Chapter 33

Mexican Knowledge of Medicinal Macrofungi

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ABSTRACT

In this chapter, the knowledge of medicinal macrofungi in Mexico is discussed from pre-Hispanic times to the present day. Earliest records for the use of macrofungi in healing rituals and/or as medicine to cure some diseases date from the 15th-16th century. This traditional knowledge have passed from generation to generation, and in many cases, it is still used in some Mexican regions. The use of bioactive macrofungi extracts in oriental countries is reviewed due to the great tradition in taking advantage of these compounds to cure diseases and because many of these species have been introduced to the Mexican market. Finally, the scientific research developed in Mexico is analyzed regarding the biological activity of fungal extracts obtained from local species. Some of the extracts had antioxidant, immunostimulant, antimicrobial, antiparasitic and cytotoxic effects, some of them also showed reduction in cholesterol and triglyceride levels, drop in weight gain, increment in the intestinal microbiota and inhibition of cancer cells proliferation. Given the great fungal diversity in Mexico and the extraordinary traditional knowledge of native people, it is fundamental that scientific research continue to be performed by multidisciplinary groups that include those who carry the ancestral wisdom.

KEYWORDS
Medicinal mushrooms, Traditional knowledge, Mexico, Biocompounds.

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INTRODUCTION

This chapter summarizes the available knowledge of medicinal fungi in Mexico, from early written sources from the pre-Hispanic period, to current research on bioactive compounds. Expertise from indigenous people included descriptions of mushroom species with geographical location, the diseases treated and the practices that have transcended time and are still in use in some communities. It also compiles bioactive properties found in fungi collected around the world and the medicinal fungal species that have been introduced to the Mexican market. Finally, it outlines researches performed in Mexico that have studied the bioactive properties of local species and their potential use to improve population's health.

Mushrooms in Traditional Mexican Medicine

Since its origins, humans have made use of the natural resources that are around them and Mexico, being a biologically megadiverse country with great cultural diversity with more than 68 indigenous peoples in its territory, has a vast knowledge of plants, animals, and mushrooms, mainly edible, medicinal and those used in ceremonies or rituals (Guzmán, 2008).

Most of our knowledge about pre-Hispanic uses for mushrooms came from sources like codex, chronicles and documents, both pre-Hispanic and colonial. In these sources, it has been documented the knowledge that the inhabitants of Mesoamerica had about sacred, edible, and medicinal mushrooms, examples are the Codex Vindobonensis, Magliabecchiano, Lienzo de Zacatepec, and Crónica Mexicana, among many others (Hernández-Santiago et al., 2017).

From the occidental perspective, the study of the mycological knowledge and practices of indigenous peoples dated back to early work by Fernando de Alva Ixtlilxóchitl and Fernando de Alvarado Tezozómoc or Chimalpain, heirs of the indigenous nobility, who perceived the importance of codex and similar documents and tried to understand them with the help of elder people (Pérez-Chávez et al., 2019).

Fray Bernardino de Sahagún in La Historia general de las cosas de Nueva España (Florentine Codex), gathers the knowledge and uses of natural resources of pre-Hispanic peoples. In this work, at least six species of edible mushrooms are described in Nahuatl, considering their morphology, growth form and ecology. In this book, *teonanácatl* is mentioned for

the first time, and the representation of this mushroom, which corresponds to a species of the genus *Psilocybe*, appears as a sacred mushroom with hallucinogenic, intoxicating and divinatory properties, which was also used to relieve cold fever and gout (Pérez-Chávez et al., 2019).

In Mexico, the use of neurotropic mushrooms of the genus *Psilocybe* in ceremonies and rituals is well known, mainly in Oaxaca. Shamans or healers ingest mushrooms together with patients, to communicate with their gods, and thus know how to help them with their sufferings such as anxiety and toothache (Guzmán, 2011).

Mushrooms are considered valuable resources in traditional medicine, which may be defined as "the set of knowledge, beliefs, practices and resources from popular culture, which the country's population makes use of to empirically solve some of their health problems." (Lozoya, 1989).

The majority of records on the traditional use of medicinal mushrooms have been documented in Nahua, Mayan and Hñähñú communities associated with temperate forests in central and southern Mexico. Little is known about these therapeutic resources in tropical and arid areas of the north of country. In Mexico, more than 350 species of fungi and lichens with some medicinal uses have been recorded. Not all of those species are used neither by indigenous peoples or mestizo communities, but about 150 health conditions are referred to be treated with mushrooms, such as: digestive, respiratory, circulatory, musculoskeletal and nervous systems diseases, skin, nose and eye conditions, as well as diseases related to "the evil eye", scare and "empacho" (Bautista-González and Herrera-Campos, 2019).

Among the most important mushrooms, the "cuitlacoche", *Mycosarcoma maydis* (DC.) Bref., stands out for its flavor and medicinal properties. It is used to treat more than 50 **healthconditions** in different indigenous peoples and mestizo communities, mainly in the central and south regions. When fresh, it is cooked in a broth to relieve colic, diarrhea, indigestion, hangover, inflammation and stomach pain. Dehydrated spores are used to treat skin burns, bleeding wounds, skin rashes, chafing, cold sores, athlete's foot, heal the navel of newborns and stop nosebleeds. In a similar way, the gleba (mass of spores) of mature sporocarps of *Astraeus, Bovista, Calvatia, Geastrum, Lycoperdon,* and *Tulostoma species,* is used to treat multiple skin conditions (Bautista-González and Moreno-Fuentes, 2014).

In the southern state of Chiapas, Ruan-Soto et al. (2021) documented the use of 19 species for medical purposes. Six correspond to species found in highlands (genera *Calvatia*, *Geastrum* and *Lycoperdon*), 12 species in lowlands, and one in both regions (*Lycoperdon perlatum*). In general, they are used as antihemorrhagic and antiseptic in superficial skin wounds; other species such as *Phaeoclavulina cokeri*, *P. zippelii* and *Ramariopsis* sp. are used to remove warts (Ruan-Soto et al., 2021).

