Influence of homogeneous magnetic field on the content of ten trace elements in stipe and cap oyster mushroom (Pleurotus Florida)

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ABSTRACT: Although a small amount of trace elements is essential for vital processes of edible mushrooms, in excess they could pose a threat to the human society's health. This survey was conducted in a completely randomized design (CRD) with 5 treatments and three replications, on the effect of homogeneous magnetic fields on the trace elements, Pb, Fe, Zn, Ni, Ag, Hg, V, As, Cd and Co, contained in the florida type of oyster mushroom. Fungus treatments involved 500g bags of oyster mushroom’s seed (seed plant coated with spawns) were exposed for 5 hours to uniform magnetic fields with inductions of 0, 5, 10, 15, and 20 mT. Then under controlled and highly standard conditions all the seeds were bag cultivated and after 30 days harvested. Being weighed and dried out, in the first pick, from each bag one single mushroom was selected as sample, which was analyzed by an inductively coupled plasma optical emission spectrometry (ICP-OES) tool. There was no arsenic, cobalt, cadmium in the samples. A decline in the concentration of vanadium, mercury, silver, and iron was occurred by a rise in intensity of the magnetic field. At 15 mT zinc and lead increased but decreased at 20 mT. Zinc and iron had the highest concentration in the mushroom’s stipe and cap respectively. Although previous findings recommend a 20 mT intensity of magnetic field for industrial cultivation of edible mushrooms, this, in time, will lead to a considerable decrease in the concentration of trace elements in oyster mushroom.

Key words: homogeneous magnetic field, trace elements, pleurotus florida.

INTRODUCTION

Each living being has a particular reaction to the electromagnetic field, which is one of the most important and complex energy resources (Ruzic et al., 1997). This has led to a lot of controversy on the natural effects of magnetic fields. For at least 40 years, scientists have been studying the probability of vital impacts of magnetic fields. People are exposed daily to a range of magnetic and electromagnetic fields. Animal’s body absorbs electromagnetic energy and changes it into thermal energy. The effects of electromagnetic energy on living tissues are the reason why they are used for agricultural development. Such effects rely upon type, seasonal life spans, field intensity, and duration of treatment (Piacentini et al., 2001). In magnetic cultivation, magnetic energy passes on to seeds, plants, water and food.

Exposure to different magnetic fields leads to change in amino acid consecution (Moore, 1979), change in enzyme functions of microsopic fungi (Novikov et al., 1999), decline in sporation celerity of alternaria alternate, curvularia inaequalis, aspergillus puniceus types of fungous, rising development of fungi hyphae and mycelia (Gow, 1994), and function enhancement of edible fungi pleurotus florida (Javanmardi et al., 2008). High-frequency electromagnetic waves, with their excessive production of heat, prevent mushrooms’ growth (Stage et al., 2001). In general, organisms react to magnetic fields by producing reactive proteins and chemical-biological changes (Goodman et al., 1994). Plasma membrane protects the contents of the cell against electromagnetic signals (Broude et al., 1994).

Human beings’ health is closely related with the food they consume. Contamination by trace metals contained in food materials has always been threat to mankind’s health. Many researches have been...
conducted on the toxic effects of trace metals contained in food materials (Orak et al., 2005; Radwan, Salama, 2006; Soylak et al., 2006). In general, mushrooms hold a geo-chemical function along with the role of conveying trace elements in the planet’s biological life cycle (Borovicka et al., 2005; Borovicka et al., 2006; Gadd, 2007).

Trace elements specifications are toxicity, accumulation, carcinogenesis, and mutagenesis. Their excessive concentration in non-toxic mushrooms produces a pseudo-toxic effect, which is one of the most dangerous types of toxicity with a high mortality rate among human beings. Consumption of such trace elements such as lead, cadmium, mercury and arsenic in food materials is highly detrimental. Generally nervous disorders such as parkinson’s, alzheimer’s, depression, and schizophrenia, various types of cancer (Mahavi, 2005), stomach and kidney diseases, decay of red blood cells’ membrane, destruction of genes, loss of appetite and in extreme cases, death are among the results of the entrance of trace metals into human body. Their accumulation in plants and entering the food cycle intensifies their potential threats. They attach proteins with enzyme functions, thus interfere with fungi’ metabolism and slow down, even hinder their growth (D’Inzeo et al., 1993).

