Medicinal mushrooms have been used in traditional medicine and human diet for thousands of years. Nowadays, medicinal mushrooms and their active compounds are being increasingly recognised by conventional medicine, since more and more scientific studies support their therapeutic value.

In this book, therapeutic properties and applications of 16 most popular medicinal mushrooms are concisely presented based on scientific research, including clinical trials. In addition, the use of medicinal mushrooms for the treatment of companion, domestic and sport animals is also described.

MEDICINAL MUSHROOMS

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FOREWORD

Fungi are vital organisms of fundamental importance to life on Earth. Epigeous fruiting bodies of fungi, visible to the naked eye, are called mushrooms. In the ground, fungi interact with a variety of organisms through mycelium, establishing a symbiosis, or as decomposers (saprobionts) compete with them for resources. For this purpose, fungi synthesise a wide array of metabolites – biologically active compounds that enable them to survive in the never-ending struggle with other organisms. When consuming mushrooms, these compounds can elicit diverse physiological responses in our body, leading to mushroom poisoning or, on the other hand, beneficial effects on human health. Thus, certain mushroom species can exhibit a broad spectrum of therapeutic activity and help with various diseases, hence are referred to as medicinal mushrooms.

I became acquainted with mushrooms in my early childhood. I grew up in the countryside, surrounded by forests, where I often went to »explore« these amazing organisms, which attracted me immensely due to their unpredictable and variable appearance. At that time, I was especially fascinated by the heterogeneity of their colours and shapes, as well as by their taste. Later, when I was doing research in fungal physiology as a biologist, I recognised their important role in nature. My childhood dream was fulfilled, when I have succeeded in experimentally cultivating my first *Pleurotus ostreatus* (oyster mushroom), *Stropharia rugosoannulata* (king stropharia), *Agaricus bisporus* (white button mushroom), *Lentinula edodes* (shiitake), *Pholiota microspora* (nameko mushroom), *Flammulina velutipes* (winter mushroom), and other species of wood-decay fungi, including medicinal mushrooms. The latter have been of particular interest to me recently, because of their remarkable therapeutic properties. Medicinal mushrooms have long been recognised in East Asian cultures, where based on empirical evidence they are ranked at the top of their traditional medicine. In the last decades, this knowledge has spread to the Western world and therapeutic properties of various mushroom species have been supported by scientific research.

However, in my opinion, we are not yet aware enough of the importance of mushrooms or fungi for the environment and humans, and their potential in medicine and biotechnology is underutilised. Undoubtedly, mushrooms are a rich source of a variety of compounds, which could be successfully applied in medicine; therefore, more thorough studies are needed to explore the mysterious world of mushrooms. In this book, the therapeutic properties and applications of 16 most popular medicinal mushrooms are concisely described,

predominantly based on clinical studies; in addition, the book finishes with a chapter on the use of medicinal mushrooms in domestic animals. I hope and wish that the present book will contribute to the popularisation of the use of mushrooms in all fields of practice. It will be informative for those interested in medicinal mushrooms and the possibilities of their use for medicinal purposes.

Prof Franc Pohleven

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INTRODUCTION

Fungi, including mushrooms, are a distinct group of organisms of great importance for the environment and humans. In nature they are essential for the cycling of organic matter, being able to decompose material not degradable by other organisms, and furthermore, are important for establishing symbiosis with plants. Fungi became of major significance for human health in the first half of the last century, when Alexander Fleming discovered the first antibiotic, penicillin, produced by *Penicillium* mould.

In higher fungi, the main part of the organism lies in the ground, out of sight. This is an extensive assimilative part of the fungus, called mycelium, where basic metabolic processes take place. When mycelium provides itself with energy, the reproductive organs – fruiting bodies or sporocarps – sprout from the ground; these are commonly called mushrooms, as people generally refer to fungi. However, the term only applies to approximately 14,000 fungal species forming fruiting bodies visible to the naked eye that come in a wide variety of shapes and colours.

Mushrooms have been important in the human diet and in traditional medicine since prehistoric times, especially in Asia, as well as America, Africa and Europe. Two mushroom species, *Piptoporus betulinus* (birch polypore) and *Fomes fomentarius* (tinder fungus) have been found with 5300-year-old mummy, Ötzi the Iceman, discovered in the Tyrolian Alps, which were presumably used for medicinal purposes or as tinder, respectively. In ancient Greece, Hippocrates, the founder of modern medicine, described the use of *Fomes fomentarius* for cauterisation, while in traditional East Asian medicine, certain medicinal mushrooms are ascribed miraculous powers of conferring longevity and have been used in various preparations, such as powders, tonics, teas and soups. Since the second half of the last century, their popularity has been growing worldwide with the development of cultivation techniques and with increasing awareness of their therapeutic properties supported by scientific research. Furthermore, mushrooms are also increasingly used for culinary purposes as healthy food, low in fat and sugar. They contain dietary fibre, vitamins and minerals, and have relatively high protein content, therefore are suitable for vegetarians and vegans.

Nowadays, numerous preparations in the form of powders, capsules, pills and tinctures are made from medicinal mushrooms, which are available on the market as dietary supplements. These are used in the prevention and treatment of various health conditions, including modern lifestyle diseases, and are recommended for active people, athletes, and the elderly. Moreover, medicinal mushroom products have been increasingly used as feed supplements to improve health or treat diseases of companion (pets), domestic and sport animals.

There are more than 50 species of mushrooms with a wide range of therapeutic properties, which are referred to as medicinal mushrooms, including the most popular *Ganoderma lucidum* (reishi), *Cordyceps* spp. (caterpillar fungus), *Lentinula edodes* (shiitake) and *Pleurotus ostreatus* (oyster mushroom). They contain a variety of biologically active compounds, among which the most important are polysaccharides, i.e. β-glucans, as well as triterpenes, polyphenols, proteins, and others, that have been scientifically proven to possess a broad spectrum of pharmacological activities. Several β-glucan compounds derived from medicinal mushrooms are approved as anticancer medicines and employed clinically in Japan, such as lentinan from *Lentinula edodes* and PSK from *Trametes versicolor* (turkey tail). Medicinal mushrooms generally strengthen the immune system and thus exhibit anticancer activity, particularly when used as a complementary therapy alongside conventional treatment (chemotherapy and radiotherapy). Furthermore, they have antioxidant, anti-inflammatory and anti-allergic properties, they regulate blood sugar and cholesterol levels as well as blood pressure, thus can help prevent diabetes, hypertension and cardiovascular disease. Mushrooms can protect against viral and other infections and are a potential source of new antibiotic compounds. In addition, they contain high amounts of ergosterol, which is, when exposed to sunlight or ultraviolet light, converted to vitamin D_2 that may play a protective role in many diseases. However, no serious adverse side effects or toxicity have been associated with the use of medicinal mushrooms, which have been proven safe even for pregnant women and their foetuses, except for species of the genus *Auricularia*, which are not recommended for use during pregnancy.

