LWT - Food Science and Technology 69 (2016) 424–429

Contents lists available at ScienceDirect

LWT - Food Science and Technology

journal homepage: www.elsevier.com/locate/lwt

Thermal processing can affect zinc availability in some edible mushrooms

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ARTICLE INFO

Article history:
Received 23 June 2015
Received in revised form
15 January 2016
Accepted 31 January 2016
Available online 2 February 2016

Keywords:
Basidiomycota
Edible mushrooms
Elements
Thermal processing
Zinc

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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http://dx.doi.org/10.1016/j.lwt.2016.01.078
0023-6438/

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

Pharmaceutical Botany, Jagiellonian University Collegium Medicum, Kraków, Poland), fresh mushrooms (50 g of each species) were frozen and immediately dried via lyophilization (Freezone 4.5, Labconco; temperature: −40 °C).

2.3. Sample preparations

Freeze-dried fruiting bodies of *B. badius, B. edulis, C. cibarius, L. scabrum, P. ostreatus,* and *S. bovinus* species were pulverized in a porcelain mortar to prepare samples of 500 mg weight. They were placed in flasks containing 10 mL of artificial saliva according to the Arvidson procedure at normal body temperature (37 °C) (Arvidson & Johasson, 1985) and shaken for one minute (shaking time in artificial saliva similar to conditions in other artificial digestive juices, i.e. gastric and intestinal juices, results from the assumed average time of food spent in the mouth). Subsequently, the suspension was centrifuged and decanted, and the remaining residues after digestion in a solution of artificial saliva were diluted in 10 mL of gastric juice.

The samples were shaken in 10 mL of artificial gastric juices for: 15, 60, 120 min. The solution was then centrifuged again and decanted, and 10 ml of artificial intestinal juice was added to the recovered residue of the tested species and shaken for another 150 min (Universal Shaker type 327) and the decanted solution was centrifuged for 30 min (Centrifuge MPW-223e). The prepared solutions were filtered through membrane filters. The filtrates collected from artificial saliva solutions, and artificial gastric and intestinal juice solutions were mineralized for 24 h via the addition of 1 mL of concentrated Suprapur® nitric(V) acid in a UV mineralizer (UV Mineral R-8 Power Supply 8) equipped with a UV lamp.

2.3.1. Sample preparations after thermal processing

The method of mushroom material preparation by thermal processing was as follows: dry materials after lyophilization were weighed (5 g of each species) and ground in a mortar; 80 mL of distilled water was added to each sample and the mixtures were boiled in a thermostated water bath (Labart Sp. z o.o., Poland) at 100 °C for 60 min in a Soxhlet apparatus. Then, the whole mixtures containing the fruiting bodies with the aqueous extracts from mushrooms were frozen and lyophilized again.

Freeze-dried material was pulverized in a porcelain mortar after cooking. Then, samples weighing 500 mg were prepared and subjected to extraction in artificial digestive juices and the whole procedure followed that for thermally-untreated fruiting bodies.

To determine zinc(II) ions via differential pulse anodic stripping voltammetry (DP-ASV), mineralized samples of thermally-unprocessed and processed samples were evaporated to almost dryness and supplemented with quadruple-distilled water. The prepared samples were then subjected to analysis.

2.4. Validation of the DP-ASV method

The method of zinc determination was validated according to ICH Q2(R1) guidelines.

2.4.1. Precision

The precision of the method was determined based on repeated measurements ($n = 3$) of the concentration of zinc ions in the tested samples using the standard addition method. The relative standard deviation (RSD) was calculated based upon the obtained results. Mean RSD for the examined samples was below 6.1%

2.4.2. Accuracy

To the best of our knowledge, there is no mushroom certified reference material (CRM). Consequently, accuracy of the method was estimated using recovery analysis. Samples with a known amount of zinc ions were spiked with increasing volumes of Zn(II) standard solution (corresponding to 50%, 100% and 150% of the previously assayed content of zinc(II) ions in the sample). Spiked samples were then subjected to the entire pretreatment process and analyzed. Experimental values were then compared with calculated concentrations of zinc (considering the amounts that were already in the sample, as well as the previous standard addition). The results are shown in Table 1.

