HEALTH AND NUTRITIONAL PROPERTIES OF MUSHROOMS
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INTRODUCTION

1. Production and consumption of mushrooms

Mushroom growing has been increasing worldwide in the past years and this trend is expected to continue in the coming years. In Europe the production of fresh mushroom is increasing, while the production of mushrooms for processing is almost stable, but slightly decreasing. The consumption of fresh mushroom is growing in most European countries, while the consumption of canned mushroom is decreasing, in particular in the countries where the consumption is traditionally higher, such as France and Germany. The overall increase in consumption is probably induced by the better knowledge of the product and its health and nutritional virtues.

China is the biggest producing country worldwide, followed by the European Union and by the United States. In Europe, the biggest producing country is Poland, followed by the Netherlands, France and Spain.

The most commonly grown mushroom in Europe is of the specie Agaricus bisporus (button mushroom), which represents 95% of the production. Other commonly grown Mushrooms are Pleurotus ostreatus (Oyster mushroom) y Lentinula edodes (shiitake). In Europe 65% of mushrooms are intended for the fresh market, and 35% are processed for the canned and the frozen industry.

The European Mushroom Growers Group (GEPC) was created in 1980 by France, Germany, and the Netherlands. Nowadays the GEPC is composed of 10 delegations representing the mushroom growers from Belgium, Denmark, France, Germany, Hungary, Ireland, Italy, the Netherlands, Poland, and Spain. In 2015, those 10 countries accounted for 90% of the overall European production of mushroom, which amounted at 1,111,700 tons – feet cut.

The GEPC defends the interests of the fresh and processed cultivated mushrooms production on a EU and international level.
Evolution of the mushroom production in Europe

Graph 1. Figures of the Agaricus bisporus mushroom production in the European Union from 2006 to 2015.
2. Mushrooms: a little known food

Traditionally, mushrooms have been used in the east both for eating and for medicinal purposes. In Europe they began to be used only relatively recently. In some countries, as is the case in Spain, their consumption is rare and they are not usually used as the main product in the meal unless they are used sporadically. People are not aware of the benefits that this food may have on health and the role they can play in the prevention of some diseases. Hence, the aim of this report is to spread this information among health and nutrition professionals, and as a consequence, to society.

Scientific studies on the nutritional and medical properties of mushrooms are becoming increasingly important. This report is a compilation of their health properties and the recent studies that exist on the subject. Better knowledge of the benefits that these products bring will help us achieve a healthier diet and improve our state of health.

From an organoleptic perspective

The first thing about mushrooms that draws our attention is their flavour, aroma and texture, i.e. their organoleptic characteristics. Mushrooms have a characteristic taste, known as umami (delicious savoury in Japanese), making them flavourful and versatile for using in various culinary dishes.

For decades we were told that there are only four basic sensations captured by the sense of taste: sweet, salty, acidic and bitter. However, there is a fifth perception of taste: the umami. This taste is found in foods rich in glutamate. Glutamate is a natural aminoacid present in almost all foods, particularly in proteins, such as dairy produce, meat and fish, and in vegetables and mushrooms. The shiitake mushroom is a good example of this taste.

Benefits of the umami taste

The umami taste, and more precisely its main ingredient glutamate, is used to reduce the intake of salt. When glutamate is added to meals, the quantity of salt can be reduced by between 30 and 40%, without affecting the palatability. Excessive intake of salt affects blood pressure, which may cause hypertension and coronary cardiac disease and, as the intake of sodium in the Spanish population exceeds the recommended limits, there are currently many scientific studies being carried out on the acceptability of substituting part of the salty taste of meals by the umami taste.

In a study done in Finland, the United States and Japan, in which glutamate was added to foods low in salt, it was observed that the consumers’ acceptance of these foods was increased. In fact, the United States Institute of Medicine found that the combination of glutamic acid with sodium forms the monosodium glutamate compound, responsible for the umami taste, and it has been proved that it is possible to maintain the palatability of foods with a lowered level of sodium when monosodium glutamate is substituted for part of the salt (Institute of Medicine, 2010; Roininen et al., 1996).
Furthermore, the intake of glutamate increases the secretion of digestive juices and insulin, which improves digestion. They also demonstrated that free glutamate plays a beneficial role in the regulation of gastrointestinal functions which could be used in the treatments of gastric illnesses such as dyspepsia and gastritis. (Nakamura et al., 2008).

**From a nutritional perspective**

Mushrooms are foods with highly valued nutritional properties. In particular is the low caloric value that they have due to their large water content (80%-90%), from 26-35 kcal for every 100 grams. In addition, they are a good source of proteins with an aminoacid composition more similar to animal protein than to vegetable, making them the ideal complement for vegetarian diets. Their high fibre content and low fat content are desirable characteristics for a healthy food.

With regard to microelements, mushrooms are an important source of group B vitamins, especially B₂ and B₃, and of vitamin D precursors like ergosterol that facilitate the absorption of calcium and phosphorus (Barros et al., 2007a). They also contain minerals essential for the correction functioning of our body, principally selenium, phosphorus and potassium (Manzi et al., 2001). Their sodium content is very low, which enables these products to be used for low salt content diets.

**From a medicinal perspective**

As mentioned previously, in the east these products have been known for thousands of years for their curative and medicinal properties. However, in the west they have only been used for a few decades. Mushrooms were used in popular Asian medicine against various illnesses because they were considered natural remedies. Chinese pharmacopeia documents the use of hundreds of species of mushrooms for a wide range of diseases. Today it is known that the health properties of mushrooms are due to the bioactive properties that they possess.

Some of the compounds and fractions isolated from medicinal fungi have shown promising immunomodulatory, antitumoral, cardio-vascular, antiviral, antibacterial, antiparasitic, hepatoprotector and antidiabetic properties. The polysaccharides obtained from mushrooms are considered to be compounds capable of modulating the immune response in animals and humans and inhibiting the growth of certain tumours (Lindequist et al., 2005; Cheung, 2008).

**Mushrooms are a valuable source of nutrients and bioactive compounds, and their characteristic flavour and aroma have recently awoken a growing culinary interest. Their potential beneficial effects on human health make them firm candidates for what may be termed functional foods.**
<table>
<thead>
<tr>
<th>Scientific name</th>
<th>Common name</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Agaricus</em></td>
<td></td>
</tr>
<tr>
<td><em>Agaricus bisporus</em></td>
<td>Common, button</td>
</tr>
<tr>
<td><em>Agaricus blazei</em></td>
<td>Brazil, sun</td>
</tr>
<tr>
<td><em>Agaricus brunnescens</em></td>
<td>Portobello</td>
</tr>
<tr>
<td><em>Pleurotus</em></td>
<td></td>
</tr>
<tr>
<td><em>P. ostreatus</em></td>
<td>Oyster</td>
</tr>
<tr>
<td><em>P. eryngii</em></td>
<td>King oyster</td>
</tr>
<tr>
<td><em>P. cornucopiae (var. citrinopileatus)</em></td>
<td>Yellow oyster</td>
</tr>
<tr>
<td><em>P. cornucopiae</em></td>
<td>Branched oyster</td>
</tr>
<tr>
<td><em>P. pulmonarius</em></td>
<td>Italian, Indian, Lung</td>
</tr>
<tr>
<td><em>P. sajor-caju (P. djamor)</em></td>
<td>Pink oyster</td>
</tr>
<tr>
<td><em>Lentinula Edodes</em></td>
<td>Shiitake</td>
</tr>
<tr>
<td><em>Agrocybe Aegerita</em></td>
<td>Poplar</td>
</tr>
<tr>
<td><em>Ganoderma lucidum</em></td>
<td>Reishi, Lingzhi</td>
</tr>
<tr>
<td><em>Pholiota Nameko</em></td>
<td>Nameko</td>
</tr>
<tr>
<td><em>Hericium Erinaceus</em></td>
<td>Lion’s mane</td>
</tr>
<tr>
<td><em>Hypsizygus Ulmarius</em></td>
<td>Elm</td>
</tr>
<tr>
<td><em>Hypsizygus Tessulatus</em></td>
<td>White beech (Shimeji)</td>
</tr>
<tr>
<td><em>Grifola frondosa</em></td>
<td>Maitake</td>
</tr>
<tr>
<td><em>Flammulina velutipes</em></td>
<td>Enoki</td>
</tr>
<tr>
<td><em>Cantharellus cibarius</em></td>
<td>Chanterelle</td>
</tr>
<tr>
<td><em>Trametes versicolor</em></td>
<td>Turkey tail</td>
</tr>
<tr>
<td><em>Auricularia auricula</em></td>
<td>Judas’ ear</td>
</tr>
</tbody>
</table>

**Table 1.** Summary of some mushrooms mentioned in this report
The table below gathers data on the nutritional content of cultivated mushrooms:

<table>
<thead>
<tr>
<th>Nutrient</th>
<th>Common (per 100g edible portion)</th>
<th>Shiitake (per 100g edible portion)</th>
<th>RDI men</th>
<th>RDI women</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy (kcal)</td>
<td>26</td>
<td>34</td>
<td>3000</td>
<td>2300</td>
</tr>
<tr>
<td>Proteins (g)</td>
<td>1.8</td>
<td>2.24</td>
<td>54</td>
<td>41</td>
</tr>
<tr>
<td>Total lipids (g)</td>
<td>0.3</td>
<td>0.49</td>
<td>&lt;100</td>
<td>&lt;77</td>
</tr>
<tr>
<td>Saturated FA (g)</td>
<td>0.07</td>
<td>-</td>
<td>&lt;23</td>
<td>&lt;18</td>
</tr>
<tr>
<td>Monounsaturated FA (g)</td>
<td>Tr</td>
<td>Tr</td>
<td>&gt;57</td>
<td>&gt;43</td>
</tr>
<tr>
<td>Polyunsaturated FA (g)</td>
<td>0.17</td>
<td>-</td>
<td>10-20</td>
<td>8-15</td>
</tr>
<tr>
<td>Ω-3 (g)</td>
<td>0.133</td>
<td>-</td>
<td>0.33-3.3</td>
<td>0.25-2.6</td>
</tr>
<tr>
<td>Ω-6 (g)</td>
<td>0.032</td>
<td>-</td>
<td>1.3-16.5</td>
<td>1.2-10.4</td>
</tr>
<tr>
<td>Cholesterol (mg)</td>
<td>0</td>
<td>0</td>
<td>&lt;300</td>
<td>&lt;230</td>
</tr>
<tr>
<td>Carbohydrates (g)</td>
<td>4</td>
<td>6.79</td>
<td>375-450</td>
<td>288-345</td>
</tr>
<tr>
<td>Fibre (g)</td>
<td>2.5</td>
<td>2.5</td>
<td>38</td>
<td>29</td>
</tr>
<tr>
<td>Water (g)</td>
<td>91.4</td>
<td>89.74</td>
<td>1000-2000</td>
<td>1000-2000</td>
</tr>
<tr>
<td>Calcium (mg)</td>
<td>9</td>
<td>2</td>
<td>800</td>
<td>800</td>
</tr>
<tr>
<td>Iron (mg)</td>
<td>1</td>
<td>0.41</td>
<td>10</td>
<td>18</td>
</tr>
<tr>
<td>Iodine (μg)</td>
<td>3</td>
<td>140</td>
<td>110</td>
<td></td>
</tr>
<tr>
<td>Magnesium (mg)</td>
<td>14</td>
<td>20</td>
<td>350</td>
<td>330</td>
</tr>
<tr>
<td>Zinc (mg)</td>
<td>0.1</td>
<td>1.03</td>
<td>15</td>
<td>15</td>
</tr>
<tr>
<td>Sodium (mg)</td>
<td>5</td>
<td>9</td>
<td>&lt;2400</td>
<td>&lt;2400</td>
</tr>
<tr>
<td>Potassium (mg)</td>
<td>470</td>
<td>304</td>
<td>3500</td>
<td>3500</td>
</tr>
<tr>
<td>Phosphorus (mg)</td>
<td>115</td>
<td>112</td>
<td>700</td>
<td>700</td>
</tr>
<tr>
<td>Selenium (μg)</td>
<td>9</td>
<td>5.7</td>
<td>70</td>
<td>55</td>
</tr>
<tr>
<td>Thiamine (mg)</td>
<td>0.1</td>
<td>0.015</td>
<td>1.2</td>
<td>0.9</td>
</tr>
<tr>
<td>Riboflavin (mg)</td>
<td>0.41</td>
<td>0.217</td>
<td>1.8</td>
<td>1.4</td>
</tr>
<tr>
<td>Niacin (mg)</td>
<td>4.6</td>
<td>3.877</td>
<td>20</td>
<td>15</td>
</tr>
<tr>
<td>Vitamin B6 (mg)</td>
<td>0.1</td>
<td>0.293</td>
<td>1.8</td>
<td>1.6</td>
</tr>
<tr>
<td>Folic acid (μg)</td>
<td>23</td>
<td>18</td>
<td>400</td>
<td>400</td>
</tr>
<tr>
<td>Vitamin B12 (μg)</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Vitamin C (mg)</td>
<td>4</td>
<td>0</td>
<td>60</td>
<td>60</td>
</tr>
<tr>
<td>Vitamin A (μg)</td>
<td>0</td>
<td>0</td>
<td>1000</td>
<td>800</td>
</tr>
<tr>
<td>Vitamin D (μg)</td>
<td>0</td>
<td>0.5</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Vitamin E (mg)</td>
<td>0.12</td>
<td>0</td>
<td>12</td>
<td>12</td>
</tr>
</tbody>
</table>

