safe for humans. Many compounds, such as b-D-glucans, heteropolysaccharides, glicoproteínas, lectines, and terpenoids inhibit tumor cell lines and did not show negative effects on treated patients. The antimicrobial properties of certain basidiomycetes provide human and plant disease control that is generally safe and effective. Several species of basidiomycetes mushrooms have demonstrated antibacterial activity against human pathogens; others have shown antifungal activity against both human and plant pathogens, while others have inhibited fitopathogenic nematodes. In conclusion, basidiomycetes offer a unique set of compounds with potential to address agricultural and medicinal challenges.

Keywords: Antibacterial, antifungal and helminticidal activities, medicinal applications, polysaccharides, lectines

Resumen
Los basidiomycetos se caracterizan en parte por producir sus basidiosporas sobre un basidio y por tener fíbulas que otros grupos de hongos no tienen. Los basidiomicetos se dividen en cuatro clases: Gasteromycetos, Ustilaginomycetos, Urediniomycetos e Hymenomycetos. Los Hymenomycetos forma sus basidios en un himenio y sus basidiocarpos macroscópicos son de formas variadas, tales como las setas, los bejines, los hongos de repisa, etc. Las setas tienen propiedades únicas que han influenciado de manera importante la historia del ser humano, religión y cultura. De todos los hongos, las setas son las más visibles y llamativas. El propósito de este trabajo fue revisar el potencial de las setas como productoras de metabolitos con aplicaciones en agricultura y medicina. Los ingredientes activos de estos hongos tienen la ventaja de ser seguros para el ser humano. Los b-D-glucanos, heteropolisacáridos, glicoproteínas, lectinas y terpenoides inhibieron células cancerígenas y no presentaron efectos negativos en los pacientes tratados. Las propiedades antimicrobianas de algunos basidiomycetes usados para el control de enfermedades de animales y de plantas generalmente también fueron seguras y efectivas. Varias especies de setas han mostrado actividad antibacteriana contra patógenos de humanos, otras han presentado actividad antifúngica contra patógenos tanto de humanos como de plantas, mientras que otras especies han inhibido nematodos fitopatógenos. En conclusión, los basidiomicetos ofrecen compuestos únicos con potencial para resolver problemas en agricultura y medicina.

Palabras clave: Actividades antibacterianas, antifúngicas y helminticidas, aplicaciones medicinales, polisacáridos, lectinas

1Facultad de Ciencias Agrotecnológicas, Universidad Autónoma de Chihuahua, Ciudad Universitaria S/N Campus 1, Chihuahua, Chih., 31310, México. Phone and Fax: (614) 439-1844
2 Dirección electronica del autor de correspondencia: lrobles@uach.mx
Introduction

Basidiomycetes are characterized in part because they produce their sexual spores (basidiospores) on a cell called basidium usually in fours. Many but not all have clamp connections. No other group of fungi has these structures. The basidium is the cell in which karyogamy (nuclear fusion) and meiosis occur, and on which usually four haploid basidiospores are formed on the tips of sterigmata, which are little prong like projections that originate from the basidium. Millions of these spores are packed together in the hymenium, which covers the exposed or enclosed surfaces of the sporocarp, which are quite variable in form.

These are then discharged a short distance into the space between the gills, tubes, or teeth, of the sporocarp. Subsequently they fall out of the cap to be carried away on air currents (Alexopolous, et al., 1996).

The phylum Basidiomycota is divided into four classes: Gasteromycetes, Hymenomycetes, Ustilaginomycetes, and Urediniomycetes. In the class Gasteromycetes (stomach fungi) the basidia are formed inside the fruiting body, which typically are one-celled. The fruiting bodies of this group remain closed during spore formation and maturation. The class Hymenomycetes is characterized by the formation of basidia in a hymenium. Members of this class typically form visible macroscopic basidiocarps of different shapes, such as mushrooms, puffballs, shelf fungi, jelly fungi, and bird’s nest fungi. The classes Ustilaginomycetes (smut fungi and allied taxa) and Urediniomycetes (rust fungi and allied taxa) comprise mostly plant parasitic taxa, and most members in both classes form teliospores, thick-walled resting spores, in which karyogamy occurs and from which basidia are formed (Alexopolous et al., 1996).