Many scientific studies, including a number of clinical trials, have been conducted over the past few decades that support the findings of traditional medicine and provide evidence for the therapeutic properties of medicinal mushrooms in humans as well as animals. Therefore, mushrooms are not only fruits of the forest used merely for human consumption, but are increasingly recognised as a cultivated natural source of pharmacologically active compounds with medicinal properties.

MEDICINAL MUSHROOMS AND THEIR THERAPEUTIC APPLICATIONS

Agaricus blazei (Royal Sun Agaricus)

Therapeutic Application: Cancer

Agaricus blazei Murrill (ABM) is a more recently discovered medicinal and culinary mushroom that is becoming increasingly popular worldwide. In contrast to most of the medicinal mushroom species, *Agaricus blazei* as well as its closely related species *Agaricus brasiliensis* and *Agaricus subrufescens*, which are used almost interchangeably, originate from America. However, the mushroom is due to its therapeutic properties now widely accepted in Japan and other East Asian countries, where it is mostly used for the prevention and treatment of different types of cancer (Firenzuoli et al. 2008).

Agaricus blazei is recognised in particular for its antitumour and immunostimulatory activity, however, studies have also shown its anti-inflammatory and anti-allergic properties, as well as liver protective (hepatoprotective) and antiviral activity. Moreover, it has been demonstrated to lower blood sugar and cholesterol levels (antihyperglycaemic and antihyperlipidaemic activities),

thus can protect against diabetes and atherosclerosis (Wang et al. 2013). The mushroom has traditionally also been used to reduce physical and emotional stress, and to treat a variety of diseases, including hepatitis, dermatitis, osteoporosis, peptic ulcers, as well as digestive and cardiovascular disorders (Firenzuoli et al. 2008).

Clinical studies involving patients with leukaemia, cervical, ovarian, endometrial, alimentary tract and breast cancer have shown that *Agaricus blazei* fruiting bodies or polysaccharide extracts used in conjunction with chemotherapy improved the treatment outcomes, enhanced the cellular immune response, reduced chemotherapy-related side effects and improved the quality of life of the patients (Powell 2010).

Polysaccharide-protein complexes from *Agaricus blazei* mycelium have been shown to reduce blood cholesterol levels in female volunteers by 11% and their body weight by 11.8%, and moreover, fruiting body extract of the mushroom reduced blood glucose levels (Firenzuoli et al. 2008). Clinical trials have also shown hepatoprotective activity of *Agaricus blazei* extracts in patients with hepatitis B and C, without eliciting any toxicity or adverse effects (Wang et al. 2013).

***Auricularia* spp. (Wood Ear)**

Therapeutic Application: Cardiovascular Protective

The genus *Auricularia* includes two closely related mushroom species used for culinary and medicinal purposes, namely *Auricularia auricula* (Jew's ear) and *Auricularia polytricha* (cloud ear, black fungus), which are commonly confused and used interchangeably. Both are highly valued in East Asian cuisine for their crunchy, rubbery texture, and have long been known for their healing properties in China and Europe, where they have traditionally been used mostly in inflammation of the throat and eye irritations. Nowadays, the species are especially popular in East Asia and are widely cultivated with the fourth-highest worldwide production among culinary and medicinal mushrooms (Hobbs 1986).

Scientific studies have shown that *Auricularia* species possess cardiovascular protective properties attributed to the antioxidant activity of polyphenols and to polysaccharides, major pharmacologically active compounds in these mushrooms. However, antifertility side effects have been reported for *Auricularia auricula* polysaccharides, therefore *Auricularia* species are not recommended for use during pregnancy or if pregnancy is planned (Hobbs 1986).
Auricularia auricula polysaccharides have been shown to reduce levels of total cholesterol, triglycerides and LDL (»bad«) cholesterol, and increase HDL (»good«) cholesterol. They also increased the antioxidant capacity and exhibited potential cardioprotective, anti-atherosclerotic and antithrombotic properties. Moreover, the polysaccharides exhibited anti-inflammatory activity, which corresponds to the traditional use of the mushroom (Chen et al. 2008a).

***Coprinus comatus* (Shaggy Mane)**

Therapeutic Application: Antioxidant

Coprinus comatus is a delicious mushroom, edible only when young. It is not particularly known for its medicinal properties, however, scientists have recently identified certain pharmacologically active compounds and shown therapeutic potential of the mushroom.
High amounts of ergothioneine with antioxidant properties, and γ-aminobutyric acid (GABA) with potential relaxing and anti-anxiety effects have been observed in *Coprinus comatus* (Cohen et al. 2014). In addition, studies on various types of tumour cells have shown its potential antitumour activity against breast (Asatiani et al. 2011), ovarian (Rouhana-Toubi et al. 2013), as well as prostate cancer by inhibiting androgen receptor function (antiandrogenic activity) (Dotan et al. 2011). *Coprinus comatus* has also shown potential hypoglycaemic activity by lowering blood glucose levels (Han et al. 2006).

***Cordyceps* spp. (Caterpillar Fungus)**

Therapeutic Application: Vitality, Against Fatigue, Physical Performance, Sexual Function

Cordyceps is a genus of unique fungal species that are parasitic primarily on insects, and includes two species, *Cordyceps sinensis* (*Ophiocordyceps sinensis*, caterpillar fungus) and *Cordyceps militaris*, which have predominantly been used in traditional medicine. These medicinal mushroom species have been highly valued remedies due to their remarkable therapeutic properties and limited supply from their remote natural habitats of high mountain areas of Asia, with prices reaching up to €50,000 per kilogram. However, in the last decades, scientists have developed techniques to cultivate *Cordyceps* with potency comparable to that of the wild varieties, and thus, the mushroom became more affordable and accessible. Moreover, the ingredients of host animal origin are avoided in cultivated *Cordyceps*, therefore it is suitable for vegetarians and vegans (Holliday & Cleaver 2008).

Cordyceps has been one of the most highly regarded medicinal mushrooms in traditional East Asian medicine, used for centuries as an invigorating tonic against fatigue, as an aphrodisiac, for fertility, and for the treatment of a number of diseases. These include cancer, cardiovascular and respiratory disorders, such as asthma, bronchitis and chronic obstructive pulmonary disease (COPD), osteoporosis, and has been used to protect the kidney and liver. Taken together, the mushroom is considered to have »anti-ageing« properties (Holliday & Cleaver 2008; Lo et al. 2013). Today, *Cordyceps* has become increasingly popular in the West and is used in various preparations and dietary supplements. Because of its specific beneficial effects, the mushroom is recommended for active people with modern lifestyles who are experiencing chronic stress that can lead to depression, or those suffering from exhaustion, as well as for athletes and the elderly. In addition, it is also used as a feed supplement for animals.