The highly toxic fungus, amanita muscaria, contains a whole lot of trace metals, vanadium in particular (Falandysz et al., 2001). Large amounts of cadmium in the oyster mushroom, pleurotus ostreatus, reduce lignocelluloses enzyme level (Baldrian, Gabriel, 2003). Metal complexes play an important role in anti-radical operations of micro-organisms (Vanco et al., 2004). Presence of iron ions in the structure of peroxides enzyme is essential of significance to edible mushrooms (Banci, 1997). For their active role in metabolism of edible mushrooms, the concentration of zinc and iron is more than other elements in mushroom’s tissue (Alonso et al., 2003; Mattila et al., 2000; Sesli, Tuzen, 1999), with the concentration much more in the cap than the stipe (Falandysz et al., 2001).

Results of international research from France (Michelot et al., 1998), Czech Republic (Svoboda et al., 2002), Poland (Falandysz et al., 2003; Malinowska et al., 2004; Rudawska, Leski, 2005), Spain (Garcia et al., 1998), Turkey (Mendil et al., 2003; Tuzen et al., 2003), The United States (Aruguete et al., 1998) and Russia (Barcan et al., 1998), show excessive amounts of the trace elements, lead, cadmium, zinc, mercury, iron, arsenic, silver, nickel and cobalt in wild edible mushrooms in forest areas.

Knowledge of the movement of trace elements from mycelium to stipe parts and the edible mushroom’s cap is so limited. Mercury tends to attach to sulphydryl groups in order to move from mycelium to edible tissues. This becomes much more complex mechanism in the case of cadmium and other trace elements (Kojo, Lodenius, 1989). Reliable findings about the biological impact of magnetic and electromagnetic fields on the florida type of oyster mushroom are hardly sufficient. Thus the following survey was conducted in order to study the effect of various facets of homogeneous magnetic field on the weight of trace elements in oyster mushroom species pleurotus florida.

MATERIALS AND METHODS

Designing of the homogenous magnetic field generator

Using solenoid is the most practical way to create a rather uniform magnetic field. A solenoid consists of a number of strands of springy wires spirally spun around a cylinder of desired radius and length. Figure 1, shows a schematic diagram of the instruments used in applying a constant magnetic field.

![Figure 1. The circuit generating a constant magnetic field.](image)

This circuit was designed and built in Islamic Azad University of Shiraz, Department of Physics, consisting of one solenoid in order to produce constant magnetic fields of desired intensities such as 0, 5, 10,
15, and 20 mT. Attached to the circuit are an ammeter to measure the current passing through solenoid, a power supply of direct current to apply appropriate driving force on both ends of the circuit, and a voltmeter to measure and display the appropriate voltage. A rheostat and an electric switch were also installed to achieve the desired current and to power the circuit on and off respectively; in addition to some strands of wire to complete the circuit. In order to achieve greater precision, a computer controls and saves the data of the circuit’s current and voltage. By comparing the relevant diagrams, it detects any possible errors to fix. A digital thermometer shows the temperature inside the solenoid all the time, which increases the precision of the experiment by a considerable degree.

The device’s induction of magnetic field was calculated according to the following formula,

\[
B = \frac{\mu_0 N I}{L}
\]

Passing index:

\[
\mu_0 = 4\pi \times 10^{-7} \text{Tm/A}
\]

\(\mu_0\): permeability of vacuum,

\(\mu_0 = 4\pi \times 10^{-7} \text{Tm/A}\)

\(N\): number of the rounds of solenoid springy wires.

\(I\): current passing through the circuit.