Felger and Moser (1974), recorded the use of several medicinal mushrooms by the Seris in Sonora, such as *Battarreoides diguetii* (Pat. and Har.) R. Heim and T. Herrera, *Podaxis pistillaris* (L.) Fr., and *Tulostoma* sp., all used for healing burns and cuts. In a recent study with Yuman peoples from Baja California (Kiliwa, Kumiai, Paipai and Cucapá), the use of 14 species of fungi (mainly gasteroids) was documented, those are used to treat skin problems, as well as food and for recreational purposes (Bautista-González et al., 2022).

It should be noted that some toxic mushrooms have also been used for healing purposes, for example, *Amanita muscaria* (L.) Lam. which is used as a diuretic and purgative (Guzmán, 2008), to treat dysentery (Montoya et al., 2002) and mitigate stomach pain and headache (Bautista-González and Moreno-Fuentes, 2014).

In different indigenous communities of Mexico, since pre-Hispanic times the conception of edible mushrooms as beneficial foods for health persists. They are considered a food that provides energy, proteins, vitamins and fiber, being tastier and more nutritious than meat (Bautista- González and Moreno-Fuentes, 2014).

Scientific Knowledge of Medicinal Fungi in the World

Although the medicinal knowledge of mushrooms is ancestral, it was not until the 20th century, when scientific interest began in knowing the active principles and biomolecules that **confer** these characteristics to mushrooms consumed directly and to the extracts obtained from them. Traditional knowledge about the medicinal properties of mushrooms is very broad in ancient cultures such as China and due to this tradition of consumption and use of mushrooms as medicines, western scientific communities have turned their attention to the research of their bioactive compounds. It has been proven that mushrooms have anti-cancer, antibiotic (bacteria, viruses and fungi), anti-parasitic, antioxidant, anti-thrombotic, anti-diabetic functional properties, reduce cholesterol and hypertension, and are immunomodulatory, anti-inflammatory, hepatoprotective, anti-allergic and help the body to overcome the effects of chemotherapies (Pérez-Armendariz et al., 2010; Patel et al., 2012; Martínez-Carrera et al., 2016; Chugh et al., 2022).

Currently, bioactive compounds have been discovered in the United States, Japan and the European Union and these products have been patented and approved. The bioactive fungal compounds modify biological responses by activating, stimulating or reinforcing various body systems, for example, the immune and the endocrine systems (Pérez et al., 2010; Martínez-Carrera et al., 2016). They help the metabolism of proteins, lipids and carbohydrates, influence the intestinal flora and induce the expression, activation or modulation of specific genes and metabolic pathways (Martínez-Carrera et al., 2016).

The functional properties of fungi are found in the mycelium and sporocarps, and as a result of their secondary metabolism, they are also found in the culture medium where they develop (Martínez-Carrera et al., 2016).

Tables 1 and 2 include some of the most popular active ingredients that have been identified and that are being further studied to precisely establish their application, dosage and mode of action. These are, for example, high molecular weight polysaccharides (alpha glucans, beta glucans, heteroglycans, proteoglycans, proteoheteroglycans and polysaccharopeptides), proteins, fats, ashes, glycosides, alkaloids, volatile oils, tocopherols, phenols, flavonoids, carotenoids,

folates, enzymes, organic acids, micronutrients, antioxidants (glycoproteins, triterpenoids, flavonoids, ergosterol) and unsaturated fatty acids. Polysaccharides are the fungal compounds with the most powerful anticancer activity. In addition, they reduce cholesterol, triglycerides and blood sugar and stimulate the immune system. Of this group, the most important are beta glucans (Pérez et al., 2010; Patel and Goyal, 2012; Chugh et al., 2022).

Table 1: Bioactive compounds present in mushrooms and their medicinal functions that have been scientifically proven in the world. Sources: (Rogers, 2011); (Roncero, 2015); (Chugh et al., 2022)

Bioactive compound	Medicinal activity proven *in vivo/in vitro*
Aplanoxidic acid	Antiviral against influenza type A
Coumaric acid, p-coumaric acid, Tr-cinnamic acid, Vanillic acid, ρ-hydroxybenzoic acid	Protectors against oxidative stress, against disorders associated with aging
Ganoderic acid	Antitumor against HIV-1
Beta-carotenes,Beta tocopherol	Antioxidants
Catechol	Protectors against oxidative stress, against disorders associated with aging
Phenolic compounds	High antioxidant capacity
Ergothioneine	Excellent antioxidant
Erigin	Antifungal
Schizophyllan	Helps in the treatment of gastric and cervical cancer
Flavoglaucine	Excellent lipid antioxidant capacity
Ganodermadiol	Antiviral against influenza type A
Ganopoly	Immunostimulant and hypoglycemic activity. Its high efficiency in reducing the effects of chemotherapies has been demonstrated.
Glycoprotein FIPs	Immunostimulant activity
Grifolan	Increases insulin production, improves the immune response, fungicide, reduces inflammation of the mucous membranes of the respiratory tract, anti-cancer
Lectins	Immunomodulatory, antiproliferative and antitumor activity, hypoglycemic, anti-inflammatory.
LEM	Immunomodulator
Lentinan	Antitumor, immunomodulator, helps in the treatment of HIV, helps with the side effects of chemotherapies and the recovery of patients, reduces inflammation and intestinal ulcers, antioxidant.
Licidadiol	Antiviral against influenza type A
Lignins	Antivirals, inhibit the development of HIV
Lovastatin	Lowers cholesterol levels
Pleuran	Anticarcinogenic, immune system stimulant, protects the respiratory tract, reduces cholesterol and LDH levels, antioxidant, antiallergic.
Pleurosthrin	Antifungal.
Peptide polysaccharide (PSP)	Important antitumor and immunomodulatory agents
Peptide polysaccharide GPP	Immunostimulant activity
Polysaccharide-K (PSK, crestine)	Important antitumor and immunomodulatory agents
Selenium	Antioxidant, helps repair DNA damage
Tyrosine	Protectors against oxidative stress, against disorders associated with aging
Triterpenes	More than 120 different ones are antivirals active against HIV and herpes type I, inhibit cholesterol synthesis, reduce the risk of atherosclerosis, stimulators of the immune system, antitumor activity.

