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ORIGINAL ARTICLE

Composition and antioxidant properties of wild mushrooms *Boletus edulis* and *Xerocomus badius* prepared for consumption

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Abstract Wild edible mushrooms *Boletus edulis* and *Xerocomus badius* were prepared for consumption by braising with 10 % canola oil (half of the batch was blanched prior to braising). Fresh *X.badius* had comparable to *B.edulis* amounts of proximate components and higher levels of most B-group vitamins and antioxidants. Analyzed mushrooms prepared for consumption fulfilled 7–14 % RDA of vitamin B_1 for healthy adults and 15–35, 18–37 and 1 % RDA of B_2, B_3 and B_3 respectively. Prepared for consumption mushrooms were rich in antioxidants containing in 100 g dry weight 164,601 mg total polyphenols, 19–87 mg total flavonoids, 22.1–27.4 mg L-ascorbic acid, 0.531–1.031 mg β-carotene, 0.325–0.456 mg lycopene and 38.64–44.49 mg total tocopherols and presented high antioxidant activity against ABTS (4.9–36.5 mmol TE), against DPPH (7.8–21.3 mmol TE) and in FRAP assay (15.0–28.1 mmol Fe^{2+}). Mushrooms prepared for consumption with blanching prior to culinary treatment showed lower antioxidant properties and vitamin content in comparison to mushrooms braised raw.

Keywords Edible mushrooms · Braising · Vitamins · Antioxidants

Introduction

Wild mushrooms are a delicacy traditionally used in national cuisine of many countries all over the world. *Boletus edulis* is one of the most appreciated mushroom species due to its exceptional flavour, high nutritional value, especially high content of proteins in comparison to other mushrooms, and high antioxidant properties (Barros et al. 2008; Kuka and Cakste 2011; Palacios et al. 2011; Tsai et al. 2007; Sarikurkcu et al. 2008). *Xerocomus badius* is a species of *Boletaceae* family, commonly used and valued in Europe as its flavour is perceived to be as interesting as flavour of *Boletus edulis*. *X. badius* is less sensitive to atmospheric conditions than *B.edulis* therefore harvest for individual use and for industrial processing of that species in Central and Northern Europe exceeds harvest of *Bolets edulis* every year. Information pertaining composition and properties of *Xerocomus badius* is lacking.

Fresh wild mushrooms are not suitable to be consumed raw therefore prior to consumption they are cooked, fried, braised, sterilized or marinated. Processing of food products, including thermal treatment may significantly influence the nutritional value. Information on the composition and nutraceutical value of mushrooms prepared for consumption is lacking. In the case of vegetables processing may lead to adverse changes such as loss of vitamins and antioxidant compounds or leaching of soluble substances occurring while boiling in water (Faller and Fiahlo 2009; Kalogeropoulos et al. 2007; Perla et al. 2012). Those changes are responsible for lower nutritional and nutraceutical value of processed vegetables in comparison to one measured for fresh vegetables.

The aim of the paper was to determine content of particular nutraceuticals such as vitamins and antioxidants and to measure antioxidant activity of two wild mushroom species prepared for consumption: *Boletus edulis* and *Xerocomus badius*. Mushrooms were prepared for consumption by braising with 10 % canola oil (half of the batch was blanched prior to braising) and analyzed directly after processing and after following storage.

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Material and methods

Material

Study material consisted of fresh and prepared for consumption by braising mushrooms: *Boletus edulis* Bull. and *Xerocomus badius* (Fr.) Kühner. The mushrooms were purchased from an approved supplier of forest mushrooms and were processed approximately 10 h after harvest. The mushrooms were healthy, fresh and young with caps 5 to 10 cm in diameter.

After sorting and disposing off infested specimens, mushrooms were rinsed in cold water and cut into 1 cm cubes. Half of the batches were blanched in water, at 98 °C for 90 s, ratio of mushrooms to blaching solution 1:5. After preliminary treatment, mushrooms were subdued to culinary treatment thus producing two types of culinary products:

- type A – raw mushrooms prepared for consumption,
- type B – blanched mushrooms prepared for consumption.

Culinary treatment consisted of braising under cover with a small amount (10 %) of canola oil and 0.5 % of table salt for 10 min. Canola oil used for braising was provided by ZT "Kruszwica" in Kruszwica (Poland) and contained 100 % fat with 10.5 % SFA, 29.5 % MUFA and 59.5 % PUFA (according to manufacturer declaration).

The following amounts of product were obtained from 1000 g raw material (fresh mushrooms and oil) after culinary processing: for *Boletus edulis* 905 g (product A) and 750 g (product B) and for *Xerocomus badius* 930 g (product A) and 800 g (product B).

After culinary treatment, the products were placed in food containers and stored for 48 h at 20 °C, and for 48 and 96 h at 4 °C.

Analysis was performed on: fresh mushrooms; unstored mushrooms prepared for consumption (A and B); and mushrooms prepared for consumption (A and B) stored for 48 h at 20 °C, and for 48 and 96 h at 4 °C. The entire product of culinary treatment (mushroom pieces together with the liquor produced during braising) were analysed.