2.4.3. Sensitivity

Limit of detection (LOD) and limit of quantification (LOQ) were used as parameters describing sensitivity (LOD $3\sigma/a$ and LOQ $10\sigma/a$, where σ is the residual standard deviation and a is the calibration curve slope). For the above measurements, the following values were obtained: LOD = 0.36 μg/L and LOQ = 1.2 μg/L.

2.4.4. Linearity

To a tested sample containing 0.2 M KNO3 supporting electrolyte, 10 μL of a 1 mg/mL standard solution of Zn(II) was added. After each addition of the standard, a voltammogram was recorded (Fig. 1). It was found that, for the concentration range of zinc ions between 10 and 100 μg/L, the curve describing the relationship between the current and the concentration was linear, and the linear equation was $y = -0.104x+0.016$. The Pearson's correlation coefficient determined was 0.9978.

2.4.5. Selectivity

In order to determine the selectivity of the DP-ASV method, zinc(II) ions were determined in the presence of copper(II), cadmium(II) and lead(II). The signal of zinc is outside the potential range of these ions and no interference was found, even with concentrations as high as 10 ppm in the voltammetric cell. Based on the obtained results, it was found that the applied method enables the determination of trace amounts of zinc(II) ions in the presence of an excess of Cu(II), Cd(II) and Pb(II).

2.5. Statistical analysis

For each mushroom, three samples were used for the determination of every quality attribute and all the analyses were carried out in triplicate. The results were expressed as mean values and standard deviations (SD). The Tukey–Kramer test was used to reveal the differences between paired groups of elements. *P* values below 0.05 were considered to be statistically significant (Statistica 12, Poland).

3. Results and discussion

The application of the developed method of sample preparation for the analysis, as well as the use of the differential pulse anodic stripping voltammetry (DP-ASV) method to determine zinc(II) ions released from the fungal material, enabled a relatively easy, and particularly accurate determination of the amount of this element in artificial digestive juices. The DP-ASV method is adequate and relatively inexpensive to determine the release of zinc(II) ions from mushroom material. In each case, the results of the conducted measurements were calculated per the amount of released zinc in 100 g d.w. of the tested species. In the tested material, the content of zinc ions released into artificial gastric juices (artificial saliva, artificial gastric and intestinal juice) under normal body temperature (37 °C) from the freeze-dried fruiting bodies of selected edible mushrooms was determined before and after thermal processing (100 °C, 60 min).

Gastrointestinal track activity was simulated by imitating

Table 1
Zinc(II) content, the observed and expected values and percentage of recovery after 15 min of incubation of Cantarellus cibarius in gastric juice.

Zn(II) content [%]	Observed value [μg/L]	Expected value [μg/L]	Percent recovery [%]
50	5.0	4.79	95.8
100	10.0	9.37	93.7
150	15.0	14.64	97.6
Average percent recovery:			96.03