Mushrooms have many unique properties that have played major roles in human history, religion, and culture. These highly adaptive organisms mainly feed on dead and occasionally living matter. Of all the fungi, these organisms are the most visible and the most colorful. Most of us recognize the value of mushrooms as food and certainly, some species as delicacies.

The medicinal properties of basidiomycete mushrooms are frequently described in ancient cultures and a few have been developed into pharmacological applications today. In Asian cultures, the holocarp of several genera are eaten, included as a garnish, or boiled as teas and applied as therapies for a variety of human ailments ranging from the common cold to cure for certain forms of cancers.

A major development in agricultural chemistry was derived from the pine cone fungus, Strobilurus tenacellus. Strobilurin fungicides have become a valuable tool for managing plant diseases. These strobilurins are site-specific (inhibition of mitochondrial respiration) and translaminar (systemic) compounds that provide control of Oomycota, Ascomycota, Basidiomycota, and Deuteromycota fungi.

The nematode-destroying fungi have diverse morphological and physiological adaptations to the environment. Some are parasitic by means of constricting rings, injectable spores, and/or adhesive peg cells. Some secrete attachments to trap and
penetrate the nematode, or by secreting toxins to inactivate the prey nematodes. Potent antibiotics may be secreted by the colonizing hyphae to protect the food source from other microorganisms (Barron, 1977).

The bactericidal activity has also been reported. When 317 strains, representing 204 species and 17 orders of basidiomycete mushrooms were screened for antimicrobial activity on human pathogens, over 45% of the tested strains were positive for antibacterial activity (Suay et al., 2000). The highest activity occurred among members of the Ganodermatales, Poriales, Agaricales, and Stereales. Eight species of the family Ganodermataceae strongly inhibited Bacillus subtilis; Fomes fomentarius inhibited growth of Pseudomonas aeruginosa, Serratia marcescens, Staphylococcus aureus, B. subtilis, and Mycobacterium smegmatis. In this review, we focus on the potential of basidiomycete mushrooms as producers of metabolites with medicinal and agricultural applications.

Medicinal Applications

Anti-cancer substances of mushroom origin

Cancer accounts for over 6 million deaths each year worldwide (Jang et al., 1997). Prostate cancer only accounts for 33% of all newly diagnosed malignancies among men in the United States (Crawford, 2003). Cancer chemopreventive agents include nonsteroidal anti-inflammatory drugs (NSAIDs), such as indomethacin, aspirin, piroxicam, and sulindac. All of these synthetic products inhibit cyclooxygenase (COX) functions. This inhibitory activity is extremely important to cancer chemoprevention because COX catalyzes the conversion of arachidonic acid to proinflammatory substances such as prostaglandins (PGs) that stimulate cell growth and suppress the immune response. COX can also activate carcinogens to damage genetic material (Jang et al., 1997). There are at least two kinds of COX enzymes, COX-1 and COX-2. COX-1 makes PGs to protect the stomach and kidney from damage; while COX-2 induced by inflammatory stimuli, such as cytokine, produces PGs that promote the pain and inflammation (Vane and Botting, 1998) and induction to tumor formation (Vane, 2000).