Table 2. Nutritional profiles from Food Comparison Tables, Moreiras et al., (2007) (MUSHROOM). Recommendations: Recommended daily intake (RDI) for men and women from 20 to 39 years with moderate physical activity
### Table 3. Differences in the nutritional composition of the mushroom depending on the culinary process used.

<table>
<thead>
<tr>
<th></th>
<th>Agaricus bisporus, raw /100 g</th>
<th>Agaricus bisporus, canned /100 g</th>
<th>Agaricus bisporus, sauteed /100 g</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Macronutrients</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Energy</td>
<td>kcal</td>
<td>25</td>
<td>21.7</td>
</tr>
<tr>
<td>Protein</td>
<td>g</td>
<td>1.8</td>
<td>2.4</td>
</tr>
<tr>
<td>Fat</td>
<td>g</td>
<td>0.43</td>
<td>0.39</td>
</tr>
<tr>
<td>FA saturated</td>
<td>g</td>
<td>0.07</td>
<td>0.11</td>
</tr>
<tr>
<td>FA poly</td>
<td>g</td>
<td>0.14</td>
<td>0.26</td>
</tr>
<tr>
<td>Cholesterol</td>
<td>mg</td>
<td>0</td>
<td>0.14</td>
</tr>
<tr>
<td>Carbohydrate</td>
<td>g</td>
<td>2.73</td>
<td>0.98</td>
</tr>
<tr>
<td>Sugars</td>
<td>g</td>
<td>0.2</td>
<td>0.2</td>
</tr>
<tr>
<td>Fibres</td>
<td>g</td>
<td>1.33</td>
<td>2.31</td>
</tr>
<tr>
<td>Water</td>
<td>g</td>
<td>92.8</td>
<td>93.1</td>
</tr>
<tr>
<td><strong>Vitamins</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vitamin B1 (Thiamin)</td>
<td>mg</td>
<td>0.09</td>
<td>0.05</td>
</tr>
<tr>
<td>Vitamin B2 (Riboflavin)</td>
<td>mg</td>
<td>0.31</td>
<td>0.12</td>
</tr>
<tr>
<td>Vitamin B3 (Niacin)</td>
<td>mg</td>
<td>3.2</td>
<td>0.5</td>
</tr>
<tr>
<td>Vitamin B5 (Phantotenic)</td>
<td>mg</td>
<td>2</td>
<td>0.34</td>
</tr>
<tr>
<td>Vitamin B6</td>
<td>mg</td>
<td>0.18</td>
<td>0.02</td>
</tr>
<tr>
<td>Vitamin B9 (Folate)</td>
<td>µg</td>
<td>33.5</td>
<td>26.3</td>
</tr>
<tr>
<td>Vitamin C (Ascorbic acid)</td>
<td>mg</td>
<td>1</td>
<td>6.5</td>
</tr>
<tr>
<td><strong>Minerals</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Calcium</td>
<td>mg</td>
<td>28.5</td>
<td>24.6</td>
</tr>
<tr>
<td>Iron</td>
<td>mg</td>
<td>1.66</td>
<td>0.9</td>
</tr>
<tr>
<td>Magnesium</td>
<td>mg</td>
<td>8.61</td>
<td>6.48</td>
</tr>
<tr>
<td>Phosphorus</td>
<td>mg</td>
<td>56.4</td>
<td>47</td>
</tr>
<tr>
<td>Potassium</td>
<td>mg</td>
<td>326</td>
<td>88.6</td>
</tr>
<tr>
<td>Sodium</td>
<td>mg</td>
<td>16.9</td>
<td>310</td>
</tr>
<tr>
<td>Copper</td>
<td>mg</td>
<td>0.54</td>
<td>0.17</td>
</tr>
<tr>
<td>Selenium</td>
<td>µg</td>
<td>5.62</td>
<td>&lt; 4.1</td>
</tr>
</tbody>
</table>

Original source: Cigsaw French food composition table version (2013)
[https://pro.anses.fr/TableCQUAL/index.htm](https://pro.anses.fr/TableCQUAL/index.htm)
1. Energy and moisture content

The calorific or energy value of a food is related to the amount of calories (Kcal) that it contains. To calculate the energy value of a food we need to know the quantity of nutrients that it contains and the calories of each (carbohydrates 4 kcal/g, proteins 4 kcal/g and lipids 9 kcal/g).

Mushrooms have approximately 26-35 kcal/100 g depending on the variety. To be precise, the common mushroom is one of the ones containing the fewest calories (26 kcal/100g) and although the shiitake is the mushroom with the greatest energy value, it only contains 35 kcal/100 g.

Figure 6. Energy content of some mushrooms in comparison to normal vegetable consumption (U.S.D.A., http://ndb.nal.usda.gov/ndb/foods)

Edible fungi have a very high percentage of moisture (81.8-94.8%). The variability of this percentage depends on the specific species, the crop, and conditions for growing and storage, etc. (Manzi et al., 1999).

Due to their high moisture content, mushrooms have a very short useful life. The food industry attempts to conserve these foods for a greater length of time and to preserve their nutritional qualities by various types of processing, such as drying, sterilisation and freezing (Barros et al., 2007b), including in recent years selling them freeze-dried (Hernando et al., 2008).

The content of dry material in fresh mushrooms is very low therefore, at around 10%, and mainly composed of carbohydrates, proteins, fibre and minerals.

Mushrooms are foods with a high satiating power and low energy density, i.e. the relation between the calories and the volume of a food. The high degree of moisture that they have is related to the sensation of satiety that they give and as they also contain very few calories, they are a very useful product for low calorie diets.
2. Carbohydrates

The total content of carbohydrates in mushrooms, including digestible and non-digestible carbohydrates, varies according to the species from **35% to 70% of the dry weight** (Diez and Álvarez, 2001; Mau et al., 2001). The types of digestible carbohydrates that are present in mushrooms are: manitol (0.3-5.5% in dry matter (Vaz et al., 2011), glucose (0.5-3.6%) (Kim et al., 2009) and glycogen (1-1.6% in dry matter) (Diez and Álvarez, 2001). Non-digestible carbohydrates include oligosaccharides such as trehalose and non-starchy polysaccharides such as chitin, β-glucans and mananos, which represent the greater part of mushroom carbohydrates.

According to the bibliography, the level of carbohydrates varies between the different types of mushroom. Reis and collaborators (2012a) carried out a study on the nutritional composition of the cultivated mushrooms most consumed on a global level. The results show that the **shiitake mushroom (17.62 g/100g)** shows the greatest quantity of total carbohydrates in comparison with the **common mushroom (5.98 g/100g)**, the oyster mushroom (9.30 g/100g) and the king oyster (8.95 g/100g). In this study they also analysed the sugar content, such as fructose, manitol and trehalose. The shiitake again presented the highest levels in these sugars in comparison with the other mushrooms. It is interesting to note that the common mushroom contains polysaccharides typical of the animal kingdom, such as glycogen, and does not contain either starch or cellulose, which are characteristic of plants.

![Figure 7. Content in carbohydrates of some mushrooms in comparison with vegetables normally consumed (U.S.D.A., http://ndb.nal.usda.gov/ndb/foods).](image)

The **glycaemic index** of a food measures its immediate effect on the increase of blood sugar and is a defined and constant number for each food. The content in complex carbohydrates and fibre shows that **mushrooms are a very low glycaemic index food (IG=15)**, so their digestion is slower and the sugar is released gradually. The foods with a low glycaemic index are recommended for people suffering from diabetes since they involve a lower increase in postprandial glycaemia.
3. Fibre

Considered to be dietary fibre are those polymers originating from plants that are formed by 10 or more monosaccharides that cannot be hydrolised endogenously by the digestive enzymes and that exercise a physiological effect that is potentially beneficial for the health. Dietary fibre includes polysaccharides, oligosaccharides and lignin. The consumption of dietary fibre and its compounds promotes the maintenance of health and the prevention of certain diseases such as diabetes, cancer, cardiovascular disease, hypercholesterolemia and obesity (Theuwissen and Mensink, 2008; Charles, 2005; Bordonaro and Sartorelli, 2008). Fibre regulates the absorption of sugar, absorbs certain organic compounds such as bile acids and can delay the intestinal absorption of sugar, which is very beneficial in the treatment of diabetes.

Mushrooms are a good source of dietary fibre. According to bibliographical data, mushrooms contain a greater quantity of insoluble fibre (2.28–8.99 g/100 g edible portion) than soluble (0.32–2.20 g/100 g edible portion) (Manzi et al., 2004). The polysaccharides that are found in greater proportions in the common mushroom fibre are β-glucans (4-13% of the total dietary fibre) followed by chitin (Guillamon et al., 2010). As with other nutrients, the fibre content will vary depending on the species, morphology and growth conditions of the mushrooms, as well as their conservation and the culinary processes that these products undergo. According to Manzi et al., (2001 and 2004), the mushrooms presenting the higher percentage of total fibre are Agrocybe aegerita, Agaricus bisporus, Pleurotus eryngii and Pleurotus ostreatus.

