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Review

Chemical composition and nutritional value of European species of wild growing mushrooms: A review

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ABSTRACT

Numerous species of wild growing mushrooms are widely consumed as a delicacy in central and eastern Europe. Credible evaluation of their nutritional value has so far been limited due to fragmentary knowledge of their composition and mainly due to the very limited information on the availability of their constituents. Dry matter content is usually about 100 g kg^{-1}. Structural polysaccharides and proteins comprise the main components of dry matter, while the lipid content is low. Chitin, glycogen, mannitol and trehalose are typical carbohydrate constituents. The proportion of essential amino acids is nutritionally favourable, while the content of $n-3$ fatty acid is negligible. Low energy, high proportion of indigestible fibre, specific β-glucans and antioxidative and flavour constituents provoke the increasing interest of both researchers and consumers. The ability of some species to accumulate several detrimental trace elements and radiocaesium, and occurrence of detrimental constituents in edible mushrooms are also briefly reviewed.

Contents

1. Introduction

Consumption of wild growing mushrooms has been preferred to eating of cultivated fungi in many countries of central and eastern Europe. Mushroom picking is a "national hobby" in the Czech Republic with a statistical mean of 5.6 kg of fresh mushrooms per household yearly (Šišák, 2007). However, some individuals consume over 10 kg yearly.

Mushrooms are consumed as a delicacy, and particularly for their specific aroma and texture. Both fresh and preserved fruiting bodies of tens of species can be culinary-processed in different

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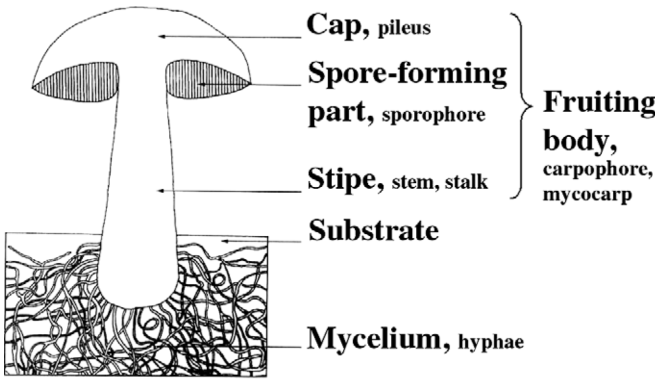

Fig. 1. A sketch of a mushroom and used mycological terms.

manners. The knowledge of the nutritional value of wild growing mushrooms has been limited when compared with other vegetables. This is not surprising, because wild growing mushrooms are widely perceived as only a delicacy. Moreover, these mushrooms are consumed only rarely in many European countries.

The aim of the review is to collect recent data on chemical composition and nutritional value of edible mushroom species growing and consumed within Europe and adjacent areas.

2. Mycological terms

The following terms describe commonly gathered edible mushrooms (higher fungi, macrofungi). The term mushroom will be used for the fruiting body (carpophore, mycocarp), mostly above ground, of higher fungi. A fruiting body is formed from spacious underground mycelia (hyphae) by the process of fructification. The lifetime of the bulk of fruiting bodies is only about 10–14 days. The basic terminology of fruiting body is given in Fig. 1.

Mycelia of ectomycorrhizal species live in symbiosis with roots of a plant, mostly a tree. Terrestrial saprobic species gain nutrients mostly from organic compounds of the plant and animal debris.

3. Dry matter, proximate composition, energy value and bioavailability

Dry matter of mushrooms is very low, usually in the range of 60–140 g kg^{-1}. Commonly, dry matter content of 100 g kg^{-1} has been used for calculations if the factual value is unknown. Such high water content and water activity affect the texture and participate in the short shelf life of fruiting bodies.

Dry matter proportion increases during mushroom cooking due to water loss. For instance, boiling, for 10 min, of the cultivated species *Agaricus bisporus* (portabella) decreases the weight by 30%, but only by 11–16% in *Grifola frondosa* (maitake) and *Flammulina velutipes* (enokitake) (Dikeman, Bauer, Flickinger, & Fahey, 2005).

Dried mushrooms are known for their hygroscopicity. Moisture sorption isotherms of mushrooms were determined by Sahbaz, Palazoglu, and Uzman (1999) and Shivrare, Arora, Ahmed, and Raghavan (2004).

Proximate composition of dry matter of several mushroom species is given in Table 1. Carbohydrates and crude proteins are the two main components. Considerable differences are apparent for three species (*Amanita rubescens, Lepista nuda* and *Tricholoma portentosum*) reported by different authors. The data on the variability of crude protein and ash within several mushroom species will be presented in following sections.

Low dry matter and lipid contents result in the low energy value of mushrooms. The values of 86.4, 165, 126, 101 and 112 kJ 100 g^{-1} of fresh mushrooms were reported for *A. bisporus, Lactarius deliciosus, Leucopaxillus giganteus, Sarcodon imbricatus* and *T. portentosum*, respectively (Barros et al., 2007a). In a further work of the same laboratory (Barros, Venturini, Baptista, Estevinho, & Ferreira, 2008), the values 118, 87.3, 131 and 159 kJ were observed for *Cantharellus cibarius, L. nuda, Lycoperdon perlatum* and *Ramaria botrytis*, respectively. Colak, Kolcuoglu, Sesli, and Dalman (2007) determined values of 155 kJ for *A. rubescens* and 259 kJ for *L. nuda*. These values are mostly comparable with the 120–150 kJ reported for several species of cultivated mushrooms (Manzi, Aguzzi, & Pizzoferrato, 2001; Mattila, Salo-Väänänen, Könkö, Aro, & Jalava, 2002a). Thus, mushrooms are a food item of low energy value.

Digestibility and bioavailability of mushroom constituents have been missing from the knowledge of mushroom nutritional value. A high proportion of indigestible chitin apparently limits availability of other components. Nevertheless, plausible data for wild growing mushrooms have been lacking.

Moreover, most data deal with fresh mushrooms. Information has been scarce on the changes of the individual constituents during different preservation methods, under storage and during different cooking processes.

