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Multielemental analysis of fruit bodies of three cultivated commercial *Agaricus* species

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ABSTRACT

The *Agaricus* genus comprises several commercially cultivated edible species, with *A. bisporus* being unambiguously the most important mushroom in this regard worldwide. The aim of study was to evaluate the content of 62 elements in fruit bodies of cultivated *A. bisporus* (brown and white strains), *A. arvensis* and *A. subrufescens* available on the Polish market during 2007–2015.

Overall, 26 elements were detected in every sample, the content of 25 elements was above the concentration 0.01 mg kg^{-1} in only some percentage of samples, while contents of Au, Be, Co, Dy, Ga, Gd, Ge, Hf, Li, Sm, Tb and Yb were below 0.01 mg kg^{-1}. As demonstrated using heatmaps, the variability of elemental composition was the lowest in *A. bisporus* and the greatest in *A. subrufescens*.

Generally, *A. bisporus* was also characterized by the lowest content of potentially toxic elements such as Al, As and Cd (3.0 ± 1.2; 0.63 ± 0.37 and 0.36 ± 0.47 mg kg^{-1} dry matter, respectively). All in all, the present study offers the broadest insight to date into the elemental composition of *Agaricus* mushrooms cultivated for human consumption, and further indicates that cultivation of *A. bisporus* is highly standardized compared to other species. It is worth pointing out that toxic element content in the studied mushrooms was generally considered low and safe.

1. Introduction

Agaricus L.: Fr. is a genus of saprobic basidiomycetes comprising more than 400 species worldwide. *Agaricus bisporus* is the world most commonly cultivated species. In the EU almost one million metric tons of *A. bisporus* are produced annually in the three leading countries alone. Polish production of button mushrooms is the largest in Europe – 330,000 tons annually, followed by The Netherlands (270,000 tons) and Spain (105,000 tons). Poland is also the greatest exporter with 35% of the world's imported *A. bisporus* originating from Polish producers (FAOSAT, 2015; IERiGŻ, 2015). Two main cultivated varieties, white (white or button mushroom) and brown (portobello), can be distinguished, with the former being more common in trade. The brown cultivars are thicker and more aromatic, and are known to be less susceptible to infections with the green mold *Trichoderma* ssp. (Sobieralski et al., 2009). *A. subrufescens* (also termed *A. brasiliensis* or *A. blazei*) is called the Almond mushroom, due to its contents of benzaldehyde and benzoic acid giving it a special almond-like smell and taste, which make it a particularly prized gourmet food (Escuto et al., 2005; Stijve et al., 2004). *A. subrufescens* is widely cultivated mainly in Asia and in South America (Wisitrassameewong et al., 2012a,b). This species is considered as a medicinal mushroom as it contains bioactive polysaccharides and protein complexes (PSPC) which have been shown to function as potent antioxidants, antitumor, and anticancer agents (Ishii et al., 2011; Oliveira Lima et al., 2011; Wang et al., 2013). *Agaricus arvensis* – the Horse mushroom – has been less cultivated, commonly fruiting from spring to autumn on meadows, pastures and on the forest edges. *A. arvensis* was found

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to secrete efficient cellulases. Saccharification of the woody biomass with A. arvensis cellulase as the enzyme source released a high level of fermentable sugars (Nguyen et al., 2010). The carpophores are edible and have a pleasant aniseed-like odor.

Mushrooms are considered as a healthy food source and a delicacy being low in calories and high in the level of some nutritional compounds, particularly as regards B vitamins, ergosterol (provitamin D_2) and polysaccharides forming dietary fiber (Kalač, 2016). Nevertheless, mushrooms are also recognized as efficient trace metal accumulators (for reviews see Kalač, 2010; Falandysz and Borovička, 2013). Trace metal contents in mushrooms are usually higher than those in agricultural crop plants, vegetables, fruits or even animal tissue (Mleczek et al., 2013). Saprobiotic mushrooms uptake organic matter osmotrophically which can be called accumulation of biogenic elements in mushrooms hyphae. Some of the elements such as carbon, hydrogen or nitrogen are usually accumulated with no harm resulting for either the mushroom itself or for the mushroom consumer. Unfortunately, some mushroom species are able to accumulate relatively high levels of these elements which can pose a threat to human health (Kalač, 2016). However, other elements can also be harmful for mushroom consumers (e.g. As, Cd, Cr(III), Hg or Pb). Elements such as Pb are accumulated commensurately (high concentration of an element in the environment is reflected in its high accumulation in the fruit body) or disproportionately – Cd and Hg (high content in mushrooms is caused by its intensive absorption from the environment but not by a high abundance of the element in the environment – hyperaccumulation) (Falandysz and Borovička, 2013). Present human health risk assessments of elements like toxic metals or metalloids are traditionally based on the total content in foods and food consumption, although, the amount of an ingested element in the diet does not always reflect the amount that is accessible to the consumer. The terms bioaccessibility and bioavailability are often used indiscriminately although their meaning is slightly different. Bioaccessibility defines the fraction of a contaminant ingested with food that is released from its matrix into the digestive juice and has the potential to be absorbed by the intestines during the digestion. Bioavailability, however, refers to the proportion of a contaminant ingested with food that is absorbed by the intestine with the subsequent potential to reach the systemic circulation and exert toxic effects (Versantvoort et al., 2005).