Over the last few decades, scientific studies including a number of clinical trials, have demonstrated a range of medicinal properties of *Cordyceps* and various pharmacologically active compounds have been identified in the mushroom. These include the main compound cordycepin, various polysaccharides, lovastatin, melanin, ergosterol and others (Lo et al. 2013).

Clinical studies have shown that *Cordyceps* reduces fatigue, increases vitality and energy (Nagata et al. 2006; Lin & Li 2011), and improves aerobic capacity and exercise performance (Chen et al. 2010a). Because of its potent tonic and invigorating effect, *Cordyceps* is often used by the elderly, individuals involved in sports or professional athletes to improve their physical and mental performance, as well as to enhance recovery after exertion. A study on long distance runners showed a significant improvement in 71% of the participants that were consuming *Cordyceps* (Powell 2010). The invigorating properties of *Cordyceps* are due to the beneficial effects on respiratory and cardiovascular function by increasing the blood flow, oxygen uptake, its utilisation and consumption by cells, and thus cellular energy (ATP) levels are elevated (Lin & Li 2011).

Cordyceps has also shown potential to improve mental health, brain function, reduce depression and desire for alcohol. In addition, it increases libido and sexual function in men and women (Holliday & Cleaver 2008; Lin & Li 2011; Lo et al. 2013).

By enhancing the cellular immune response and strengthening the immune system, *Cordyceps* acts against tumours and viral infections, such as influenza; antiviral properties are, in addition, exerted through the inhibition of viral replication (Powell 2010; Lin & Li 2011). The antitumour activity of *Cordyceps* has been shown in clinical studies on patients with lung cancer and several other types of tumours who were administered the mushroom in conjunction

with conventional treatment. The mushroom increased the effectiveness of radiation and chemotherapy and reduced their side effects (Holliday & Cleaver 2008).

Furthermore, *Cordyceps* has antioxidant properties and regulates blood cholesterol, thus can help prevent cardiovascular disease (Holliday & Cleaver 2008; Lin & Li 2011). It also protects against diabetes by regulating insulin function and reducing blood sugar levels, which was demonstrated in 95% of patients treated with *Cordyceps* mycelium. Moreover, a protective effect of *Cordyceps* on the liver and kidney has been shown in clinical trials on patients with hepatitis and other hepatic or renal diseases (Lin & Li 2011).

***Fomes fomentarius* (Tinder Fungus)**

Therapeutic Application: Antiviral, Antimicrobial

Fomes fomentarius is an inedible polypore fungus, the fruiting bodies of which have traditionally been used as tinder, or as a styptic to stop bleeding and for treating wounds (Hobbs 1986). The mushroom was found with the mummified prehistoric Ötzi the Iceman (Peintner et al. 1998) and its medicinal uses were first described in ancient Greece by Hippocrates, the founder of modern medicine, who recommended the fungus for cauterisation to treat certain complaints and affected organs (Buller 1915). In traditional medicine, *Fomes fomentarius* was also used to relieve pain, treat rheumatism, painful menstruation (dysmenorrhoea), haemorrhoids and bladder disorders. Furthermore, oesophageal, gastric and uterine cancers were treated with the fungus (Grienke et al. 2014).

Recently, scientists have shown potential therapeutic effects of *Fomes fomentarius* as it contains compounds that exhibit strong antiviral activity against human immunodeficiency virus (HIV)-1, and antimicrobial properties against the fungus *Candida albicans* and bacteria *Helicobacter pylori* (Seniuk et al. 2011). Moreover, it inhibited the growth of several other pathogenic bacteria, *Pseudomonas aeruginosa*, *Serratia marcescens*, *Staphylococcus aureus*, *Bacillus subtilis*, and *Mycobacterium smegmatis* (Robles-Hernández et al. 2008). In addition, compounds with potential antitumour, immunomodulatory and anti-inflammatory activity were identified in *Fomes fomentarius*, which have also shown potential for the treatment of diabetes (Grienke et al. 2014).

***Fomitopsis pinicola* (Red Belted Polypore)**

Therapeutic Application: General Immunity, Anti-Inflammatory, Antimicrobial

Inedible fruiting bodies of *Fomitopsis pinicola* have been used as tinder or as a traditional medicine in the form of tonic, tea, paste, or soup. The fungus improves general immunity and has been used for the treatment of cancer, headache, nerve pain (neuralgia), nausea, inflammation of the digestive tract, dysentery, diarrhoea, constipation, liver problems, jaundice, excessive urination, and as an emetic for purification, anti-inflammatory agent, or as a styptic to treat bleeding wounds (Hobbs 1986; Grienke et al. 2014).
Research studies have shown that *Fomitopsis pinicola* extracts exert potential antitumour activity (Wu et al. 2014) and activity against diabetes, while triterpenes possess anti-inflammatory, antioxidant, and antimicrobial properties against *Bacillus subtilis* and *Bacillus cereus* (Grienke et al. 2014).

***Ganoderma lucidum* (Reishi, Lingzhi)**

Therapeutic Application: Overall Health, General Immunity, Anti-Ageing, Various Diseases

Ganoderma lucidum is the most famous and highly regarded of all medicinal mushrooms due to its wide range of medicinal properties. It has been used in traditional East Asian medicine for thousands of years to »promote health and longevity« and is still considered a superior remedy. In China and Japan it is called lingzhi or reishi, respectively, which means »miraculous«, »divine« or »mushroom of immortality«. Because of its remarkable therapeutic properties and rarity, reishi used to be so precious that was reserved only for emperors and nobility. However, since the second half of the last century, the development of techniques for the cultivation of *Ganoderma lucidum* has made the mushroom more accessible, thus becoming one of the most widespread and studied medicinal mushrooms worldwide (Hobbs 1986; Wachtel-Galor et al. 2011).

Because of the bitter taste and hardness of its fruiting bodies, reishi is only used for medicinal purposes. Fruiting bodies or mycelium can be dried and ground or infused, and consumed as powder or tea; moreover, numerous *Ganoderma lucidum* products are available on the market as dietary supplements in the form of capsules, tablets, extracts, tinctures, or as various foods and beverages containing the mushroom. Nowadays, spores of reishi are also widely used since they contain higher amounts of pharmacologically active compounds. To facilitate the absorption of these compounds into the body, the spore walls are broken or removed by special mechanical procedures (Wachtel-Galor et al. 2011).