All types of culinary products were produced in two batches and analysis were performed on every batch in four independent replications (n=8).

Methods

Proximate composition

The proximate composition of fresh and prepared for consumption mushrooms was determined according to the AOAC (2005) method. The dry matter was estimated by drying at 105 °C (930.04), the nitrogen was estimated by the Kjeldahl method (978.04) and converted to crude protein using 4.38 factor (Barros et al. 2008), the crude fat was determined by extracting a sample with diethyl ether in a Soxhlet apparatus (920.39) and the ash content was determined by incineration at 485 °C (920.05). Total carbohydrates were calculated by difference using the formula: Total carbohydrates = (g dry weight) – (g crude protein) – (g fat) – (g mineral salts). The energy value was calculated using the formula: Energy (kJ)=17× (g raw protein)+15.4 × (g total carbohydrates)+38 × (g fat) (Manzi et al. 2001).

B-group vitamins

All B group vitamins were analyzed in freeze-dried material.

Vitamin B_1 and B_2 content was established according to HPLC methods EN 14122:2003 and EN 14152:2003 respectively. Thiamine and riboflavin were detected simultaneously using a Merck liquid chromatograph with fluorescence detector. Analysis was carried out on an Onyx Monolithic C18 column (100×4.6 mm) with precolumn, and was conducted at a wavelength excitation and emission: 360/503. Water and acetonitrile (t=0 w/ac 88/12; t=12 w/ac 0/100) were used as mobile phase in gradient elution with flow rate 1 $cm^3 \cdot min^{-1}$.

Vitamin B_3 content was established according to modified method described by Juraja et al. (2003) using a Merck liquid chromatograph with UV/VIS detector. Samples were subdued to alkaline hydrolysis at 121 °C with sonification. The analysis was carried out on a Phenomenex LUNA C18 column (150×2.00 mm) with precolum. Niacin was determined at a wavelength of 220 nm. Isocratic elution was performed using a solution of metanol and Pic-A reagent (tetrabutylammonium hydrogen sulphate) in water (1:99); the concentration of Pic-A was 0.005 M, the flow rate was 0.1 $cm^3 \cdot min^{-1}$.

Vitamin B_6 content was determined using the chromatographic method (EN 14164:2008). The analysis was carried out on a Merck liquid chromatograph fitted with a fluorescence detector, on a Phenosphere-Next C18 (150×4.60 mm) monolithic column with a precolumn. Isocratic elution was performed at a flow rate of 0.9 $cm^3 \cdot min^{-1}$. Measurements were performed at excitation/emission wavelengths of 290/390. Mobile phase was a mixture of sulphuric acid (c=0.015 $mol \cdot dm^{-3}$) and trichloroacetic acid (TCA) of ≥99 % purity (c=0.005 $mol \cdot dm^{-1}$).

Antioxidants

The total polyphenol content and the total flavonoid content were determined in 80 % methanol extracts acidified with 0.5 % HCl by spectrophotometry using the Folin-Ciocalteu reagent and the solutions of $AlCl_3$ and $NaNO_2$. The content of these compounds was determined according to the standard curves prepared for the (+)-catechin. Absorbance was

measured at λ=765 nm for total polyphenols and at λ= 510 nm for total flavonoids.

Vitamin C and L-ascorbic acid content was established according to HPLC methods EN 14130:2003. For vitamin C and L-ascorbic acid content estimation lyophilized mushroom samples were diluted with 0.1 M metaphosphoric acid and centrifuged. The analysis was carried out on a Thermo Scientific DIONEX ULTIMATE 3000 UPLC chromatograph with DAD Detector. Sample was injected into a Onyx Monolithic C18 column (100×4.6 mm) with precolumn. The elution was carried out using 0.1 M metaphosphoric acid, the flow rate was 1 $cm^3 \cdot min^{-1}$. The absorbance was monitored at 254 nm. The sum of L-ascorbic acid and L-dehydroascorbic acid was determined after reduction with L-cysteine according to EN 14130:2003 standard.

β-carotene and lycopene contents were analyzed by spectrophotometry using extracts prepared with acetone and hexane mixture (4:6) by sonification according to Barros and coworkers (2008). Absorbance was measured at wavelengths 453; 505; 663 nm. The content of carotenoids (mg) in 100 cm^3 of extract was calculated as follows: β-carotene= $0.216 \cdot A_{663} - 0.304 \cdot A_{505} + 0.452 \cdot A_{453}$; lycopene=- $0.458 \cdot A_{663} + 0.372 \cdot A_{505} - 0.806 \cdot A_{453}$.

Tocopherols content was established according to Katsanidis and Addis (1999) modified method using a normal phase HPLC. Tocopherols were extracted with hexane mixed with BHT. The analysis was carried out on a Merck liquid chromatograph with fluorescence detector. Sample was injected into a LUNA NH2 column (250×4.6 mm) with precolumn. The isocratic elution was carried out using mixture of n-hexane and 2-propanol (95:5) at flow rate of 2.5 $cm^3 \cdot min^{-1}$. The wavelengths of excitation/emission were 290/330. Vitamin E activity was calculated as a α-tocopherol equivalents (α-TE) per 100 g of dry weight according to equation: Vitamin E activity=1 × α-tocopherol+0.5 × β-tocopherol+0.1 × γ-tocopherol+0.03 × δ–tocopherol.