Table 1
Proximate composition of mushroom fruiting bodies (% of dry matter)

Species	Crude protein	Lipids	Ash	Fibre	Carbohydrates	Reference
Agaricus arvensis	56.3	2.7	3.5	–	37.5	Barros et al. (2007a)
Amanita rubescens	31.9	27.5	10.0	–	30.6	Colak et al. (2007)
	26.0	7.2	4.6	–	62.2	Ouzouni and Riganakos (2007)
Armillariella mellea	21.9	1.8	–	–	16.4	Florczak, Karmańska, and Wędzisz (2004)
Boletus edulis	26.5	2.8	5.3	–	65.4	Ouzouni and Riganakos (2007)
Cantharellus cibarius	53.7	2.9	11.5	–	31.9	Barros et al. (2008)
Lactarius deliciosus	29.8	2.2	5.1	–	62.9	Barros et al. (2007a)
Lepista nuda	44.2	9.0	5.4	–	41.4	Colak et al. (2007)
	19.8	3.2	6.0	–	71.0	Ouzouni and Riganakos (2007)
	59.4	1.8	18.5	–	20.3	Barros et al. (2008)
Lycoperdon perlatum	17.2	0.4	32.0	–	50.4	Barros et al. (2008)
Macrolepiota procera	23.9	2.3	5.4	–	68.4	Ouzouni and Riganakos (2007)
Ramaria botrytis	39.0	1.4	8.8	–	50.8	Barros et al. (2008)
Suillus granulatus	16.5	4.0	5.2	–	74.3	Ouzouni and Riganakos (2007)
Tricholoma flavovirens	18.1	2.0	–	–	37.0	Florczak et al. (2004)
Tricholoma portentosum	19.6	5.8	9.9	30.1	34.6[a]	Díez and Alvarez (2001)
	30.5	5.5	11.7	–	52.3	Barros et al. (2007a)
Tricholoma terreum	20.1	6.6	12.1	30.1	31.1[a]	Díez and Alvarez (2001)
Mixtures of dried *Boletus* spp. (eight samples)	21.6–25.8	3.0–5.8	5.7–8.2	–	61.7–75.0	Manzi et al. (2004)

[a] Calculated content of carbohydrates without fibre.

4. Proteins and amino acids

The informative data on crude protein content and variability in eight mushroom species are given in Table 2. Comparable data were reported by Bauer-Petrovska (2001). She determined the mean crude protein content of 32.6% in dry matter of 47 species of Macedonian edible mushrooms. However, wide variations occurred. The highest contents of 48.8% and 51.2% were observed in *Calocybe gambosa* and *Macrolepiota mastoidea*, respectively, while the lowest value of only 16.2% was in the widely consumed *C. cibarius*. However, Barros et al. (2008) reported 53.7% in the latter species (Table 1). Crude protein variability within a species can be seen not only in Table 2, but also in values of Table 1 reported by different laboratories (e.g. for *L. nuda*).

For the calculation of crude protein content in mushrooms, if determined by the Kjeldahl method, a specific converting factor has to be used. This is due to the high proportion of non-protein nitrogen, mainly in chitin. The factor of 4.16 was recommended by Bauer-Petrovska (2001), who observed a mean proportion of 33.4% of non-protein nitrogen (from total nitrogen) in the abovementioned numerous samples. Data on crude protein content in Tables 1 and 2 should thus be considered with caution. The converting factor 6.25 was widely used in cited papers; however, Barros et al. (2007a, 2008) used the factor 4.38. Crude protein is thus overestimated in some articles. Consequently, also the calculated carbohydrate contents in Table 1 are of limited credibility with a risk of underestimation.

The distribution of proteins within a fruiting body and changes in protein content during the development of a fruiting body remain mostly unclear. Vetter and Rimóczi (1993) reported the highest crude protein content, together with the highest digestibility of 92%, in cultivated *Pleurotus ostreatus* (oyster mushroom) at a cap diameter of 5–8 cm. At that stage of the development, crude protein contents were 36.4% and 11.8% in cap and stipe, respectively. Thereafter, both crude protein and its digestibility decreased. Thus, further studies on the changes in bioavailable nutritional content, during the development of both cultivated and wild growing mushrooms, are needed.

Protein content, expressed as a proportion in dry matter, virtually did not change during air-drying of mushrooms at 40 °C or on freezing to −20 °C, while boiling of fresh mushrooms caused a significant decrease (Barros, Baptista, Correia, Morais, & Ferreira, 2007b).

A unique paper on mushroom protein fractions in 24 mushroom species reported mean levels of albumins, globulins, glutelin-like material, glutelins, prolamins and prolamine-like material of 24.8%, 11.5%, 7.4%, 11.5%, 5.7% and 5.3%, respectively (Bauer-Petrovska, 2001).

Data on the proportion of essential amino acids in proteins of several mushroom species are given in Table 3. The composition of mushroom proteins seems to be of a higher nutritional value than that of most plant proteins (Belitz & Grosch, 1999).

The content of free amino acids in mushrooms is low, only about 1% of dry matter. Their nutritional contribution is thus limited. However, they participate in the taste of mushrooms. Glutamic acid and alanine were reported as prevailing free amino acids in *T. portentosum* and *T. terreum* (Díez & Alvarez, 2001). Tens of milligrammes of free ornithine and γ-aminobutyric acid in 100 g of fresh matter, however, with very wide variation, were determined in cultivated oyster mushroom (Manzi, Gambelli, Marconi, Vivanti, & Pizzoferrato, 1999).

5. Lipids

The content of total lipids (crude fat) ranges mostly from 2% to 6% of dry matter (Tables 1 and 4). The only outlying value is that of *A. rubescens* in Table 1. Within fatty acid composition (Table 4), polyunsaturated linoleic acid ($C_{18:2n-6}$), monounsaturated oleic acid ($C_{18:1n-9}$) and nutritionally undesirable saturated palmitic acid ($C_{16:0}$) prevail. The proportions of nutritionally neutral saturated stearic acid ($C_{18:0}$), and especially of desirable α-linolenic acid ($C_{18:3n-3}$), are low. However, very high proportions of 20.3% and 15.6% of total fatty acids were reported for α-linolenic acid in *Hydnum repandum* and *Macrolepiota procera*, respectively, while only 3.5% was determined in *H. repandum* in another laboratory (Table 4). Other fatty acids are present at only low levels. Contents of odd- and branched-chain acids and hydroxy fatty acids are negligible (Nedelcheva et al., 2007; Řezanka, Rozentsvet, & Dembitsky, 1999). The occurrence of *trans* fatty acids in mushrooms has not been reported and it is not expected.

Phosphatidylcholine was the major phospholipid present in 55 of 58 wild growing mushroom species of several families (Vaskovsky, Khotimchenko, & Boolukh, 1998).