Ganoderma lucidum has traditionally been used to improve overall health and immunity, for the prevention and treatment of a wide variety of diseases, and has been known for its »anti-ageing« properties. Numerous scientific studies have confirmed its medicinal properties, including strengthening the immune system and anticancer activity, antioxidant, anti-inflammatory, anti-allergic and neuroprotective properties; *Ganoderma lucidum* also prevents cardiovascular disease, diabetes, respiratory and gastrointestinal disorders, has beneficial effects on the liver and kidney, and, moreover, exhibits antiviral and antibacterial activity (Wachtel-Galor et al. 2011; Hobbs 1986). However, no significant adverse side effects or toxicity have been observed with reishi (Jin et al. 2012).

A diverse array of about 400 biologically active compounds have been identified in reishi, belonging to the groups of polysaccharides, terpenes, steroids, phenols, nucleosides, proteins and peptidoglycans, that confer such a broad range of therapeutic properties to the mushroom. The most pharmacologically important are polysaccharides and triterpenes, with more than 200 or 130 found in reishi, respectively (Wachtel-Galor et al. 2011).

Studies have shown that polysaccharides from *Ganoderma lucidum* stimulate the immune system at multiple levels, predominantly through enhanced cellular immunity (Lin 2005; Wachtel-Galor et al. 2011). Thus, the mushroom exhibits antitumour activity shown in clinical trials on cancer patients, with best results obtained when *Ganoderma lucidum* polysaccharides were administered as an adjunct to conventional treatment. The polysaccharides enhanced the immunity and antitumour immune response, as well as improved the quality of life of the patients (Wachtel-Galor et al. 2011; Jin et al. 2012). Moreover, triterpenes also exhibited potential antitumour, antioxidant and anti-inflammatory activity in diseases such as rheumatoid arthritis and bronchitis, as well as anti-allergic properties by inhibiting histamine release (Hobbs 1986; Wachtel-Galor et al. 2011).

Reishi exerts a broad spectrum of effects against cardiovascular disease and diabetes. It prevents blood clot formation (thrombosis), lowers blood pressure and cholesterol levels as shown in clinical study on patients with coronary heart disease (Gao et al. 2004a), and reduced blood sugar levels in patients with type 2 diabetes (Gao et al. 2004b) who were receiving a polysaccharide extract from reishi.

Ganoderma lucidum also helps with respiratory disorders and in a study exhibited an improvement in 60–90% of patients with bronchitis or asthma (Hobbs 1986). Moreover, it has potential in the treatment of liver diseases, as demonstrated in patients with hepatitis B, and in the treatment of kidney inflammation (nephritis) and gastric ulcers (Hobbs 1986; Wachtel-Galor et al. 2011).

Ganoderma lucidum constitutes a promising natural source of new antibiotics and antiviral agents, since it showed antibacterial activity against various bacteria, and inhibitory effect on HIV-1, herpes simplex virus type 1 and 2, hepatitis B, and vesicular stomatitis virus (New Jersey serotype) (Wachtel-Galor et al. 2011).

Furthermore, reishi also has sedative properties, helps relieve insomnia and anxiety, and is recommended for »mental stabilisation«. In addition, it exhibits neuroprotective effects in diseases such as Alzheimer's disease (Powell 2010).

***Grifola frondosa* (Maitake, Hen of the Woods)**

Therapeutic Application: Anticancer, General Immunity

Grifola frondosa is a gourmet and medicinal mushroom, especially popular in Japan, where it is called maitake. The mushroom is renowned for its taste and texture, while its polysaccharide extracts, »maitake D-fraction« and »maitake MD-fraction«, have been clinically applied for the treatment of different types of cancer. For medicinal purposes, various dietary supplements derived from cultivated maitake are available on the market (Hobbs 1986; Mayell 2001).
In addition to its prominent antitumour activity, maitake also strengthens the immune system, protects against hypertension, hyperlipidaemia and diabetes. Moreover, it has antioxidant, liver protective, antiviral and antimicrobial properties and increases vitality (Boh & Berovič 2007). The therapeutic effects of maitake are predominantly attributed to the unique β-glucan polysaccharides,

which are its major pharmacologically active compounds, and in addition, the mushroom contains other compounds, such as ergosterol (provitamin D_2) (Mayell 2001).
Clinical studies on patients with different types of cancer who were receiving maitake polysaccharides (MD-fraction), have shown tumour regression with significant improvement observed in patients with liver (58.3%), breast (68.8%), and lung (62.5%) cancer, while less than 10–20% improvement was noted for leukaemia, gastric and brain cancer. Furthermore, when maitake polysaccharides were administered in conjunction with chemotherapy, response rates were increased by 12–28%, immune responses enhanced 1.2–1.4-fold, and in addition, the side effects of chemotherapy were reduced. The mushroom exerts an antitumour effect primarily by stimulating the immune system through the activation of immune cells and increased production of cytokines – mediators of the immune response (Nanba 1997; Kodama et al. 2002).
Maitake polysaccharides have been shown to exert hypoglycaemic effects in patients with type 2 diabetes by reducing their blood sugar levels by over 30% (Konno et al. 2002). Moreover, a study on patients with high blood pressure (hypertension) who were receiving maitake extract has demonstrated a decrease in their blood pressure – systolic of 7% and diastolic of 9.4% (Hobbs 1986). Maitake has also been shown to be beneficial in treating patients with fatigue, hepatitis B, HIV and *Candida albicans* infections (Nanba et al. 2000; Mayell 2001).

***Hericium erinaceus* (Lion's Mane)**

Therapeutic Application: Neuroprotective, Dementia, Multiple Sclerosis, Gastric Problems

Hericium erinaceus is a delicious culinary and medicinal mushroom with a distinctive appearance. In traditional Chinese medicine it has long been recognised for a variety of therapeutic properties, which are nowadays supported by scientific research, especially for its beneficial effects on the nervous system. Hence, the mushroom has been referred to as »nature's nutrient for the neurons« (Powell 2010).

Hericium erinaceus has neuroprotective properties, prevents dementia and neurodegenerative diseases, improves brain function, and relieves depression, anxiety and symptoms associated with menopause. Moreover, it exerts antitumour activity by stimulating the immune system and is used to treat gastric and oesophageal cancer, as well as gastritis, gastric and duodenal ulcers. The mushroom has antioxidant properties, lowers blood pressure, cholesterol and

sugar levels, thus preventing the development of cardiovascular disease and diabetes. *Hericium erinaceus* has also been shown to possess antimicrobial activity against various, including antibiotic-resistant, pathogenic bacteria. However, no adverse side effects have been observed with the mushroom (Khan et al. 2013; Friedman 2015).

Hericium erinaceus is a tasty and healthy food, low in fat, contains predominantly unsaturated fatty acids, and has relatively high protein content and quality, which makes it a good substitute for meat in vegetarian cuisine. Due to its nutritional and medicinal value, the mushroom is appropriate to incorporate it into everyday diet by making healthy meals or by consuming *Hericium erinaceus* dietary supplements (Powell 2010).