In searching for new cancer treatments over the past several years, many species of basidiomycete mushrooms have been investigated for their anti-cancer properties (Yang and Jong, 1989). Lucas, (1957) first demonstrated the anti-cancer activity of mushrooms. He used extracts of fruiting bodies of Boletus edulis and other mushrooms in tests against implanted Sarcoma 180 line in mice. The anti-cancer calvacin, a conjugated protein containing one or more carbohydrate residues was extracted from the giant puffball Calvatia gigantea and tested against many experimental tumors, such as Sarcoma 180, mammary adenocarcinoma 755, leukemia L-1210, and HeLa cell lines presenting significant growth inhibition on those types of cancer (Lucas, 1957). Many other anti-cancer compounds of mushroom origin, including b-D-glucans, heteropolysaccharides, glycoproteins, lectines, and terpenoids have been investigated. The primary sources of these compounds are discussed below.

b-D-Glucans

b-D-Glucans are homopolysaccharides that contain only glucose monomeric units
-D-glucans with anti-cancer activity have been identified from several species of mushrooms belonging to the orders Auriculariales, Tremellales, and Polyporales; families Gasteromycetidae, and Agaricomycetidae through screening against Sarcoma 180 in mice (Mizuno, 1995). Lentinan, and other glucans isolated from the shiitake mushroom Lentinus edodes, have shown anti-cancer activities. Lentinan showed prominent anti-cancer activity against implanted Sarcoma 180 and other synergic and autochthonous tumors (Wasser, 2002), while a-glucan, administered at a dose of 20 mg/kg of body weight to BALB/C mice having implanted solid Sarcoma 180 was effective with an inhibition rate of 42% (Zhang and Cheung, 2002).

b-D-glucans sometimes are referred as biological response modifiers (BRMs) because they activate the host immune system. They bind to lymphocyte surfaces or serum specific proteins, which activate macrophage, T-helper, NK, and other cellular effectors. All of the above increase the production of antibodies as well as interleukins (IL-1, IL-2) and interferon IFNg (Mizuno, 1995). The main component of these substances is (1à3)-b-D-glucan (Wasser and Weis, 1999) arranged in a triple helical tertiary configuration as illustrated in Figure 1. This configuration is known to be important for the immune-stimulating activity. For example, when lentinan and schizophyllan were denatured to their primary structure with dimethyl sulfoxide, urea, or sodium hydroxide, significant reduction in tumor inhibition was observed. These findings confirmed the correlation between anti-cancer activity and the triple helix structure (Wasser, 2002).

Mushroom b-D-Glucans preventing oncogenesis, showed direct anti-cancer activity against various allogeneic and syngenic tumors, and tumor metastasis (Wasser, 2002). Significant reductions in size of the tumors were observed in mice treated with lentinan. Lymphocytes extracted from AKR mice treated with lentinan for 7 days were inoculated into the nude mice. This was followed by...
implantation of human colon-carcinoma cell lines into these mice. The nude mice treated with lymphocytes extracted from the AKR mice, developed much smaller tumors than those non-treated with the same lymphocytes (Ng and Yap, 2002).

**Heteropolysaccharides**

Heteropolysaccharides consist of monosaccharides linked together by glycosidic bonds. They are heteropolysaccharides because they contain more than one type of monomeric unit, such as D-glucose, D-fructose, D-galactose, L-galactose, D-mannose, L-arabinose, and D-xylose (Garrett and Grishman, 1999; Voet and Voet, 1995). Anti-cancer heteropolysaccharides containing chains of xylose, mannose, galactose, and uronic acid have been isolated from several species of basidiomycete mushrooms (Wasser and Weis, 1999). For example, EA501, isolated from golden needle *Flammulina velutipes* consisted of D-glucose 42.3%, D-galactose 17.3%, D-mannose 12.2%, D-xylose 6.7%, and L-arabinose 14.7% (Ikekawa et al., 1982). Several other heteropolysaccharides have been identified from the Chinese mushroom ‘huangmo.’ F10 (a mixture of galactose-containing heteroglycan and b-d-glucan), FA-1 and FA-2 (containing b-d-glucan with galactose, hetero-glycan and protein), FII-2 (consisting of b-D-glucan), FIII-1-b and FIII-2-b [containing (1â6) b-D-glucosyl branched (1â3) b-D-glucan] reduced cancer activity in mice implanted with Sarcoma 180 cells (Ma et al., 1991).