Medicinal Fungi Currently Introduced in Mexico

Since the end of the 20th century, the consumption and knowledge of mushrooms and their derivatives have become very popular around the world, and Mexico is no exception to this great flow of information. With the introduction of nutraceutical foods, adaptogenic mushrooms and the popularization of superfoods, many products containing mushrooms and their derivatives are being introduced into the market, which are sold in various presentations, such as food supplements, aqueous or alcoholic extracts, purified extracts, capsules, tablets and drinks (Roncero, 2015). Electronic commerce is making the introduction of these products into the Mexican market much easier and it is possible to acquire any mushroom and its derivatives from anywhere in the world. The countries that export the largest volumes of mushrooms to Mexico are the United States, Spain and Italy (Secretaría de Economía, 2023) and it is increasingly common to find them in local naturopathic stores and pharmacies. Table 2 includes the mushrooms that are most frequently available in Mexico through e-commerce.

Table 2: Mushrooms sold in Mexico through e-commerce, in health food stores and pharmacies in the form of pills, capsules, flour and as ingredients in food supplements.

	Species	Active ingredients	Applications	References
1	*Agaricus blazei* Murrill	Agartine, proteroglycans, ergosterol, beta glucans, blazein	Immunomodulatory, anticancer, antimutagenic, antioxidant, antibacterial, anti-inflammatory, cytotoxic in myeloma cells. Inhibits the proliferation of prostate, lung and stomach cancer cells. Reduces xenograft tumors. Agaritine has inhibitory action against monocytic lymphoma of leukemia. The extracts are used against leukemia. Aqueous extracts may be beneficial in treating allergic reactions. It improves the quality of life of patients with chemotherapy, increases the immune response by inducing the production of interleukin-12 and interferon gamma.	Choi et al., 2006; Yuminamochi et al., 2007; Itoh et al., 2008; Patel and Goyal, 2012; Tangen et al., 2017
2	*Cordyceps militaris* (L.) Link	Cordlan, cordycepin. Mannitol, trehalose, polyunsaturated fatty acids, delta tocopherol, oxalic, citric, fumaric, p-hydroxybenzoic and cinnamic acids have been found in its extracts. b-(1R3)-D-glucan	It showed effectiveness against several types of cancer: prostate, colon, hepatoma, breast, lung, uterine, cervical, it is an activator of the immune system and acts against leukemia. It presents strong antioxidant, antibacterial, antifungal and anti-inflammatory activity.	Patel and Goyal, 2012; Filipa et al., 2013; Reis et al., 2013; Smiderle et al., 2014
3	*Flammulina velutipes* (Curtis) Singer.	FIP-five protein, flamulina velutipes peptidoglycan, β1,3-D-glucan, flammin,velina, velutin, lovastatin	FIP-five presents immunomodulatory activity, activates T lymphocytes, and antitumor activity in liver cancer. Flamulin demonstrated antitumor activity. A hemagglutinin inhibits the proliferation of L1210 leukemia cells. Aqueous extracts demonstrated activity against breast cancer. It has anti-cancer, anti-inflammatory activity. Stops atherosclerosis, reduces cholesterol levels, inhibits thrombosis, anti-aging, restores neurotransmitters associated with memory and learning, helps in cases of Parkinson's and Alzheimer's.	Patel and Goyal, 2012; Tang et al., 2016; Chugh et al., 2022; Liuzi et al., 2023
4	*Ganoderma lucidum* (Curtis) P. Karst.	Ac. **g**anoderic T, LZ-D-4; LZ-D; dichloromethane, triterpenoids and their derivatives such as ganoderal, ac. ganodermic, lucidone, ganodermanondiol, ganodermanontriol, lucidon. Adenosine, FIP-glu.	It has effects against gastric cancer, ac. **G**anoderic**o** produced inhibition of tumor invasion and metastasis. It is a promising agent against colon cancer. LZ-D showed positive results for the control of lymphocytic leukemia. Dichloromethane has action against human papilloma oncoprotein and cervical squamous cell carcinoma. Lowers cholesterol, blood pressure and prevents cardiovascular diseases. Antiallergic, cytotoxic, neuroprotective, anti-inflammatory. Antibacterial, antifungal, antimalaria, antiviral.	Patel and Goyal, 2012; Chugh et al., 2022; Sułkowska-Ziaja et al., 2023
5	*Grifola frondosa* (Dicks.) Gray	Beta glucano, grifola frondosa lectina,	It produces vitality, improves the action of anti-cancer medications, and its activity has been demonstrated against gastric carcinoma. Controls the growth of tumors. Powerful immunomodulator. Lowers cholesterol, blood pressure and prevents cardiovascular diseases. Anti-inflammatory and controls atherosclerosis, hypoglycemic, hypotensive.	Kodama et al., 2002; Patel and Goyal, 2012; Chugh et al., 2022
6	*Hericium erinaceus* (Bull.) Pers.	Erinacins, hericenones. Polysaccharides such as: **X**ylans, glucoxylans, heteroxyloglucans, galatoxyloglucans.	Antitumor and immunomodulatory effects. It stimulates the growth of nervous factors, acting in the conservation, regeneration and survival of neurons. Positive effects in cases of dementia, Parkinson's and Alzheimer's. Antihyperglycemic and antihypercholesterolemic. Anti-aging and antioxidant.	Patel and Goyal, 2012; Thongbai et al., 2015; Chugh et al., 2022; Yanshree et al., 2022

7	*Inonotus obliquus* (Fr.) Pilat	Sclerotin. Contains antioxidants (superoxide dismutase, melanin); triterpenes (lupeol, betulin, inotodiol); polyphenols, sterols, polysaccharides. Ac, betulinic.	Extracts in hot water and ethanol induced apoptosis in colon cancer cells, presented antiproliferative properties in melanoma cells, sclerotin presented antitumor activity. Antioxidants, anti-allergy, anti-aging, anti-inflammatory.	Patel and Goyal, 2012; Thongbai et al., 2015; Chugh et al., 2022; Yanshree et al., 2022
8	*Lentinula edodes* (Berk.) Pegler	Lentin, emitanin, heteromannans, heterogalactans.	Suppresses the proliferation of leukemia. Lowers blood pressure and prevents cardiovascular diseases. Immune system modulator, antitumor, antiviral, antimicrobial, cholesterol regulator, anti-**a**therosclerotic, antidiabetic, antioxidant regulator of homocysteine metabolism.	Patel and Goyal, 2012; Chugh et al., 2022; Ponnusamy et al., 2022
9	*Trametes versicolor* (L.) Lloyd	Kresina, musarin, tramesan	Activity has been demonstrated against several types of cancer including prostate, gastric, lung, leukemia, lymphoma, breast, liver and melanoma	Patel and Goyal, 2012; Scarpari et al., 2017; Chugh et al., 2022; He et al., 2022; Lowenthal et al., 2023