Scientists have identified about 70 different biologically active compounds in *Hericium erinaceus*. These include pharmacologically important β-glucan polysaccharides that strengthen the immune system, thus exerting antitumour activity, phenols with antioxidant properties, and ergosterol. The latter is in the presence of sunlight or ultraviolet light converted to vitamin D_2, which has potential protective effects against various diseases, such as multiple sclerosis (Munger et al. 2004; Friedman 2015). However, the main groups of compounds in *Hericium erinaceus* that exhibit neuroprotective properties are erinacines and hericenones. These and related compounds stimulate the synthesis of nerve growth factor involved in maintaining and organising the function of neurons, thus can prevent neurodegenerative diseases, such as dementia or Alzheimer's disease, depression, and have shown neuroregenerative and therapeutic potential in the treatment of multiple sclerosis (Ma et al. 2010; Khan et al. 2013; Friedman 2015).

A clinical trial involving patients with mild cognitive impairment who were administered *Hericium erinaceus* has shown the improvement in their cognitive function, while in another study the mushroom reduced depression and anxiety in women (Friedman 2015). Furthermore, *Hericium erinaceus* extracts have been demonstrated to promote the regeneration of injured nerves in the early stage of recovery (Wong et al. 2012), and enhance the myelination process – the formation of myelin sheath, which is damaged in multiple sclerosis (Kolotushkina et al. 2003).

In addition, clinical studies have shown the antibacterial properties of *Hericium erinaceus*. MRSA (methicillin-resistant *Staphylococcus aureus*), a pathogenic bacterium that has developed resistance to a range of antibiotics has been cleared in a number of patients whose diet was supplemented with the mushroom (Powell 2010). Moreover, *Hericium erinaceus* suppressed the infection in 89.5% of patients with *Helicobacter pylori*, a major cause of gastric ulcers and gastritis (Donatini 2014).

***Lentinula edodes* (Shiitake)**

Therapeutic Application: Cholesterol Control, Anticancer

Lentinula edodes or shiitake, which is its Japanese and most common name worldwide, is a delicious and very popular edible and medicinal mushroom of high nutritional value. In Japan and China, the mushroom has been cultivated for centuries and is in their traditional medicine regarded as the »elixir of life« that promotes vitality and energy. Shiitake is now widely cultivated worldwide with the second-highest production among edible mushrooms in the world. The mushroom is valued for its culinary, nutritional as well as therapeutic properties, and is one of the most studied mushrooms in medicine (Wasser 2005; Bisen et al. 2010).

Shiitake is a source of a number of compounds with proven pharmacological activity, including eritadenine, protein lentin, extracts LEM, LAP and KS-2,

and in particular lentinan – a polysaccharide from *Lentinula edodes*, which has been approved in Japan as an adjuvant in the treatment of gastric cancer. Various dietary supplements or concentrated preparations from shiitake are available on the market in the form of extracts or powder from fruiting bodies or mycelium, which are preferred for medicinal use due to the higher concentration of pharmacologically active compounds (Wasser 2005; Bisen et al. 2010).

Lentinula edodes has a number of therapeutic properties – strengthens the immune system, exhibits antitumour activity, prevents cardiovascular disease and diabetes. It also possesses antioxidant, anti-inflammatory, liver protective (hepatoprotective) properties, and helps with bronchitis and allergies. Moreover, it displayed activity against viral, bacterial, fungal and parasitic infections, such as candidiasis, common cold and influenza (Wasser 2005; Powell 2010). In addition, shiitake has relatively high nutritional value and is a good source of proteins containing essential amino acids, dietary fibre, vitamins, minerals and ergosterol (provitamin D_2), while being low in fat and predominantly contains unsaturated fatty acids (Wasser 2005; Bisen et al. 2010). Therefore *Lentinula edodes* is a healthy food, which is also suitable for vegetarians and vegans.

Clinical trials on patients with gastric, colorectal, liver, breast and metastatic prostate cancer, who were receiving β-glucan polysaccharide lentinan from shiitake as an adjunct to chemotherapy, have shown increased survival, reduced side effects from chemotherapy and improved quality of life of the patients (Powell 2010). Lentinan and other shiitake polysaccharides have been proposed to exhibit antitumour activity through the activation of immune response, and thus also exerted beneficial effects in patients with hepatitis and AIDS (Wasser 2005).

Furthermore, eritadenine, a secondary metabolite from shiitake, reduces blood lipid levels by increased excretion of dietary cholesterol and its metabolic degradation, thus preventing cardiovascular disease. *Lentinula edodes* administration to patients with high blood cholesterol (hypercholesterolaemia) and other lipids (hyperlipidaemia) led to a decrease in total cholesterol of 7–12% and triglycerides of 6–7% (Wasser 2005).

***Monascus purpureus* (Red Yeast Rice)**

Therapeutic Application: Cardiovascular Protective, Cholesterol Control

Monascus purpureus is a fungus that has been used for centuries in East Asian cuisine as a natural food colouring, preservative, and for the fermentation of rice to produce a traditional food product called »red yeast rice«. In addition to its culinary use, the fungus has also been known in traditional medicine for its therapeutic properties. Scientists have identified a number of pharmacologically active compounds in *Monascus purpureus*, of which the most important and studied are statins – monacolins and related compounds, which lower cholesterol levels in the blood; furthermore, a variety of pigments with other biological activities have also been found in the fungus. Nowadays, various dietary supplements in the form of extracts or encapsulated powder are prepared from red yeast rice. They have been shown to possess medicinal properties, which are presumably the result of the synergistic action of the compounds contained, without eliciting adverse side effects (Patakova 2013).

Monascus purpureus is most notable for its beneficial effects on the cardiovascular system, since it regulates blood cholesterol levels, has anti-inflammatory and antioxidant properties, thus preventing cardiovascular disease, such as coronary heart disease and stroke. Moreover, the fungus has shown potential for treating diabetes, cancer, osteoporosis, fatty liver disease, fatigue, dementia or Alzheimer's disease (Yang & Mousa 2012).

Clinical studies using various preparations from red yeast rice in patients with high blood cholesterol (hypercholesterolaemia) and other lipids (hyperlipidaemia) have shown a reduction in total cholesterol of 11–44%, triglycerides of 7–44%, LDL (»bad«) cholesterol of 0–32%, and an increase in HDL (»good«) cholesterol of 0–55%. Furthermore, red yeast rice has been demonstrated to reduce the risk of coronary heart disease, myocardial infarction and associated deaths in patients with hyperlipidaemia. However, no serious adverse side effects have been observed in participants who were receiving red yeast rice preparations (Fang & Li 2000; Liu et al. 2006; Yang & Mousa 2012).