\(L\): length of the solenoid.

**Treatment of inoculants and planting of oyster mushroom**

All the planting and production levels in this experiment were conducted similar to the usual commercial method. First, 45 kg of wheat straw were chopped into 7 cm pieces, soaked in water for 12 hours, boiled for 90 minutes, and cooled down in cucumber bags of 100 cm length and 40 cm diameter. 10 cm apart from one another, a 50g layer of treated seed was set. This was done for all the bags. Around each bag 17 holes of 1.5 cm were dug, in which cotton balls dipped in 1 cc of alcohol 50 plus 1cc of formalin were inserted. During the growth period, the conditions inside the lab were as follows: Co2:1200ppm, the temperature from the beginning to the end of the experiment: 25°C, lighting: absolute darkness in the first 15 days, 1600 lux the next 15 days, humidity: %75 the first 15 days, %85 the next 15 days. Magnetic treatment of seeds was accomplished prior to the cultivation by the magnetizer at 0, 5, 10, 15, and 20mT, so that each 500 g of seed as a single unit of experiment was frozen in plastic bags and uniformly magnetized for 5 hours according to the desired treatment. Three units out of 15 were put aside as control, without magnetization and 12 units of experiment were magnetized. After 30 days of standard cultivation of oyster mushroom, the samples were harvested to be studied and analyzed for the percentage of existing trace elements with ICP-OES.

**Fresh and dry weight measurements**

After harvest of the first stage, samples were weighed and then dried out in the oven at 75°C for 24 hours. Dried samples were weighed as well, using a highly sensitive scale made by Sa-Iran Co. to have measured each bag’s particular outcome. Then from each unit bag one single mushroom was picked as sample.

**Analysis of trace elements**

These samples were divided into two categories, stipe and cap. Wet digestion was used. 1 g of each sample was heated in 10 cc of thick nitric acid for 30 minutes up to the point of boiling, and then was let to reach ambient temperature. Then 4 cc of perchloric acid 80 was added to the sample and reheated up to the point of boiling. After cooling down, the sample was filtrated in 100 cc balloon and reached the necessary volume using distilled water. The resulting solution was analyzed by ICP-OES tool (Optima 2000 DV, Perkin-Elmer) for the concentration level of trace elements.

**Statistical data analysis**

Analyses were done using the SPSS version 16 software. Differences between means were determined by Duncan’s Multiple Range Tests (DMRT) at %5 probability level.

**RESULTS AND DISCUSSION**

Reports of variance analysis reveal significant difference, at %1 probability level (table 1), between the treatments, before and after drying the mushrooms of each bag. There was no arsenic, cobalt, and cadmium in the mushrooms’ stipe. The results of variance analysis of existing trace elements in the stipe showed there was no significant difference between the treatments except for Fe.
Table 1. Analysis of variance mean squares of trace elements and total weight of the fungus.

<table>
<thead>
<tr>
<th>Source of variance</th>
<th>df</th>
<th>Fresh mushrooms per bag (g)</th>
<th>Dry weight of mushrooms per bag (g)</th>
<th>Pb</th>
<th>Fe</th>
<th>Zn</th>
<th>Ni</th>
<th>Ag</th>
<th>Hg</th>
<th>V</th>
<th>Pb</th>
<th>Fe</th>
<th>Zn</th>
<th>Ag</th>
<th>Hg</th>
<th>V</th>
</tr>
</thead>
<tbody>
<tr>
<td>treatments</td>
<td>4</td>
<td>53891.9**</td>
<td>8682.4**</td>
<td>652.8ns</td>
<td>5266.2**</td>
<td>76.2ns</td>
<td>0.9ns</td>
<td>0.1ns</td>
<td>1.5ns</td>
<td>1.5ns</td>
<td>168.2ns</td>
<td>4085.2ns</td>
<td>972.2ns</td>
<td>0.7ns</td>
<td>4.5ns</td>
<td>3.9ns</td>
</tr>
<tr>
<td>Error</td>
<td>10</td>
<td>130.0</td>
<td>13.5</td>
<td>2</td>
<td>7</td>
<td>8</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>3</td>
<td>9</td>
<td>6</td>
<td>75.2</td>
<td>0.9</td>
<td>4.5</td>
<td>3.9</td>
</tr>
<tr>
<td>Total</td>
<td>14</td>
<td></td>
<td></td>
<td>2</td>
<td>7</td>
<td>8</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>3</td>
<td>9</td>
<td>6</td>
<td>75.2</td>
<td>0.9</td>
<td>4.5</td>
<td>3.9</td>
</tr>
</tbody>
</table>