Table 2
Variability of crude protein content in several mushroom species (Vetter, 1993a)

Species	Number of samples (*n*)	Mean (% of dry matter)	Standard deviation (% of dry matter)	Relative standard deviation (%)
Armillariella mellea	6	22.3	5.4	24.2
Boletus edulis	10	33.1	3.1	9.4
Cantharellus cibarius	8	18.7	5.9	31.5
Clitocybe nebularis	6	39.0	4.4	11.3
Craterellus cornucopioides	6	22.3	5.5	24.7
Leccinum scabrum	9	30.5	4.1	13.4
Marasmius oreades	3	52.8	2.1	4.0
Xerocomus subtomentosus	7	33.2	6.8	20.5

Table 3
Proportion of essential amino acids (% of total amino acids) in mushroom proteins

Species	Val	Leu	Ile	Thr	Met	Lys	Phe	Trp	Reference
Cantharellus cibarius	3.5	16.3	3.3	4.2	1.0	4.3	3.2	1.7	Surinrut, Julshamn, and Njaa (1987)
Hydnum repandum	3.9	14.5	3.2	4.4	1.0	4.2	3.4	1.4	Surinrut et al. (1987)
Tricholoma portentosum	7.8	9.4	3.7	9.5	3.0	8.6	4.4	1.0	Díez and Alvarez (2001)
Tricholoma terreum	8.9	8.2	3.6	9.1	3.5	7.6	6.6	1.1	Díez and Alvarez (2001)
Five species of genus *Agaricus* (mean)	4.4	7.5	5.0	4.8	1.3	6.5	4.9	–	Vetter (1993b)
Five species of genus *Russula* (mean)	6.9	8.4	5.3	5.3	1.4	6.8	5.3	–	Vetter (1993b)
Standard protein	5.0	7.0	4.0	4.0	3.5	5.4	6.1	1.0	

Table 4
Lipids (crude fat) content (% of dry matter) and proportion of major fatty acids (% of total fatty acids)

Species	Lipids	Palmitic	Stearic	Oleic	Linoleic	Linolenic	Reference
Agaricus arvensis	2.7	14.6	3.4	15.5	56.1	0.2	Barros et al. (2007a)
Boletus edulis	2.6	9.8	2.7	36.1	42.2	0.2	Pedneault, Angers, Gosselin, and Tweddell (2006)
	3.3	21.6	9.1	31.1	33.8	1.7	Kavishree, Hemavathy, Lokesh, Shashirekha, and Rajarathnam (2008)
Boletus erythropus	2.0	11.2	1.3	18.0	63.0	0.2	Pedneault et al. (2006)
Calvatia utriformis	1.8	12.2	3.6	23.0	42.4	0.8	Nedelcheva et al. (2007)
Cantharellus cibarius	2.3	18.3	6.0	35.4	17.3	Traces	Kavishree et al. (2008)
	2.9	7.2	3.3	8.1	50.0	0.1	Barros et al. (2008)
Clitocybe nebularis	–	18.8	5.8	5.3	65.2	0.6	Senatore (1992)
Hydnum repandum	–	15.8	6.0	19.2	48.7	3.5	Senatore, Dini, and Marino (1988)
	4.7	15.7	0.9	26.4	47.5	20.3	Kavishree et al. (2008)
Lactarius deliciosus	2.2	12.1	25.3	41.3	17.1	0.3	Barros et al. (2007a)
Leccinum rufum	2.0	16.5	0.9	21.1	52.9	0.2	Pedneault et al. (2006)
Leccinum scabrum	3.1	13.8	1.1	37.8	42.3	0.1	Pedneault et al. (2006)
Lepista nuda	1.8	11.8	2.4	29.5	51.5	0.2	Barros et al. (2008)
Lycoperdon perlatum	3.4	14.5	6.4	24.1	37.6	3.9	Nedelcheva et al. (2007)
	0.4	12.9	3.0	8.6	64.2	0.1	Barros et al. (2008)
Macrolepiota procera	2.9	4.6	Traces	17.2	47.0	15.6	Kavishree et al. (2008)
Morchella esculenta	–	11.0	3.2	24.1	12.6	3.6	Řezanka et al. (1999)
Ramaria botrytis	1.4	9.9	2.4	43.9	38.3	0.2	Barros et al. (2008)
Russula cyanoxantha	–	17.2	4.7	26.0	47.4	0.3	Senatore et al. (1988)
Russula xerampelina	–	19.1	4.5	20.5	50.5	Traces	Senatore et al. (1988)
Suillus granulatus	–	17.7	6.5	14.8	56.3	0.9	Senatore et al. (1988)
	3.2	12.0	3.3	34.2	46.6	0.2	Pedneault et al. (2006)
Suillus grevillei	5.4	8.9	1.5	43.9	40.1	0.2	Pedneault et al. (2006)
	–	11.9	0.6	0	67.1	1.4	Karliński, Ravnskov, Kieliszewska-Rokicka, and Larsen (2007)
Suillus luteus	–	15.7	4.6	19.0	54.5	2.0	Senatore et al. (1988)
	–	13.4	2.2	16.4	27.3	6.2	Řezanka et al. (1999)
Tricholoma portentosum	5.8	7.6	3.4	58.0	27.9	–	Díez and Alvarez (2001)
	5.5	5.6	2.3	58.4	35.4	0.2	Barros et al. (2007a)
Tricholoma terreum	6.6	10.1	1.8	56.7	29.7	–	Díez and Alvarez (2001)
Xerocomus badius	–	20.2	0	2.2	70.9	Traces	Karliński et al. (2007)
Xerocomus subtomentosus	–	18.5	0.1	7.3	66.7	0	Karliński et al. (2007)
	2.2	16.3	1.7	31.7	42.2	0.3	Pedneault et al. (2006)

A dependence of fatty acid composition on ambient temperature, during fructification, was reported. In cultivated oyster mushroom, growth temperatures below 17 °C resulted in an increase of unsaturated fatty acid proportion as compared with mushrooms produced at temperatures above 17 °C (Pedneault, Angers, Avis, Gosselin, & Tweddel, 2007).

The nutritional value of wild growing mushroom lipids is thus limited, due to a low total lipid content and a low proportion of desirable $n-3$ fatty acids.

6. Carbohydrates

Carbohydrates usually account for the prevailing component of fruiting bodies (Table 1).

Glucose, mannitol and α, α-trehalose are the main representatives of monosaccharides, their derivatives and oligosaccharide groups, respectively. Usual contents of glucose and trehalose are low, in the order of g 100 g^{-1} of dry matter. The content of mannitol, which participates in volume growth and firmness of fruiting bodies, differs widely. The values 1.0%, 6.5% and 13.7% of dry matter were found in *T. portentosum, Agaricus arvensis* and *L. deliciosus*, respectively (Barros et al., 2007a) and 0.2%, 0.8%, 11.7% and 13.9% of dry matter in *L. perlatum, L. nuda, R. botrytis* and *C. cibarius*, respectively (Barros et al., 2008). The contents of trehalose and mannitol decreased considerably during boiling of fresh mushrooms, while drying and freezing resulted in only limited losses (Barros et al., 2007b).