The cardiovascular protective properties of *Monascus purpureus* or red yeast rice are primarily the result of the inhibition of cholesterol synthesis by natural statins monacolins, of which the main compound is monacolin K or lovastatin. In addition, other biologically active compounds from the fungus contribute to the lipid-lowering effect, including phytosterols, β-sitosterol and campesterol that inhibit the absorption of dietary cholesterol, as well as isoflavones, unsaturated fatty acids, dietary fibre, and vitamin B (niacin). Several clinical studies have indicated that *Monascus purpureus* has, due to the synergistic action of its compounds, the same effectiveness as statins, which can elicit severe adverse effects. Therefore, preparations of red yeast rice could potentially be used as a substitute treatment for hyperlipidaemic patients who cannot tolerate synthetic statins (Yang & Mousa 2012).

In addition, a clinical trial involving patients with type 2 diabetes who were receiving a red yeast rice product, has shown a decrease in their blood glucose levels (Fang & Li 2000).

***Piptoporus betulinus* (Birch Polypore)**

Therapeutic Application: Antimicrobial, Antiparasitic, Anti-Inflammatory

Piptoporus betulinus is a polypore mushroom that has been used for medicinal purposes since prehistoric times. It was found with a 5300-year-old mummy, Ötzi the Iceman, who was presumably using *Piptoporus betulinus* fruiting bodies for their antibiotic properties and against parasites (Capasso 1998).
In traditional medicine, tea prepared from young fruiting bodies of the fungus has been used to reduce fatigue, soothe, strengthen the immune system, and for the treatment of different types of cancer in humans as well as in domestic animals. *Piptoporus betulinus* has also been used as antiseptic, pain reliever, and externally as styptic (Grienke et al. 2014).
Despite the lack of clinical evidence, scientists have demonstrated antimicrobial activity of *Piptoporus betulinus* against several pathogenic bacteria and fungi with active compound piptamine (Schlegel et al. 2000). Potential antitumour activity (Lemieszek et al. 2009) and anti-inflammatory properties of triterpene acids (Kamo et al. 2003) have also been shown for the fungus.

***Pleurotus ostreatus* (Oyster Mushroom)**

Therapeutic Application: Cholesterol Control, Cardiovascular Protective, Overall Health

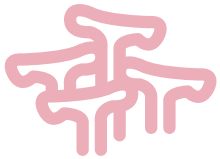
Pleurotus ostreatus is one of the most popular and widespread cultivated edible mushrooms, which has, in addition to good taste, relatively high nutritional value and is easy to grow. The mushroom is a healthy food, low in fat, containing mainly unsaturated fatty acids and ergosterol (provitamin D_2), and has a high content of dietary fibre and good quality proteins with most of the essential amino acids, which makes it suitable for vegetarians and vegans. Moreover, *Pleurotus ostreatus* contains pharmacologically active compounds with therapeutic properties known in traditional medicine of Asia, as well as Europe, South America and Africa. *Pleurotus ostreatus* is therefore not only a tasty edible mushroom easy to grow, but could be on the basis of tradition-

al knowledge and increasing scientific evidence also viewed as a medicinal mushroom with therapeutic potential (Gunde-Cimerman 1999).

Pleurotus ostreatus is recognised as a natural regulator of cholesterol and other lipids, and in addition lowers blood pressure and sugar levels, prevents the formation of blood clots (antithrombotic activity), and has anti-inflammatory properties. Thus, it protects against arterial wall thickening (atherosclerosis), cardiovascular disease and diabetes. The mushroom also strengthens the immune system, has antitumour properties, beneficial effects on the liver (hepatoprotective activity), and improves antioxidant status. Taken together, *Pleurotus ostreatus* helps prevent age-associated diseases, therefore is considered to have anti-ageing properties, and moreover, exhibits antimicrobial and antiviral activities (Gunde-Cimerman 1999; Gunde-Cimerman & Plemenitaš 2001; Patel et al. 2012).

Clinical studies have shown that *Pleurotus ostreatus* reduces cholesterol and triglyceride levels, without any deleterious effect on the liver and kidney (Khatun et al. 2007). The hypocholesterolaemic activity is due to the combined action of dietary fibre and primarily of a natural statin lovastatin or mevinolin, the most important pharmacologically active compound in *Pleurotus ostreatus*, which inhibits cholesterol synthesis. Lovastatin reduces blood levels of total cholesterol, triglycerides, and LDL (»bad«) cholesterol, whereas increases HDL (»good«) cholesterol. It has been proposed that the addition of 5% dried *Pleurotus ostreatus* to a high-cholesterol diet could effectively improve blood lipid profile (Gunde-Cimerman & Plemenitaš 2001). The mushroom also reduced blood sugar levels, as well as systolic and diastolic blood pressure in patients with type 2 diabetes and high blood pressure (hypertension) (Khatun et al. 2007; Choudhury et al. 2013).

In addition, β-glucans, including pleuran and related polysaccharides from *Pleurotus ostreatus*, have been shown to possess antitumour and antiviral properties, which are the result of the activation of the cellular immune response against tumour cells and viral infections. A clinical trial involving athletes has demonstrated that pleuran protects against respiratory tract infections (Majtan 2012), therefore *Pleurotus ostreatus* β-glucans represent promising natural compounds for strengthening the immune system. The mushroom also contains terpenes, lectin proteins, and other compounds with potential antitumour properties, as well as antibiotic and fungicidal activities (Gunde-Cimerman 1999).



***Polyporus umbellatus* (Umbrella Polypore)**

Therapeutic Application: Diuretic, Urinary Tract, Anticancer

Polyporus umbellatus is a fungus with edible fruiting bodies, while its underground structures, called sclerotia, have been used for thousands of years in traditional medicine in China, Japan and India. Sclerotia of the fungus are commonly used as an ingredient in various traditional Asian herbal preparations, mainly as a diuretic for the treatment of oedema or swelling, kidney or urinary tract infections and disorders, scanty and painful urination, jaundice, leucorrhoea (vaginal discharge), and diarrhoea (Hobbs 1986; Zhao 2013).