Other heteropolysaccharides isolated from culture fluids of *Agaricus blazei* containing glucomannan with a chain of b-D-glucopyranosyl-3-0-b-glucopyranosyl residues as a side chain also reduced cancer activity in mice implanted with Sarcoma 180 cells (Mizuno et al., 1999). Another anti-cancer water-soluble heteropolysaccharide, S-3-B (1â6)-branched (1â3)-b-glucan was isolated from the fruiting bodies *Cryptoporus volvatus*. Enzymatic analysis using exo-(1â3)-b-D-glucosidase and methylation analysis indicated that this heteropolysaccharide has a main chain composed of b-(1â3)-linked D-glucopyranosyl residues and b-(1â6)-linked D-glucopyranosyl residues attached as side chains approximately every fourth sugar residue of the main chain. This polysaccharide showed anti-cancer activity when tested against Sarcoma 180 implanted in mice (Kitamura et al., 1994). In a recent study, a new heteropolysaccharide, Ganopoly®, extracted from *Ganoderma lucidum*, increased production of antibodies and concentrations of interleukin-2, interleukin-6 and interferon IFNg, and reduced levels of tumor-necrosis factor (TNF-a) in most patients (Gao et al., 2003).

**Glycoproteins**

Glycoproteins, are proteins covalently attached to carbohydrates such as glucose, galactose, lactose, fucose, sialic acid, N-acetylglucosamine, N-acetylgalactosamine, etc. (Donald and Judith, 1995). Several glycoproteins produced by basidiomycetes have been studied for their anti-cancer activity. For instance, KS-2 extracted from mycelia of *Lentinus edodes* containing a-amanan product linked to a peptide composed of serine, threonine, alanine, and other amino acid residues inhibited growth of both Sarcoma 180 and Ehrlich tumors (Fujii et al., 1978). Flo-A, a water-soluble glycoprotein, isolated from the mycelia of *Ganoderma tsugae* showed anti-cancer activity on Sarcoma 180 implanted in mice.
Flo-A consisted of 9.3% protein, heteroglyco-chain of mannose and xylose (Zhang et al., 1994). Flo (water-soluble glycoprotein) and FIII-1 and FIII-2 (water-insoluble glycoproteins) extracted from the oyster mushroom Pleurotus citrinopileatus presented a very strong anti-cancer activity against Sarcoma 180 implanted in mice. The Flo glycoprotein consisted of protein, mannose, glucose, arabinose, and galactose. Both the water-insoluble, FIII-1 and FIII-2, showed protein-containing β-D-glucans (Zhang et al., 1994). Similar anti-cancer glycoproteins were identified from fruiting bodies of Tricholoma giganteum. FII-a glycoprotein (water-soluble) was composed of a mixture of α-D-glucan and xyloglucomannan. FA-1 contained 1% of protein, FII-1, contained 7.8% protein, and FII-2-a, b, and c, consisted of xylose, galactose, and protein. Both water-soluble and water-insoluble glycoproteins showed strong anti-cancer activity against Sarcoma 180 implanted in mice (Mizuno et al., 1995).

Lectins

Lectins are glycoproteins that bind carbohydrates with high specificity. They agglutinate red blood cells or precipitate polysaccharides. They identify vital cells, such as erythrocytes, and bind complex carbohydrates and proteins. (Donald and Judith, 1995). It has been reported that some species of basidiomycetes, including Agaricus sp., Polyporus sp., Agrocybe sp. produce lectins that are useful to study polysaccharides and glycoproteins, as well as enzymatic modifications and cellular membranes. Because of their characteristic sequences, lectins can be used to diagnose cancer cells, or as specific binding moieties for targeted cancer therapy. For example, N-acetylglactosamine, a specific lectin isolated from Grifola frondosa, agglutinated all types of erythrocytes equally (Griffin, 1994; Wassser and Weis, 1999). Agaricus bisporus agglutinin (ABA) reacted with monosaccharides and possessed a potent anti-cancer effect on malignant colon epithelial cells (Wu et al., 2003). A lectin, AAL, isolated from the edible mushroom Agrocybe aegerita, showed strong growth inhibition of human tumor cell lines, such as HeLa, SW480, SGC-7901, MGC80-3, BGC-823, HL-60, and mouse Sarcoma 180 (Zhao et al., 2003). Another lectin isolated from the mushroom Polyporus adusta showed antiproliferative activity against tumor cell lines and mitogenic activity of splenocytes. A large range of other carbohydrates inhibited the hemagglutinating activity of this lectin. 

