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Thermal processing can affect zinc availability in some edible mushrooms

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ABSTRACT

The differential pulse anodic stripping voltammetry method was used for the determination of zinc released into artificial digestive juices from selected fruiting bodies of edible mushrooms (*Boletus badius, Boletus edulis, Cantharellus cibarius, Leccinum scabrum, Pleurotus ostreatus, Suillus bovinus*) before and after thermal processing which imitated food preparation. The total amount of zinc released from thermally-processed mushrooms ranged within 2.22–20.68 mg/100 g dry weight. The highest amount of zinc was determined in artificial digestive juices in thermally-processed fruiting bodies of *B. badius* and *B. edulis*. For *C. cibarius* fruiting bodies, thermal processing resulted in a slight increase in the release of zinc compared to the unprocessed fruiting bodies.

In *P. ostreatus* species, the amount of zinc released into digestive juices before and after thermal processing was at almost the same order of magnitude. Thermal processing of fruiting bodies of *B. badius, B. edulis* and *C. cibarius* resulted in the release of significantly larger amounts of zinc into artificial digestive juices, which made them a very good source of zinc. In terms of fruiting bodies of *S. bovinus* and *L. scabrum*, an increase in temperature caused a partial reduction of zinc content; however, cooked mushrooms still remained an effective source of zinc.

1. Introduction

Disorders of zinc homeostasis in human cells are involved in the pathogenesis of many dermatological-, inflammatory- and degenerative-related diseases. Zinc (Zn) must be supplemented in the diet at a daily dose of approximately 12 mg (Black, 2003; Hambidge & Krebs, 2007). Its presence has been detected and determined in a number of species of edible mushrooms (Alonso, García, Pérez-López, & Melgar, 2003). Zinc plays a role in many biochemical reactions. It is involved in the metabolism of nucleic acids, and the biosynthesis of RNA, DNA and proteins (Wu & Wu, 1987). It also exhibits antioxidant activity and supports the storage and secretion of insulin in the pancreas (Arquilla, Packer, Tarmas, & Miyamoto, 1978; Noormagi, Gavrilova, Smirnova, Tougu, & Palumaa, 2010).

Mushrooms constitute a large group of organisms that have a significant ecological and therapeutic function and represent an important element of food composition (Barros, Cruz, Baptista, Estevinho, & Ferreira, 2008). Edible mushrooms are a good source of bioelements (e.g., Zn) necessary for life. Fruiting bodies of mushrooms and their spores demonstrate excellent ability to accumulate micro- and macroelements (Chudzyński, Jarzyńska, Stefańska, & Falandysz, 2011; Kalač, Svoboda, & Havlíčkova, 2004a). The most important mechanism for the accumulation of elements by mushrooms is based on binding those elements to metallothionein – a low-molecular-weight protein which exhibits affinity particularly towards metals (Sanglimsuwan, Yoshida, Morinaga, & Murooka, 1993). Absorption of these elements depends on the pH of the soil, individual development of the mushroom, and the bioavailability of metals (Falandysz, 2008; Falandysz, Gucia, Skwarzec, Frankowska, & Klawikowska, 2002). Location has an effect on the concentration of microelements in the soil and in mushrooms. Based on literature data, zinc content in edible mushroom species is in the range of 25–200 mg/kg dry weight (Kalač, Svoboda, & Havlíčková, 2004b; Ribeiro, Guedes de Pinho, Andrade, Baptista, & Valentao, 2009).