Biological Activity of Macroscopic Fungi Collected in Mexico

In Mexico there are several research groups interested in using mushroom extracts to solve some public health problems. Table 3, shows recent studies that assessed the biological activity of some Basidiomycota metabolites collected in 10 Mexican states. They used different extracts to perform *in vitro* or *in vivo* assays and found that some fungal strains had antioxidant, immunostimulant, antimicrobial, antiparasitic and cytotoxic effects. They also showed reduction in the cholesterol and triglyceride levels, drop in weight gain, increment in the intestinal microbiota and inhibition of cancer cells proliferation.

The information included in Table 3 is only a sample of the multidisciplinary academic community that is actively investigating the properties of fungal extracts in the field of medicine and nutrition. Although most of the studies are not intended to discover and describe the extract's active ingredients, the chemical characterization would allow a better understanding of the action mechanism and would guarantee their safety. This is particularly relevant, because in Mexico, there is a large market for food supplements made out of fungi, however, most of the research in this regard is in its initial phase.

Table 3: Biological activity of macrofungi collected in Mexico

Fungal species	Extract type	Cell lines or organisms assessed	Biological activity	Citation
Lentinus lepideus (Fr.) Fr. *Armillaria tabescens* (Scop.) Emel *Calvatia cyathiformis* (Bosc) Morgan *Coriolus versicolor* (L.) Quél. *Ganoderma applanatum* (Pers.) Pat. *Ganoderma* sp. *Suillus luteus* (L.) Rousel *Suillus lakei* (Murrill), A.H. Sm. and Thiers *Ganoderma lobatum* (Cooke) G.F. Atk. *Armillaria mellea* (Vahl) P. Kumm.	Filtered and lyophilized culture broth	Dichlorodihydrofluorescein diacetate assay (antioxidant activity), Cunningham's technique in BALB7c male mice (immunomodulating activity), *Escherichia coli*, *Staphylococcus aureus*, *Candida albicans*, *Mycobacterium smegmatis* and *Sporothrix schenkii* (antimicrobial activity)	*Suillus luteus*, *Lentinus lepideus* and *Suillus lakei* showed antioxidant activity. A *Suillus lakei* sample demonstrated immunomodulating activity. *Ganoderma applanatum*, *Armillaria mellea* and *Suillus lakei* showed antimicrobial activity	González-Barranco et al., 2010
Phellinus badius (Cooke) G. Cunn. *Phellinus gilvus* (Schwein.) Pat. *Phellinus rimosus* (Berk.) Pilát	Methanolic	Antioxidant activity assessed *in vitro*, antifungal activity tested against *Alternaria alternata*	All the species showed antioxidant activity and *P. gilvus* had the highest effect. All the species have effective and similar antifungal activity	Ayala-Zavala et al., 2012
Lentinus lepideus (Fr.) Fr. *Calvatia cyathiformis* (Bosc) Morgan *Ganoderma applanatum* (Pers.) Pat.	Aqueous and methanolic	Male Wistar rats with alloxan-induced diabetic condition	Glucose levels in blood decreased with both extracts. Non-significant reduction in cholesterol levels was observed	Tamez de la O et al., 2013

Ganoderma lucidum (Curtis) P. Karst.	Aqueous	HeLa and SiHa cervical cell lines transformed by human papillomavirus and C-33A cancer cells	Extracts inhibited cell growth and induced apoptosis	Hernández -Márquez et al., 2014
26 fungal species in total: 19 Agaricales, 5 Boletales, 1 Geastrales and 1 Russulales	Ethanolic	Lung cancer cell lines H-460	*Agaricus xanthodermus*, *Boletus amygdalinus* and *Geastrum corolinum* showed cytotoxic activity	López-Sánchez et al., 2016
Ganoderma lucidum (Curtis) P. Karst.	Hydroalcoholic	Male mice C57BL/6 fed with 7 different diets high in cholesterol	Reduction in total serum cholesterol, low density lipoprotein cholesterol, triglyceride concentration, hepatic cholesterol and hepatic triglycerides. Increase in gut microbiota	Meneses et al., 2016
Pleurotus levis (Berk. and M.A. Curtis) Singer *Pleurotus ostreatus* (Jacq.) P. Kumm. *Pleurotus pulmonarius (*Fr.) Quél. *Pleurotus tuber-regium* (Fr.) Singer	Hydroalcoholic	Antioxidant activity assessed *in vitro*, antibacterial effect tested against 8 bacterial species	High antioxidant and antibacterial effects in *P. levis* and *P. tuber-regium*	Adebayo et al., 2018
Pleurotus djamor var. *djamor* (Rumph. ex Fr.) Boedijn *Pleurotus djamor* var. *roseus* Corner	Methanolic	Antioxidant activity assessed *in vitro*	Hybrid strains H1 and H3 showed the highest antioxidant effects	Oropeza-Guerrero et al., 2018
Ganoderma lucidum (Curtis) P. Karst.	Hydroalcoholic	Male mice C57BL/6	Hypocholesterolemic and prebiotic activity	Romero-Córdoba et al., 2021
Amanita rubescens Pers. *Astraeus hygrometricus* (Pers.) Morgan *Laccaria laccata* (Scop.) Cooke *Lycoperdon perlatum* Pers.	Ethanolic and methanolic	Antioxidant activity assessed *in vitro*, antibacterial effect tested against *Staphylococcus aureus, Streptococcus agalactiae, Candida albicans* and *Candida* sp.	High antimicrobial activity detected in *A. hygrometricus* and *L. perlatum*. All the strains showed antioxidant effects.	Martínez-Escobedo et al., 2021
Ganoderma curtisii (Berk.) Murrill *G. australe* (Fr.) Pat. *G. applanatum* (Pers.) Pat. *G. colossus* (Fr.) C.F. Baker *G. lobatum* (Cooke) G.F. Atk. *G. oregonense* Murrill *G. resinaceum* Boud.	Chloroform-methanol	Tumor-derived cell lines (lung, breast, cervix and colon). Antioxidant activity assessed *in vitro*, antibacterial effect tested against *Staphylococcus aureus, Pseudomonas aeruginosa, Enterococcus faecalis* and *Escherichia coli*.	Some strains showed considerable antiproliferative, antibacterial and antioxidant activity	Serrano-Márquez et al., 2021
Ganoderma oerstedii (Fr.) Murrill *G. weberianum* (Bres. and Henn. ex Sacc.) Steyaert *G. subincrustatum* Murrill	Ethanolic	HeLa, A549 and RAW 264.7 cancer cell lines. *Staphylococcus aureus* and *Escherichia coli*. Anti-inflammatory and antioxidant activity assessed *in vitro*	Anti-proliferative activity in cancer and non-cancer cell lines. Moderate antioxidant effects.	Bacallao-Escudero et al., 2023
Ganoderma tuberculosum Murrill	Hexane	*Leishmania amazonensis, Trypanosoma cruzi, Acanthamoeba castellanii* and *Naegleria fowleri* Murine macrophages	Some of the compounds showed high anti-parasitic activity and low macrophage cytotoxicity	Espinosa-García et al., 2023