A study carried out in the United Kingdom shows that 100 g of fresh mushrooms contains between 5% and 25% of the recommended daily intake of fibre (18 g fibre/day in UK) (Manzi et al., 2001).

![Figure 8. Amount of fibre of some mushrooms in comparison to vegetables normally consumed (U.S.D.A., http://ndb.nal.usda.gov/ndb/foods)](image)
As has already been described above, fibre has many **beneficial effects for health**. In recent years numerous studies have been carried out on the effect that mushroom fibre has on health. Firstly, eating more fibre helps to regulate intestinal transit. In addition, fibre’s bioactive compounds, type β-glucans, are considered bioactive compounds that have the effect, among others, of stimulating the immune response, and are anticancer, hypoglycaemic and antioxidant.

It has been observed that a β-glucan isolated from the fruiting body of *Lentinula edodes*, i.e. lentinan, stimulates the immune system in animals, inhibiting the proliferation of cancer cells. β-glucans are being used as immunomodulators in anticancer therapies with some success (Reshetnikov et al., 2001).

Currently, much attention is being given, particularly commercially, to the functional properties that certain compounds of mushroom fibre possess. Particularly worthy of note are the β-glucans of the *Pleurotus* type for their immunomodulatory properties. In addition, it has been demonstrated that Pleuran, a β-glucan of this type, has a suppressive effect on tumours (Karácsonyi & Kuniak, 1994).

### 4. Lipids

Generally, mushrooms are **low in fat (less than 5% in dry weight)**. The environmental factors that affect the lipid content in mushrooms, their concentration depending on the growing conditions, can be nutritional factors, oxygen, temperature and nature of the substrate (Pedneault et al., 2007). Unsaturated fatty acid content is predominant in mushrooms and therefore is in greater quantities than saturated. Linoleic acid is that present in a greater proportion in mushrooms (Díez and Álvarez, 2001).

Linolenic and linoleic acids are essential fatty acids for the human being and, since our body does not synthesise them, we must ingest them with food. Linoleic acid is an omega 6 fatty acid and linolenic is omega 3, both polyunsaturates, from which can be synthesised the rest of the omega 6 and omega 3 fatty acids. In addition to the nutritional importance of linoleic acid, its precursor function in mushrooms of volatile compounds should also be highlighted, such as 1-octen-3-ol, 3-octanol, 1-octen-3-ona and 3-octanone (Combet et al., 2006), which are the main aromatic compounds in the majority of the species (Maga, 1981). These compounds also contribute to the flavour of the majority of the mushroom species analysed (Guedes de Pinho et al., 2008).

According to the work of Reis et al., (2012a), in which a comparative study of different cultivated mushrooms was carried out, it was concluded that the shiitake is the one with the highest levels of polyunsaturates and a lower amount of saturates than the rest of the mushrooms studied. The species of the genus *Pleurotus* has a very similar fatty acid profile and is notable as the one presenting the most monounsaturated fatty acids.
5. Proteins

The protein content of mushrooms varies between **15 and 35% of dry weight**, depending on the species, varieties and stage of development of the fruiting body (Manzi et al., 2004; Diez and Álvarez, 2001). **The protein digestibility of mushrooms in general is quite good**, for *P. ostreatus* and *L. edodes* it is 73.4% and 76.3%, respectively (Adewusi et al., 1993; Dabbour and Takruri, 2002). These values are comparable with those for legumes (70-80%) (Wong and Cheung, 1998) but are lower than those of animal protein that has a digestibility of more than 90% (McDonough et al., 1990).

The common mushroom, unlike the rest of vegetables, **contains all the essential aminoacids** (Ile, Leu, Lys, Met, Phe, Thr, Trp, Val), which are those that the human body cannot generate on its own and that have to be ingested in the diet. According to the World Health Organisation (WHO), common mushrooms are particularly rich in glutamic acid, aspartic acid and arginine. The aminoacids that present in greatest quantities in the common mushroom are methionine and cysteine (Manzi et al., 1999). The genus *Pleurotus* seems to be the one presenting the greatest protein quality; some of the varieties of this genus have a good distribution of both essential and non-essential aminoacids (Dundar et al., 2008; Patil et al., 2010).

![Figure 9. Protein content of some mushrooms in comparison to vegetables normally consumed (U.S.D.A., http://ndb.nal.usda.gov/ndb/foods)](Image)

The presence of aminoacids in free form is rare. Some of them that can be found are glutamic acid, ornithine and alanine (Kim et al., 2009). Their basic importance is that they contribute to the particular aroma and flavour of the mushrooms, for example **glutamic acid is principally responsible for the umami taste**.

According to the Food and Agriculture Organisation (FAO), **the protein quality of mushrooms is better than that of most vegetables** (FAO, 1981). The composition in aminoacids of the proteins of the mushrooms **is comparable to animal protein**, which
Health and nutritional properties of mushrooms

is important today in countering a high consumption of protein foods of animal origin, particularly in developed countries (Guillamon et al., 2010).

American scientists carried out a study on healthy and obese individuals in which they substituted beef in lunch by common mushrooms for 4 consecutive days. The result was that the amount of energy and fat ingested on the day reduced when the mushroom was introduced into the diet compared with the diet that includes meat. With regard to the subjects’ assessment of the meals’ palatability and sensation of appetite and satiety, no significant differences were observed when they were eating the various culinary preparations. The authors suggest including more low density calories, such as the common mushroom, into foods in the daily diet in place of foods with higher energy density, as a strategy to reduce the prevalence of obesity and overweight in the population (Cheskin et al., 2008).

6. Minerals

Minerals are chemical elements that are fundamental for the normal metabolic functioning of our body. The mineral nutrients play essential structural and metabolic roles. The diet must contain them in sufficient but not excessive quantities, in order to cover the body’s requirements, as well as accessibly, so that needs can be satisfied.

Some are required in quantities greater than 100 milligrams per day (calcium, phosphorus, sodium and potassium) and others, called oligoelements (iron, fluoride, iodine, copper, zinc, selenium, etc.), are needed in lesser amounts.

The mineral content in mushrooms varies between 6 and 11% in dry matter, according to the species. For example, Pleurotus ostreatus has 6.90%, Pleurotus eryngii 8.60%, Lentinula edodes 5.85% and Hericium erinaceus 9.35%.

Compared with other vegetables, mushrooms contain a reasonable quantity of minerals (Manzi et al., 1999). The macroelements that abound in cultivated mushrooms are calcium, phosphorus, potassium and magnesium and the microelements that dominate are copper, selenium, iron and zinc (Cheung, 2008).

Some of the more common cultivated mushrooms, A. bisporus, P. ostreatus and L. edodes, among others, are rich in potassium (2670-4730 mg/100g in dry matter) and are considered a good source of phosphorus (493-1390 mg/100g in dry matter), magnesium (20-200 mg/100g in dry matter), zinc (4.70-9.20 mg/100g in dry matter) and copper (0.52-3.50 mg/100g in dry matter) (Cheung, 2008).

With regard to the mineral content of mushrooms, it should be pointed out that the majority of cultivated mushrooms and also some species of the genus Boletus are rich in selenium in natural form (Cocchi et al., 2006).

Sodium

Sodium requirements in humans are about 3 g/day. Usually, the population consumes much more sodium than the recommended amount, which is due mainly to the greater consumption of pre-cooked meals. Excessive consumption of salt causes a greater risk of high blood pressure.
Mushrooms contain a very low amount of sodium, which means they are the **ideal food for a low-salt diet**. In addition, they have the advantage that they contain glutamate in natural form. This aminoacid is responsible principally for the umami taste. The umami taste enables reduction of the amount of salt in meals without losing the perception of salt.

**Potassium**

The common mushroom contains relatively high concentrations of potassium with levels equivalent to 7-9% of the recommended daily intake in an 85 g portion.

**Phosphorus**

Phosphorus is an essential compound in living organisms since it participates in numerous vital functions. Phosphorus and potassium are the major elements in the common mushroom. Mushrooms contain a greater quantity of phosphorus than other vegetables.
Selenium

Compared with other trace minerals such as copper, magnesium and zinc, selenium is an element that is required in a smaller dose. The recommended daily intake of selenium for humans is 57 µg (although the values vary between 30 and 80 µg depending on the bibliography). The maximum recommended intake varies between 100 and 200 µg per day (Jarzynska and Falandysz, 2011). Although only a small amount is required to cover requirements of selenium, it is not always easy to obtain the recommended amount through the normal diet.

The foods considered to be good sources of selenium are, among others: crab, liver, seafood and fish (Rayman, 2000). Currently, mushrooms are also considered to be rich in selenium. In general, fruit and vegetables are very low in this mineral that is normally plentiful in fish and meat.

The selenium content in the common mushroom varies from 0.46 to 5.63 ppm in dry matter depending on the species (Clement, 1998), the average being between 1 and 2 ppm of selenium in dry matter. This quantity represents 15% of the recommended daily intake in the EEUU. Mushrooms accumulate selenium as a function of the element’s availability in the medium in which they are growing.

Among selenium’s roles in our body, its antioxidant capacity is foremost, and it also helps to neutralise free radicals, induces apoptosis, stimulates the immune system and intervenes in the function of the thyroid gland. Selenium is a compound of various selenoproteins with a preventive role for some forms of cancer (Lu and Holmgren, 2009). Supplementing with selenium in low doses seems to be beneficial not only in preventing cancer, but it can also have a positive influence on many other functions in the body through the reduction of inflammation, heart disease and the regulation of blood pressure (Brozmanova et al., 2009). The efficacy of selenium compounds as chemopreventive agents in vivo correlates with its capacity to produce cellular cycle
regulation, stimulate apoptosis and inhibit the migration of tumour cells and invasion \textit{in vitro} (Zeng and Combs, 2008).

![Selenium content of some mushrooms in comparison with vegetables normally consumed (U.S.D.A., http://ndb.nal.usda.gov/ndb/foods)](image)

**Figure 12.** Selenium content of some mushrooms in comparison with vegetables normally consumed (U.S.D.A., http://ndb.nal.usda.gov/ndb/foods)

Selenium and zinc are trace minerals with a known antioxidant potential. Selenium performs an antioxidant activity through selenoproteins like glutathione peroxidase and thioredoxin reductase. Zinc is an important co-factor of the antioxidant enzyme superoxide dismutase. A deficiency in selenium or in zinc entails a reduction in the antioxidant capacity and the reverse has been demonstrated, that when there is a supplement of one or both of these, the oxidative condition is improved (Hu et al., 2010; Sahin and Kucuc, 2003).

In a recent study (Yan and Chang, 2012), \textit{Pleurotus ostreatus} is enriched with selenium and zinc and this food is introduced into the diet of experimental animals to test whether the antioxidant and antitumoral activity were increasing. \textit{Pleurotus ostreatus} is capable of accumulating large quantities of trace elements and incorporating them as organic compounds. This mushroom in itself has a high antioxidant capacity and if we further enrich it with selenium and zinc it can be seen to increase this capacity. The results of the study showed that \textit{Pleurotus ostreatus} enriched with selenium and zinc improved the antioxidant activity and was preventing the development of lung cancer in mice. According to the authors, supplementing mushrooms with these minerals is cheap and safe and can help increase their antioxidant capacity, thus boosting their antitumoral property.
Earlier investigations carried out at CTICH, that consist in enriching the common mushroom with selenium in the growing cycle, succeeded in adding value to this product, through increasing its content. Fortifying substrates is also a potential route for increasing the level of trace elements in cultivated mushrooms.