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For the purposes of this study, only the most popular wild grown species were selected (*Boletus badius*, *Boletus edulis*, *Cantharellus cibarius*, *Leccinum scabrum*, Pleurotus ostreatus, *Suillus bovinus*). This decision was taken for therapeutic reasons as well as on the basis of their popularity among consumers. *B. edulis* is also a rich source of selenium (Falandysz, 2008). Strong antioxidant properties are exhibited by tocopherols occurring in high amounts in this species. Similar to other mushrooms, this species contains essential amino acids characteristic for food of animal origin (Barros, Venturini, Esterinho, & Ferreira, 2008; Berheret, 1997; Cheung, 2010; Reczyński, Muszyńska, Opoka, Smalec, & Sułkowska-Ziaja, 2013). Among fatty acids, the largest quantities of monounsaturated fatty acids, particularly oleic acid, have been reported in *B. edulis*. In terms of the group of polyunsaturated fatty acids, there have been reports of high contents of linoleic and palmitic acids and sterols: ergosterol, ergosta-7,22-dienol, ergosta-5,7-dienol, and ergosta-7-enol (Barros et al., 2007). All these compounds are characterized by strong antioxidant and antitumor activity (Lian, 2008; Muszyńska, Sułkowska-Ziaja, & Ekiert, 2012a; Muszyńska, Sułkowska-Ziaja, & Ekiert, 2012b).

B. badius is a very popular edible species because of an aroma similar to *B. edulis* (King Bolete). It is interesting that the most phenolic compounds (protocatechuic acid, *p*-hydroxy benzoic acid, *p*-coumaric acid and cinnamic acid, which mostly occur in the highest quantities) have been found in this species and this explains the high total antioxidant activity of the extracts detected in this species (Muszyńska et al., 2012b) (the percentage inhibition of methanol extracts from dried fruiting bodies of bay bolete at a concentration of 100 μg/mL was estimated at 99.2% in linoleic acid oxidation tests, as reported by Elmastas in 2007 (Elmastas, Isildak, Turkekul, & Temur, 2007; Muszyńska, Sułkowska-Ziaja, & Ekiert, 2009; Muszyńska, Sułkowska-Ziaja, & Ekiert, 2010).

In turn, *C. cibarius* is a species which, among other mushrooms, is characterized by the highest content of vitamins B, A, E and C, and as such is similar to baking yeast. Moreover, *C. cibarius* is a rich source of ergocalciferol (vitamin D_2) (Muszyńska, Sułkowska-Ziaja, & Ekiert, 2013a; Muszyńska, Sułkowska-Ziaja, & Ekiert, 2013b; Ng & Wang, 2004; Pinho et al., 2008; Rangel-Castro, Staffas, & Danell, 2002; Valentao et al., 2005). Rough-stemmed bolete is a good source of minerals. Dry extracts from fruiting bodies of rough-stemmed bolete exhibit antiulcer and anticancer properties (Muszyńska et al., 2013b).

Pleurotus ostreatus was first cultivated for culinary purposes during World War I in Germany. It is a valuable species in terms of diet, because it contains easily digestible proteins, folic acid and minerals (Eger, Eden, & Wissig, 1976). It has been classified as a medicinal mushroom, as it contains statins: i.e. lovastatin, a hypolipidemic drug used for the treatment of diseases of the circulatory system, heart and strokes (Conlon, Eriksson, Grimelius, Oberg, & Thims, 1987; Ey, Schömi, & Taubert, 2007; Ferreira, Baptista, Vilas-Boas, & Barros, 2007; Gunde-Cimerman & Cimerman, 1995; Hossain, Hashimoto, & Choudhury, 2003; Laws, Spark, Cowled, & Fitridge, 2004; Manzon & Rollini, 2002; Nosál'ová, Bobek, Černá, Galbavý, & Štvrtina, 2001; Seeger, Wallwiener, & Mueck, 2003; Silva, 1992; Slejfer, Van der Gaast, Planting, Stoter, & Verweij, 2005; Smiderle et al., 2008).