Antioxidant activity

Antioxidant activity was determined in 80 % methanol extracts prepared with heat treatment against the DPPH (2,2-diphenyl-1-picrylhydrazyl) radical (Pekkarinen et al. 1999) and against ABTS (2,2′-azino-bis[3-ethylbenzothiazoline-6-sulphonic acid]) radical cation (Re et al. 1999), as well as by the Ferric Reducing/Antioxidant Power method (Benzie and Strain 1996). The value of the antioxidant activity was determined according to the standard curve prepared for Trolox Eqivalent (6-hydroxy-2,5,7,8-tetramethylchroman-2-carboxylic acid) for ABTS and DPPH and to the standard curve prepared for iron ions (II) for FRAP method.

Statistical analysis

The results of the investigation were analyzed statistically using one - way analysis of variance based on Duncan range test at $P<0.05$. Linear correlation coefficiency between the results of antioxidant compounds and antioxidant activity values was also established. The Statistica 10.0 (Stat - Soft) program was used for statistical calculations.

Results and discussion

Proximate composition

Proximate composition of fresh and prepared for consumption wild edible mushrooms is presented in Table 1. Statistical analysis revealed no significant changes in proximate composition of culinary treated mushrooms during storage, therefore data presented in Table 1 in case of mushrooms prepared for consumption are mean values calculated from results obtained immediately after braising and during whole storage period.

Proximate composition and energetic value of fresh *Boletus edulis* was typical according to available literature (Caglarirmak et al. 2002; Jaworska and Bernaś 2009; Ouzouni and Riganakos 2007). *Xerocomus badius* mushrooms contained less dry weight than *Boletus edulis* by 2 g per 100 g of fresh mushrooms, which corresponded with lower level of proteins and fat, however ratio of basic components was comparable.

Preparing mushrooms for consumption by braising with addition of canola oil led to water evaporation and saturation of mushrooms with oil, which resulted in changes of proximate composition and energetic value. Mushrooms prepared for consumption contained significantly more dry matter than fresh mushrooms and dominant component was fat, while total carbohydrates accounted 34–40 % of all components. There was also a small increase in proteins and ash levels observed. There were differences between proximate composition of mushrooms prepared for consumption basing on the preliminary treatment used prior to braising, mostly corresponding to changes resulting from leaching of solutes during blanching. Changes in proximate composition of *Boletus edulis* and *Xerocomus badius* mushrooms during preparation for consumption are consistent with previous findings for *Lactarius delicious* (Pogoń et al. 2013).

B-group vitamins

Content of B-group vitamins in fresh and prepared for consumption wild edible mushrooms is presented in Table 2. Of both analyzed species *Xerocomus badius* was better source of most B-group vitamins containing in 100 g of dry weight 0.06 mg less of B_1 and 2.40, 15.23 and 200 mg more of B_2,

Table 1 Proximate composition of fresh and prepared for consumption *Boletus edulis* and *Xerocomus badius* (g per 100 g fresh weight, $n=8$)

Component	*Boletus edulis*			*Xerocomus badius*		
	FM fresh mushrooms	A raw mushrooms prepared for consumption	B blanched mushrooms prepared for consumption	FM fresh mushrooms	A raw mushrooms prepared for consumption	B blanched mushrooms prepared for consumption
Moisture	88.84±0.66[a]	81.68±0.34[b]	78.20±0.43[c]	90.93±0.91[a]	82.84±0.75[b]	76.28±0.62[c]
Proteins	2.27±0.03[a]	2.25±0.05[a]	2.61±0.06[b]	1.62±0.18[a]	1.71±0.13[a,b]	1.84±0.18[b]
Fat	0.87±0.03[a]	8.76±0.13[b]	9.22±0.30[b]	0.71±0.06[a]	8.35±0.65[b]	8.48±0.72[b]
Total carbohydrates	7.37±0.41[a,b]	6.41±0.83[a]	8.74±0.23[b]	6.08±0.51[a]	6.94±0.55[a]	8.18±0.73[c]
Ash	0.66±0.04[a]	0.90±0.01[b]	0.82±0.04[c]	0.66±0.07[a]	0.86±0.07[b]	0.73±0.05[a,b]
Energy (kcal)	45±3[a]	112±8[b]	130±5[c]	36±3[a]	112±8[b]	114±10[b]

[a,b] different letters represent statistical differences between samples per one mushroom species and one component (at $P<0.05$)

B_3 and B_6 respectively than *Boletus edulis*. In *Boletus edulis* pyridoxiamine was the most abundant form of B_6 vitamin, while in *Xerocomus badius* it was pyridoxal. Fresh mushrooms are considered a good source of B group vitamins with levels of some significantly higher than in plant tissues (Bernaś et al. 2006; Mattila et al. 2001). One hundred grams of dry weight of fresh *B.edulis* may contain 0.54–2.92 mg of vitamin B_1, 0.47–9.36 mg of vitamin B_2 and 31.2–69.5 mg of niacin, while information on presence of vitamin B_6 in discussed mushroom species is lacking (Caglarirmak et al. 2002; Karkocha and Młodecki 1965; Jaworska and Bernaś 2009). There are no reports available on B-group vitamins in *X.badius*.