7. Vitamins

Vitamins are organic compounds fundamental to life that, when ingested in a balanced way and in essential doses, promote correct physiological function. The majority of essential vitamins cannot be synthesised by the body, which means that they can only be obtained through the intake of food. Each vitamin plays a particular role in the body. Some, known as co-enzymes, form part of enzymatic systems and catalyse certain chemical reactions in food metabolism. Mushrooms are considered a good source of vitamins, especially riboflavin ($B_2$), niacin ($B_3$) and folates ($B_9$) that are those contained in the greatest amounts.

Mattila et al., (2001) published some data on the content of various vitamins in cultivated mushrooms, the concentration varying from 1.8 to 5.1 mg/100 g dry matter for riboflavin, from 31 to 65 mg/100 g dry matter for niacin and from 0.30 to 0.64 mg/100 g dry matter for folates. It is notable that mushrooms contain folates in quantities that are relatively high and very similar to the concentration that vegetables present (Beelman and Edwards, 1989). The riboflavin content in mushrooms is also higher than the concentration present in vegetables and, in addition, some varieties of Agaricus bisporus present riboflavin concentrations as high as those that can be found in eggs and cheese (Mattila et al., 2001).
In cultivated mushrooms, the vitamin content can vary from one species to another. In the case of niacin, it is observed that *P. ostreatus* presents quantities that vary between 34 and 109 mg/100 g in dry matter, *L. edodes* between 12 and 99 mg/100 g in dry matter and *A. bisporus* between 36 and 57 mg/100 g in dry matter (Crisan and Sands, 1978; Bano and Rajarathnam, 1986).

Vitamins $B_1$, $B_{12}$ and $C$ are also present in mushrooms although in smaller quantities (Mattila et al., 2002). The vitamin $B_1$ or thiamine content in mushrooms varies between approximately 0.60 and 0.90 mg/100 g in dry matter. In the case of vitamin $B_{12}$, the amount present is much smaller, between 0.60 and 0.80 µg/100 g in
dry weight. Even so, mushrooms contain more B\textsubscript{12} than vegetable since these contain hardly any of this vitamin. Vegetarian diets are therefore lacking in B\textsubscript{12}.

**Vitamin D**

Vitamin D plays an important part in maintaining the organs and systems through multiple functions, such as the regulation of calcium and phosphorus levels in the blood, promoting their intestinal absorption from foods and their re-absorption at renal level. With this, they contribute to bone formation and mineralisation, essential for skeletal development. In addition, vitamin D has been the subject of much attention in recent years for its role in muscular function, immunology, the heart, cardiovascular disease and cancer, etc. (Phillips et al., 2012).

With regard to vitamin D, **mushrooms are the only non-animal food that contains this vitamin (in precursor form)** and because of this are the natural source of vitamin D for vegetarians. The content of D\textsubscript{2} (ergocalciferol), one of the forms of vitamin D, is present in a greater quantity in species of wild mushrooms than in cultivated species. More specifically, in common mushrooms it has been shown that in fact the presence of vitamin D\textsubscript{2} is greater in wild mushrooms than in cultivated ones. Furthermore, this vitamin’s distribution has been studied in the fruiting body of different species, the cap of the mushroom being the part with the greatest concentration (Mattila et al., 2002).

![Figure 16. Vitamin D content of some mushrooms in comparison with vegetables normally consumed (U.S.D.A., http://ndb.nal.usda.gov/ndb/foods).](image)

As already described, vitamin D is not present as such in mushrooms but it is its precursor, ergosterol, which is present. The levels of ergosterol, the provitamin of ergocalciferol (vitamin D\textsubscript{2}), are relatively high (400 to 600 mg/100 g in dry matter) (Mattila et al., 2002). The presence of vitamin D in mushrooms is attributed to exposure to sunlight, which catalyses the conversion of ergosterol in mushrooms into vitamin D\textsubscript{2} through a series of photochemical reactions.
Mushroom growers have incorporated UV light treatments into their growing, and in this way the mushrooms contain a quantity of vitamin D similar to wild ones (Simon et al., 2013). Recent analyses in the EEUU carried out on 10 different species of cultivated mushrooms show that the concentration of vitamin D$_2$ varied between 0.03 and 63.2 mg/100 g (1.2 to 2528 IU/100 g) in fresh weight, it being found that the highest levels corresponded to the mushrooms that had been exposed to UV rays during their production (Phillips et al., 2011). Many articles (Ko et al., 2008; Koyyalamudi et al., 2009; Simon et al., 2011) confirm that exposure to UV light considerably raises the bio-available content of vitamin D$_2$. It seems that the treatment is more effective if the packets are arranged in a single layer and uniformly distributed. The vitamin D$_2$ content can reach a level of 100 mg/kg in dry matter in optimum conditions (Kalăc, 2013).
Figure 17. Comparison of the content in some micronutrients between mushrooms and other vegetables (USDA Nutrient Data Laboratory, 2010). Based on the standard portion of mushrooms (84 g) and vegetables (85 g) of the FDA. (www.ars.usda.gov/nutrientdata)
Traditionally, scientific investigations have been centred on the nutritional properties of mushrooms. In the last decade, as well as the study of the nutritional composition of mushrooms, the study of the biologically active compounds that they contain has become more important, as well as those they have tested with significant beneficial properties for health.

Numerous bioactive compounds have been identified in mushrooms. The concentration of these will depend on the variety, substrate, crop, storage and processing conditions, etc. (Barros et al., 2007b). Among the bioactive compounds are polysaccharides, proteins, phenolic compounds (flavonoids, lignans and phenolic acids) lignins, triterpenes, etc. These compounds are responsible for the medicinal properties that mushrooms have, such as their antioxidant capacity, immunomodulatory property and anticarcinogenic and hepatoprotector capacities, among others.

1. Polysaccharides

Among the bioactive compounds in mushrooms, polysaccharides are those that show most antitumoral, antiviral and immunomodulatory activity (Mizuno and Nishitani, 2013). In particular the polysaccharides that are found on the cellular wall are those that show most bioactivity.

These polysaccharides are: chitin, cellulose and β-glucans polysaccharide-protein complexes (Zhang et al., 2007). These biologically active polysaccharides can be found in fruiting bodies and cultivated mycelium and can also be extracted from the environment in which they are grown. There are numerous studies, both in vivo and in vitro, in which β-glucans and polysaccharide-protein complexes have been isolated from different mushrooms and it has been shown that they have important biological properties as immunomodulatory, antitumoral, hypoglycaemic and antioxidant agents (Cheung, 2010). Recent investigations have observed that the polysaccharides of mushrooms can help avoid ontogenesis, through their direct antitumoral activity against various tumours and also prevent metastasis of the tumour. The effects are better when they are used together with chemotherapy (Wasser, 2002).

Below are highlighted some of the better known polysaccharides present in mushrooms, to which are attributed numerous medicinal properties.

β-glucans

- Pleuran. Is a type β-glucan polysaccharide that is found in species of mushrooms that belong to the genus Pleurotus. This polysaccharide has significant anticarcinogenic activity and stimulates immunity (Khan and Tania, 2012). In the study of Jesenak et al., (2013), it is shown that Pleuran reduces morbidity caused by recurrent infections of the respiratory passages through changes in the humoral and cellular immunity.
Positive effects have been associated to this compound in the reduction of cholesterol levels in the blood of rats (Bobek et al., 2001) and hamsters (Cheung, 1998). In humans the β-glucans derived from mushrooms also seem to reduce cholesterol (Braaten et al., 1994) and LDL in the blood (Behall et al., 1997). Among the activities of β-glucan, Pleuran stands out as having the best antioxidant status (it increases the activities of superoxide dismutase, glutathione peroxidase and glutathione reductase in the liver), as is demonstrated in a trial carried out on rats (Bobek and Galbavy, 2001).

**Lentinan.** Polysaccharide of the mushroom *Lentinula edodes* (shiitake). According to the bibliography consulted, Lentinan and Pleuran are the two β-glucans most used by the pharmaceutical industry since they seem to be those with the best biological activity. Lentinan stands out mainly for its antitumoral and immunomodulatory activity. Various studies have demonstrated that this polysaccharide stimulates the immune function, for example, in the work of Gordon et al., (1995) with patients with HIV, the treatment of this disease was combined with 2 mg de Lentinan and the disease’s evolution was improved thanks to its immunomodulatory effect.

Along the same lines as the polysaccharide from *Pleurotus*, Lentinan also has antitumoral activity (Rathee et al., 2011). It was observed that the administration of Lentinan together with the cancer treatment (chemotherapy) prolonged patients’ survival time, improved the immunological parameters and increased the quality of life of patients with cancer of the stomach, cancer of the colon and other carcinomas, in comparison with patients who were only treated with chemotherapy (Hazama et al., 1995).

Other effects that have been related to this β-glucan are that it increases resistance to intestinal mucus inflammation (Zeman et al., 2001) and inhibits the development of intestinal ulcers (Nosalova et al., 2001). In addition, it shows a positive effect in peristalsis (Van Nevel et al., 2003). Finally, its capacity to promote antioxidant enzymatic activity is also significant.

![Lentinan](http://www.biospectrum.com)

**Figure 18.** Structure of the polysaccharide lentinan (http://www.biospectrum.com).

**Ganopoly.** This polysaccharide has been isolated from *Ganoderma lucidum*, one of the mushrooms with the most medicinal properties known. The bioactive properties of Ganopoly align with that written above for Pleuran and Lentinan. It
has high antitumoral activity; its clinical effectiveness has been demonstrated in anticancer therapies because it improves the symptoms arising from this disease (Gao et al., 2003).

The antidiabetic activity that is associated with it is determined by its ability to lower the postprandial glucose level in patients with type II diabetes (Gao et al., 2004). It has also been shown that this polysaccharide can act as a powerful immunostimulant (El Enshasy and Hatti-Kaul, 2013).

- Grifolan. β-glucan extracted from the mushroom Grifola frondosa. This compound possesses important medicinal properties, including promoting microphage activity and increasing the production of interleukin IL-1 improving the immune response.

It has been shown that the polysaccharide Grifolan is capable of increasing the production of insulin, which means that this compound could be used for the treatment of diabetes (Manohar et al., 2002). Antifungal activity is also attributed to this compound. According to Uchiyama et al., (2002), it is able to suppress the pathogenic fungus Candida albicans that can cause infections in the oral cavity membranes and systemically, including infections of the lungs, lymph nodes, liver and spleen.

In addition to the properties already described for this β-glucan, in a study on mice it was observed that Grifolan can suppress the inflammation of the mucus membranes of the respiratory tract (Korpi et al., 2003). This polysaccharide also has anticancer activity because it is capable of restoring the cellular immunity that is destroyed as a result of the radio- and chemotherapy treatments (Ooi and Liu, 2000).

**Polysaccharide-protein complex**

The polysaccharide-protein complexes of mushrooms increase the immune response, both innate and cellular, and also show antitumoral activity in animals and humans (Mizuno, 1999; Reshetnikov et al., 2001). The stimulation of the host’s immune defence by bioactive polysaccharides derived from medicinal mushrooms has a significant effect on the maturation, differentiation and proliferation of many types of immune cells in the host (Wasser, 2011).