Pleurotus ostreatus (Jacq.) P. Kumm. *Ganoderma lucidum* (Curtis) P. Karst. *Ustilago maydis* (DC.) Corda	Powdered basidiomata and galls were used	Male Wistar rats fed with 6 different diets high in fat and amended with saccharose.	Reduction in weight gain, fat mass, serum biochemical parameters levels and endoplasmic reticulum stress in subcutaneous adipose tissue. Maintenance of fat-free mass. Prevention of adipocyte hypertrophy and collagen deposition	González-Ibáñez et al., 2023
Ganoderma lucidum (Curtis) P. Karst.	Hydroalcoholic	Male and female Wistar rats	Toxicity effects were not recorded in kidney or liver tissues. Considerable prebiotic activity	Meneses et al., 2023
Trametes versicolor (L.) Lloyd	Aqueous and ethanolic	Human lymphoid cells	Increment in the lymphocyte count. Genetic damage detected at high doses	Salinas-Solis et al., 2023

Conclusions

Based on traditional knowledge of medicinal macrofungi, numerous scientific investigations have characterized bioactive compounds with multiple therapeutic properties. In researches performed around the world, more than 157 macrofungi active ingredients with multiple medicinal properties have been characterized. To date, active biocompounds continue to be identified, so the list will keep growing in the following decades. For future studies, we believe that it is relevant to consider macrofungi with traditional-medicinal use, in order to take advantage of the knowledge generated for centuries in Mexico. Fungal species from Mexico may represent a unique source of new bioactive metabolites that could be used to improve population's health. It is fundamental that studies involve a multidisciplinary group of scientists that pay special attention to the collection, identification, cultivation and preservation of the fungal material, standardize the extraction **protocols,characterize** the active ingredients of the extracts, perform the *in vitro* and *in vivo* assays and analyze the results.

REFERENCES

Adebayo, E. A., Martínez-Carrera, D., Morales, P., Sobal, M., Escudero, H., Meneses, M. E., Avila-Nava, A., Castillo, I., and Bonilla, M. (2018). Comparative study of antioxidant and antibacterial properties of the edible mushrooms Pleurotus levis, P. ostreatus, P. pulmonarius and P. tuber-regium. *International Journal of Food Science and Technology*, *53*(5), 1316–1330. https://doi.org/10.1111/ijfs.13712

Ayala-Zavala, J. F., Silva-Espinoza, B. A., Cruz-Valenzuela, M. R., Villegas-Ochoa, M. A., Esqueda, M., González-Aguilar, G. A., and Calderón-López, Y. (2012). Antioxidant and antifungal potential of methanol extracts of Phellinus spp. from Sonora, Mexico. *Revista Iberoamericana de Micología*, *29*(3), 132–138. https://doi.org/10.1016/j.riam.2011.09.004

Bacallao-Escudero, A., Guerrero-Germán, P., Torres-Moreno, H., Vidal-Gutiérrez, M., López-Romero, J. C., Tejeda-Mansir, A., Esqueda, M., and Robles-Zepeda, R. E. (2023). Biological Activity of Ganoderma Species (Agaricomycetes) from Sonoran Desert, Mexico. *International Journal of Medicinal Mushrooms*, *25*(10), 65–76. https://doi.org/10.1615/IntJMedMushrooms.2023049938

Bautista-González, J. A., and Moreno-Fuentes, Á. (2014). Los hongos medicinales de México. In Á. Moreno-Fuentes and R. Garibay-Orijel (Eds.), *La Etnomicología en México. Estado del Arte* (pp. 145–176). Red de Etnoecología y Patrimonio Biocultural (CONACYT)-Universidad Autónoma del Estado de Hidalgo-Instituto de Biología UNAM-Sociedad Mexicana de Micología-Asociación Etnobiológica Mexicana A.C.-GIDEM.

Bautista-González, J. A., and Herrera-Campos, M. A. (2019). Hongos y líquenes en la medicina tradicional mexicana. *Arqueología Mexicana Edición Especial*, *87*, 62–65. https://dialnet.unirioja.es/ejemplar/524298

Bautista-González, J. A., Montoya, A., Bye, R., Esqueda-Valle, M., and Herrera-Campos, M. A. (2022). Traditional knowledge of medicinal mushrooms and lichens of Yuman peoples in Northern Mexico. *Journal of Ethnobiology and Ethnomedicine*, 1–17. https://doi.org/10.1186/s13002-022-00550-8

Choi, Y. H., Yan, G. H., Chai, O. H., Choi, Y. H., Zhang, X., Lim, J. M., Kim, J.-H., Lee, M. S., Han, E.-H., Kim, H. T., and Song, C. H. (2006). Inhibitory effects of Agaricus blazei on mast cell-mediated anaphylaxis-like reactions. *Biological and Pharmaceutical Bulletin*, *29*(7), 1366–1371. https://doi.org/10.1248/bpb.29.1366

Chugh, M. R., Mittal, P., Namratha, M.P., Arora, T., Tanima Bhattacharya, T., Hitesh Chopra, H., Simona Cavalu, S., Rupesh K. and Gautam, K. R. (2022) Fungal Mushrooms: A Natural Compound With Therapeutic Applications. *Frontiers in Pharmacology*. July, Volume 13 Article 925387. doi:10.3389/fphar.2022.925387.