The reserve polysaccharide of mushrooms is glycogen, not starch as in plants. The usual content is 5–10% of dry matter. Glycogen is widely consumed, mainly in meat, and its low intake from mushrooms thus seems to be nutritionally negligible.

Chitin is a water-insoluble structural polysaccharide, accounting for up to 80–90% of dry matter in mushroom cell walls. Data on its content in wild growing mushrooms have been scarce. Contents of 6.8–10.2% of dry matter, reported for eight samples of *Boletus* spp. mixtures (Manzi, Marconi, Aguzzi, & Pizzoferrato, 2004), are well comparable with values observed in several cultivated species (Vetter, 2007). Chitin is indigestible for humans and, as mentioned above, it apparently decreases the availability of other mushroom components.

Information on dietary fibre content in wild growing mushrooms has also been very limited. Besides the data for two species given in Table 1, Manzi et al. (2004) reported, for the above-mentioned *Boletus* spp. mixtures, contents of 4.2–9.2% and 22.4–31.2% of dry matter for soluble and insoluble fibre, respectively. These values are well comparable with data for cultivated oyster mushroom and *A. bisporus* (Manzi et al., 2001). It is apparent from the data on fibre composition, that mushrooms contain other structural polysaccharides in addition to chitin. Cheung (1997) determined mainly hemicelluloses and pectic substances. The high proportion of insoluble fibre seems to be nutritionally desirable.

Evidently, information on chitin and fibre changes during different preservation and cooking treatments has been lacking.

Great attention has recently been paid to mushroom β-glucans, due to their health-positive effects. β-Glucan research and applications have been successful, mainly in the east-Asian countries and deal mostly with cultivated mushroom species. Overall information is available in the review of Wasser (2002).

7. Mineral composition

7.1. Ash

Ash content of mushroom is usually 5–12% of dry matter (Table 1) and its variability (Table 5) seems to be lower than that

Table 5
Variability of ash content in several mushroom species (Vetter, 1993a)

Species	Number of samples (n)	Mean (% of dry matter)	Standard deviation (% of dry matter)	Relative standard deviation (%)
Armillariella mellea	6	15.15	1.44	9.5
Boletus edulis	10	7.45	0.68	9.1
Cantharellus cibarius	8	19.96	4.60	23.0
Clitocybe nebularis	6	10.89	1.09	10.0
Craterellus cornucopioides	6	16.90	8.10	47.9
Leccinum scabrum	9	11.53	1.22	10.6
Marasmius oreades	3	11.71	0.51	4.4
Xerocomus subtomentosus	7	10.54	0.15	1.4

of crude protein content (Table 2). Numerous data on the contents of major elements, and especially trace elements, have been available.

7.2. Major elements

Usual contents of major mineral elements are given in Table 6. The vast data for more than 1000 samples of over 400 mushroom species, not exceeded until now, were published in the 1970s and 1980s by the laboratory of Ruth Seeger in Würzburg University, Bavaria. Namely, for sodium (Seeger, Trumpfheller, & Schweinshaut, 1983), potassium (Seeger, 1978), calcium (Seeger & Hüttner, 1981) and magnesium (Seeger & Beckert, 1979). As follows from the cited papers, potassium is not distributed evenly within fruiting body. Its concentration decreases in the order cap > stipe > spore-forming part > spores. Potassium levels are between 20- and 40-fold higher in fruiting bodies than in underlying substrates. Bioaccumulation was not reported for sodium and calcium. Magnesium levels in fruiting bodies were even lower than those in substrates.

Table 6
Usual content (mg kg^{-1} of dry matter) of major mineral elements in wild growing mushrooms

Element	Usual content
Sodium	100–400
Potassium	20,000–40,000
Calcium	100–500
Magnesium	800–1800
Phosphorus	5000–10,000
Sulphur	1000–3000

Total phosphorus content of 825 samples was determined by Quinche (1997). Mean levels were 6100 and 13,700 mg kg^{-1} dry matter in 51 ectomycorrhizal and 42 saprobic species, respectively. These values significantly differed. Usual contents were 5000–7000 mg kg^{-1} dry matter in the popular mushrooms of the *Boletaceae* family, and 13,000–23,000 mg kg^{-1} dry matter in the genus *Lepista*. Mushrooms are able to accumulate phosphorus in their bodies. Its concentrations were between 10- and 50-fold higher than those in the underlying substrates.

Mean total sulphur content 2200 ± 1100 mg kg^{-1} dry matter was found in eight widely consumed species with ranges between 900 and 4400 mg kg^{-1} dry matter for *A. rubescens* and *Xerocomus chrysenteron*, respectively (Rudawska & Leski, 2005).

Data on chlorine content in mushrooms have been lacking.

Overall, ash content of mushrooms is somewhat higher or comparable with the most vegetables. Mushrooms contain elevated levels of phosphorus and potassium and relatively high contents of magnesium. However, the availability of these elements remains unknown.

7.3. Trace elements

Several hundreds of original papers were published on trace element contents in wild growing mushrooms since the 1970s. Overall information is available in a review (Kalač & Svoboda 2000) and in papers with numerous references (Borovička & Řanda, 2007; Svoboda & Chrastný, 2008). The basic data on content of 19 essential and harmful elements are given in Table 7. The usual contents refer to values observed for non-accumulating species from unpolluted sites. Considerably elevated contents, even one or two orders of magnitude higher, occur in some accumulating species or in mushrooms growing in highly polluted areas, such as in the

Table 7
Usual content of trace elements (mg kg^{-1} of dry matter) in fruiting bodies of mushrooms from unpolluted areas and accumulating genera and species (adapted from Kalač and Svoboda (2000))

Element	Content	Accumulators
Antimony	0.05–0.15	*Suillus* spp., *Laccaria amethystina*, *Amanita rubescens*
Arsenic	<1	*Laccaria amethystina*, *L. laccata*, *Agaricus* spp., *Lepista nuda*, *Lycoperdon perlatum*
Beryllium	<0.5–0.5	
Cadmium	0.5–5	*Agaricus* spp. (group *flavescentes)*
Caesium	3–12	
Chromium	0.1–2	*Agaricus* spp., *Macrolepiota procera*, *Lactarius deliciosus*
Cobalt	<0.1–3	*Agaricus arvensis*
Copper	10–70	*Agaricus* spp., *Macrolepiota procera*, *M. rhacodes*
Gold	<0.02	*Boletus edulis*, *Morchella esculenta*
Iron	30–150	*Suillus variegatus*, *Suillus luteus*, *Hygrophoropsis aurantiaca*
Lead	1–5	*Macrolepiota rhacodes*, *M. procera*, *Lycoperdon perlatum Agaricus* spp., *Lepista nuda*
Manganese	5–60	*Agaricus* spp.
Mercury	<0.5–5	*Agaricus* spp., *Macrolepiota procera*, *M. rhacodes*, *Lepista nuda*, *Calocybe gambosa*
Nickel	0.4–2	*Laccaria amethystina*, *Leccinum* spp.
Selenium	1–5	*Albatrellus pes-caprae*, *Boletus edulis*, *B. pinicola*, *B. aestivalis*, *Xerocomus badius*
Silver	0.2–3	*Amanita strobiliformis*, *Agaricus* spp., *Boletus edulis*, *Lycoperdon perlatum*
Strontium	5–10	
Thallium	<0.25	
Zinc	30–150	*Suillus variegatus*, *Suillus luteus*, *Lycoperdon perlatum*

vicinity of metal smelters or within cities. Unfortunately, only very limited information is available on the elements' speciation and on their bioavailability in humans.