Due to the above, these specific species were selected for the current study. There are numerous reports describing the content of biologically active compounds and elements in the fruiting bodies of edible mushrooms. However, there is a lack of information on their bioavailability to the human organism. This is the first study to evaluate the content of zinc released into artificial gastric juices (saliva, gastric and intestinal juices) under conditions that simulate the human gastrointestinal tract. Since mushrooms are rarely consumed in unprocessed form, the aim of this study was to determine the zinc content in the fruiting bodies before and after thermal processing, which imitates the procedure of preparing food using mushrooms. This will enable an estimation of the usefulness of fruiting bodies from edible mushrooms as a source of alimentary zinc. To determine the zinc(II) ions in the selected fruiting bodies from mushrooms, the differential pulse anodic stripping voltammetry (DP-ASV) method was used.

2. Materials and methods

2.1. Reagents and standards

Zinc sulfate was obtained from OUM-7 Łódź; zinc hydroaspartate was purchased from Farmapol (Poland); citric acid, NaOH, K_2HPO_4, Na_2HPO_4, and $KHCO_3$ were obtained from the Polish Company of Chemistry (Gliwice, Poland); $NaHCO_3$, and NaCl were purchased from PPH Golpharm (Kraków, Poland); $MgCl_2$ was acquired from Chempur (Kraków, Poland); $CaCl_2$ was obtained from Pharma Zentrale GmbH (Germany); bile salts and pepsin were bought from BTL (Łódź, Poland); pancreatic extract, HCl, KCl were all of analytical grade. HNO_3 concentrated Suprapur® and KNO_3 Suprapur® were purchased from Merck (Darmstadt, Germany). Quadruple-distilled water with a conductivity of less than 1 μS cm^{-1} was obtained using an S2-97A2 distillation apparatus (Chemland, Stargard Szczecin, Poland).

2.1.1. Preparation of solutions of artificial gastric juices

2.1.1.1. Artificial saliva. Liquid simulating conditions in the oral cavity was prepared according to the Arvidson model. Artificial saliva, pH 6.7, was prepared by mixing quadruple-distilled water with 100 mL of 25 mM KH_2PO_4, 100 mL 24 mM Na_2HPO_4, 100 mL 150 mM $KHCO_3$, 100 mL 100 mM NaCl, 100 mL 1.5 mM $MgCl_2$, 6 mL 25 mM citric acid and 100 mL of 15 mM $CaCl_2$. In this model, digestive enzymes were not considered (α-salivary amylase, salivary lipase) to be present in saliva (Arvidson & Johasson, 1985).

2.1.1.2. Artificial gastric juices. In the stomach, pH ranges from 1.0 to 3.5; however, in most artificial gastric juice models, pH is equal to 2.0. The solution of this artificial body fluid was prepared according to Polish Pharmacopoeia IX, by dissolving 2.0 g of sodium chloride (NaCl) and 3.2 g of pepsin in quadruple-distilled water. Then, to control pH, 80 mL of 1 M hydrochloric acid was added and supplemented with quadruple-distilled water to 1000 mL (Polish Pharmacopoeia, 9th ed., 2011).

2.1.1.3. Artificial intestinal juices. Artificial intestinal juices used in the model for *in vitro* study were prepared by dissolution 5 mL of pancreatic extract (4 g/L) and bile salts (25 g/L) in 0.1 M NaHCO3 solution followed by supplementation with quadruple-distilled water to 1000 mL (Neumann, Goderska, Grajek, & Grajek, 2006).

All artificial digestive juices were checked for Zn content. The determined concentration of this compound in artificial saliva, and gastric and intestinal juices was below 10 μg/L.

2.2. Materials

The study material comprised fresh fruiting bodies of species including: *B. badius* (Fr.) Fr. – Bay bolete, *B. edulis* Bull. – King bolete, *C. cibarius* Fr. – Yellow Chanterelle, *L. scabrum* Bull. – birch bolete, *P. ostreatus* (Jacq. ex Fr.) – Oyster mushroom, and *S. bovinus* (L.) Roussel – Jersey cow mushroom. These were all collected in natural conditions (mixed forests, southern Poland) in the autumns of 2013 and 2014. After taxonomic identification according to Knudsen & Vesterholt (Knudsen & Vesterholt, 2008) (representative samples of mushrooms were deposited at the Department of