ns and **: non significant and significant at 1% probability level.

There was no arsenic, cobalt, cadmium, and nickel in the cap. The results of variance analysis of existing trace elements in the cap showed there was no significant difference between the treatments except for Fe and Zn. Results of mean comparison (table 2), employing Duncan’s Multiple Range Tests (DMRT) at probability level %5, revealed that the treatments of a magnetic field at 20 mT had the highest fresh (2523.7 g), and dried (278.0 g) weights of the mushrooms of each bag, whereas the control treatment had the lowest fresh (2196.3 g), and dried (140.0 g) weights. Results of mean comparison in the mushrooms’ cap revealed the control treatment had the highest amount of Fe (123.9 ppm). There was no significant difference between other treatments, not even for other trace metals. Results of mean comparison in the mushrooms’ cap revealed the control treatment had the highest amount of Fe (106.5 ppm), and there was no significant difference between other treatments. Zn had its highest amount (91.1 ppm) at a magnetic field of 15 mT and no significant difference at 20 mT. Also there was no significant difference between the treatments for any others of the trace elements.

Table 2. Mean comparison of total weight of the mushroom and content of trace elements (mg/kg dry matter) in fruit bodies as affected by different treatments of inoculants with magnetic field.

<table>
<thead>
<tr>
<th>Treatments (mT)</th>
<th>Fresh mushrooms per bag (g)</th>
<th>Dry weight of mushrooms per bag (g)</th>
<th>Fe</th>
<th>Pb</th>
<th>Zn</th>
<th>Ni</th>
<th>Ag</th>
<th>Hg</th>
<th>V</th>
<th>Fe</th>
<th>Pb</th>
<th>Zn</th>
<th>Ag</th>
<th>Hg</th>
<th>V</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>2196.3e</td>
<td>140.0e</td>
<td>123.9a</td>
<td>2.8a</td>
<td>47.7a</td>
<td>NDa</td>
<td>NDa</td>
<td>1.6a</td>
<td>1.6a</td>
<td>106.5a</td>
<td>3.5a</td>
<td>55.6b</td>
<td>0.6a</td>
<td>2.8a</td>
<td>2.6a</td>
</tr>
<tr>
<td>5</td>
<td>2248.0d</td>
<td>182.0d</td>
<td>25.5b</td>
<td>9.8a</td>
<td>33.8a</td>
<td>1.3a</td>
<td>0.8a</td>
<td>NDa</td>
<td>22.0b</td>
<td>1.5a</td>
<td>44.9b</td>
<td>NDa</td>
<td>NDa</td>
<td>NDa</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>2381.7c</td>
<td>228.7c</td>
<td>24.9b</td>
<td>0.4a</td>
<td>38.1a</td>
<td>0.4a</td>
<td>NDa</td>
<td>NDa</td>
<td>NDa</td>
<td>18.9b</td>
<td>0.5a</td>
<td>53.3b</td>
<td>NDa</td>
<td>NDa</td>
<td>NDa</td>
</tr>
<tr>
<td>15</td>
<td>2433.0b</td>
<td>241.7b</td>
<td>31.8b</td>
<td>35.7a</td>
<td>40.6a</td>
<td>NDa</td>
<td>0.5a</td>
<td>NDa</td>
<td>NDa</td>
<td>50.2b</td>
<td>18.0a</td>
<td>91.1a</td>
<td>1.0a</td>
<td>NDa</td>
<td>NDa</td>
</tr>
<tr>
<td>20</td>
<td>2523.7a</td>
<td>278.0a</td>
<td>55.1b</td>
<td>1.9a</td>
<td>39.4a</td>
<td>NDa</td>
<td>NDa</td>
<td>NDa</td>
<td>NDa</td>
<td>24.3b</td>
<td>0.4a</td>
<td>68.8ab</td>
<td>NDa</td>
<td>NDa</td>
<td>NDa</td>
</tr>
</tbody>
</table>