Together with the polysaccharide-protein complexes, glycoproteins and polysaccharide-peptide complexes also pursue important antitumoral and immunomodulatory activity. For example, the study of the mushroom Trametes versicolor enabled the discovery of two very interesting compounds, a water-soluble polysaccharide-protein complex, polysaccharide-K (PSK), commercial name Krestino, and a polysaccharide-peptide (PSP), both obtained from the mycelium, and with an extraordinary immunopotentiating and anticancer activity (Rowan et al., 2002). In other mushrooms, polysaccharides with immunomodulatory properties have also been identified, such as the polysaccharide-protein complex known as LEM, in the mycelium of Lentinula edodes, glycoproteins with immunostimulating activity (FIPs) and a polysaccharide-peptide complex (GPP) in Ganoderma lucidum (Rop et al., 2009).
2. Other bioactive compounds

Besides polysaccharides and proteins, mushrooms contain other bioactive compounds that are classified according to their molecular weight. The compounds with the greatest molecular weight are the lignins and lectins, among others, and those with lowest weight are notably the triterpenes and phenolic compounds (Lindequist et al., 2005).

Compounds with low molecular weight

Triterpenes represent one of the largest groups of bioactive compounds that are found in medicinal mushrooms. *Ganoderma lucidum* is a good example since it has more than 120 different triterpenes (Kim and Kim, 1999). It has been shown that various triterpenes from *G. lucidum* are antiviral agents active against type I HIV and against the herpes type I virus (El-Mekkawy et al., 1998; Mothana et al., 2003). Others can inhibit cholesterol synthesis (Komoda et al., 1989) and, in addition, some are capable of inhibiting the enzymes that participate in the conversion of angiotensin (Morigiwa et al., 1986) or platelet aggregation (Su et al., 1999), thus being able to reduce the risk of atherosclerosis.

Phenolic compounds, also bioactive compounds of mushrooms, are characterised by their high antioxidant capacity. Numerous works conducted on various species of mushroom, including *G. frondosa*, *H. erinaceus*, *L. edodes* and *P. ostreatus*, among others, have shown that their aqueous and metanolic extracts are rich in phenolic compounds and that they have a high antioxidant capacity *in vitro* (Mau et al., 2002; Elmastas et al., 2007). Phenolic compounds have also been found with antioxidant power in other species of mushrooms as well as those named above.

Flavoglaucin, a phenolic compound isolated from the mycelium of the mushroom *Eurotium chevalieri*, is an excellent antioxidant in vegetable oils in a concentration of 0.05% (Elmastas et al., 2007). In most of these studies, a positive correlation is found between the total phenolic content in extracts from mushrooms and its antioxidant properties, which confirms that edible mushrooms have an important role as natural antioxidants due to the ability of their phenolic compounds to inhibit the oxidation of lipids.

Besides phenolic compounds, mushrooms also have other compounds with antioxidant activity, like β-tocopherol and β-carotene.

Compounds with high molecular weight

Lectins are proteins that attach to sugars with a high specificity. Lectins derived from mushrooms are characterised by their activities: immunomodulatory, antiproliferative and antitumoral (El Enshasy and Hatti-Kaul, 2013). These compounds modulate the human immune system because they stimulate the maturation of the immune cells *in vitro* (Wang et al., 1996; Lin et al., 2009).
It has been shown that lectins also have a hypoglycaemic activity. In the study of Ahmad et al., (1984) lectins were isolated from the *Agaricus campestris* and *Agaricus bisporus* mushrooms and it was observed that they were able to increase the release of insulin in islets of Langerhans extracted from rats.

In some species of *Pleurotus*, lectins have been isolated that contain aminoacids like glucose, arabinose, galactose, manose and xilose with anti-inflammatory properties, among which species are *P. japonicus* (Lindequist et al., 2005), *P. ostreatus* and *P. cornucopiae* (Yoshida et al., 1994).

**Lignins** are polymers present in the cellular walls of mushrooms. It has been shown that lignins soluble in water, isolated from *Lentinula edodes*, have antiviral activity since they are able to inhibit to some extent the development of HIV (Lindequist et al., 2005).
HEALTH PROPERTIES OF MUSHROOMS

For thousands of years, mushrooms have been used in traditional eastern medicine, although it has not been until the last two or three decades that studies have begun to evolve to demonstrate the properties of their extracts in the prevention and treatment of various diseases, including cancer, Alzheimer’s, diabetes and obesity, etc. (Cheung, 2008). Thanks to these studies, it has been shown that the consumption of mushrooms or their isolated bioactive compounds entails a benefit for health (Lakhanpal and Rana, 2005). Some of the health properties that mushrooms present and their bioactive compounds are explained below:

1. Antioxidant

Currently, the antioxidant capacity of foods is gaining increasing importance as a means for combating oxidative stress. Cellular metabolism naturally produces species that are reactive to oxygen, known as “free radicals”. When the antioxidant mechanism is not able to detoxify an excess of these species, the result is oxidative stress.

Antioxidants can be endogenous, generated by the body itself, or exogenous, which are those coming from the diet. Increasing the intake of antioxidants helps to protect the body from free radicals and slow down the progress of many chronic illnesses (Liu et al., 2013). There are various types of antioxidants depending on their action mechanism: preventive, those that inhibit the formation of free radicals; free radical sequestrant, and repair enzymes that are responsible for repairing the damage once it has occurred.

There is a wide variety of foods rich in compounds with recognised antioxidant activity, including mushrooms. The antioxidant potential of mushrooms, both cultivated and wild, is today the motive for many scientific studies and publications. The antioxidant value of mushrooms is comparable with that of foods of vegetable origin, the compounds responsible for the antioxidant power in mushrooms being various: selenium, phenolic compounds, ergothioneine, tocopherols, carotenoids, etc. It has been shown that a good number of edible mushrooms could be used as natural antioxidants for their high potential against oxidative stress (Kim et al., 2008; Liu et al., 2012; Palacios et al., 2011; Reis et al., 2012b).

Among the phenols identified in the common mushroom are tyrosine, catechol, phenolic acids, ρ-hydroxybenzoic acid, tr-cinnamic acid, ρ-coumaric acid and vanillic acid (Dubost, 2007). In animals, it has been shown that the extract from Pleurotus protects the organs of older rats against oxidative stress and the bases have been laid to be able to prove the activity of these extracts in humans (Jayakumar et al., 2007; Jayakumar et al., 2006). In addition, this author suggested incorporating the extract in the diet as a nutritional supplement to increase the body’s defences against oxidative
stress (Jayakumar et al., 2007). In another study by the same author also with rats of an advanced age, it was observed that an extract from *P. ostreatus* was increasing gene expression for the antioxidant catalase enzyme and reducing the incidence of protein oxidation induced by free radicals, which means that this extract seems to protect against the appearance of disorders associated with age in those where free radicals are implicated (Jayakumar et al., 2010).

With regard to polyphenols, the common mushroom is the one that contains the highest level of these antioxidants. A portion of common mushrooms (85 g) contains between 43 and 75 mg of total phenols. A positive relation has been found between this high phenol content and the free radical sequestration ability, as these phenols are the compounds that contribute most to the antioxidant capacity (Dubost, 2007).

In addition, the mushroom polysaccharides can boost the defence systems *in vivo* against oxidative damage. The fruiting bodies of *Pleurotus abalonus* produce a polysaccharide-peptide complex (F22) capable of increasing the activity and gene expression of antioxidant enzymes and of reducing lipid peroxidation in mice with accelerated senescence (Li et al., 2007). Pleuran, another β-1,3-D-glucan that is extracted from *Pleurotus ostreatus*, improves the antioxidant status of rats, increases the activity of the superoxide dismutase enzyme (SOD), glutathione peroxidase (GSH-PX) and glutathione reductase (GRD) (Bobek and Galbavy, 2001).

**Ergothioneine** is a compound found in mushrooms that is an excellent antioxidant *in vivo* (Dubost et al., 2007) and furthermore protects the cells against oxidative damage (Aruoma et al., 1999). *Boletus edulis* is the mushroom that presents the highest concentration of all foods (528.1 mg/kg of moist matter) (Ey et al., 2007). Other less common mushrooms like *A. bisporus* show concentrations that hover around 0.21-0.47 mg/g in dry matter (Dubost et al., 2006; Dubost et al., 2007), although *P. ostreatus* (2-2.59 mg/g in dry matter) and *L. edodes* (1.98-2.09 mg/g in dry matter) show higher levels. Thus, edible mushrooms contain a quantity of ergothioneine suited to improving the antioxidant capacity of meals.

**Selenium** plays a very important role in the antioxidant systems of the human body, acting as a co-factor in glutathione peroxidase, boosting the activities of α-tocopherol and helping the DNA repair mechanisms. As mentioned previously, mushrooms of the genus *Boletus* possess high concentrations of this compound, from 1 to 5 mg/kg in dry matter (*B. edulis, B. pinicola* and *B. aestivalis*) (Kalac, 2009). The cultivation substrates of other mushroom species that present lower concentrations of this mineral, like *Agaricus bisporus*, can be supplemented by adding sodium selenite to increase the concentration (Spolar et al., 1999).

At CTICH, studies have been carried out on the antioxidant capacity of mushrooms. Specifically, the antioxidant activity was determined of 10 mushroom species that had been cultivated on La Rioja’s own substrate. The results obtained suggested that mushrooms like *Agaricus bisporus*, *Hypsizygus ulmarius*, *Agrocybe aegerita* and *Pleurotus ostreatus* have a high antioxidant capacity and a high concentration of phenols (Grifoll et al., 2014).
2. Antitumoral

In most countries, cancer is the second cause of mortality in the population and is considered as a global epidemic. It is possible to prevent almost 30% of cases of cancer by modifying the main risk factors, such as food, tobacco, alcohol and lack of physical exercise. According to many studies, a diet rich in fruit, vegetables, whole grain, dietary fibre and certain micronutrients (vitamins and minerals), helps to protect the body against certain types of tumour (Menendez and Lupu, 2006).

Mushrooms contain a series of compounds, already mentioned above, that display anticancer activity. The consumption of mushrooms can reduce the risk of suffering from certain tumours or prevent them. For example, in a study carried out among Korean postmenopausal women, it was observed that the regular consumption of mushrooms reduced the risk of breast cancer (Hong, 2008).

Epidemiological studies have shown that the habitual intake, as part of a normal diet, of mushrooms that display anticancer activity reduces the risk of tumour formation. The mortality levels for cancer in population groups that were eating Agaricus blazei and Flammulina velutipes as part of their regular diet were significantly lower than those for the rest of the world’s population (Gi-Young et al., 2005). Consumption of the Maitake mushroom increases the activity of the auxiliary T cells that attack cancer cells (Israilides et al., 2008) and has a positive effect on breast (Chan et al., 2011), colon (Masuda, 2009) and prostate cancer (Fullerton, 2000). The works of Tanaka et al., (2011) and Sliva (2003) also show that shiitake and reishi mushrooms also have antitumoral activity in studies in vivo with animals. Some mushrooms of the
genus *Cordyceps* are capable of inhibiting the division and proliferation of cancer cells (Das et al., 2010). The common white mushroom can also modulate the aromatase enzyme activity and reduce the production of oestrogen *in situ* in postmenopausal women, which makes it an excellent chemopreventive agent in breast cancer (Chen et al., 2006).