To date, the most commonly evaluated elements in *Agaricus* mushrooms are Ca, Cd, Cu, Fe, Hg, K, P, Se and Pb; less commonly: Al, B, Cr, Mg, Mn, Ni and very rarely: Ag, Ba, Co, Cs, Na, Sr, Ti, Th, U and V. The summarized levels of these elements from available literature in the species analyzed in this work are listed in Table 1.

The present research was undertaken in an effort to update information on the elemental composition of fruit bodies of cultivated species belonging to the genus *Agaricus*. To achieve this goal, inductively coupled plasma optical emission spectrometry (ICP-OES) was applied and a screening of 62 elements was conducted. This method has been used successfully to compare element contents in six cultivated species of the genus *Pleurotus* (Siwulski et al., 2017). The present study extends the body of knowledge on the elemental composition of *Agaricus* mushrooms – globally the most important cultivated genus.

Table 1
The summary of literature data on elements content (mg kg^{-1} dm) reported for *A. arvensis*, *A. bisporus* and *A. subrufescens*.

Element	Agaricus arvensis (wild)[a]	Agaricus bisporus (cultivars/wild)[b]	Agaricus subrufescens (cultivars)[c]
Ca	1090–1280	860–1400	958–1520
K	43 432	38,105–40,371	25,000–30,170
Mg	890–1070	1099–1400	995–1167
Na	230–283	545–957	140–188
P	13,419	10,430–12,475	6792–11,775
Ag	5.5–84.1	–	–
Al	3–128	19–548	312–334
As	0.63–8.25	0.07–4.31	0.5–4
Au	5.5	–	–
B	3.35	3.7–19.4	30.8–32.7
Ba	4.1	1.39–2.37	1.53–1.69
Bi	–	0.53–5.65	–
Cd	2.5–54.2	0.01–10.59 (wild)	3–35
Co	1.2–5.09	0.002–0.09	0.1–0.2
Cr	0.8–5.5	0.7–22.6 (wild)	0.05–1.95
Cu	45–187	3–65	73–151
Fe	740–1056	44–190 (wild)	99–181
Hg	3.15–5.22	0.002–9.21	0.08–0.52
Li	0.074–0.3	0.169	–
Mn	33–87.5	5.7–28.8 (wild)	6.08–8.84
Mo	0.83	–	0.1–0.2
Ni	2.1–5.01	0.35–9.02	0.84–1.39
Pb	1.19–29.1	0.06–2.44	0.7–5.5
Se	2.54–4.38	1.88–4.21	0.1–0.2
Sr	6.42	4.13–6.7	4.98–5.79
Ti	2.29	0.91	0.96–1.1
Th	0.00569	–	–
V	–	<0.05	0.1–0.2
U	0.0263	–	–
Zn	85–142	4–81 (wild)	143–254

[a] *Agaricus arvensis* (wild) – (Gyorfi et al., 2010; Vetter, 2003a, 2004, 2005; Cocchi et al., 2006; Tuzen et al., 2007; Borovička et al., 2010, 2011; Sarikurkcu et al., 2011; Petkovšek and Pokorny, 2013; Schlecht and Säumel, 2015).
[b] *Agaricus bisporus* (cultivar/wild) – (Cocchi et al., 2006; Gyorfi et al., 2010; Jain et al., 2013 (wild); Mleczek et al., 2016b; Muñoz et al., 2005; Schlecht and Säumel, 2015 (cultivar expsed for urban conditions of Berlin); Vetter, 2003a,b, 2004; Zhu et al., 2011 (wild)).
[c] *Agaricus subrufescens* (cultivar) – (Huang et al., 2008; Liu et al., 2008; Gyorfi et al., 2010; Largeteau et al., 2011; Sun et al., 2012).