Preparation of analyzed mushrooms for consumption led to significant changes in contents of B-group vitamins. Mushrooms prepared for consumption contained 27–43 % less B_1, 26–77 % less B_2, 15–57 % less B_3 and less 22–79 % B_6 vitamins in comparison to fresh mushrooms. Higher reductions of B-group vitamins were observed in *Xerocomus badius* prepared for consumption than in *Boletus edulis*, which in case of riboflavin and niacin resulted in comparable content in culinary products obtained in both mushroom species. Blanching prior to braising led to more significant losses (up to 26 %) of B-group vitamins in *B.edulis*, while in *X.badius* only culinary products obtained from blanched (type B) mushrooms contained more B_1, B_2 and B_6 vitamins by 5–16 % than culinary products obtained from raw mushrooms (type A). B-group vitamins are susceptible to processing and it was reported before by Jaworska et al. (2008), Jaworska and Bernaś (2009) and Martin-Belloso and Llanos-Barriobero (2001) that blanching in different solutions and sterilizing of *Agaricus bisporus* or *Boletus edulis* mushrooms can lead to 13–76 % reduction in vitamin B_1, B_2 and B_6 levels. According to FAO (2002) human vitamin requirements 100 g of *B.edulis* and *X.badius* prepared for consumption can fulfil 7–14 % RDA of vitamin B_1 for healthy adults and 15–35, 18–37 and 1 % RDA of B_2, B_3 and B_6 respectively.

Mushrooms prepared for consumption after storage contained less B-group vitamins than immediately after braising, which was most significant in case of niacin content in *X.badius* prepared for consumption in which after storage discussed vitamin was not detected. There was no explicit influence of storage time and temperature on the content of all B-group vitamins observed in mushrooms prepared for consumption. Storage of frozen mushrooms also leads to losses of B-group vitamins but reductions are significant after several months (Jaworska et al. 2008; Jaworska and Bernaś 2009).

Antioxidants

Content of analyzed antioxidants in fresh and prepared for consumption wild edible mushrooms is presented in Tables 3 and 4. Of both analyzed mushroom species fresh *X.badius* was better source of some antioxidants containing in 100 g of dry weight 118 mg more total polyphenols, 125 mg more total flavonoids, 4.8 mg more vitamin C, 0.162 mg more β-carotene than fresh *B.edulis*. Level of lycopene in both mushroom species was comparable and *B.edulis* contained more total tocopherols with higher vitamin E activity in comparison to *X.badius*, even though in both mushroom species α-tocopherol was most abundant of tocopherols. *B.edulis* analyzed in this study contained comparable levels of total polyphenols, total flavonoids, β-carotene and lycopene as pilei of this species described in literature (Barros et al. 2008; Kuka and Cakste 2011; Palacios et al. 2011; Tsai et al. 2007; Sarikurkcu et al. 2008). In light of available data it can be conclude that analyzed *B.edulis* mushrooms were rich in vitamin C as previous reports show range of content in 100 g dry matter from 0 mg reported by Barros et al. (2008) to 17.9 mg reported by Jaworska and Bernaś (2009). Also reported earlier amounts of total tocopherols were lower than in analyzed in this study mushrooms, while Barros et al. (2008) showed greater share of β-tocoherol and Tsai et al. (2007) reported greater share of α-tocopherol in total tocopherols. There are no reports available on antioxidants in *Xerocomus badius*.

Table 2 B group vitamins in fresh and prepared for consumption *Boletus edulis* and *Xerocomus badius* (per 100 g dry weight, $n=8$)