Among the compounds with antitumoral activity in mushrooms, polysaccharides seem to be the most powerful. Scientific studies show that *the polysaccharides of the common mushroom can avoid oncogenesis*, through their direct antitumoral activity against various tumours and *furthermore prevent metastasis of the tumour*. Its activity is increased when it is used in conjunction with chemotherapy (Wasser, 2011). Another example is the administration of lentinan during chemotherapy treatment, which has been observed to increase the quality of life of patients with stomach and colon cancer and other carcinomas, in comparison with patients who have only been treated with chemotherapy (Hazama et al., 1995).

More polysaccharides have been studied in detail, such as schizophyllan from *Schizophyllum commune*. Clinical trials on humans with this compound have demonstrated its beneficial activity in patients with an inoperable and recurrent gastric cancer. Other studies indicate its activity as an inhibitor in second stage cervical cancer and advanced grades of cervical carcinoma (Hobbs, 1995; Borchers et al., 1999). Also noteworthy are the clinical studies carried out with Ganopoly, the polysaccharide extracted from *Ganoderma lucidum*, in which it was detected that symptoms related to the cancer, such as perspiration or insomnia, improved when they were treated with Ganopoly three times a day (dose: 1800 mg).

### 3. Immunomodulatory

An immunomodulatory is a substance that modifies (can increase or decrease) the immune system’s capacity to perform one or more of its functions, such as the production of antibodies, antigenic recognition or the secretion of inflammatory mediators. Modulation of the immune system through its stimulation or suppression can contribute to the maintenance of a good state of health. The use of agents that activate the host’s defence mechanisms (immunostimulators or immunopotentiators), would provide an additional therapeutic tool to conventional chemotherapy in immunocompromised people.

Edible mushrooms comprise a *source of compounds that “boost the host’s defence” through their stimulatory activity on the immune system*. Various substances with an immunostimulant effect have been isolated from mycelium and from the fruiting bodies of different mushrooms, basically polysaccharides with type β-glucan structure, lectins and terpenes. These compounds stimulate different cellular populations like macrophages, NK cells (a type of lymphocyte), neutrophils or lymphocytes and induce the synthesis of cytokines (Chen and Seviour, 2007). Thus, some polysaccharides or polysaccharide-protein complexes of mushrooms are able to stimulate the non-specific immune system and perform antitumoral activity through the stimulation of the hosts’ defence mechanisms (Rathee et al., 2012).
Depending on the molecular weight of the polysaccharides extracted from mushrooms, the immunomodulatory action mechanism will be different. Low molecular weight polysaccharides can penetrate into the cells and thus have a booster effect on the immune system. When those with greater molecular weight cannot enter the cell, they attach to specific receptors of the cellular membrane and propagate the response in this way (El Enshasy and Hatti-Kaul, 2013).

![MODE OF ACTION](https://www.progal-bt.com)

**Figure 20.** Action mechanism of a β-glucan as modulator of the immune system (www.progal-bt.com).

There are many mushroom species that have immunomodulatory activity. One of the most representative is *Ganoderma*. Studies carried out with polysaccharides of *Ganoderma lucidum* show that these compounds are able to stimulate the immune system of immunodepressed mice. The authors state that these compounds could be used as potentiaters to palliate immunosupression induced through chemotherapy (Zhu et al., 2007).

The immunomodulatory activity of *Grifola frondosa* must also be taken into account since various investigations suggest that the antitumoral activity mechanism of the grifolan polysaccharide is strongly related to immunomodulation. It has been shown that this polysaccharide activates the macrophages *in vitro* to produce the tumoral necrosis factor (TNF-α) (Ishibashi et al., 2001).

Bioactive compounds of other mushrooms like *Agaricus brazei*, *Lentinula edodes*, *Hericium erinaceus* and *Pleurotus ostreatus* are able to induce the production of TNF-α and increase the expression of cytokines and interleukins (IL-1β, IL-4, IL-8, IL-12), thus activating the immune system and thereby acting as immunomodulators (Lee et al., 2009; El Enshasy and Hatti-Kaul, 2013).
4. Anti-Obesity and Antihyperlipidemic Properties

Obesity is a serious public health problem that has reached epidemic proportions in many developed countries. In fact, the World Health Organisation (WHO) has defined it as the "Epidemic of the 21st Century". Increased body fat accompanying obesity may be due to a change in the number and/or size of adipocytes, the most abundant adipose tissue cells. Excess energy intake is stored inside adipocytes as triglycerides and when the body needs energy, these triglycerides are hydrolysed into free fatty acids and glycerol in a process called lipolysis.

In recent years several studies have shown the beneficial effects of certain mushroom varieties in the prevention of obesity and associated disorders (Handayani et al., 2014; Kanagasabapathy et al., 2013; Schneider et al., 2011). Jeong and colleagues (2010) found that oral administration of Agaricus bisporus to rats fed a hypercholesterolemic diet reduces both plasma triglycerides and glucose levels, so it follows that this mushroom is beneficial in lipid metabolism, which could be very advantageous in the treatment of obesity.

It has been shown that the Pleurotus species prevents weight gain and hyperlipidemia in C57BL/6J mice fed a high-fat diet, as it is capable of inducing lipolysis and inhibiting adipocyte differentiation. For example, β-glucans from the Pleurotus sajor-caju mushroom prevent the development of obesity and oxidative stress in mice fed a high-fat diet (Kanagasabapathy et al., 2013). Previous studies carried out in the CTICH in collaboration with the CIBIR showed that applying a Pleurotus ostreatus extract treatment in cell cultures of subcutaneous adipocytes increased lipolysis, this could be a mechanism with which the extracts of this mushroom are able to decrease the adipocyte size, and therefore, the adipose tissue (Aguilera-Lopez et al., 2013). Additionally, treatment with P. ostreatus decreased leptin levels in subcutaneous adipocytes, a hormone that is normally found at higher levels in obesity. Cumulatively, all this data suggests that the oyster mushroom offers potential protective effects for obesity and its associated disorders.

Continuing with the lipid lowering effects of the Pleurotus species, it has been found that polysaccharides of the Pleurotus eryngii are capable of lowering the level of blood lipids in mice fed a high-fat diet (Chen et al., 2012). It has also been shown to be more effective in inhibiting the accumulation of lipids than other polysaccharides extracted from mushrooms such as Hericium erinaceus, Ganoderma lucidum, Lentinula edodes or Pleurotus ostreatus (Chen et al., 2013).

Shiitake mushrooms are also known for their beneficial effects in relation to obesity, since they may help reduce the level of lipids in plasma and prevent weight gain. Administration of this mushroom to rats with a high-fat diet led to a 55% reduction of plasma cholesterol levels and lower fat accumulation, compared to another group of rats that consumed only a high-fat diet without shiitake mushrooms (Handayani et al., 2011). A later study by the same author correlated a β-glucan of shiitake mushrooms with a lower level of blood triglycerides, reduction of fat...
accumulation, lower body weight gain and decreased fat accumulation in the liver (Handayani et al., 2014).

The PNPS-1 polysaccharide of Pholiota nameko also has a significant hypolipidemic effect, since it has been confirmed that it can decrease both serum and liver lipid levels. Moreover, it has also been found that this polysaccharide reduced weight gain and visceral fat accumulation, which is very interesting since the increase of visceral fat is one of the primary causes of metabolic syndrome (Li et al., 2010).

5. Cholesterol-lowering properties

Mushrooms and their extracts could be considered as a new source of compounds with hypocholesterolemic effects, as they are rich in ergosterol derivatives, β-glucans and inhibitors of the HMG-CoA reductase enzyme. There are different studies, some of which are already mentioned above, which describe the beneficial effects of mushrooms on blood cholesterol levels (Gil-Ramirez et al., 2011; Gil-Ramirez et al., 2013a).

Among various species of mushrooms, the Pleurotus species stands out as a potential regulator of cholesterol metabolism. These mushrooms are able to synthesise lovastatin, a highly hypocholesterolemic statin that inhibits the HMG-CoA reductase enzyme, a key enzyme in the regulation of cholesterol biosynthesis in the liver (Gil-Ramirez et al., 2013b). Lovastatin also increases the activity of LDL cholesterol receptors. Moreover, some beta-glucans of Pleurotus are capable of binding to bile acids, reducing the formation of micelles and cholesterol absorption (Fidge, 1993; Bobek and Galbavy, 1999).

![Figure 21. Effect of mushrooms on cholesterol metabolism (Guillamón et al., 2010).](image)

In the case of mushrooms, their cholesterol-lowering effect has been described in many studies, such as the study by Jeong et al. (2010), which supplemented a high-fat diet with mushrooms for rats and found that blood cholesterol decreased in these animals compared to controls without mushrooms. The same effect was observed years before in another study when this mushroom was added to a fibre-rich diet. It
also showed that the cholesterol level was lower when the animals consumed the diet with mushrooms (Fukushima et al., 2000).

<table>
<thead>
<tr>
<th>Mushrooms</th>
<th>Hypcholesterolemic properties</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Agaricus bisporus</strong></td>
<td>↓ LDL Cholesterol ↓ Total serum cholesterol</td>
</tr>
<tr>
<td></td>
<td>↓ HDL Cholesterol</td>
</tr>
<tr>
<td></td>
<td>↑ Hepatic LDL receptor</td>
</tr>
<tr>
<td></td>
<td>↓ Fatty deposits ↓ Triglycerides in liver</td>
</tr>
<tr>
<td><strong>Auricularia auricula</strong></td>
<td>↓ LDL Cholesterol ↓ Total serum cholesterol</td>
</tr>
<tr>
<td><strong>Lentinus edodes</strong></td>
<td>↓ Cholesterol level</td>
</tr>
<tr>
<td></td>
<td>↓ Plasma phospholipids</td>
</tr>
<tr>
<td></td>
<td>Modification of hepatic phospholipid metabolism</td>
</tr>
<tr>
<td><strong>Pleurotus citrinopileatus</strong></td>
<td>↓ Total lipids ↓ Total cholesterol</td>
</tr>
<tr>
<td></td>
<td>↓ Triglycerides in liver and plasma</td>
</tr>
<tr>
<td></td>
<td>↑ Excretion of bile acids</td>
</tr>
<tr>
<td></td>
<td>HMG-CoA reductase inhibitors</td>
</tr>
<tr>
<td><strong>Pleurotus ostreatus</strong></td>
<td>↓ VLDL Cholesterol ↓ LDL Cholesterol</td>
</tr>
<tr>
<td></td>
<td>↓ Total serum cholesterol</td>
</tr>
<tr>
<td></td>
<td>↓ Plasma triglycerides</td>
</tr>
<tr>
<td></td>
<td>↓ Blood pressure</td>
</tr>
<tr>
<td></td>
<td>↓ Antioxidant activity of glutathione peroxidase</td>
</tr>
<tr>
<td></td>
<td>HMG-CoA reductase inhibitors</td>
</tr>
</tbody>
</table>

Table 4. Hypcholesterolemic properties of mushrooms (Guillamón et al., 2010).

Compounds obtained from *Ganoderma lucidum* such as ganoderic and triterpene acids, have been shown to posses hypocholesterolemic properties, as well as polysaccharides from the *Auricularia auricula* (Hobbs, 1995; Rowan et al., 2002).