Terpenoids

Terpenoids are the combination of two or more molecules of 2-methyl-2, 3-butadiene, also known as isoprene (a five-carbon unit that is abbreviated C5). Terpenoids are subdivided according to the number of carbon atoms. For example, a monoterpenoid (C10) consists of two subunits of isoprene, a sesquiterpene (C15) consists of three isoprene units, and so on (Garrett and Grishman, 1999). Many terpenoids isolated from Polyporales and Ganodermales mushrooms have anti-cancer properties. There have been reported about 100 different types of terpenoids obtained from fruiting bodies of...
Ganoderma lucidum and G. applanatum. For instance, ganoderic acids, furanoganodic acids (Figure 2), lucidinic acids, ganolucidinic acids, lucidic acids (Figure 3) and other triterpenoid components, including methyl lucidenate P, methyl ganoderic acid O, trideacetyl ganoderic acid T have been investigated (Iwatsuki et al., 2003; Wasser and Weis, 1999).

Omphalotus olearius and Lampteromyces japonicus produce a cytotoxic tricyclic sesquiterpene, illudin S=lampterol, which has strong anti-cancer properties and inhibits cancer cell growth by a unique mechanism. Activated by glutathione, it is then bound to DNA. This prevents DNA replication and leads to cell death (Wasser and Weis, 1999). Three different triterpene aldehydes, including lucidaldehydes A, B, and C, were isolated from fruiting bodies of G. lucidum. Their structures were determined and their cytotoxicity tested against Lewis lung carcinoma, T47D, Sarcoma 180, and Meth...
A tumor cell lines. Of these three lucidaldehyde terpenoids, lucealdehyde C showed the highest cytotoxicity in all the tumor cell lines tested (Gao et al., 2002).

Agricultural Applications

Antibacterial Activity

When 317 strains, representing 204 species and 17 orders of basidiomycete mushrooms were screened for antimicrobial activity on human pathogens, over 45% of the tested strains were positive for antibacterial activity (Suay et al., 2000). The highest activity occurred among members of the Ganodermatales, Poriales, Agaricales, and Stereales. Eight species of the family Ganodermae: including three strains of Ganoderma lucidum, three of G. pfeifferi, and two of G. resinaceum strongly inhibited Bacillus subtilis. Members of the family Coriolacea, for instance Laetiporus sulphureus showed bactericidal activity against Serratia marcescens, Staphylococcus aureus, and Bacillus subtilis (Suay et al., 2000). Ganoderma applanatum inhibited Gram-positive bacteria such as Bacillus cereus and Staphylococcus aureus were less inhibitory against Gram-negative bacteria, including Escherichia coli and Pseudomonas aeruginosa (Smania et al., 2001). The woody tinder fungus, Fomes fomentarius inhibited growth of P. aeruginosa, Serratia marcescens, S. aureus, B. subtilis, and Mycobacterium smegmatis, a relative of the pathogenic Mycobacterium tuberculosis. Other reports have shown that Ganoderma lucidum has antibacterial activity against Staphylococci, Streptococci, and Bacillus pneumoniae and against Gram-positive bacteria (Brian, 1951). Lentinan from shiitake mushroom Lentinus edodes inhibited Mycobacterium tuberculosis and Listeria monocytogenes (Chihara, 1992). Three antibacterial substances extracted with chloroform, ethyl acetate, or water from fruiting bodies of L. edodes are active against Streptococcus sp., Actinomyces sp., Lactobacillus sp., Prevotella sp., and Porphyromonas sp. Other bacteria, such as Enterococcus sp., Staphylococcus sp., Escherichia sp., and Bacillus sp. were relatively resistant to these substances. It was suggested that these active compounds might be similar to lenthionine, disulphide derivative and lentinan types, respectively (Hirasawa et al., 1999). Crude culture fluids of L. edodes presented antibacterial activity against Streptococcus pyogenes, Staphylococcus aureus, and Bacillus megaterium (Hatvani, 2001). Coprinol is isolated from culture fluids of Coprinus sp. with antibacterial activity against many multi-drug resistant Gram-positive bacteria in-vitro (Johansson et al., 2001). The fungicide strobilurin, F 500 enhances resistance of tobacco to the wild fire pathogen Pseudomonas syringae pv. tabaci. The mechanism of action of strobilurin F 500 is by inducing cellular responses to the pathogen attack. It induces production of endogenous salicylic acid and pathogenesis-related proteins that usually are used as molecular markers for disease resistance (Herms et al., 2002).