Vitamin	Storage	*Boletus edulis*		*Xerocomus badius*	
		A raw mushrooms prepared for consumption	B blanched mushrooms prepared for consumption	A raw mushrooms prepared for consumption	B blanched mushrooms prepared for consumption
B_1 (mg)	Fresh mushrooms	0.94 ± 0.11^{a}		0.88 ± 0.03^{a}	
	0 h	0.46 ± 0.01^{b}	$0.43\pm0.01^{b,c}$	0.50 ± 0.04^{b}	0.64 ± 0.01^{e}
	48 h/20 °C	0.42 ± 0.01^{c}	0.37 ± 0.02^{c}	0.29 ± 0.05^{c}	0.39 ± 0.03^{f}
	48 h/4 °C	0.38 ± 0.01^{c}	0.39 ± 0.01^{c}	0.16 ± 0.01^{d}	0.21 ± 0.01^{d}
	96 h/4 °C	0.32 ± 0.02^{d}	0.37 ± 0.01^{c}	0.15 ± 0.01^{d}	0.16 ± 0.02^{d}
B_2 (mg)	Fresh mushrooms	2.57 ± 0.02^{a}		4.97 ± 0.13^{a}	
	0 h	1.91 ± 0.08^{b}	1.38 ± 0.08^{e}	1.13 ± 0.14^{b}	1.38 ± 0.01^{f}
	48 h/20 °C	1.62 ± 0.12^{c}	1.02 ± 0.02^{d}	0.30 ± 0.02^{c}	0.39 ± 0.03^{c}
	48 h/4 °C	$1.80\pm0.01^{b,c}$	1.29 ± 0.01^{f}	0.92 ± 0.03^{d}	0.91 ± 0.15^{d}
	96 h/4 °C	1.13 ± 0.17^{d}	0.82 ± 0.04^{g}	0.75 ± 0.04^{e}	$0.80\pm0.07^{d,e}$
B_3 (mg)	Fresh mushrooms	22.89 ± 0.51^{a}		38.12 ± 5.65^{a}	
	0 h	19.54 ± 0.18^{b}	13.57 ± 0.05^{e}	30.22 ± 4.16^{b}	16.56 ± 1.88^{d}
	48 h/20 °C	10.13 ± 0.07^{c}	8.74 ± 0.06^{f}	0.00 ± 0.00^{c}	9.87 ± 1.56^{e}
	48 h/4 °C	15.85 ± 0.07^{d}	17.56 ± 0.19^{g}	0.00 ± 0.00^{c}	0.00 ± 0.00^{c}
	96 h/4 °C	14.20 ± 0.18^{d}	14.72 ± 0.16^{d}	0.00 ± 0.00^{c}	0.00 ± 0.00^{c}
B_6 sum of pyridoxine, pyridoxiamine and pyridoxal (μg)	Fresh mushrooms	9 ± 2^{a}		209 ± 11^{a}	
	0 h	7 ± 1^{b}	7 ± 1^{b}	49 ± 5^{b}	64 ± 2^{e}
	48 h/20 °C	$8\pm1^{a,b}$	6 ± 1^{b}	43 ± 1^{c}	45 ± 5^{c}
	48 h/4 °C	6 ± 1^{b}	6 ± 1^{b}	32 ± 6^{d}	22 ± 1^{f}
	96 h/4 °C	7 ± 2^{b}	6 ± 1^{b}	40 ± 4^{c}	20 ± 3^{f}

[a,b] different letters represent statistical differences between samples per one mushroom species and one vitamin (at $P<0.05$)

Wild edible mushrooms prepared for consumption by braising contained significantly different amounts of antioxidants than fresh mushrooms. Culinary treatment led to reduction of total polyphenols, total flavonoids, vitamin C and carotenoids up to 77 % in comparison to fresh mushrooms. Only in case of *X.badius* prepared for consumption from raw edible parts (type I) there was 7 % increase in total polyphenols observed, which may be attributed to structural changes of phenolics compounds, which affects reactivity with Folin-Ciocalteu reagent (Makris and Rossirer 2001). Reductions of antioxidants were comparable in both analyzed mushrooms species. Most antioxidants are sensitive to heat treatment, especially phenolic compounds and vitamin C.

A significant decrease in polyphenol and vitamin content can be observed during cooking and frying of many vegetables (Faller and Fiahlo 2009; Kalogeropoulos et al. 2007; Perla et al. 2012). During culinary treatment of *Lactarius deliciosus* a decrease of 15–20 % of total polyphenols and total flavonoids expressed in fresh weight was reported previously (Pogoń et al. 2013). In case of mushrooms also preliminary treatment influences significantly the content of phenolics compounds which is due to high phenol oxidaze and phenol peroxidaze activity. Those enzymes are activated immediately after the tissue is disrupted and lead to changes in content and reactivity of phenolics compounds (Czapski and Szudyga 2000). Carotenoids are considered most thermally stabile of antioxidant compounds, several authors even reported increase of carotenoids as a result of thermal treatment (Bunea et al. 2008), while according to Rickman and coworkers (2007) reductions of carotenoids during cooking and blanching amount to twenty percent. It was noted that losses of all discussed antioxidants were higher in mushrooms blanched prior to culinary treatment (products type B). This can be mostly attributed to longer exposure to high temperature.

Braising of wild edible mushrooms with 10 % addition of canola oil led to 7-13-fold increase of total tocopherols and significant increase of vitamin E activity. Wild mushrooms prepared for consumption contained amounts of tocopherols comparable peanut oil (FAO 2002). It can be assumed that composition of tocopherols in prepared for consumption mushrooms was a strict reflection of rapeseed oil composition. According to Lechner et al. (1999) canola oil contains 0.037 g tocopherols per 100 g, comprising of γ-tocopherol (59 %), α-tocopherol (36 %) and δ-tocopherol (5 %); β- tocopherol was

Table 3 Total phenols, total flavonoids, vitamin C and carotenoids in fresh and prepared for consumption *Boletus edulis* and *Xerocomus badius* (mg per 100 g dry weight, $n=8$)