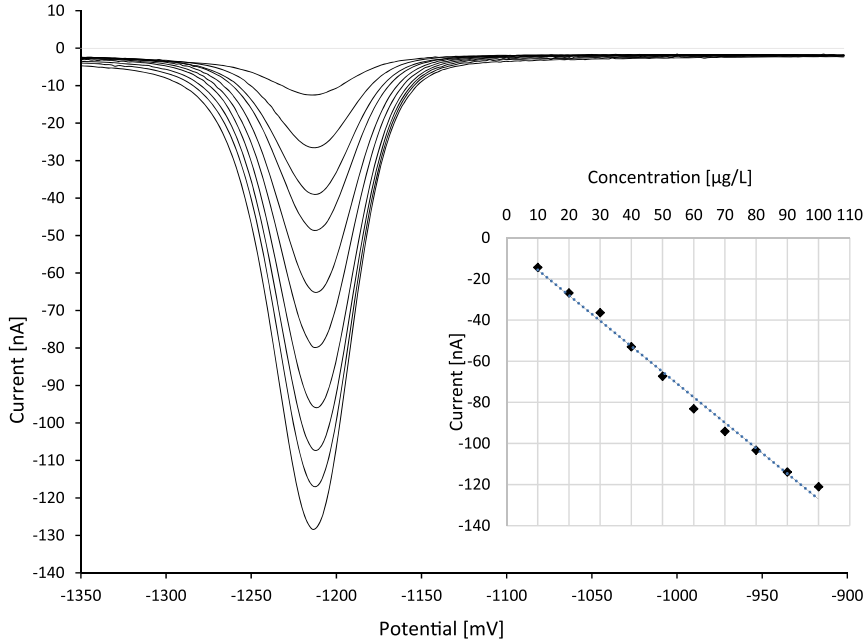

Fig. 1. Calibration curve after ten 10 μL additions of 1 μg/ml Zn(II), mean curves from 4 replicate measurements after background signal subtraction.

natural digestive conditions, considering temperature, the order of the applied digestive juices and digestive juice movements in the system designed for the release (Gastroel-2014). Studies on release into artificial gastric juices have been performed by Muszyńska (Muszyńska et al., 2015); however, these studies were related to the analysis of indole compounds via RP-HPLC. The presence of indole compounds was found in each extract (artificial saliva, and gastric and intestinal juices) with the largest amount of 5-hydroxy-L-tryptophan and L-tryptophan (Muszyńska et al., 2015). Analysis of the results obtained in the current study has shown that thermal processing does not inhibit zinc release from mushroom material.

The factors which influence the accumulation of metals in mushrooms are: structure and growth, biochemical composition, decomposition activity, and morphology, along with environmental factors (metal concentrations in the soil, contamination by atmospheric deposition and soil pH).

Moreover, the time needed to maintain the material under conditions simulating the human gastrointestinal tract to release of zinc(II) ions appeared to be significant. Five experimental variants for the incubation time of biomass from *in vitro* cultures were applied: three in artificial gastric juices (15, 60 and 120 min), one in artificial saliva (1 min) and one in intestinal juices (150 min). The highest amounts of zinc(II) ions were determined after 120 min of incubation of thermally-unprocessed material in gastric juices. The highest total amount of zinc released (including artificial saliva, artificial gastric juice and artificial intestinal juice) was determined in the majority of samples in gastric juices after prior extraction over 15 and 60 min, respectively.

The amount of zinc released from thermally-processed fruiting bodies ranged within 0.44–5.37 mg/100 g d.w., while in the unprocessed samples, it was found to be within 0.37–15.02 mg/100 g d.w (Table 2). For the total zinc content from the tested species, the amounts were within a similar order of magnitude and were estimated at 2.22–20.68 mg/100 g and 1.50–20.28 mg/100 g (Fig. 2) in the processed and unprocessed fruiting bodies, respectively.

The highest concentration of zinc was determined in artificial digestive juices (saliva, and gastric and intestinal juices) after incubation for 15 and 60 min in artificial gastric juices of thermally processed fruiting bodies of the two representatives of *Boletaceae*: *B. badius* and *B. edulis*.

In relation to the species, 120 min incubation of the processed fruiting bodies in gastric juices led to a decrease in the quantity of zinc released into the solution. For the fruiting bodies of *C. cibarius,* thermal processing resulted in a slight increase in the release of zinc (in a range between 3.83 and 4.99 mg/100 g d.w.) compared to the untreated fruiting bodies (2.69–3.75 mg/100 g d.w., respectively). *L. scabrum* and *S. bovinus* were found to be species for which thermal treatment appeared to be unfavorable in terms of zinc content in the artificial digestive juices. For *P. ostreatus*, the amount of zinc released into digestive juices before and after thermal processing was almost of the same order of magnitude (5.98–11.98 mg/100 g d.w. and 4.90–10.37 mg/100 g d.w., respectively). The amount of zinc obtained in the present study correlates with earlier results of total zinc amount in fruiting bodies of *B. badius* obtained by Isildak (Isildak Turkekul, Elmastas, & Tuzen, 2004).

Our studies confirmed that mushrooms are a good source of zinc and can constitute an alternative to food of animal origin in the vegetarian diet (FAO/WHO Standards, 1999). Oysters and meat are

Table 2
Zinc content (mg/100 g d.w. ± SD) after 1 min incubation in artificial saliva, after 15, 60, 120 min in artificial gastric juice and 150 min in artificial intestinal juice in the fruiting bodies of some species of edible mushrooms, before and after thermal processing.