Antifungal Activity

In addition to their antibacterial potential, some basidiomycete mushrooms have antifungal activity. For instance, the oyster mushroom Pleurotus ostreatus inhibits the growth of Aspergillus niger the causal agent of aspergillosis, a lung disease that seriously threatens people with compromised immune systems (Gerasimenya et al., 2002). A member of the Poriales, Gloephyllum sepiarium,
inhibited growth of *Sacharomyces cerevisiae* and *Aspergillus fumigatus* (Suay et al., 2000). A novel ribosome-inactivating protein, hypsin, isolated from fruiting bodies of the edible mushroom *Hypsizigus marmoreus*, inhibited the mycelial growth of several fungal species, such as *Mycosphaerella arachidicola*, *Physalospora piricola*, *Fusarium oxysporum*, and *Botrytis cinerea* with an IC$_{50}$ of 2.7, 2.5, 14.2, and 0.06 mM, respectively (Lam and Ng, 2001b). Another ribosome-inactivating protein, lyophyllin, isolated from fruiting bodies of the mushroom *Lyophyllum shimeji* showed antifungal activity against *P. piricola* and *M. arachidicola* with an IC$_{50}$ of 70 mM (Lam and Ng, 2001a). The 10-oxo-trans-8-decenoic acid (ODA) and 1-octen-3-ol produced by *Agaricus bisporus* and other species of mushrooms during the enzymatic breakdown of linoleic acid (Champavier et al., 2000; Okull et al., 2003) inhibited the mycelial growth of *Penicillium expansum*, the common food spoilage organism, at concentrations of 1.25 mM and at pH 3.5 (Okull et al., 2003). Lentin, a new antifungal protein of 27.5 MW extracted from fruiting bodies of *Lentinus edodes* inhibits *P. piricola*, *Botrytis cinerea*, and *M. arachidicola* (Ngai and Ng, 2003). Three different triterpenes, applanoxidic acids A, C, and F, isolated from *Ganoderma annulare* inhibit mycelial growth of *Microsporum cannis* and *Trichophyton mentagrophytes* at concentrations of 500 to 1000 mg/ml (Smania et al., 2003). Some isolates of *G. applanatum* were highly antagonistic against to the rhizomorph of *Armillaria luteobubalina* (Perch, 1990).