Espinosa-García, V., Fernández, J. J., San Nicolás-Hernández, D., Arberas-Jiménez, I., Rodríguez-Expósito, R. L., Souto, M. L., Piñero, J. E., Mendoza, G., Lorenzo-Morales, J., and Trigos, Á. (2023). Antiparasitic activity of compounds isolated from Ganoderma tuberculosum (Agaricomycetes) from Mexico. *International Journal of Medicinal Mushrooms*, *25*(9), 63–72. https://doi.org/10.1615/IntJMedMushrooms.2023049446

Felger, R. S., and Moser, M. B. (1974). Seri Indian pharmacopoeia. *Economic Botany*, *28*(4), 415–436. https://doi.org/10.1007/BF02862858

Filipa, S. R., Barros, L., Calhelha, R.C., Círic, A., van Griensven, L.J.L.D., Sokovic´, M. and Ferreira, I. C.F.F. (2013). The methanolic extract of Cordyceps militaris (L.) Link fruiting body shows antioxidant, antibacterial, antifungal and antihuman tumor cell lines properties. *Food and Chemical Toxicology* 62, 91–98. http://dx.doi.org/10.1016/j.fct.2013.08.033

González-Barranco, P., Garza Ocanas, L., Vera Cabrera, L., Salinas Carmona, M. C., Garza Ocanas, F., Ramírez Gómez, X. S., and Rangel, R. L. (2010). Evaluation of antioxidant, immunomodulating, cytotoxic and antimicrobial properties of different strains of Basidiomycetes from Northeastern Mexico. *Journal of Medicinal Plants Research*, *4*(17), 1762–1769. https://doi.org/10.5897/JMPR10.288

González-Ibáñez, L., Meneses, M. E., Sánchez-Tapia, M., Pérez-Luna, D., Torres, N., Torre-Villalvazo, I., Bonilla, M., Petlacalco, B., Castillo, I., López-Barradas, A., Macías, A., Tovar, A. R., and Martínez-Carrera, D. (2023). Edible and medicinal mushrooms (Pleurotus ostreatus, Ustilago maydis, Ganoderma lucidum) reduce endoplasmic reticulum stress and inflammation in adipose tissue of obese Wistar rats fed with a high fat plus saccharose diet. *Food and Function*, *14*(11), 5048–5061. https://doi.org/10.1039/d3fo00089c

Guzmán, G. (2008). Diversity and use of traditional Mexican medicinal fungi. A review. *International Journal of Medicinal Mushrooms*, *10*(3), 209–217. https://doi.org/10.1615/IntJMedMushr.v10.i3.20

Guzmán, G. (2011). El uso tradicional de los hongos sagrados: pasado y presente. *Etnobiología*, *9*, 1–21.

He, Z., Lin, J., He, Y., and Liu, S. (2022). Polysaccharide-Peptide from Trametes versicolor: The Potential Medicine for Colorectal Cancer Treatment. *Biomedicine* 10, 2841. https://doi.org/10.3390/biomedicines10112841

Hernández-Márquez, E., Lagunas-Martínez, A., Bermudez-Morales, V. H., Burgete-García, A. I., León-Rivera, I., Montiel-Arcos, E., García-Villa, E., Gariglio, P., Madrid-Marina V., V., and Ondarza-Vidaurreta, R. N. (2014). Inhibitory activity of Lingzhi or Reishi medicinal mushroom, Ganoderma lucidum (Higher Basidiomycetes) on transformed cells by human Papillomavirus. *International Journal of Medicinal Mushrooms*, *16*(2), 179–187. https://doi.org/10.1615/IntJMedMushr.v16.i2.80

Hernández-Santiago, F., Martínez-Reyes, M., Pérez-Moreno, J., and Mata, G. (2017). Pictographic representation of the first dawn and its association with entheogenic mushrooms in a 16th century Mixtec Mesoamerican Codex. *Scientia Fungorum*, *46*, 19–28.

Itoh, H., Ito, H., and Hibasami, H. (2008). Blazein of a new steroid isolated from Agaricus blazei Murrill (himematsutake) induces cell death and morphological change indicative of apoptotic chromatin condensation in human lung cancer LU99 and stomach cancer KATO III cells. *Oncology Reports* 20: 1359-1361. https://doi.org/10.3892/or_00000152.

Kodama, N., Komuta, K., Sakai, N., and Nanba, H. (2002). Effects of D-fraction, a polysaccharide from Grifola frondosa on tumor growth involve activation of NK cells. *Biological and Pharmaceutical Bulletin*, *25*(12), 1647–1650. https://doi.org/10.1248/bpb.25.1647

Liuzzi, G.M., Petraglia, T., Latronico, T., Crescenzi, A., and Rossano, R. (2023) Antioxidant Compounds from Edible Mushrooms as Potential Candidates for Treating Age-Related Neurodegenerative Diseases. *Nutrients* 15;1913. https://doi.org/10.3390/nu15081913.