Means with the same letter(s) in each column is not significantly different (P= 5%, Duncan’s Multiple Range Test).

Figure 2 shows the effect of magnetic fields of different intensities on the trace metals in the cap. The magnetic field at 0 mT resulted in lead (2.75 ppm), silver (59.33 ppm), zinc (55.57 ppm), iron (106.52 ppm), mercury (3.56 ppm), and vanadium (2.55 ppm). Arsenic, cadmium, cobalt, or nickel was not found at 0 mT. Mean value of trace metals at 5 mT decreased to zero for nickel, silver, mercury, and vanadium. Mean value for lead was 1.53 ppm, iron (22.01 ppm), and zinc (44.95 ppm) at 5 mT. At 10 mT the mean value for nickel, silver, mercury, and vanadium was also zero, lead (0.53), iron (18.91 ppm), and zinc (53.28 ppm). At 15 mT the mean value for nickel, mercury, and vanadium was zero as well, whereas silver increased to 1.04 ppm, zinc (91.07 ppm), lead (18.04 ppm), and iron (50.20 ppm). At 20 mT the mean value for nickel, silver, mercury, and vanadium was zero, lead was 0.40, zinc (68.78 ppm), and iron (24.32 ppm).
Figure 3 reveals the effect of magnetic fields of different intensities on the trace metals in the stipe. The magnetic field at 0 mT resulted in lead (1.60 ppm), zinc (47.66 ppm), iron (123.88 ppm), and vanadium (1.60 ppm), but no arsenic, cadmium, cobalt, silver, or nickel. At 5 mT an increasing occurred in the mean value for lead (9.82 ppm), nickel (1.28 ppm), but silver and vanadium were zero, iron decreased to 25.49 ppm, mercury (0.80 ppm), and zinc 33.78 ppm. At 10 mT the mean value for silver, mercury, and vanadium was zero, nickel and lead both decreased to 0.39 ppm, iron increased to 24.90 ppm, and zinc to 38.10 ppm. At 15 mT the mean value for nickel, mercury, and vanadium was zero, and there was an increase for zinc (40.61 ppm), lead (35.71 ppm), and iron (31.80 ppm). At 20 mT the mean value for nickel, silver, mercury, and vanadium was zero, iron increased to 55.08 ppm, and zinc was almost constant (39.35 ppm) and lead was decreased to 1.94 ppm.

Figure 4 shows that with an increase in the intensity of the magnetic field on oyster mushroom, a parallel increase occurred in both the weight of the control of the fresh mushrooms, from 2196.3 g to 2523.7 g, and the control of the dried ones, from 140 g to 278 g, at 20 mT.

The reports of the correlation coefficients (table 3) in the mushrooms’ stipe revealed that Fe had a positive and significant correlation with Zn and V, meaning that with an increase in the amount of iron in the stipe, an increase in Zn and V occurs. Pb also had a positive and significant correlation with Ag. There was a negative and significant correlation between the fresh and dry weights of the mushrooms and the metal, Hg.
meaning that with an increase in the mushrooms' weight, a decrease in the weight of Hg in the stipe occurs. There was a positive and significant correlation between the fresh and the dry weights of mushrooms.