Strobilurins is another class of fungicidal compounds extracted from mycelia of the mushroom *Strobilurus tenacellus*. Strobilurins A and B were highly active by inhibiting respiration of yeast and other filamentous fungi (Anke and Oberwinkler, 1977). The biological activity of strobilurins involve ubihydroquinone cytochrome C reductase, which plays a crucial role in respiration (Gatti and Tzagoloff, 1990). Its activity, however, depends of the presence of (E)-b-methoxyacrylate moiety (Fredenhagen et al., 1990). The antifungal (E)-b-methoxyacrylates of strobilurin C and outdemansin B from cultures of *Xerula longipes* inhibit many phytopathogenic fungi. Like the strobilurins A and B, they also inhibit fungal respiration (Anke et al., 1983). Strobilurin E is another antifungal compound of the (E)-b-methoxyacrylate class extracted from mycelial cultures of *Crepidotus fulvotomentosus*. In addition to inhibiting fungal respiration, it can induce cell deformations (Weber et al., 1990). Strobilurins D and F are other strobilurins, extracted from mycelial cultures of the basidiomycete *Cyphellopsis anomala* that have cytostatic and antifungal antibiotics of the (E)-b-methoxyacrylate class. These strobilurins inhibit many fungi, and like strobilurins A and B, they also are potent inhibitors of respiration (Weber et al., 1990). Strobilurin M isolated from the mushroom *Mycena* sp. also showed antifungal and cytostatic activities (Defernet al., 1998). Other strobilurins F, G, and H extracted from culture fluids of *Bolina lutea* Sacc. inhibit *Aspergillus fumigatus*, *Botrytis cinerea*, *Microsporum cannis* and *Sporotrichum schenckii*. These compounds reduce fungal respiration; however, they might be different from the analogs previously described (Fredenhagen et al., 1990).

**Strobilurins**

There are abundant nutrients and a large variety of life forms in soil. There are groups of microorganism for relationships and associations that includes predation or
parasitism. The relationship between fungi and nematodes is especially interesting to scientists. Nematode destroying fungi are those that trap and feed on nematodes by predation and parasitism. Fungal species that trap or consume nematodes mainly belong to Zygomycetes, Basidiomycetes and Hyphomycetes found in agricultural soil and in decaying organic debris (Barron, 1977).

Fresenius in 1852 (cited in Barron, 1977) observed a fungus that produced scattered conidiophores and clusters of large two-celled conidia. He named this fungus *Arthrobotrys oligospora*. Later, Woronin (1870) [cited in Barron, 1977] observed that aerial hyphae of *Arthrobotrys* curved and fused with themselves to form nets of hyphae. Finally, Zopf (1888) [cited in Barron, 1977] proved that these hyphal nets trapped motile nematodes and penetrated them. The fast growing hyphae consumed and killed the nematodes. Approximately fifty years later, Drechsler (1933) [cited in Barron, 1977] showed that adhesive fungal nets were responsible for holding the captured nematodes.

The nematode-destroying basidiomycetes, the Nematoctonus, were first described by Drechsler (1941) [cited in Barron, 1977] as he discovered that two species possessed clamp connections but lacked sexual states. To date, a total of nine species have been described having this Nematoctonus predatory and endoparasitic ability. Predaceous species capture nematodes by means of adhesive knobs on prostrate hyphae. Endoparasitic species have adhesive knobs on the spores, which attach directly to the cuticle of the nematode (Barron, 1977). The adhesive device is a secretory cell with an hourglass shape. The cells bind the so tightly that they completely immobilize nematodes (Barron, 1977; Thorn and Barron, 1984).

Some species of Nematoctonus produce small basidiocarps in-vitro similar to the *Agaricales* of the hymenial basidiomycetes. The basidiospores produced are discharged and germinate in the presence of nematodes and form adhesive knobs (Barron, 1977; Thorn and Barron, 1984). *Hohenbuehelia*, a gilled fungus in the Pleurotiales (Agaricales, Hymenomycetes), is teleomorphic. At least 10 species of gilled fungi belonging to the genera *Hohenbuehelia*, *Pleurotus*, and *Resupinate* can attack nematodes by adhesion or through the production of toxins (Thorn and Barron, 1984).

Some species of Nematoctonus, such as Nematoctonus haptoclados and *N. concurrens* produce nematotoxins. As nematodes touch the adhesive spores of these species, they became immobile and die before being penetrated. Nematode death occurs within 24 hours after attachment. This immobilization prevents host from escaping. When the female nematodes are attacked, the nematotoxin prevents eggs to hatch (Barron, 1977).