López-Sánchez, H., Ayala Sánchez, N., Rodríguez Alcantar, O., Portillo López, A., Íñiguez Martínez, A., and Soria Mercado, I. (2016.). Actividad citotóxica de extractos de hongos silvestres de Ensenada, Baja California, México. *Revista Mexicana de Micología*, *43*, 37-42. https://doi.org/10.33885/sf.2016.3.1154

Lowenthal, R., Taylor, M., Gidden, J.A., Heflin, B., Lay Jr. J. O., Avaritt, N., Tackett, A.J., and Urbaniak , A. (023) The mycelium of the Trametes versicolor synn. Coriolus versicolor (Turkey tail mushroom) exhibit anti-melanoma activity *in vitro. Biomedicine and Pharmacotherapy* 161: 114424. https://doi.org/10.1016/j.biopha.2023.114424

Lozoya, L. X. (1989). La medicina tradicional en la realidad político-social de México. *Ciencias, Revista de Difusión*, *14*, 27–33. https://www.revistas.unam.mx/index.php/cns/issue/view/868

Martínez-Carrera, D., Larqué-Saavedra, A., Tovar-Palacio, A., Torres, N., Meneses, M. E., Sobal-Cruz, M., Morales-Almora, P., Bonilla-Quintero, M., Escudero-Uribe, H., Tello-Salgado, I., Bernabé-González, T., Martínez-Sánchez, W., and Mayett, Y. (2016). Contribución de los hongos comestibles, funcionales y medicinales a la construcción de un paradigma sobre la producción, dieta, la salud y la cultura en el sistema agroalimentario de México. In D. Martínez-Carrera and J. Ramírez-Juárez (Eds.), *Ciencia, tecnología e innovación en el sistema agroalimentario de México* (pp. 581–640). Editorial del Colegio de Postgraduados-AMC-CONACYT-UPAEP-IMINAP.

Martínez-Escobedo, N. A., Vázquez-González, F. J., Valero-Galván, J., Álvarez-Parrilla, E., Garza-Ocañas, F., Najera-Medellin, J. A., and Quiñónez-Martínez, M. (2021). Actividad antimicrobiana, contenido de compuestos fenólicos y capacidad antioxidante de cuatro hongos macromicetos comestibles de Chihuahua, México. *TIP Revista Especializada En Ciencias Químico-Biológicas*, *24*, 1-11. https://doi.org/10.22201/fesz.23958723e.2021.318

Meneses, M. E., Martínez-Carrera, D., González-Ibáñez, L., Torres, N., Sánchez-Tapia, M., Márquez-Mota, C. C., Rendón, G., Mitzi, V., Morales, A., Tello-Salgado, I., and Tovar, A. R. (2023). Effects of Mexican Ganoderma lucidum extracts on liver, kidney, and the gut microbiota of Wistar rats: A repeated dose oral toxicity study. *PLOS ONE*, *18*(4), e0283605. https://doi.org/10.1371/journal.pone.0283605

Meneses, M. E., Martínez-Carrera, D., Torres, N., Sánchez-Tapia, M., Aguilar-López, M., Morales, P., Sobal, M., Bernabé, T., Escudero, H., Granados-Portillo, O., and Tovar, A. R. (2016). Hypocholesterolemic properties and prebiotic effects of

Mexican Ganoderma lucidum in C57BL/6 Mice. *PLOS ONE*, *11*(7), e0159631. https://doi.org/10.1371/journal.pone.0159631

Montoya, A., Estrada-Torres, A., and Caballero, J. (2002). Comparative ethnomycological survey of three localities from La Malinche Vulcano, Mexico. *Journal of Ethnobiology and Ethnomedicine*, *22*(1), 103–131.

Nguyen, P. C., Nguyen, M. T. T., Truong, B. T., Kim, D.-R., Shin, S., Kim, J.-E., Park, K.-B., Park, J.-H., Tran, P. L., Ban, S.-Y., Kim, J., and Park, J.-T. (2023). Isolation, physicochemical characterization, and biological properties of inotodiol, the potent pharmaceutical oxysterol from chaga mushroom. *Antioxidants*, *12*(2), 447. https://doi.org/10.3390/antiox12020447

Oropeza-Guerrero, M. P., Santos-Sánchez, N. F., Salas-Coronado, R., Valadez-Blanco, R., Hernández-Carlos, B., and Guadarrama-Mendoza, P. C. (2018). Productivity and antioxidant activity of wild, reconstituted, and hybrid strains of the pink oyster mushroom, Pleurotus djamor (Agaricomycetes), from Mexico. *International Journal of Medicinal Mushrooms*, *20*(7), 607–621. https://doi.org/10.1615/IntJMedMushrooms.2018026382

Patel, S., and Goyal, A. (2012). Recent developments in mushrooms as anti-cancer therapeutics: A review. *3 Biotech*, *2*(1), 1–15. https://doi.org/10.1007/s13205-011-0036-2

Pérez-Armendáriz, B., Mayett, Y., Jiménez, F. R., Sobal, M., Morales, P., Bonilla, M., Ramírez-Carrasco, P., Tello, I., Trigos, A., Mendoza, G., Soriano-Santos, J., and Martínez-Carrera, D. (2010). Desarrollo de bebidas y alimentos funcionales a partir de recursos genéticos de hongos comestibles y medicinales en México. In D. Martínez-Carrera, N. Curvetto, M. Sobal, P. Morales, and V. M. Mora (Eds.), *Hacia un desarrollo sostenible del sistema de producción-consumo de los hongos comestibles y medicinales en Latinoamérica: Avances y perspectivas en el siglo XXI* (pp. 221–240). Red Latinoamericana de Hongos Comestibles y Medicinales-COLPOS-UNS-CONACYT-AMC-UAEM-UPAEP-IMINAP.

Pérez-Chávez, T., Cortina-Gómez, E., Briones-Pérez, C., and Moreno-Fuentes, Á. (2019). Hongos silvestres en el México antiguo. *Arqueología Mexicana (Edición Especial)*, *87*, 62–65. https://dialnet.unirioja.es/ejemplar/524298

Ponnusamy, C., Uddandrao, V. V. S., Pudhupalayam, S. P., Singaravel, S., Periyasamy, T., Ponnusamy, P., Prabhu, P., Sasikumar, V., and Ganapathy, S. (2022). Lentinula edodes (edible mushroom) as a nutraceutical: A review. *Biosciences Biotechnology Research Asia*, *19*(1), 1–11. https://doi.org/10.13005/bbra/2964

Reis, F.S., Barros, L., Calhelha, C.L., Ciric, A., Van Griensven, L.J.L.D., Marina Sokovic, M., and Ferreira, I.C.F.R. (2013) The methanolic extract of Cordyceps militaris (L.) Link fruiting body shows antioxidant, antibacterial, antifungal and antihuman tumor cell lines properties. *Food and Chemical Toxicology* 62: 91–98. http://dx.doi.org/10.1016/j.fct.2013.08.033.