Several papers dealing with methylmercury and arsenic compound occurrence in mushrooms were reviewed earlier (Kalač & Svoboda, 2000). Among recent papers, the speciation of chromium (Figueiredo, Soares, Baptista, Castro, & Bastos, 2007) and arsenic, cadmium, lead, mercury, silver, and tin (Wuilloud, Kannamkumarath, & Caruso, 2004) in mushrooms was described.

Relatively high selenium content in an attractive group of *Boletus* mushrooms seems to be promising as a source of this nutritionally deficient element. However, Mutanen (1986) reported its very low availability.

It should be mentioned that contents of risk elements in cultivated mushrooms are commonly low.

7.4. Radioactivity of mushrooms

The radioactivity of wild growing mushrooms was extensively studied, mainly in the decade following the Chernobyl disaster of 1986. The literature until 2000 was reviewed (Kalač, 2001). Some widely consumed species (Table 8) accumulated high levels of both ^{134}Cs (half-life 2.06 years) and of the more important ^{137}Cs (half-life 30.17 years). Nevertheless, even high consumption of highly accumulating mushroom species was not a health risk. The low radioactivity of cultivated mushrooms is caused mainly by the natural potassium isotope, ^{40}K.

Table 8
Mushroom species with different rates of radiocaesium accumulation (from Kalač (2001))

High	Medium	Low
Xerocomus badius	*Leccinum scabrum*	*Boletus edulis*
Xerocomus chrysenteron	*Leccinum aurantiacum*	*Cantharellus cibarius*
Suillus variegatus	*Agaricus silvaticus*	*Macrolepiota procera*
Cantharellus tubaeformis		*Armillariella mellea*
Cantharellus lutescens		*Amanita rubescens*
Rozites caperata		*Laccaria laccata*
Hydnum repandum		*Lycoperdon perlatum*
Laccaria amethystina		*Calocybe gambosa*
Russula cyanoxantha		*Pleurotus ostreatus*

Table 9
Content of mycosterols (mg 100 g^{-1} of dry matter) in some mushroom species

Species	Ergosterol	Fungisterol	Reference
Boletus edulis			Mattila, Lampi, Ronkainen, Toivo, and Piironen (2002b)
– Complete fruiting body	489	–	
– Cap	589	–	
– Stipe	444	–	
– Sporophore	549	–	
– Dried fruiting body	241	–	Teichmann, Dutta, Staffas, and Jägerstad (2007)
Cantharellus cibarius			Mattila et al. (2002b)
– Complete fruiting body	304	–	
– Cap	140	–	
– Stipe	100	–	
– Sporophore	278	–	
– Dried fruiting body	348	–	Teichmann et al. (2007)
Cantharellus tubaeformis	173	–	Teichmann et al. (2007)
Clitocybe nebularis	638	104	Senatore (1992)
Hydnum repandum	628	85	Senatore et al. (1988)
Russula cyanoxantha	632	128	Senatore et al. (1988)
Russula xerampelina	655	112	Senatore et al. (1988)
Suillus granulatus	702	80	Senatore et al. (1988)
Suillus luteus	662	83	Senatore et al. (1988)

8. Vitamins and their precursors

Information on vitamin contents of wild growing mushrooms has been lacking. Thus, data for cultivated species (Mattila et al., 2001) could be used. Mushrooms seem to be relatively rich in riboflavin, niacin and ergocalciferol. Available data on ergosterol, the provitamin of ergocalciferol, are given in Table 9. The relatively high ergosterol content could be of significance for individuals with a limited intake of ergocalciferol from foods of animal origin, e.g. for vegetarians and vegans. The occurrence of carotenoids, including those which can act as precursors of retinol, is limited in mushrooms compared to plants.

Unfortunately, information on the bioavailability of vitamins from mushrooms has been lacking.

9. Flavour components

The characteristic flavour of mushrooms, mainly dried, is highly appreciated by many consumers. Hundreds of odorous compounds have been identified. According to their chemical structure, they can be classified as derivatives of octane and octenes, lower terpenes, derivatives of benzaldehyde, sulphur compounds and others. Earlier reviews on the topic are available (Gross & Asther, 1989; Maga, 1981).

The derivatives of octane, 1-octene and 2-octene, alcohols and their esters with volatile fatty acids, and ketones, form the very characteristic group of mushroom aroma. The main role is ascribed to "mushroom alcohol", 1-octen-3-ol (e.g. Fons, Rapior, Eyssartier, & Bessière, 2003). The (*R*)-(−)-enantiomer was found to account, usually, for more than 90% (Zawirska-Wojtasiak, 2004). In the same work, there were reported contents of 1-octen-3-ol of 0.6–6.8 mg 100 g^{-1} of fresh matter in cultivated species, *Xerocomus badius* and *M. procera*, and 15.6 mg 100 g^{-1} in *Boletus edulis*.

The origin of 1-octen-3-ol and related flavour constituents in mushrooms was explained by Wurzenberger and Grosch (1982). Free linoleic acid is oxidised under catalysis of lipoxygenase and hydroperoxide lyase. Such a process is characteristic for mushrooms and it is very intensive during drying. The current state of knowledge of eight-carbon volatiles formation and properties was thoroughly reviewed by Combet, Henderson, Eastwood, and Burton (2006).

10. Health-promoting constituents

Historical traditions and the extensive research in the east-Asian countries prove the preventive and therapeutic properties of many mushroom species. Knowledge of European species has so far been very limited. An overview of the pharmacological potential of mushrooms was recently published by Lindequist, Niedermayer, and Jülich (2005). Recent interest is focused mainly on β-glucans, mentioned in Section 6 and on the constituents with antioxidative properties.