Concluding Remarks

Basidiomycetes is a highly evolved group of fungi. These fungi convert organic carbon to inorganic carbon in the carbon cycle. Edible species of basidiomycetes are well known. The commercial mushrooms *Agaricus bisporus*, *shiitakii mushroom* (*Lentinus edodes*) and *oyster mushroom* (*Pleurotus spp.*) are the most common. However, many wild mushrooms, such as *Fistulina hepatica*, *Sparassis crispa*, *Albatrellus sp.*, *Grifola frondosa*, the bear’s head (*Hericium erinaceum*), and chicken of the woods (*Laetiporus sulphureus*) are also edible. Medicinal mushrooms offer an advantage in that their active ingredients are safe for humans. Many compounds, such as b-D-glucans, heteropolysaccharides,
glycoproteins, lectins, and terpenoids inhibit tumor cell lines. The antimicrobial properties by certain basidiomycetes provide human and plant disease control that is generally safe and effective. Several species of basidiomycetes inhibit both Gram-positive and Gram-negative human pathogenic bacteria. Other basidiomycetes have demonstrated antifungal activity against both human and plant pathogens and the Nematoconus, are active against several plant pathogenic nematodes. Basidiomycetes offer a unique set of compounds with potential to address agricultural and medicinal challenges.

Literature Cited


LORETO ROBLES-HERNÁNDEZ, ANA CECILIA-GONZÁLEZ-FRANCO, JUAN MANUEL SOTO-PARRA AND FEDERICO MONTES-DOMÍNGUEZ: Review of agricultural and medicinal applications of basidiomycete mushrooms


Este artículo es citado así:


Resúmenes curriculares de autor y coautores

Loreto Robles-Hernández. Es profesor de la Facultad de Ciencias Agrotecnológicas de la Universidad Autónoma de Chihuahua. Obtuvo su Doctorado en la Universidad de Idaho, USA, su Maestría y Licenciatura en la Universidad Autónoma de Chihuahua. Actualmente conduce su investigación sobre enfermedades de plantas. El Dr. Robles imparte los cursos de Fitopatología, Microbiología, Control Biológico y Fisiología de Poscosecha. Es asesor de estudiantes de posgrado y forma parte de comité de asesores del posgrado. Actualmente es responsable del área de diagnóstico de enfermedades y fisiología de poscosecha en el laboratorio de Microbiología Aplicada, Fitopatología y Fisiología de Poscosecha de la Facultad de Ciencias Agrotecnológicas-UACH.
ANA CECILIA GONZÁLEZ-FRANCO. Es profesor de la Facultad de Ciencias Agrotecnológicas de la Universidad Autónoma de Chihuahua. Obtuvo su Doctorado en la Universidad de Idaho, USA, su Maestría y Licenciatura en la Universidad Autónoma de Chihuahua. Actualmente conduce su investigación sobre enfermedades fúngicas, enfermedades virales y control biológico. Imparte las cátedras de Interacción microorganismo planta, Bioquímica, Química y Biotecnología. Asesora estudiantes de posgrado y forma parte del comité de asesores de posgrado. Es miembro del Sistema Nacional de Investigadores. Actualmente es responsable del área de microbiología aplicada y biología molecular en el laboratorio de Microbiología Aplicada, Fitopatología y Fisiología de Postcosecha de la Facultad de Ciencias Agrotecnológicas-UACH.


FEDERICO MONTES-DOMÍNGUEZ. Es profesor de la Facultad de Ciencias Agrotecnológicas de la Universidad Autónoma de Chihuahua. Obtuvo su Maestría en 1998 y su licenciatura en 1989 en la misma institución; realiza investigación en las áreas de Fisiología y Nutrición Vegetal, con énfasis en la Fisiología de la Producción en los cultivos del manzano y nogal pecanero. Actualmente ocupa el cargo de Responsable Técnico en la Unidad Experimental «la Semilla» de la Universidad Autónoma de Chihuahua.