Hypocholesterolemic properties are also attributed to the shiitake mushroom, in particular the effect is due to eritadenine, this compound exerts its effect by reducing cholesterol secretion from the liver into the bloodstream and/or through increased distribution of cholesterol from the plasma to the peripheral tissues (Shimada et al., 2003). Additionally, it has been shown that supplementation with shiitake mushrooms and eritadenine compound inhibits the development of hypercholesterolemia resulting from a high-fat diet (Yang et al., 2013).
6. Antidiabetic Properties

According to the WHO, diabetes is a chronic disease that occurs when the pancreas does not produce enough insulin or when the body does not effectively use the insulin it produces. Insulin is a hormone that regulates blood sugar. The effect of uncontrolled diabetes is hyperglycemia (excess blood sugar), which gradually causes serious damage to many organs and systems, especially to nerves and blood vessels.

A great number of studies have been carried out regarding the role of mushrooms in the dietary management of diabetes, which conclude that mushrooms are the ideal food for the prevention of hyperglycemia due to their high content of fibre and protein and for the bioactive compounds they posses, such as polysaccharides and lectins (Alarcon-Aguilara et al., 1998; Horio et al., 2001; Kiho et al., 2002).

Glucans extracted from the *Agaricus blazei* reduce the level of glucose, triglycerides and blood cholesterol simulating the effect of insulin. The study was conducted on rats with induced diabetes who were fed daily with sweet potato (*Ipomoea batatas*) and *A. blazei*. Researchers observed decreased plasma glucose, when on an empty stomach, and glycated hemoglobin, as well as a decrease in body weight loss due to the diabetes (Mascaro et al., 2014).

In another study, in this case with the *Agaricus sylvaticus*, it showed a beneficial effect in controlling type I diabetes by reducing blood glucose levels, cholesterol and triglycerides. Additionally, it improved pancreatic function by increasing the number of cells of the islets of Langerhans with good results in the symptoms of the disease (Mascaro et al., 2014).

Experimental studies with the *Pleurotus* species show very good results regarding the hypoglycemic effect of these mushrooms. Oral administration of *P. ostreatus* to rats reduced blood sugar levels in both insulin-dependent animals and those who were not dependent on insulin (Chorváthová et al., 1993). Subsequent studies, in vitro, in which subcutaneous adipocytes were treated with this mushroom showed significant insulin-sensitizing effects by significantly increasing glucose intake while releasing glycerol (Aguilera-Lopez et al., 2013). Introducing *P. eryngii* at 7% in the diet also led to an improvement in insulin sensitivity as well as a decrease in glucose and cholesterol levels in rats with induced diabetes (Kim et al., 2010). The aqueous extract of *P. pulmonarius* and *P. citrinopileatus* also revealed a powerful antidiabetic effect, lowering glucose levels of diabetic rats (Badole et al, 2008; Hu et al., 2006).

There is not only evidence of hypoglycemic activity in the *Pleurotus* species from animal testing, but studies on humans have also been carried out. Agrawal et al. (2010) an experimental study on 120 diabetic patients obtained the following results: the consumption of *Pleurotus sajor-caju* significantly reduced blood glucose levels on an empty stomach (P<0.005), and blood cholesterol (P<0.05) and HbA1c (glycosylated hemoglobin) (P<0.05).

Administration of *Grifola frondosa* at 20% in the diet of rats with induced diabetes resulted in increased excretion of insulin and decreased levels of blood glucose (Kurushima et al., 2000).
A polysaccharide of *Ganoderma lucidum*, Ganopoly, is also known for its hypoglycemic effect. In a study of 71 type II diabetic patients treated with Ganopoly, it was observed that postprandial glucose levels decreased significantly compared to the group not taking the extract (Gao et al., 2004).

### 7. Antihypertensive Properties

Arterial hypertension is a chronic disease characterized by a continued increase in arterial blood pressure. It is associated with significantly high morbidity and mortality rates, thus considered one of the most serious public health problems, especially in developed countries, affecting nearly one billion people worldwide.

Various antihypertensive compounds have been identified in vegetables and other foods. Many antihypertensives are inhibitors of the angiotensin converting enzyme (ACE inhibitors), which inhibit a series of reactions (renin angiotensin aldosterone system) that regulate blood pressure. ACE inhibitors have been detected in various mushrooms: *Grifola frondosa* (Choi et al., 2001), *Ganoderma lucidum* (Morigiwa et al., 1986) or *Pleurotus cornucopiae* (Jang et al., 2011), among others.

### Table 5. ACE inhibitor activity of various mushrooms.

<table>
<thead>
<tr>
<th>Mushrooms</th>
<th>ACE inhibitor activity IC50 (mg/ml)</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Agrocybe</em> sp.</td>
<td>0.890 ± 0.046</td>
</tr>
<tr>
<td><em>Auricularia auricula-judae</em></td>
<td>0.510 ± 0.018</td>
</tr>
<tr>
<td><em>Ganoderma lucidum</em></td>
<td>0.050 ± 0.009</td>
</tr>
<tr>
<td><em>Hericium erinaceus</em></td>
<td>0.580 ± 0.023</td>
</tr>
<tr>
<td><em>Pleurotus cystidiosus</em></td>
<td>0.054 ± 0.002</td>
</tr>
<tr>
<td><em>Pleurotus eryngii</em></td>
<td>0.067 ± 0.026</td>
</tr>
<tr>
<td><em>Pleurotus flabellatus</em></td>
<td>0.058 ± 0.002</td>
</tr>
<tr>
<td><em>Pleurotus florida</em></td>
<td>0.050 ± 0.013</td>
</tr>
<tr>
<td><em>Pleurotus sajor-caju</em></td>
<td>0.056 ± 0.012</td>
</tr>
<tr>
<td><em>Schizophyllum commune</em></td>
<td>0.320 ± 0.007</td>
</tr>
<tr>
<td><em>Volvariella volvacea</em></td>
<td>0.760 ± 0.023</td>
</tr>
</tbody>
</table>

The following describes certain studies that show antihypertensive effects of mushrooms. Aqueous extracts of the *Hypsizygus marmoreus* mushroom showed a clear antihypertensive effect with ACE inhibitor activity in a study of rats with hypertension (Kang et al., 2013). Another mushroom, *Maitake*, with which several
studies have been carried out, **has also shown favourable effects for hypertension.** Talpur et al. (2002) also showed potential antihypertensive effects of the Maitake mushroom in a study with hypertensive rats. Years earlier, Kabir and Kimura (1989) carried out another study feeding hypertensive rats with Maitake mushrooms for 8 weeks and found that blood pressure decreased significantly.

Abdullah et al. (2012) analysed the potential of ACE inhibitors in several species of mushrooms, the results are shown in Table 5, with the *Ganoderma lucidum* mushroom showing more antihypertensive effects.

In addition to the many beneficial properties already described for the *Pleurotus* species, these mushroom species also have antihypertensive effects through ACE inhibitors. Oral administration of *P. nebrodensis* and *P. cornucopiae* extracts reduced blood pressure in hypertensive rats in an experimental study (Miyazawa et al, 2008; Hagiwara et al., 2005).

### 8. Hepatoprotective Properties

The liver is one of the most complex and important organs in our body. It performs singular vital functions such as the synthesis of plasma proteins, vitamin and glycogen storage, etc. Additionally, it is in charge of removing substances from the blood that may be harmful to the body, transforming them into other harmless substances. The liver is involved in the metabolism of proteins, fats and carbohydrates, it maintains a stable level of blood glucose, storing it when in high quantity in the blood (gluconeogenesis) and releasing it (glycogenolysis) as needed.

The role of **mushrooms and their bioactive compounds** in liver functions has been undergoing research for several years. It has been found that these compounds can repair liver damage from toxins, protect against toxic agents, regenerate damaged hepatocytes, reduce inflammation, etc.

Most studies on the hepatoprotective role of mushrooms have been conducted with *Ganoderma lucidum* or extracts. Isolated Sterols from *Ganoderma lucidum* exert a powerful anti-inflammatory effect on butyl hydroperoxide or carbon tetrachloride induced liver cell line damage (Ha do et al, 2013; Sudheesh et al, 2012). It has also been found that *G. lucidum*, through an antioxidant mechanism, may protect liver cells poisoned with alpha-amanitin (one of the most potent liver toxins, obtained from the Amanita mushroom family) (Wu et al., 2013). Another study found that pure spore powder of the *Ganoderma lucidum* is particularly beneficial for liver cell damage caused by cadmium poisoning (Jin et al., 2013). It has even been shown that *G. lucidum* acts against hepatitis B. A clinical study was carried out in which treatment using polysaccharides of this mushroom reduced hepatitis B in HIV patients after 12 weeks (Gao et al., 2002).

The hepatoprotective effect has also been attributed to the *Pleurotus* species. There are studies using animals which confirm the protective effect of *P. ostreatus* (Jayakumar et al., 2006) and *P. florida* (Arunavadas and Umadevi, 2008) against carbon tetrachloride induced liver damage. Additionally, *P. ostreatus*, *P. sajor-caju* and *P. florida* can protect the liver from lipid peroxidation according to studies carried
out on liver tissue samples in hypercholesterolemic conditions (Hossain et al., 2003; Alam et al., 2009). In another study with an aqueous extract of P. eryngii, rich in polysaccharides, an increase in the activity of antioxidant enzymes and lower concentration of free radicals in the damaged liver was observed (Chen et al., 2012). Based on these studies, it follows that the potential of Pleurotus mushrooms against liver damage is due to its antioxidant effect.

Finally, it has also been found that the polysaccharides of the Hericium erinaceus mushroom possess strong antioxidant effects in vitro and a power hepatoprotective effect in vivo. The authors suggest that these polysaccharides may be used as antioxidant supplements in the prevention of liver diseases (Zhang et al., 2012).

9. Antiallergenic Properties

An allergy is a hypersensitivity to a particle or substance, which, if inhaled, ingested or touched, produces certain characteristic symptoms. It is a type of exaggerated immunological response to a non-pathogenic stimulus for the majority of the population. Its clinical manifestations are diverse, since they depend on the causative agent and the affected organ. Currently, more than one third of the world population suffers from some disease of allergic origin.

Extracts of certain mushrooms are able to stimulate the immune system, which might be interesting for the treatment of allergies. As is the case of aqueous extracts obtained from H. marmoreus, F. velutipes, P. nameko and P. eryngii, which have shown significant antiallergic effects in studies carried out on allergy induced mice (Sano et al., 2002).

Certain compounds extracted from Ganoderma lucidum (ganoderic acids C and D) can inhibit histamine release from rat mast cells, reducing allergic reaction (Kohda et al., 1985; Tasaka et al., 1988).

The isolated β-glucan of the Pleurotus ostreatus, Pleuran, has also been studied in relation to the antiallergenic effect of mushrooms. The prevalence of atopy in a group of children with recurrent respiratory tract infection and antiallergenic effect of Pleuran on markers of inflammation was researched. Active Pleuran treatment showed a potential antiallergic effect (Jesenak et al., 2014).

Most of the published research uses extracts or compounds derived from mushrooms, but there are very few publications that administer the entire mushroom, such as the case studying Tricholoma populinum, which observed that consumption of this mushroom led to a disappearance of the allergy symptoms in patients with hives (Kreisel et al., 1990).