<table>
<thead>
<tr>
<th>Fe</th>
<th>Pb</th>
<th>Zn</th>
<th>Ni</th>
<th>Ag</th>
<th>Hg</th>
<th>V</th>
<th>Fresh weight</th>
<th>Dry weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fe</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Pb</td>
<td>.322</td>
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<td></td>
</tr>
<tr>
<td>Zn</td>
<td>.893</td>
<td>.052</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Ni</td>
<td>-.483</td>
<td>-.129</td>
<td>-.762</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ag</td>
<td>-.273</td>
<td>.970</td>
<td>.075</td>
<td>-.337</td>
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<td></td>
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<td>-.284</td>
<td>.522</td>
<td>.139</td>
<td>-.375</td>
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<tr>
<td>V</td>
<td>.956</td>
<td>-.277</td>
<td>.861</td>
<td>-.337</td>
<td>-.250</td>
<td>.875</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Fresh weight</td>
<td>-.461</td>
<td>.195</td>
<td>-.245</td>
<td>-.433</td>
<td>.319</td>
<td>-.895*</td>
<td>-.668</td>
<td>1</td>
</tr>
<tr>
<td>Dry weight</td>
<td>-.580</td>
<td>.186</td>
<td>-.387</td>
<td>-.295</td>
<td>.287</td>
<td>-.926*</td>
<td>-.770</td>
<td>.988** 1</td>
</tr>
</tbody>
</table>

* and **: significant at probability levels 5 and 1 percent, respectively.

The reports of the correlation coefficients (table 4) in the mushrooms’ cap revealed that Fe had a positive and significant correlation with Hg and V, meaning that with an increase in the weight of iron in the cap, an increase in Hg and V occurs. Pb also had a positive and significant correlation with Ag. There was a %100 positive and significant correlation between Hg and V, meaning that with the increase of the mushroom’s weight, this metal’s weight also increases. There was also a positive and significant correlation between the fresh and dry weights of mushrooms.

<table>
<thead>
<tr>
<th>Fe</th>
<th>Pb</th>
<th>Zn</th>
<th>Ag</th>
<th>Hg</th>
<th>V</th>
<th>Fresh weight</th>
<th>Dry weight</th>
</tr>
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<tbody>
<tr>
<td>Fe</td>
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<td></td>
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<td></td>
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<td>.845</td>
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<td></td>
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<tr>
<td>Ag</td>
<td>.634</td>
<td>.902</td>
<td>.725</td>
<td>1</td>
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<td></td>
</tr>
<tr>
<td>Hg</td>
<td>.941*</td>
<td>-.095</td>
<td>-.221</td>
<td>.340</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>V</td>
<td>.941*</td>
<td>-.095</td>
<td>-.221</td>
<td>.340</td>
<td>1.000**</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Fresh weight</td>
<td>-.560</td>
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<td>.623</td>
<td>-.080</td>
<td>-.668</td>
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<td>1</td>
</tr>
<tr>
<td>Dry weight</td>
<td>-.677</td>
<td>.138</td>
<td>.550</td>
<td>-.170</td>
<td>-.770</td>
<td>-.770</td>
<td>.988**</td>
</tr>
</tbody>
</table>

* and **: significant at probability levels 5 and 1 percent, respectively.

Knowledge of the effect of homogeneous magnetic fields on the weight of trace metals in mushrooms is limited. In general magnetic fields could leave their effect by stimulating and controlling of certain ions. Magnetic fields of 0 mT up to 20 mT affect the mushrooms’ growth by increasing K⁺ and Ca²⁺ ions, decreasing Na⁺ and phosphate ions in mycelium, and stimulating the normal operations of ionic currents in hyphae (Krizaj, Valencic, 1989). It also appears that, in a similar fashion, in some processes, trace metals stimulate the exchange of ions in the mushroom’s metabolism (Gow, 1994). Finally, it is recommended that: Same experiments to be done on other species of cultivated edible fungi and investigate the percentage effect of homogeneous magnetic field and fungi’s biologic reaction and relation of operation with field’s intensity.

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