Component	Storage	*Boletus edulis*		*Xerocomus badius*	
		A raw mushrooms prepared for consumption	B blanched mushrooms prepared for consumption	A raw mushrooms prepared for consumption	B blanched mushrooms prepared for consumption
Total phenols	Fresh mushrooms	446±9[a]		564±21[a]	
	0 h	267±6[b]	164±6[c]	601±22[b]	295±16[d]
	48 h/20 °C	267±6[b]	161±4[c]	563±26[a]	282±8[d]
	48 h/4 °C	265±4[b]	144±4[c]	555±19[a]	297±22[d]
	96 h/4 °C	251±6[b]	153±7[c]	530±26[c]	312±19[d]
Total flavonoids	Fresh mushrooms	32±2[a]		157±13[a]	
	0 h	26±2[b]	19±2[c,d]	87±19[b]	81±12[c]
	48 h/20 °C	18±1[c]	12±1[e]	93±17[b]	91±8[b]
	48 h/4 °C	22±2[d]	17±2[c]	90±5[b]	77±5[c]
	96 h/4 °C	20±2[c,d]	14±1[e]	94±3[b]	62±10[d]
L-ascorbic acid	Fresh mushrooms	22.1±1.4[a]		27.4±1.4[a]	
	0 h	10.1±0.1[b]	7.7±0.0[c]	9.0±0.2[b]	6.4±0.3[c]
	48 h/20 °C	6.7±0.2[c]	2.0±0.1[d]	8.0±0.1[b]	5.4±0.5[d]
	48 h/4 °C	10.0±0.2[b]	7.4±0.0[c]	6.9±0.2[c]	6.4±0.1[c]
	96 h/4 °C	9.9±0.1[b]	7.3±0.1[c]	6.5±0.3[c]	5.4±0.2[d]
Vitamin C	Fresh mushrooms	29.9±0.6[a]		34.7±0.7[a]	
	0 h	15.6±0.3[b]	11.5±0.2[c]	11.9±0.8[b]	9.0±0.1[b,c]
	48 h/20 °C	15.4±0.2[b]	9.9±0.3[c]	11.0±0.5[b]	7.5±0.1[c]
	48 h/4 °C	14.5±0.2[b]	14.4±0.1[b]	9.7±0.7[b,c]	8.6±0.3[b,c]
	96 h/4 °C	10.6±0.1[c]	9.3±0.1[c]	9.2±0.1[b,c]	7.2±0.3[c]
β-carotene	Fresh mushrooms	1.062±0.034[a]		1.224±0.022[a]	
	0 h	1.027±0.027[a]	0.784±0.041[d]	1.031±0.041[b]	0.531±0.034[d]
	48 h/20 °C	0.996±0.026[b,c]	0.770±0.037[d]	0.962±0.029[c]	0.497±0.038[d]
	48 h/4 °C	1.012±0.019[a]	0.790±0.024[d]	1.044±0.032[b]	0.501±0.029[d]
	96 h/4 °C	0.897±0.009[c]	0.782±0.021[d]	1.072±0.029[b]	0.460±0.021[d]
Lycopene	Fresh mushrooms	0.686±0.043[a]		0.684±0.066[a]	
	0 h	0.456±0.023[b]	0.367±0.017[c]	0.385±0.035[b,c]	0.325±0.017[b]
	48 h/20 °C	0.420±0.022[b]	0.299±0.031[d]	0.425±0.041[c]	0.253±0.034[d]
	48 h/4 °C	0.451±0.019[b]	0.355±0.023[c]	0.351±0.037[b]	0.329±0.021[b]
	96 h/4 °C	0.443±0.034[b]	0.328±0.021[c]	0.321±0.023[b]	0.329±0.035[b]

[a,b] different letters represent statistical differences between samples per one mushroom species and one component (at $P<0.05$)

not found. Goffman and Becker (2002) showed that there is a significant genetic variation of tocopherols in rapeseed. Also composition of tocopherols present in canola oil might be affected by the technological enrichment in commercial mixture of tocopherols used as antioxidants, which might explain differences between tocopherols fractions in prepared for consumption *B.edulis* and *X.badius*. It can be expected that culinary treatment did not cause a significant reductions of tocopherols since these compounds are very thermally stable. In an experiment conducted by Rossi et al. (2007), the tocopherol content and vitamin E activity in various fats kept at 180 °C for 1 h was reduced by less than 10 %.

During storage of wild edible mushrooms prepared for consumption slight fluctuations in content of all analyzed antioxidants was observed, but the differences were mostly statistically insignificant. Only in case of total flavonoids and vitamin C content reductions were more significant reaching 37 % and differences were more pronounced after 96 h storage at 4 °C rather than after 48 h at 20 °C. While storing fried *Lactarius deliciosus* for 48 h at 20 °C or 96 at 4 °C Pogoń et al. (2013) noted increase in total polyphenol content up to 24 %, and decrease in total flavonoid content up to 19 % in comparison to freshly fried mushrooms.