Several original papers dealing with antioxidant activity of European wild growing mushrooms have been published. The comparison of the results is somewhat complicated by different analytical assays used for the screening of the antioxidant properties. Different phenolic compounds seem to be the most effective group of antioxidants, while the role of tocopherols seems to be limited and that of β-carotene and lycopene vestigial (Barros et al., 2008). Ergothioneine is another compound with antioxidant effect, with a very high content of 528 mg kg^{-1} fresh weight in *B. edulis*, by far the highest level among many food items (Ey, Schömig, & Taubert, 2007).

Biological relevance of determined antioxidant capacity depends considerably on the used assay. Dubost, Ou, and Beelman

(2007) measured antioxidant capacity by four methods in five species of cultivated mushrooms. Values of oxygen radical absorbance capacity (ORAC) assay ranged between 39 and 138 μmol of trolox equivalents per g dry matter. Such values are comparable with most fresh fruits and vegetables. *A. bisporus* had the highest antioxidant capacity, mainly portabella, the fully developed brown variety. A good correlation was found between ORAC values and polyphenol contents.

Portuguese authors have reported most of the data recently available for wild growing mushrooms. Ribeiro et al. (2006) found the highest antioxidant capacity of *Tricholomopsis rutilans* among nine dried species. *B. edulis* (Ramírez-Anguiano, Santoyo, Reglero, & Soler-Rivas, 2007; Ribeiro et al., 2008) and *L. giganteus* (Barros et al., 2007c) were reported among the mushrooms with high antioxidant activity, while the widely consumed *C. cibarius* was counted among the species with the lowest capacity. A higher capacity of caps, as compared to stipes, was observed (Ferreira, Baptista, Vilas-Boas, & Barros, 2007; Ribeiro et al., 2008). The activity of oxidative enzymes, polyphenol oxidases and peroxidase, can destroy part of the antioxidant capacity (Ramírez-Anguiano et al., 2007). These enzymes are activated by mechanical damage of mushroom tissues. The antioxidant activity decreased in boiled mushrooms, while it increased during drying at 40 °C and remained virtually stable in frozen mushrooms (Barros et al., 2007b).

11. Detrimental and antinutritional components of edible mushrooms

The dangerous constituents of toxic mushrooms have been extensively studied. However, some natural detrimental compounds occur also in edible species. Interest has been focused on hydrazines with pro-carcinogenic activity, agaritine in *Agaricus* spp. (for an overview see Andersson & Gry, 2004) and gyromitrin in *Gyromitra esculenta* (Karlson-Stiber & Persson, 2003). Wild mushroom allergenicity has been reported (Helbling, Brander, Horner, & Lehrer, 2002). Consumption of several *Coprinus* spp. induces ethanol intolerance due to the presence of the free amino acid, coprine, which is converted to toxic cyclopropanone hydrate, blocking oxidation of acetaldehyde to acetic acid (Matthies & Laatsch, 1992). *T. equestre* (or *T. flavovirens*) was recently reported as a cause of several outbreaks of rhabdomyolysis and also as the species with cardio- and hepatotoxic effects (Nieminen, Kärjä, & Mustonen, 2008). Trypsin inhibitor activity was observed in numerous wild growing mushroom species with considerable variation within species (Vetter, 2000).

A short shelf life is typical for mushrooms. Biogenic amines are expected among the products of protein degradation. Considerably increased contents of putrescine and cadaverine were observed in intact fruiting bodies, wet slices and stewed slices of *X. badius*, *X. chrysenteron* and *Suillus variegatus* stored at 6 °C for two days. However, the most biologically active amines, histamine and tyramine, were not detected (Kalač & Křížek, 1997).

12. Concluding remarks

Tens of wild growing mushroom species have been widely consumed as a delicacy by part of the European population. The credible evaluation of their nutritional value has so far been limited, due to the fragmentary knowledge of their composition and mainly due to the poor information on the bioavailability of their constituents.

Dry matter content is very low, commonly about 100 g kg^{-1}. A low proportion of lipids and glycogen results in a low energy value. A relatively high proportion of insoluble fibre, comprised of chitin and other structural polysaccharides, seems to be nutritionally profitable. The proportion of essential amino acids is contributive, while that of $n-3$ fatty acids is nutritionally negligible. The contents of potassium and phosphorus are higher than in most vegetables. A relatively high ergosterol content could be of significance for individuals with a low intake of ergocalciferol. Some mushroom species have relatively high antioxidant capacity. Specific β-glucans have been studied for pharmacological use.

Several species, e.g. the genus *Agaricus*, accumulate high levels of several trace elements. Mainly cadmium and mercury contents may pose a risk. Consumption of those species, as well of mushrooms gathered from polluted areas, should thus be limited. Some species, including those highly consumed, accumulate radioactive isotopes of caesium. However, the health risk has been assessed as negligible.

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References

Andersson, H. C., & Gry, J. (2004). *Phenylhydrazines in the cultivated mushroom (Agaricus bisporus)* – Occurrence, biological properties, risk assessment and recommendations. Copenhagen: Nordic Council of Ministers. 123pp.

Barros, L., Baptista, P., Correia, D. M., Morais, J. S., & Ferreira, I. C. F. R. (2007b). Effects of conservation treatment and cooking on the chemical composition and antioxidant activity of Portuguese wild edible mushrooms. *Journal of Agricultural and Food Chemistry, 55*, 4781–4788.

Barros, L., Baptista, P., Correira, D. M., Casa, S., Oliveira, B., & Ferreira, I. C. F. R. (2007a). Fatty acid and sugar compositions, and nutritional value of five wild edible mushrooms from Northeast Portugal. *Food Chemistry, 105*, 140–145.

Barros, L., Venturini, B. A., Baptista, P., Estevinho, L. M., & Ferreira, I. C. F. R. (2008). Chemical composition and biological properties of Portuguese wild mushrooms: A comprehensive study. *Journal of Agricultural and Food Chemistry*. doi:10.1021/jf8003114.

Barros, L., Ferreira, M. J., Queiros, B., Ferreira, C. F. R., & Baptista, P. (2007c). Total phenols, beta-carotene and lycopene in Portuguese wild edible mushrooms and their antioxidant activities. *Food Chemistry, 103*, 413–419.

Bauer-Petrovska, B. (2001). Protein fractions in edible Macedonian mushrooms. *European Food Research and Technology, 212*, 469–472.

Belitz, H.-D., & Grosch, W. (1999). *Food chemistry*. Berlin: Springer.

Borovička, J., & Řanda, Z. (2007). Distribution of iron, cobalt, zinc and selenium in macrofungi. *Mycological Progress, 6*, 249–259.

