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Nutrients in edible mushrooms: an inter-species comparative study

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Abstract

A comparative study on various components of nutritional interest, such as water, protein, total amino acids, ash and minerals, in mushrooms of different species (*Pleurotus ostreatus, Pleurotus eryngii, Pleurotus pulmunarius* and *Lentinula edodes*) was carried out. Mushrooms were cultivated on the same compost (wheat straw added with 15% of sugar beet) and analysed immediately after harvest to avoid any interfering parameters. The limiting amino acid was also evaluated and the relevant protein chemical score was calculated. The moisture content of the edible mushrooms studied is high (ranging from 85.2 to 94.7%) and the ash contents range from 6.9 to 10.5% on a dry basis. Potassium is the most abundant mineral element followed by magnesium. Total nitrogen varies from 3.47 to 7.93% (dry basis), and *P. ostreatus* species has the largest variability among the samples analysed. The most abundant amino acids in mushrooms, expressed as percentages of total amino acids, are glutamic acid (12.8–20.9%), aspartic acid (9.1–12.1%) and arginine (3.7–11.7%), but in the analysed *P. pulmunarius* and *L. entinus* edodes a particularly low percentage of arginine (3.7 and 5.7%) has been detected. The chemical score generally ranges from 96 to 110%, the limiting amino acid being leucine or/and lysine.

1. Introduction

Human relationships with mushrooms are ancient and fascinating. The Egyptians believed that they were a gift from the god Osiris, while the ancient Romans called them a "divine food" because they thought that mushrooms resulted from the lightning thrown to earth by Jupiter during storms.

Mushrooms are healthy foods, poor in calories and in fat, rich in vegetable proteins, chitin, vitamins and minerals and constitute an increasing share in the Italian diet. The most cultivated specie in Italy is *Agaricus bisporus* but there are also other species such as *Pleurotus ostreatus* or *Lentinula edodes* that are now widely produced.

Edible mushrooms can be saprophytes, symbiontes and parasites of different plants. All need organic matter to grow (heterotrophic organisms) but the most commonly for used controlled production are the saprophytes. These mushrooms secrete enzymes to digest surrounding foodstuffs and to obtain their nourishment from organic matter. The growth compost, a mixture of straw or hay, corn cobs, water cotton seed meal and nitrogen supplements, can influence the chemical composition and, as a consequence, the nutritional value of the cultivated mushrooms (Tshinyangu, 1996). Mushroom quality is also influenced by other parameters such as the stage of development and pre and post-harvest conditions. All these interfering parameters justify the variability in composition data published by different authors working with even the same species of mushroom (Bano & Rajarathnam, 1988).

This paper has the aim to compare the chemical compositions of different species of mushrooms (*P. ostreatus, P. pulmunarius, P. eryngii* and *L. edodes*) cultivated on the same compost (wheat straw plus 15% of sugar beet) and analysed immediately after harvest. In particular this study refers to various components of nutritional interest such as protein content, total amino acids, ash and minerals.

2. Materials and methods

2.1. Samples

P. ostreatus (SMR 122, SMR 125, SMR 127, SMR 128, SMR 129, SMR 131, SMR 132, SMR 138), *P.*

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pulmunarius (SMR 126), *P. eryngii* (SMR 172, SMR 173, SMR 133) and *L. edodes* (SMR 90), belonging to the Mushroom Collection of the National Research Council (Montelibretti, Roma-I), were cultivated in an Italian farm (Castelluccio, Senise Potenza-I) and analysed immediately after harvesting.

2.2. Chemicals

All reagents (Carlo Erba, Milan, I) were of analytical or HPLC grade, as required. Standards of amino acids and minerals were obtained from Beckman Inc. (Palo Alto, CA) and from Merck (Darmstadt, Germany), respectively.

2.3. Equipment

A Dionex–Biolc Ion system equipped with a Dionex CS12 Ion Pac column with a Suppressed Conductivity Detector (Camberly, UK) was used for mineral determination.

Amino acids were analysed by a Beckman 120C amino acid analyser (Beckman Instruments Inc., Palo Alto, CA,) utilising a column 32×0.9 cm packed with a resin of polysulphonic acid and an ISCO spectrophotometer detector (Hengoed, UK).

An HPLC analytical system comprising a Waters (Milford MA) model 501 solvent delivery system with a C18 column 25 cm×5 μ (Supelco) and a spectrofluorometer model LS 40 (Perkin–Elmer) was used for tryptophan determination.

2.4. Methods

2.4.1. Proximate composition

Water and nitrogen contents were determined according to the AOAC (1995) procedures.

2.4.2. Minerals

The samples were analysed after ashing. A 200–500 mg amount was weighed into crucible and ashed in the furnace at 500°C for 24 h. The ashes were dissolved with a few drops of nitric acid (70%) and diluted to 50 ml with deionized water. Sodium, potassium, magnesium and calcium were separated by an isocratic elution with a solution of methane sulfonic acid (20 mM) at 1 ml/min flow rate (Gambelli, Ingrao, Pizzoferrato, & Santaroni, 1996) and revealed with a suppressed conductivity detector.