Roncero, I. (2015). *Propiedades nutricionales y saludables de los hongos*. www.ctich.com

Rogers, R. (2011). *The Fungal Pharmacy. The Complete Guide to Medicinal Mushrooms and Lichens of North America*. North Atlantic Books. ISBN 978-1-55643-953-7

Romero-Córdoba, S. L., Salido-Guadarrama, I., Meneses, M. E., Cosentino, G., Iorio, M. V., Tagliabue, E., Torres, N., Sánchez-Tapia, M., Bonilla, M., Castillo, I., Petlacalco, B., Tovar, A. R., and Martínez-Carrera, D. (2021). Mexican Ganoderma lucidum extracts decrease lipogenesis modulating transcriptional metabolic networks and gut microbiota in C57BL/6 mice fed with a high-cholesterol diet. *Nutrients*, *13*(1), 38. https://doi.org/10.3390/nu13010038

Ruan-Soto, F., Cifuentes, J., Pérez-Ramírez, L., Ordaz-Velázquez, M., and Caballero, J. (2021). Hongos macroscópicos de interés cultural en los Altos de Chiapas y la Selva Lacandona, México. *Revista Mexicana de Biodiversidad*, *92*. https://doi.org/10.22201/IB.20078706E.2021.92.3525

Salinas-Solis, L. de J., Gaytán-Oyarzun, J. C., and Octavio-Aguilar, P. (2023). Detection of mitogenic and genotoxic effects of the turkey tail medicinal mushroom (Trametes versicolor, Agaricomycetes) extracts from Mexico on human lymphocyte cultures. *International Journal of Medicinal Mushrooms*, *25*(12), 33–41. https://doi.org/10.1615/IntJMedMushrooms.2023050464

Scarpari, M., Reverberi, M., Parroni, A., Scala, V., Fanelli, C., Pietricola, C., Zjalic, S., Maresca, V., Tafuri, A., Ricciardi, M. R., Licchetta, R., Mirabilii, S., Sveronis, A., Cescutti, P., and Rizzo, R. (2017). Tramesan, a novel polysaccharide from Trametes versicolor. Structural characterization and biological effects. *PLOS ONE*, *12*(8), e0171412. https://doi.org/10.1371/journal.pone.0171412

Secretaría de Economía. (2023). *Setas y demás hongos, comestibles, frescas o refrigeradas (Exc. hongos del género "Agaricus" y trufas)*. Data México, Gobierno de México. https://www.economia.gob.mx/datamexico/es/profile/product/mushrooms-groceries-fresh-or-chilled-excl-mushrooms-of-the-genus-agaricus-and-truffles

Serrano-Márquez, L., Trigos, Á., Couttolenc, A., Padrón, J. M., Shnyreva, A. V., and Mendoza, G. (2021). Antiproliferative and antibacterial activity of extracts of Ganoderma strains grown *in vitro*. *Food Science and Biotechnology*, *30*(5), 711–721. https://doi.org/10.1007/s10068-021-00903-1

Smiderle, F. R., Baggio, C. H., Borato, D. G., Santana-Filho, A. P., Sassaki, G. L., Iacomini, M., and Van Griensven, L. J. L. D. (2014). Anti-Inflammatory properties of the medicinal mushroom Cordyceps militaris Might be related to its linear (1→3)-β-D-glucan. *PLOS ONE*, *9*(10), e110266. https://doi.org/10.1371/journal.pone.0110266

Sułkowska-Ziaja, K., Balik, M., Szczepkowski, A., Trepa, M., Zengin, G., Kała, K., and Muszyńska, B. (2023). A review of chemical composition and bioactivity studies of the most promising species of Ganoderma spp. *Diversity*, *15*(8), 882. https://doi.org/10.3390/d15080882

Tamez de la O, E. J., Garza-Ocañas, L., Zanatta-Calderón, M. T., Lujan-Rangél, R., Garza-Ocañas, F., Badillo-Castañeda, C. T.,

and Gómez-Ramírez, X. S. (2013). Hypoglycemic and hypocholesterolemic effects of aqueous and methanolic extracts of Lentinus lepideus, Calvatia cyathiformis and Ganoderma applanatum, from Northeastern Mexico, in Wistar rats. *Journal of Medicinal Plants Research*, *7*(11), 661–668. https://doi.org/10.5897/JMPR012.875

Tang, C., Hoo, P. C.-X., Tan, L. T.-H., Pusparajah, P., Khan, T. M., Lee, L.-H., Goh, B.-H., and Chan, K.-G. (2016). Golden needle mushroom: A culinary medicine with evidenced-based biological activities and health promoting properties. *Frontiers in Pharmacology*, *7*. https://doi.org/10.3389/fphar.2016.00474

Tangen, J.-M., Holien, T., Mirlashari, M. R., Misund, K., and Hetland, G. (2017). Cytotoxic effect on human myeloma cells and leukemic cells by the Agaricus blazei Murill based mushroom extract, Andosan™. *BioMed Research International*, *2017*, 1–7. https://doi.org/10.1155/2017/2059825

Thongbai, B., Rapior, S., Hyde, K. D., Wittstein, K., and Stadler, M. (2015). Hericium erinaceus, an amazing medicinal mushroom. *Mycological Progress*, *14*(10), 91. https://doi.org/10.1007/s11557-015-1105-4

Yanshree, Yu, W. S., Fung, M. L., Lee, C. W., Lim, L. W., and Wong, K. H. (2022). The monkey head mushroom and memory enhancement in Alzheimer's disease. *Cells*, *11*(15), 2284. https://doi.org/10.3390/cells11152284

Yuminamochi, E., Koike, T., Takeda, K., Horiuchi, I., and Okumura, K. (2007). Interleukin-12- and interferon-γ-mediated natural killer cell activation by Agaricus blazei Murill. *Immunology*, *121*(2), 197–206. https://doi.org/10.1111/j.1365-2567.2006.02558.x