Cheung, P. C-K. (1997). Dietary fibre content and composition of some edible fungi determined by two methods of analysis. *Journal of the Science of Food and Agriculture, 72*, 255–260.

Colak, A., Kolcuoglu, Y., Sesli, E., & Dalman, O. (2007). Biochemical composition of some Turkish fungi. *Asian Journal of Chemistry, 19*, 2193–2199.

Combet, E., Henderson, J., Eastwood, D. C., & Burton, K. S. (2006). Eight-carbon volatiles in mushrooms and fungi: Properties, analysis, and biosynthesis. *Mycoscience, 47*, 317–326.

Díez, A. A., & Alvarez, A. (2001). Compositional and nutritional studies on two wild edible mushrooms from northwest Spain. *Food Chemistry, 75*, 417–422.

Dikeman, C. L., Bauer, L. L., Flickinger, E. A., & Fahey, G. C. Jr., (2005). Effects of stage of maturity and cooking on the chemical composition of select mushroom varieties. *Journal of Agricultural and Food Chemistry, 53*, 1130–1138.

Dubost, N. J., Ou, B., & Beelman, R. B. (2007). Quantification of polyphenols and ergothioneine in cultivated mushrooms and correlation to total antioxidant capacity. *Food Chemistry, 105*, 727–735.

Ey, J., Schömig, E., & Taubert, D. (2007). Dietary sources and antioxidant effects of ergothioneine. *Journal of Agricultural and Food Chemistry, 55*, 6466–6474.

Ferreira, I. C. F. R., Baptista, P., Vilas-Boas, M., & Barros, L. (2007). Free-radical scavenging capacity and reducing power of wild edible mushrooms from northeast Portugal: Individual cap and stipe activity. *Food Chemistry, 100*, 1511–1516.

Figueiredo, E., Soares, M. E., Baptista, P., Castro, M., & Bastos, M. L. (2007). Validation of an electrothermal atomization atomic absorption spectrometry method for quantification of total chromium and chromium(VI) in wild mushrooms and underlying soils. *Journal of Agricultural and Food Chemistry, 55*, 7192–7198.

Florczak, J., Karmańska, A., & Wędzisz, A. (2004). A comparison of chemical composition of selected wild-growing mushrooms. *Bromatologia i Chemiczna Toksykologia, 37*, 365–370 [in Polish].

Fons, F., Rapior, S., Eyssartier, G., & Bessière, J.-M. (2003). Volatile compounds of genera *Cantharellus*, *Craterellus* and *Hydnum*. *Cryptogamie, Mycologie, 24*, 367–376 [in French].

Grosch, M., & Wurzenberger, W. (1982). The enzymic oxidative breakdown of linoleic acid in mushrooms (*Psalliota bispora*). *Zeitschrift für Lebensmittel Untersuchung und Forschung, 175*, 186–190.

Gross, B., & Asther, M. (1989). Flavour of *Basidiomycetes*: Characteristics, analysis and production. *Sciences des Aliments, 9*, 427–454 [in French].

Helbling, A., Brander, K. A., Horner, W. E., & Lehrer, S. B. (2002). Allergy to Basidiomycetes. *Chemical Immunology, 81*, 28–47.

Kalač, P. (2001). A review of edible mushroom radioactivity. *Food Chemistry, 75*, 29–35.

Kalač, P., & Křížek, M. (1997). Formation of biogenic amines in four edible mushroom species stored under different conditions. *Food Chemistry, 58*, 233–236.

Kalač, P., & Svoboda, L. (2000). A review of trace element concentrations in edible mushrooms. *Food Chemistry, 69*, 273–281.

Karliński, L., Ravnskov, S., Kieliszewska-Rokicka, B., & Larsen, J. (2007). Fatty acid composition of various ectomycorrhizal fungi and ectomycorrhizas of Norway spruce. *Soil Biology & Biochemistry, 39*, 854–866.

Karlson-Stiber, C., & Persson, H. (2003). Cytotoxic fungi – An overview. *Toxicon, 42*, 339–349.

Kavishree, S., Hemavathy, J., Lokesh, B. R., Shashirekha, M. N., & Rajarathnam, S. (2008). Fat and fatty acids in Indian edible mushrooms. *Food Chemistry, 106*, 597–602.

Lindequist, U., Niedermayer, T. H. J., & Jülich, W.-D. (2005). The pharmacological potential of mushrooms. *Evidence-based Complementary and Alternative Medicine, 2*, 285–299.

Maga, J. A. (1981). Mushroom flavor. *Journal of Agricultural and Food Chemistry, 29*, 1–4.

Manzi, P., Aguzzi, A., & Pizzoferrato, L. (2001). Nutritional value of mushrooms widely consumed in Italy. *Food Chemistry, 73*, 321–325.

Manzi, P., Gambelli, L., Marconi, S., Vivanti, V., & Pizzoferrato, L. (1999). Nutrients in edible mushrooms: An inter-species comparative study. *Food Chemistry, 65*, 477–482.

Manzi, P., Marconi, P., Aguzzi, A., & Pizzoferrato, L. (2004). Commercial mushrooms: Nutritional quality and effect of cooking. *Food Chemistry, 84*, 201–206.

Matthies, L., & Laatsch, H. (1992). Unusual mushroom intoxication: Coprine, emetic compound of alcohol intolerance. *Pharmazie in unserer Zeit, 21*, 14–20 [in German].

Mattila, P., Könkö, K., Eurola, M., Pihlava, J.-M., Astola, J., Vahteristo, L., et al. (2001). Contents of vitamins, mineral elements, and some phenolic compounds in cultivated mushrooms. *Journal of Agricultural and Food Chemistry, 49*, 2343–2348.

Mattila, P., Lampi, A.-M., Ronkainen, R., Toivo, J., & Piironen, V. (2002b). Sterol and vitamin D_2 contents in some wild and cultivated mushrooms. *Food Chemistry, 76*, 293–298.

Mattila, P., Salo-Väänänen, P., Könkö, K., Aro, H., & Jalava, T. (2002a). Basic composition and amino acid contents of mushrooms cultivated in Finland. *Journal of Agricultural and Food Chemistry, 50*, 6419–6422.

Mutanen, M. (1986). Bioavailability of selenium in mushrooms, *Boletus edulis*, to young women. *International Journal for Vitamin and Nutrition Research, 56*, 297–301.

Nedelcheva, D., Antonova, D., Tsvetkova, S., Marekov, I., Momchilova, S., Nikolova-Damyanova, B., et al. (2007). TLC and GC–MS probes into the fatty acid composition of some *Lycoperdaceae* mushrooms. *Journal of Liquid Chromatography & Related Technologies, 30*, 2717–2727.