Recent scientific research on therapeutic properties of *Polyporus umbellatus* supports the findings of traditional medicine and has demonstrated a potent diuretic effect of the fungus showing 62% increase in urine output (Powel 2010). In addition, the fungus has been shown to have a stimulatory effect on the immune system, potential antitumour properties, beneficial effects on the kidney and liver (nephroprotective and hepatoprotective activities), as well as

anti-inflammatory and antioxidant activities (Zhao 2013).
Two main groups of pharmacologically active compounds have been identified in *Polyporus umbellatus*, i.e. polysaccharides and phytosterols, including ergosterol and ergone, which is the main compound responsible for diuretic and nephroprotective properties of the fungus. Other compounds have also been identified in the fungus and contribute to its diuretic activity, such as triterpenoids, mannitol etc (Zhao 2013).
Clinical studies using polysaccharides from *Polyporus umbellatus* as an adjunct to chemotherapy have shown that they enhanced the immune system and improved the treatment outcomes in patients with leukaemia, lung, liver, oesophageal, throat and nasal cancer. Furthermore, the polysaccharides improved the quality of life of the patients by reducing chemotherapy-related side effects (Hobbs 1986; Powel 2010). Clinical symptoms were also improved in patients with hepatitis who were administered *Polyporus umbellatus* polysaccharides. No negative reactions to *Polyporus umbellatus* have, however, been reported in clinical trials (Hobbs 1986).

***Poria cocos* (Hoelen, Poria Mushroom)**

Therapeutic Application: Overall Health

Poria cocos or *Wolfiporia extensa* has been in traditional Chinese and Japanese medicine used as a diuretic, sedative, and tonic for overall health and vitality. For therapeutic purposes, powdered underground fungal sclerotia have been used, which resemble a coconut, hence the scientific name of the fungus. These have been rarely used alone, but rather as a component of many traditional Asian herbal formulae (Ríos 2011).
Scientists have identified several pharmacologically active compounds in *Poria cocos*, including triterpenes, which are in addition to polysaccharides the main compounds of the fungus with a broader spectrum of activity. There is a lack of clinical studies on the fungus; nevertheless, its medicinal properties have been demonstrated in different experimental models (Ríos 2011).

Triterpenes of *Poria cocos* have been shown to exhibit potent anti-inflammatory activity by suppressing dermatitis and oedema, as well as have potential antitumour properties (Powell 2010; Ríos 2011). Antitumour activity has also been shown for polysaccharides from the fungus, such as PCS3-II, which exhibited the effects by potentiating the immune response (Chen et al. 2010b; Ríos 2011). Furthermore, an immunomodulatory protein PCP has been isolated from *Poria cocos* (Chang et al. 2009).

Poria cocos has also been shown to have therapeutic potential in diabetes by reducing blood glucose levels (antihyperglycaemic activity), as well as in nephritis and hepatitis B. The fungus also exhibited activity against parasites, including *Trypanosoma cruzi* and several nematode species (Ríos 2011).

***Trametes versicolor* (Turkey Tail)**

Therapeutic Application: Anticancer, Antiviral, Immunity

Trametes versicolor or *Coriolus versicolor* is one of the most studied and clinically important medicinal mushrooms used for the treatment of a variety of cancers. The research has focused primarily on the antitumour properties of the two pharmacologically active polysaccharide-protein complexes or proteoglycans, called PSK (Polysaccharide-K or Krestin) and PSP (Polysaccharide-Peptide), which have been evaluated in large-scale clinical trials. The compounds have been shown to be very effective immunotherapeutics in cancer management, especially when combined with conventional treatment, without exhibiting toxicity or serious adverse side effects (Kidd 2000).

PSK is the first approved medicine derived from a mushroom and is one of the most widely accepted for the treatment of certain types of cancer, particularly in Japan. In numerous clinical studies, PSK has shown impressive results

in patients with gastric, as well as colorectal, oesophageal, nasopharyngeal, uterine, lung and breast cancer, and leukaemia. In conjunction with conventional treatment, PSK significantly (up to several times) extended the survival, enhanced the immune system by increasing immune cell count, reduced side effects of radiation and chemotherapy, and improved the quality of lives of the patients. In addition, PSK also possesses antioxidant properties (Kidd 2000). Similarly, clinical studies have shown that PSP prolonged the survival of patients with oesophageal cancer and potentiated the immune response in 70–97% of patients with gastric, oesophageal, lung, ovarian and endometrial cancer. Furthermore, PSP reduced side effects of chemotherapy and improved the quality of life in more than 70% of patients, while enhancing its therapeutic effects (Kidd 2000).

Trametes versicolor has also been shown to exhibit antiviral activity in patients with human immunodeficiency virus (HIV) and herpes simplex virus. Moreover, it has been shown to have beneficial effects on the liver (hepatoprotective activity), and in patients with fatigue (Powell 2010).

USES OF MEDICINAL MUSHROOMS IN ANIMALS

Throughout history, humans have been constantly observing animals, learning from them, and thus have discovered beneficial properties of certain mushroom species. Herders in the Himalayas, for example, noticed improved performance of their domestic animals, yaks, goats and sheep, after consuming *Cordyceps sinensis* (caterpillar fungus) during grazing, and thus began to explore the beneficial effects of the mushroom. They started to intentionally feed the animals with the mushroom to increase milk production, and improve reproductive capacity and vitality of their cattle. Eventually, the use of *Cordyceps* has expanded to traditional medicine (Panda & Swain 2011). Today, a number of medicinal mushrooms are used in animals for a variety of purposes presented below.

Curative Treatment of Domestic Animals Using Medicinal Mushrooms

Therapeutic properties of medicinal mushrooms on animals have been mainly investigated by *in vitro* studies and experiments on laboratory animals, or deduced from human clinical trials. Controlled scientific studies on the potential of medicinal mushrooms in the treatment of certain animal disease are scarce. There is a study on the activity of *Ganoderma lucidum* (reishi) against coccidiosis in broiler chickens. Coccidiosis is an animal disease caused by coccidian parasites, which represents a major problem in chicken and rabbit meat production. *Ganoderma lucidum* has been shown to be a promising new strategy to control chicken coccidiosis caused by *Eimeria tenella*, whereas an effective alternative for other coccidian parasites has not yet been discovered (Ogbe et al. 2009).
A number of individual case studies have been conducted on the treatment of domestic animals, which are largely limited to companion animals (pets), involving dogs, cats, and horses. These animals are predominantly administered medicinal mushrooms for the treatment of cancer, and such therapy is chosen by veterinarians familiar with alternative medicine, or by animal owners themselves (Robinson 2007).

Medicinal Mushrooms in Sport Animals

Certain medicinal mushroom species are, as by athletes, also used in animals involved in sports, since they improve their physical and mental performance, as well as overall health. Race horses and dogs, trotters, dressage horses, show jumpers, sledge dogs, agility dogs etc., can be supported by specific mushroom preparations when subjected to excessive physiological and psychological stress due to intensive training, competitions and transportation. However, the owners or persons responsible for animals that participate in professional sports competitions should consult an anti-doping organisation regarding the potentially prohibited substances contained in medicinal mushroom feed supplements before administering to animals.
A mixture of several mushroom species is usually used in such feed supplements, including the indispensable species of the genus *Cordyceps*, which increase the blood flow, oxygen utilisation and consumption by cells, and thus increase cellular energy (ATP) levels. Moreover, the invigorating properties of *Cordyceps* and neuroprotective effects of *Hericium erinaceus* (lion's mane) can help improve cognitive-behavioural function in animals. Mushroom blends usually also contain *Grifola frondosa* (maitake, hen of the woods) to increase the production of blood cells (haematopoietic effect), and *Ganoderma lucidum* to improve overall health (adaptogenic effect) and strengthen the immune system of animals.