Artificial juice	Artificial saliva [mg/100 g d.w.]	Artificial gastric juice [mg/100 g d.w.]			Artificial intestine juice [mg/100 g d.w.]		
Time [min]	1	15	60	120	150	150	150
Species		(after 1 min in artificial saliva)			(after incubation in gastric juice)		
Boletus badius	0.85 ± 0.02^{a}	1.09 ± 0.06^{a,b}	0.92 ± 0.06^{b,c}	2.07 ± 0.02^{a,b,c,d}	1.09 ± 0.06^{a,c,d,e}	0.41 ± 0.02^{a,b,c,d,e,f}	0.50 ± 0.04^{a,b,c,d,e}
Boletus edulis	1.01 ± 0.05^{a}	0.71 ± 0.05^{a,b}	0.67 ± 0.35^{a,c}	2.12 ± 0.01^{a,b,c,d}	0.98 ± 0.03^{b,c,d,e}	1.01 ± 0.12^{b,c,d,f}	1.33 ± 0.09^{a,b,c,d,e,f}
Cantharellus cibarius	1.14 ± 0.09^{a}	0.82 ± 0.02^{a,b}	0.77 ± 0.02^{a,c}	1.00 ± 0.06^{b,c,d}	1.79 ± 0.04^{a,b,c,d,e}	1.44 ± 0.06^{a,b,c,d,e,f}	0.80 ± 0.06^{a,b,d,e,f}
Leccinum scabrum	2.94 ± 0.13^{a,b}	0.32 ± 0.04	3.77 ± 0.03^{a,b,c}	15.02 ± 0.1^{a,b,c,d}	1.14 ± 0.03^{a,b,c,d,e}	3.43 ± 0.05^{a,b,d,e,f}	1.89 ± 0.30^{a,b,c,d,e,f}
Pleurotus ostreatus	2.33 ± 0.09^{a}	2.25 ± 0.06^{b}	1.14 ± 0.14^{a,b,c}	8.33 ± 0.02^{a,b,c,d}	0.41 ± 0.03^{a,b,c,d,e}	1.59 ± 0.06^{a,b,c,d,e,f}	0.16 ± 0.01^{a,b,c,d,e,f}
Suillus bovinus	2.33 ± 0.07^{a}	7.18 ± 0.16^{a,b}	1.94 ± 0.05^{a,b,c}	4.15 ± 0.07^{a,b,c,d}	1.87 ± 0.04^{a,b,d}	1.78 ± 0.22^{a,b,d,}	2.06 ± 0.15^{b,d,}
Fruiting bodies after thermal treatment							
Boletus badius	5.95 ± 0.13^{a}	4.09 ± 0.12^{a,b}	5.37 ± 0.08^{a,b,c}	4.63 ± 0.22^{a,b,c,d}	3.44 ± 0.05^{a,b,c,d,e}	10.68 ± 0.16^{a,b,c,d,e,f}	1.96 ± 0.21^{a,b,c,d,e,f}
Boletus edulis	5.24 ± 0.06^{a}	4.08 ± 0.08^{a,b}	3.11 ± 0.01^{a,b,c}	3.92 ± 0.22^{a,b,d}	4.27 ± 0.09^{a,c,e}	3.38 ± 0.27^{a,b,c,d,e}	3.32 ± 0.05^{a,b,d,}
Cantharellus cibarius	1.42 ± 0.03^{a}	1.86 ± 0.01^{a,b}	1.47 ± 0.08^{b,c}	1.05 ± 0.03^{a,b,c,d}	1.79 ± 0.03^{a,c,d,e}	1.87 ± 0.01^{a,c,d,f}	1.10 ± 0.08^{a,b,c,e,f}
Leccinum scabrum	1.82 ± 0.04^{a}	2.74 ± 0.02^{a,b}	2.80 ± 0.20^{a,c}	4.46 ± 0.03^{a,b,c,d}	1.60 ± 0.02^{b,c,d,e}	1.36 ± 0.11^{a,b,c,d,f}	4.66 ± 0.24^{a,b,c,e,f}
Pleurotus ostreatus	2.35 ± 0.13^{a}	2.41 ± 0.04^{b}	2.65 ± 0.08^{a,b,c}	0.78 ± 0.06^{a,b,c,d}	2.18 ± 0.05^{b,c,d}	2.22 ± 0.06$^{c,d.}$	2.23 ± 0.09$^{c,d.}$
Suillus bovinus	1.17 ± 0.09^{a}	0.44 ± 0.03^{a,b}	2.46 ± 0.01^{a,b,c}	2.14 ± 0.04^{a,b,c,d}	0.72 ± 0.08^{a,b,c,d,e}	3.25 ± 0.15^{a,b,c,d,e,f}	1.35 ± 0.11^{b,c,d,e,f}