Table 4 Tocopherols in fresh and prepared for consumption *Boletus edulis* and *Xerocomus badius* (mg per 100 g dry weight, n=8)

Tocopherol	Storage	*Boletus edulis*		*Xerocomus badius*	
		A raw mushrooms prepared for consumption	B blanched mushrooms prepared for consumption	A raw mushrooms prepared for consumption	B blanched mushrooms prepared for consumption
α	Fresh mushrooms	3.21±0.05[a]		2.37±0.09[a]	
	0 h	18.36±0.12[b]	19.11±0.05[b]	18.55±0.41[b]	19.29±0.37[b]
	48 h/20 °C	15.51±0.05[c]	19.51±0.99[b]	17.96±0.12[b]	19.08±1.57[b]
	48 h/4 °C	18.30±0.08[b]	16.24±0.29[b,c]	18.50±0.02[b]	19.48±0.01[b]
	96 h/4 °C	17.65±0.06[b]	16.09±0.24[b,c]	15.83±0.08[c]	17.88±0.36[b]
β	Fresh mushrooms	1.59±0.07[a]		0.51±0.06[a]	
	0 h	19.89±0.58[b]	20.56±0.43[b]	nd[b]	
	48 h/20 °C	19.19±0.43[b]	19.80±0.51[b]		
	48 h/4 °C	20.46±0.04[b]	16.98±0.11[b]		
	96 h/4 °C	19.04±0.17[b]	16.88±0.41[b]		
γ	Fresh mushrooms	0.09±0.01[a]		0.13±0.05[a]	
	0 h	nd[b]		22.56±0.05[b]	25.20±0.03[b]
	48 h/20 °C			22.11±0.26[b]	24.70±0.68[b]
	48 h/4 °C			22.65±0.04[b]	20.88±0.19[b]
	96 h/4 °C			20.00±0.05[b]	16.8±0.36[c]
δ	Fresh mushrooms	0.05±0.03[a]		0.06±0.04[a]	
	0 h	0.39±0.03[b]	0.44±0.02[c]	nd[b]	
	48 h/20 °C	0.37±0.02[b]	0.44±0.03[c]		
	48 h/4 °C	0.47±0.05[c]	0.40±0.04[b,c]		
	96 h/4 °C	0.40±0.03[b,c]	0.40±0.03[b,c]		
Sum	Fresh mushrooms	4.94±0.05[a]		3.08±0.18[a]	
	0 h	38.64±0.53[b]	40.11±0.41[b]	44.11±0.41[b]	44.49±0.38[b]
	48 h/20 °C	35.79±0.41[c]	39.74±1.07[b]	40.07±0.27[c]	43.78±2.22[b]
	48 h/4 °C	39.24±0.15[b]	33.62±0.32[c,d]	41.15±0.06[c]	40.36±0.19[c]
	96 h/4 °C	32.67±0.81[d]	33.37±0.68[c,d]	35.83±0.10[d]	34.68±0.48[d]
Vitamin E activity	Fresh mushrooms	4.01±0.02[a]		2.64±0.12[a]	
	0 h	28.32±0.25[b]	29.40±0.46[b]	20.80±0.41[b]	21.81±0.37[b]
	48 h/20 °C	25.48±0.19[c]	29.42±1.00[b]	20.17±0.12[b]	21.55±1.63[b]
	48 h/4 °C	28.55±0.09[b]	24.74±0.29[c]	20.77±0.02[b]	21.57±0.02[b]
	96 h/4 °C	27.17±0.82[b]	24.54±0.45[c]	17.3±0.38[c]	19.56±0.36[b]

nd not detected

[a,b] different letters represent statistical differences between samples per one mushroom species and one component (at P<0.05)

Antioxidant activity

Antioxidant activity of fresh and prepared for consumption wild edible mushrooms is presented in Table 5. Fresh *Xerocomus badius* showed higher antioxidant activity against ABTS radical in comparison to *Boletus edulis*, while in DPPH and FRAP assay both mushrooms presented comparable activity. According to Kuka and Cakste (2011), Sarikurkcu et al. (2008) and Tsai et al. (2007) methanolic, ethanolic and water extracts of *B.edulis* are characterized by high DPPH scavenging ability, reducing power, chelating power and high abilities to inhibit lipid peroxidation and β-carotene bleaching compared to other mushroom species. EC_{50} value for *B.edulis* DPPH radical scavenging activity reported by Tsai et al. (2007) was 1.75 mg per ml, which is comparable to activity presented in this study. There are no reports available on antioxidant activity of *Xerocomus badius*.

Wild edible mushrooms prepared for consumption showed lower antioxidant activity than fresh mushrooms by 23–63 % in ABTS assay, by 21–69 % in DPPH assay and by 23–58 % in FRAP assay. Lower values of antioxidant activity measured by three assays were noted in culinary products type B prepared with mushrooms blanched prior to thermal treatment in comparison to mushrooms braised raw. Reductions in antioxidant

Table 5 Antioxidant activity of fresh and prepared for consumption *Boletus edulis* and *Xerocomus badius* (per 100 g dry weight, $n=8$)