Preventive Care and Improvement of Production Performance of Economically Important Animals

Most of the scientific research on the use of medicinal mushrooms in animals has been conducted in an effort to improve production performance and maintain health of economically important (farm) animals. Since 2006, when the European Union banned the use of nutritional antibiotics as growth promoters and production enhancers in production animals, the intensive search of natural feed supplements has begun, which would be as effective, or even more so, in maintaining health and high productivity of animals.

Numerous basic research studies have focused on the effects of medicinal mushrooms on the immune system of animals, since a potent immune response can protect them against diseases. In addition, the effects of medicinal mushrooms on production performance of farm animals have also been studied, mostly in broiler chickens, laying hens and pigs, which is measured or assessed by monitoring their growth performance, weight gain, as well as feed consumption and conversion.

The majority of studies on pigs have focused on weaning phase of piglets, when they are subjected to the highest physiological stress. During that time, they change the environment, are separated from their mothers, completely stop suckling, and switch exclusively to feed of plant origin. Accordingly, piglets lose the protection provided by their mother's milk and are in a vulnerable period, when their immune system has not yet fully developed, therefore are more susceptible to infections. *Ganoderma lucidum* has been shown to be an effective feed supplement for weanling pigs, since it enhances their immune response to viruses and improves their growth performance (Chen et al. 2008b).

Mushroom species of the genus *Cordyceps* have been used in traditional medicine to enhance sexual function and fertility, and could also be applied in animal husbandry to improve reproductive function of animals. Scientists have shown that *Cordyceps militaris* can increase the production, motility and morphology of sperm in subfertile boars. The effect was observed for another two weeks after the end of the treatment with the mushroom (Lin et al. 2007). *Cordyceps* species have, therefore, further potential application in increasing the reproductive capacity also of other animal species.

Several studies have been conducted on the beneficial effects of mushrooms on broiler chickens. *Agaricus bisporus* (white button mushroom)-supplemented diet (20 g/kg of feed) has been shown to improve growth performance and feed conversion efficiency in broiler chickens, as well as antioxidant status in chicken tissue. The latter, provides protection for the animal itself and also prevents the oxidation of its meat (Giannenas et al. 2010a). Essentially the same results were obtained in the study with fermentation concentrate of *Hericium caput-medusae* (Shang et al. 2014a), whereas *Agaricus brasiliensis* has been demonstrated positive effects on the production performance and immune system of broiler chickens (Guimarães et al. 2014). Furthermore, microbiological analysis has demonstrated a prebiotic effect of *Agaricus bisporus*, *Lentinula edodes* (shiitake), and *Hericium caput-medusae*, which were shown to promote probiotic bacteria in the intestine of chickens supplemented with the three mushroom species (Guo et al. 2004; Giannenas et al. 2010b; Shang et al. 2014b).

Polysaccharides from *Ganoderma lucidum* have been shown to be a potential vaccine adjuvant against Newcastle disease, a viral infectious disease affecting many domestic (poultry) and wild avian species. Adjuvant is immunological agent, which is added to a vaccine to prolong and potentiate the immune responses by increasing antibody production or to direct the immune response to particular types of immune cells. *Ganoderma lucidum* polysaccharides promoted lymphocyte proliferation and increased antibody titre in the serum of chickens vaccinated with Newcastle disease vaccine (Zhang et al. 2014).

However, medicinal mushrooms are not only used in most common terrestrial domestic animals; their effects have also been studied in fish farming, especially in trouts. Lentinan, a β-glucan from *Lentinula edodes*, has been shown to inhibit the expression of genes involved in acute inflammatory reactions in rainbow trout (*Oncorhynchus mykiss*), while its immune response remained unchanged. Thus, lentinan has potential as an immunomodulator that enhances beneficial and reduces detrimental immune responses (Djordjevic et al. 2009).

Functional (Designer) Foods of Animal Origin

Functional foods are foods containing biologically active compounds, which promote health and prevent or control certain diseases. The most common functional foods of animal origin are foods rich in omega-3 unsaturated fatty acids or antioxidants (Se, vitamin E), with low cholesterol and saturated fatty acids contents, foods supplemented with probiotic bacteria, lactose-free foods etc. Research on medicinal mushrooms used in farm animal feed has shown that certain biologically active compounds can be transferred from mushrooms to animal products, thus altering the product composition and exerting indirect effects on the consumers of such functional foods.

Supplementation of laying hens with *Lentinula edodes* has been shown to increase their egg production, improve egg quality and fatty acid composition

(increased linoleic acid, omega-6 and polyunsaturated fatty acids contents), and reduce the cholesterol content in egg yolk. Despite the change in the composition of the eggs, no adverse effects on their sensory properties (flavour, colour etc) have been observed (Hwang et al. 2012).
In addition, cordycepin, the main active compound in mushroom species of the genus *Cordyceps*, has been shown to be highly effective in transferring to animal products (Chen et al. 2014). Designer eggs obtained by standardised feeding of laying hens with mycelium of *Cordyceps*, and containing cordycepin and 30% less cholesterol, are already available on the Asian market. The effect of these eggs on a consumer is double. Since they contain less cholesterol, they are beneficial for people with high cholesterol levels (hypercholesterolaemia); moreover, cordycepin consumed with designer eggs has further favourable effects on cholesterol metabolism and other physiological functions in humans.

Mushrooms – Feed Supplement with a Positive Impact on the Environment

Mushroom species of the genus *Cordyceps* also show potential for reducing methane emissions from modern intensive cattle farming, which is often accused of being a major contributor to global warming. Methane is a potent greenhouse gas produced by microorganisms and protozoa in an anaerobic environment of the ruminant stomach (namely, in the rumen), and released to the atmosphere. A study has shown that *Cordyceps militaris* stimulated the mixed ruminal microorganism fermentation and was effective in reducing methane production in ruminal fluids from cattle (Kim et al. 2014).

The use of medicinal mushrooms in the prevention and treatment of animal diseases, as well as for improving the production performance of animals has only seen the light of day in the West. Since there is restricted use of certain pharmacological compounds and because of the increasing demand for natural forms of animal treatment, medicinal mushrooms with their therapeutic properties have potential for their application in veterinary practices as well as animal husbandry.

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