Data are presented as the mean ± SD (Standard deviation); n = 3 repetitions; Significant differences were presented as the same letter in each row (for $p < 0.05$) by GraphPad InStat 3 v 3.1.

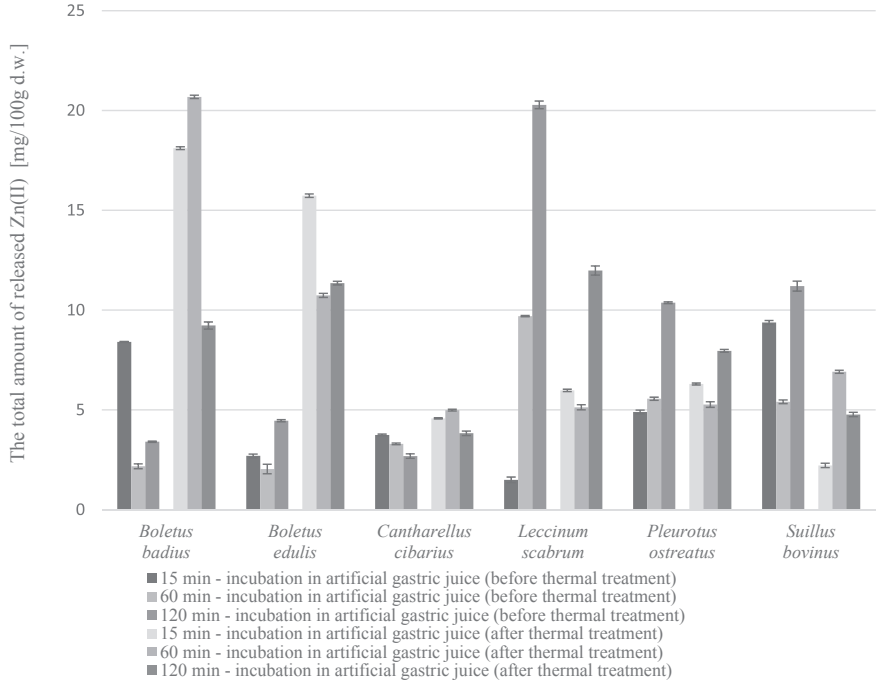

Fig. 2. Total content of zinc(II) ions in fruiting bodies of selected edible mushrooms released to artificial gastric juices before and after thermal processing.

the best sources of Zn and they additionally constitute rich sources of easily digestible proteins which promote the absorption of Zn in the gastrointestinal tract. In terms of plants, low zinc content and a large amount of carbohydrates hamper the absorption of this element and cause zinc deficiency in vegetarians. In contrast, the absorption of this micronutrient from/in mushrooms additionally provides a high content of proteins particularly rich in essential amino acids (typical for animal protein) and dietary fiber (chitin and chitosans) (Bakan, Birmingham, Aeberhardt, & Goldner, 1993; FAO/WHO Standards, 1999; Hunt, 2003; Johnson, 2003).

4. Conclusions

It can be concluded that edible mushrooms are good sources of zinc. The processes involved in the thermal processing of mushrooms may cause changes in the release of zinc, which may be related to the type of species tested. Thermal processing of *B. badius, B. edulis* and *C. cibarius* results in the release of significantly larger amounts of zinc into artificial gastric juices, which makes them a good source of zinc in the diet (the daily requirement for the human body is 15 mg) and which may even satisfy the requirement for this element (according to FAO/WHO standards).

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