Antioxidant activity	Storage	*Boletus edulis*		*Xerocomus badius*	
		A raw mushrooms prepared for consumption	B blanched mushrooms prepared for consumption	A raw mushrooms prepared for consumption	B blanched mushrooms prepared for consumption
ABTS method (mmol TE)	Fresh mushrooms	11.8±0.1[a]		47.3±1.7[a]	
	0 h	7.2±0.2[b]	4.9±0.1[c]	36.5±0.8[b]	17.5±0.6[c]
	48 h/20 °C	7.2±0.5[b]	5.0±0.6[c]	33.6±1.2[b]	18.0±0.4[c]
	48 h/4 °C	7.1±0.1[b]	5.3±0.2[c]	36.4±0.9[b]	18.2±0.5[c]
	96 h/4 °C	7.2±0.0[b]	4.6±0.4[d]	36.2±1.2[b]	19.4±1.1[c]
DPPH method (mmol TE)	Fresh mushrooms	27.1±1.2[a]		25.2±2.8[a]	
	0 h	21.3±0.5[b]	14.4±0.2[c]	18.1±0.7[b]	7.8±0.3[c]
	48 h/20 °C	21.3±0.3[b]	14.1±0.5[c]	16.0±0.6[b]	9.7±1.2[c]
	48 h/4 °C	20.7±0.7[b]	13.0±0.2[c]	17.9±0.4[b]	9.1±0.5[c]
	96 h/4 °C	21.1±1.1[b]	13.0±0.4[c]	17.0±0.3[b]	9.5±1.2[c]
FRAP method (mmol Fe^{2+})	Fresh mushrooms	35.6±1.0[a]		36.4±1.8[a]	
	0 h	19.5±0.3[b]	15.0±0.2[c]	28.1±0.7[b]	16.4±0.9[c]
	48 h/20 °C	19.5±0.4[b]	15.1±0.5[c]	26.7±0.9[b]	18.2±0.9[c]
	48 h/4 °C	18.4±0.5[b]	14.7±0.3[c]	27.9±0.5[b]	17.0±0.4[c]
	96 h/4 °C	17.8±0.3[b]	14.5±0.3[c]	28.1±0.8[b]	17.5±1.5[c]

[a,b] different letters represent statistical differences between samples per one mushroom species and one type of analysis (at $P<0.05$)

activity were similar for both analyzed mushrooms species. Modifications of antioxidant activity during preparation for consumption were positively correlated with changes in contents of particular antioxidants. Antioxidant activity against ABTS radical was highly correlated with content of total polyphenols ($r=0.89$), total flavonoids ($r=0.95$) and total tocopherols ($r=0.69$), antioxidant activity against DPPH radical was correlated with level of L-ascorbic acid ($r=0.79$), carotenoids ($r=0.89$) and total tocopherols ($r=0.76$), while reducing power measured by FRAP assay was correlated with all analyzed antioxidants except total tocopherols with linear correlation coefficient values between 0.59 and 0.86. According to Barros et al. (2007) antioxidant activity of wild edible mushrooms measured by different methods (DPPH assay, β-carotene bleaching assay and erythrocyte hemolysis mediated by peroxyl free radicals assay) is strongly correlated to phenol content measured by Folin-Ciocalteu method, while carotenoids and vitamin C contribute less to the total antioxidant capacity. Jaworska et al. (2014) on the other hand noted in dried *Boletus edulis* that the antioxidant activity measured by ABTS and FRAP assay is correlated to the content of total polyphenols, total flavonoids, vitamin C, sum of tocopherols and β-carotene ($r=0.69–0.86$), while values of antioxidant activity measured by DPPH assay are not strongly correlated to the content discussed antioxidants ($r=0.11–0.56$). In case of *Lactarius deliciosus* mushrooms frying led to changes in antioxidant activity expressed per fresh weight from −39 to +6 % in ABTS assay and from −14 to +19 % in DPPH and FRAP assay with highly correlated antioxidant activity and level of total polyphenols (Pogoń et al. 2013). Storage of wild edible mushrooms prepared for consumption did not influence antioxidant activity significantly. Similar results were obtained by Jaworska et al. (2015) during storage of commercial mushrooms *Agaricus bisporus* and *Pleurotus ostreatus* where antioxidant activity was high and stable during whole storage period while content of particular antioxidants changed importantly. This phenomenon may be explained by very high synergistic effects of bioactive compounds present in mushroom tissue which was described by Ferreira et al. (2009). Due to that effect the decrease in antioxidants may not influence the level of antiradical potential and reducing power of mushroom tissue significantly.

Conclusions

Comparing fresh *Boletus edulis* and *Xerocomus badius* mushrooms as sources of nutraceuticals it can be concluded that *Xerocomus badius* was a better source of most B-group vitamins and antioxidants with higher values of antioxidant activity. Both *Boletus edulis* and *Xerocomus badius* mushrooms prepared for consumption by braising with canola oil were characterized by different antioxidant properties and vitamin content in comparison to fresh mushrooms. In general culinary treatment led to decrease of B-group vitamins, total polyphenols, total flavonoids, vitamin C and carotenoids up to 77 %, while content of total tocopherols increased 7 to 13-fold. Antioxidant activity of braised mushrooms after storage

was comparable to the values obtained directly after thermal treatment with some differentiations in the content of particular antioxidants. However storage of mushrooms prepared for consumption resulted in the lower content of B-group vitamins. Therefore it is advised to consume wild edible mushrooms directly after braising.

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