10. Antimicrobial Properties

Natural antimicrobial compounds have the ability to inhibit the growth of microorganisms and are synthesized by some types of plants and vegetables. Mushrooms and fungi also produce antibacterial and antifungal substances to fend off other species, which confer antimicrobial properties against bacteria, yeasts and other
fungi. Different antimicrobial compounds have been isolated from the mushrooms (Rathee et al., 2012). **Many of the secondary metabolites secreted by mushrooms and fungi are used to fight bacterial and fungal infections and prolong the shelf life of other food products.**

One of the most studied mushrooms, in terms of its antimicrobial properties, is *Lentinula edodes*. Extracts isolated from this mushroom are shown to be active against some bacteria such as *Actinomyces* spp., *Lactobacillus* spp. and *Pophyromonas* spp. (Hirasawa et al., 1999). It seems that oxalic acid is one of the agents responsible for the antimicrobial effect of *L. edodes* against *Staphylococcus aureus* and other bacteria (Bender et al., 2003). Additionally, a protein called lentina has been extracted from the fruiting bodies of *L. edodes* with significant antifungal effect (Ngai and Ng, 2003). This protein with a molecular weight of 27.5 kDa inhibits mycelium growth in a large number of fungi, including *Physalospora piricola, Botrytis cinerea* and *Hycosphaerella arachidicola*.

Studies carried out with *Ganoderma lucidum* and other Ganoderma species show that these mushrooms produce several antimicrobial compounds that are capable of inhibiting growth of gram positive and/or gram negative bacteria. Aqueous extracts of *G. lucidum* fruiting bodies are capable of inhibiting growth of 15 types of gram positive and gram negative bacteria, especially of *Micrococcus luteus* (Yoon et al., 1994). It has also been found that extracts of *G. pfeifferi* inhibit the growth of microorganisms responsible for skin diseases (*Pityrosporum ovale, Staphylococcus epidermidis, Propionibacterium acnes*) (Mothana et al., 2000).

*Pleurotus* mushrooms, extracts and bioactive compounds also have notable antimicrobial activity. Some volatile compounds extracted from the fruiting body of *Pleurotus ostreatus* had strong antibacterial effect against *B. cereus, B. subtilis, E. coli* and *S. typhimurium* (Beltran-Garcia et al., 1997). Additionally, from this fungus was extracted a peptide with antifungal capability, called pleurostrin, which inhibits mycelial growth of the fungi *Fusarium oxyporum, Mucosphaerella arachidicola* and *Physalospora piricola* (Chu et al., 2005). From the *Pleurotus eryngii* mushroom, another antifungal peptide, called erygin, which inhibits growth of *Fusarium oxyporum* and *Mycosphaerella arachidicola* was isolated (Wang and Ng, 2004).
Although there have been few studies on wild mushrooms regarding antimicrobial effects and corresponding bioactive compounds, some studies found that a peptide produced by the *Boletus* species exhibited antimicrobial effects against gram positive bacteria (Lee et al., 1999; Barros et al., 2007b). Isobaric acids and 10-hydroxy-8-decanoic obtained from *Cantharellus cibarius* have also shown some antimicrobial effects (Anke et al., 1996).

### 11. Antiviral Properties

Viral diseases cannot be treated with common antibiotics, rather specific drugs against viruses that cause these infections are required. Antiviral activity in mushrooms is described for both entire mushrooms as well as and for bioactive compounds extracted therefrom. In the case of mushrooms, antiviral action can occur directly by inhibiting certain viral enzymes, through the synthesis of some nucleic acids of the virus or by absorption and replication of the virus in the cells; and also indirectly, by stimulating the immune system (Brandt and Piraino, 2000). The type of action against the virus is determined by the size of the fungi molecules.

Among the smaller molecules isolated from different mushrooms are several triterpenes isolated from *Ganoderma lucidum*, ganoderic acid for example, which has demonstrated significant antiviral activity against HIV type 1 (HIV-1) (El- Mekkawy et al., 1998). In the same way, the ganoderadiol, licidiadiol and aplanoxídico acid, from *Ganoderma pfeifferi*, posses antiviral effects against the type A influenza virus. Additionally, ganoderadiol also inhibits replication of the herpes simplex type 1 virus (Mothana et al., 2003).

As for the antiviral activity of more complex molecules, it has been shown that water soluble lignins, isolated from *Fuscoporia obliqua* are active against HIV (Ichimura et al., 1998). Also, water soluble lignins isolated from *L. edodes* and a polysaccharide called lentinar are capable of inhibiting the development of HIV to some extent (Lindequist et al., 2005). In this sense, a polysaccharide isolated from *Agaricus brasiliensis* has been shown to inhibit infection by the poliovirus type 1 (Faccin et al., 2007). Furthermore, proteins bound to polysaccharides isolated from *Ganoderma lucidum* are also capable of delaying development of the herpes viruses, as it inhibits the binding and subsequent penetration of the virus into cells (Eo et al., 2000).

**Also noteworthy is the antiviral effect of the Pleurotus species,** scientific studies show that *P. ostreatus*, an enzyme isolated from this mushroom, is capable of inhibiting the entry of the hepatitis C virus into blood cells, thus preventing replication (El-Fakharany et al., 2010). Another enzyme, extracted this time from *P. cornucopiae*, can reduce the activity of the HIV type 1 virus (Wong et al., 2010). Other Pleurotus species, such as *P. sajor-caju* and *P. citrinopileatus*, have also shown to have a strong antiviral effect against the HIV virus (Kidukuli et al., 2010). Additionally, polysaccharides obtained from the sclera of *P. tuber-regium* show antiviral effects against the herpes simplex type 1 and type 2 viruses (Zhang et al., 2004).
12. Role of mushrooms in neurodegenerative diseases

Neurodegenerative diseases, particularly Alzheimer’s, are diseases related to ageing and increasingly affect the population over 65 years of age. The number of cases increases every year worldwide; according to the WHO, 0.5% of the world population suffers from some form of dementia.

Among the species of mushrooms known for their biological effects related to the nervous system and brain health are: *Sarcodon scabrosus, Ganoderma lucidum, Grifola frondosa and Hericium erinaceus* (Sabaratnam et al., 2013). *Ganoderma lucidum* contains neuroactive compounds that can induce neural differentiation and prevent apoptosis of NGF-dependent neurons (Transforming growth factor) (Cheung et al., 2000). However, up until now, the mushroom that has more effect against neurodegenerative diseases and has received more attention from the scientific community is *Hericium erinaceus* (common name: Lion’s Mane).

One of the functions of *H. erinaceus* for the nervous system is that it can regulate the growth and development of neurons. It has been shown that exopolysaccharides of mycelium of *H. erinaceus* enhance growth of adrenal nerve cells of rats and neurite extension of PC12 cells (Park et al. 2002; Mori et al., 2008).

Another study by Kolotushkina et al. (2003) found that extracts of this mushroom promote the development of cerebellar cells and regulates the process of myelination in vitro. In line with these results, Moldavan et al. (2007) reported that *H. erinaceus* improved the process of myelination of mature myofibers and that it could also exert neurotrophic action. This mushroom is even involved in the expression of certain genes and proteins that can promote regeneration of axons and reinnervation of motor end plates (Jiang et al., 2014).

In Alzheimer’s there is a progressive loss of neural function. Studies that have been carried out to date show that *H. erinaceus* relieves mild cognitive impairment resulting from Alzheimer’s (Mori et al., 2009) as well as some symptoms associated with the disease, for example, it improves sleep quality and ameliorates depression (Nagano et al., 2010). In order to examine the effectiveness of oral administration of *H. erinaceus*, a study was conducted in 2009 with Japanese men and women, aged 50 to 80 years, diagnosed with mild cognitive impairment, demonstrating that subjects of the group that took *H. erinaceus* (3 times a day for 16 weeks) improved cognitive function compared to the control group (Mori et al., 2009).
Mushrooms are a food with valuable nutritional properties. Being low in calories and a good source of fibre, they are ideal for daily consumption and weight-loss diets. Mushrooms are also a good choice for low-salt diets due to their low sodium content. They also have an aroma and taste, which is highly valued by consumers.

Mushrooms are naturally very low in fat. Of the total lipid content, about 80% are unsaturated fatty acids; commonly referred to as "good fat" and contain no cholesterol. This makes mushrooms a highly recommended food to prevent cardiovascular risk.

Mushrooms are considered a nutritious and healthy food, rich in minerals and vitamins. They stand out as being an important source of B vitamins, especially B2 and B3, and vitamin D precursors, such as ergosterol, which promotes absorption of calcium and phosphorus. They also contain essential minerals for the proper functioning of our body, mainly selenium, phosphorus and potassium.

Numerous studies being carried out today on the presence of bioactive compounds in mushrooms provide scientific evidence to what is already known and applied in traditional oriental medicine, where mushrooms are used in the treatment of many diseases. Mushrooms and their bioactive compounds are currently considered a potential tool in the maintenance and promotion of health, longevity and quality of life.

Their therapeutic implications are enormous. As reflected throughout this report, they have significant health properties that make them potential therapeutic agents for diseases such as cancer, Alzheimer's and cardiovascular diseases. Mushrooms are also used for the prevention of diseases such as atherosclerosis and diabetes due to their ability to reduce cholesterol and blood glucose and also due to their high antioxidant content.

In conclusion, mushrooms are an ideal food to be included in our daily diet due to their nutritional and health properties, which improve health and facilitate disease prevention.
BIBLIOGRAPHIC REFERENCES


Health and nutritional properties of mushrooms


Health and nutritional properties of mushrooms


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5 a day

The 5 a Day programme, an international movement that promotes consumption of fruit and vegetables, is active in more than 40 countries across 5 continents. Its name is based on the minimum daily serving of fruit and vegetables recommended by the scientific and medical communities for a healthy diet.

All fruit and vegetables, including fresh and packaged mushrooms, count in achieving this objective (www.5aldia.org). Mushrooms are a healthy, nutritious and tasty food; a perfect way for children to eat one of the five daily servings of fruit and vegetables.

Tips and tricks

<table>
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<tr>
<th>In the store</th>
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<tbody>
<tr>
<td>Cultivated mushrooms can be found in the supermarket year-round.</td>
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<td>Fresh mushrooms should be firm with a dry surface and display their characteristic colour.</td>
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<tr>
<th>At home</th>
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<tr>
<td>Mushrooms are perishable products; it is recommended to consume them within a few days after purchase. Always store in the refrigerator.</td>
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<td>They should be kept in an open container or bag to prevent condensation and increase their shelf life.</td>
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<th>Cleaning</th>
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<tr>
<td>Mushrooms should not be washed or left to soak. Clean with a damp kitchen cloth. If they’re extremely dirty, rinse with water and dry quickly with a paper towel to remove moisture.</td>
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<th>In the kitchen</th>
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<td>When eating uncooked mushrooms, for example in a salad or carpaccio, it is recommended to heat them for about 10 seconds in the microwave, oven or grill. Mushrooms are very easy to prepare and you can make delicious recipes in just a few minutes.</td>
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Mushrooms: healthy, nutritious and tasty food

An ideal food for a NUTRITIOUS and HEALTHY diet

- Low in salt
- High-quality protein
- Fibre-rich
- Low in fat
- 0% Cholesterol
- Rich in vitamin and minerals