Nieminen, P., Kärjä, V., & Mustonen, A.-M. (2008). Indications of hepatic and cardiac toxicity caused by subchronic *Tricholoma flavovirens* consumption. *Food and Chemical Toxicology, 46*, 781–786.

Ouzouni, P. K., & Riganakos, K. A. (2007). Nutritional value and metal content of Greek wild edible fungi. *Acta Alimentaria, 36*, 99–110.

Pedneault, K., Angers, P., Avis, T. J., Gosselin, A., & Tweddel, R. J. (2007). Fatty acid profiles of polar and non-polar lipids of *Pleurotus ostreatus* and *P. cornucopiae* var. *citrino-pileatus* grown at different temperatures. *Mycological Research, 111*, 1128–1234.

Pedneault, K., Angers, P., Gosselin, A., & Tweddell, R. J. (2006). Fatty acid composition of lipids from mushrooms belonging to the family *Boletaceae*. *Mycological Research, 110*, 1179–1183.

Quinche, J.-P. (1997). Phosphorus and heavy metals in some species of fungi. *Revue Suisse Agriculture, 29*, 151–156 [in French].

Ramírez-Anguiano, A. C., Santoyo, S., Reglero, G., & Soler-Rivas, C. (2007). Radical scavenging activities, endogenous oxidative enzymes and total phenols in edible mushrooms commonly consumed in Europe. *Journal of the Science of Food and Agriculture, 87*, 2272–2278.

Řezanka, T., Rozentsvet, O. A., & Dembitsky, V. M. (1999). Characterization of the hydroxy fatty acid content in *Basidiomycotina*. *Folia Microbiologica, 44*, 635–641.

Ribeiro, B., Lopes, R., Seabra, R. M., Gonçalves, R. F., Baptista, P., Quelhas, I., et al. (2008). Comparative study of phytochemicals and antioxidant potential of wild edible mushroom cap and stipes. *Food Chemistry, 110*, 47–56.

Ribeiro, B., Rangel, J., Valentão, P., Baptista, P., Seabra, R. M., & Andrade, P. B. (2006). Contents of carboxylic acids and two phenolics and antioxidant activity of dried Portuguese wild edible mushrooms. *Journal of Agricultural and Food Chemistry, 54*, 8530–8537.

Rudawska, M., & Leski, T. (2005). Macro- and microelement contents in fruiting bodies of wild mushrooms from Notecka forest in west-central Poland. *Food Chemistry, 92*, 499–506.

Sahbaz, F., Palazoglu, T. K., & Uzman, D. (1999). Moisture sorption and the applicability of the Brunauer–Emmet–Teller (BET) equation for blanched and unblanched mushrooms. *Nahrung, 43*, 325–329.

Seeger, R. (1978). Content of potassium in higher fungi. *Zeitschrift für Lebensmittel Untersuchung und Forschung, 167*, 23–31 [in German].

Seeger, R., & Beckert, M. (1979). Magnesium in higher fungi. *Zeitschrift für Lebensmittel Untersuchung und Forschung, 168*, 264–281 [in German].

Seeger, R., & Hüttner, W. (1981). Calcium in mushrooms. *Deutsche Lebensmittel-Rundschau, 77*, 385–392 [in German].

Seeger, R., Trumpfheller, S., & Schweinshaut, P. (1983). Sodium content in mushrooms. *Deutsche Lebensmittel-Rundschau, 79*, 80–87 [in German].

Senatore, F. (1992). Chemical constituents of some mushrooms. *Journal of the Science of Food and Agriculture, 58*, 499–503.

Senatore, F., Dini, A., & Marino, A. (1988). Chemical constituents of some *Basidiomycetes*. *Journal of the Science of Food and Agriculture, 45*, 337–345.

Shivrare, U. S., Arora, S., Ahmed, J., & Raghavan, G. S. V. (2004). Moisture adsorption isotherms for mushroom. *Lebensmittel-Wissenschaft und Technologie, 37*, 133–137.

Šišák, L. (2007). The importance of mushroom picking as compared to forest berries in the Czech Republic. *Mykologický Sborník, 84*(3), 78–83 [in Czech].

Surinrut, P., Julshamn, K., & Njaa, L. ER. (1987). Protein, amino acids and some major and trace elements in Thai and Norwegian mushrooms. *Plant Foods for Human Nutrition, 37*, 117–125.

Svoboda, L., & Chrastný, V. (2008). Levels of eight trace elements in edible mushrooms from a rural area. *Food Additives and Contaminants, 25*, 51–58.

Teichmann, A., Dutta, P. C., Staffas, A., & Jägerstad, M. (2007). Sterol and vitamin D2 concentrations in cultivated and wild grown mushrooms: Effects of UV irradiation. *LWT – Food Science and Technology, 40*, 815–822.

Vaskovsky, V. E., Khotimchenko, S. V., & Boolukh, E. M. (1998). Distribution of diacylglycerotrimethylhomoserine and phosphatidylcholine in mushrooms. *Phytochemistry, 47*, 755–760.

Vetter, J. (1993a). Chemical composition of eight edible mushrooms. *Zeitschrift für Lebensmittel Untersuchung und Forschung, 196*, 224–227 [in German].

Vetter, J. (1993b). Amino acid composition of edible mushrooms of genera Russula and Agaricus. *Zeitschrift für Lebensmittel Untersuchung und Forschung, 197*, 381–384 [in German].

Vetter, J. (2000). Trypsin inhibitor activity of basidiomycetous mushrooms. *European Food Research and Technology, 211*, 346–348.

Vetter, J. (2007). Chitin content of cultivated mushrooms *Agaricus bisporus*, *Pleurotus ostreatus* and *Lentinula edodes*. *Food Chemistry, 102*, 6–9.

Vetter, J., & Rimóczi, I. (1993). Crude, digestible and indigestible protein in fruiting bodies of *Pleurotus ostreatus*. *Zeitschrift für Lebensmittel Untersuchung und Forschung, 197*, 427–428 [in German].

Wasser, S. P. (2002). Medicinal mushrooms as a source of antitumor and immunomodulating polysaccharides. *Applied Microbiology and Biotechnology, 60*, 258–274.

Wuilloud, R. G., Kannamkumarath, S. S., & Caruso, J. A. (2004). Speciation of essential and toxic elements in edible mushrooms: Size-exclusion chromatography separation with on-line UV-inductively coupled plasma mass spectrometry detection. *Applied Organometallic Chemistry, 18*, 156–165.

Zawirska-Wojtasiak, R. (2004). Optical purity of (*R*)-(−)-1-octen-3-ol in the aroma of various species of edible mushrooms. *Food Chemistry, 86*, 113–118.