2.4.3. Total amino acids

Total amino acid analysis was carried out according to the method of Spackman, Moore, and Stein, (1958) by ion-exchange chromatography after protein hydrolysis. Methionine and cysteine were first oxidised

Table 1
Moisture in edible mushrooms (g/100 g). Values are means of triplicates ± standard deviations

Mushroom		Moisture
P. ostreatus	(SMR 122)	85.24 ± 0.20
P. ostreatus	(SMR 125)	88.66 ± 0.13
P. ostreatus	(SMR 127)	91.44 ± 0.29
P. ostreatus	(SMR 128)	93.02 ± 0.08
P. ostreatus	(SMR 129)	93.49 ± 0.10
P. ostreatus	(SMR 131)	92.48 ± 0.15
P. ostreatus	(SMR 132)	94.70 ± 0.21
P. ostreatus	(SMR 138)	86.52 ± 0.25
P. eryngii ferulae	(SMR 133)	88.13 ± 0.16
P. eryngii	(SMR 172)	91.69 ± 0.11
P. eryngii	(SMR 173)	91.45 ± 0.10
P. pulmunarius	(SMR 126)	87.70 ± 0.20
L. edodes	(SMR 90)	90.00 ± 0.26

Table 2
Nitrogen and protein contents in edible mushrooms (g/100 g). Data are means of triplicates ± standard deviations

Edible mushrooms		N		P[a]		P[b]	
		d.w.	w.w.	d.w.	w.w.	d.w.	w.w.
P. ostreatus	(SMR 122)	7.93 ± 0.08	1.12 ± 0.01	34.73 ± 0.35	4.92 ± 0.05	38.96 ± 0.66	5.75 ± 0.10
P. ostreatus	(SMR 125)	6.05 ± 0.10	0.65 ± 0.01	26.50 ± 0.43	2.83 ± 0.05	30.49 ± 0.38	3.46 ± 0.04
P. ostreatus	(SMR 127)	4.55 ± 0.05	0.39 ± 0.00	19.93 ± 0.20	1.70 ± 0.02	23.09 ± 1.41	1.98 ± 0.12
P. ostreatus	(SMR 128)	7.13 ± 0.02	0.50 ± 0.00	31.23 ± 0.10	2.19 ± 0.01	34.07 ± 1.06	2.38 ± 0.10
P. ostreatus	(SMR 129)	6.72 ± 0.07	0.44 ± 0.00	29.43 ± 0.03	1.92 ± 0.02	32.29 ± 1.02	2.10 ± 0.10
P. ostreatus	(SMR 131)	6.18 ± 0.02	0.46 ± 0.00	27.07 ± 0.07	2.01 ± 0.02	29.80 ± 0.86	2.24 ± 0.06
P. ostreatus	(SMR 132)	5.11 ± 0.01	0.27 ± 0.00	22.38 ± 0.03	1.18 ± 0.01	23.79 ± 1.01	1.26 ± 0.11
P. ostreatus	(SMR 138)	6.47 ± 0.01	0.82 ± 0.00	28.34 ± 0.07	3.61 ± 0.01	29.60 ± 0.87	3.99 ± 0.12
P. eryngii	(SMR 172)	5.20 ± 0.03	0.43 ± 0.00	22.74 ± 0.11	1.88 ± 0.01	22.35 ± 0.65	1.86 ± 0.05
P. eryngii	(SMR 173)	5.23 ± 0.04	0.45 ± 0.00	22.89 ± 0.17	1.97 ± 0.01	22.30 ± 0.80	1.91 ± 0.07
P. eryngii ferulae	(SMR 133)	5.30 ± 0.04	0.60 ± 0.01	23.21 ± 0.19	2.65 ± 0.02	25.41 ± 0.88	3.02 ± 0.11
P. pulmunarius	(SMR 126)	6.96 ± 0.05	0.72 ± 0.01	30.48 ± 0.22	3.17 ± 0.02	23.86 ± 1.07	2.93 ± 0.21
L. edodes	(SMR 90)	3.47 ± 0.06	0.35 ± 0.01	15.19 ± 0.26	1.53 ± 0.03	13.54 ± 0.6	1.35 ± 0.06

d.w. = dry weight; w.w. = wet weight.
[a] Calculated as: $P = N \times 4.38$.
[b] Calculated as sum of amino acid contents.

Table 3
Amino acid content (g/100 g) of edible mushrooms

AA	*P. ostraetus* (SMR 122)	*P. ostraetus* (SMR 125)	*P. ostreatus* (SMR 127)	*P. ostreatus* (SMR 128)	*P. ostreatus* (SMR 129)	*P. ostreatus* (SMR 131)	*P. ostreatus* (SMR 132)	*P. ostraetus* (SMR 138)	*P. pulmunarius* (SMR 126)	*P. eryngii ferulae* (SMR 133)	*P. eryngii* (SMR 172)	*P. eryngii* (SMR 173)	*L. edodes* (SMR 90)
ASP	11.57	12.08	10.55	9.99	10.19	9.19	9.67	12.05	9.14	12.09	10.80	11.20	10.19
THR	4.98	4.74	5.29	4.97	5.12	5.30	5.16	4.65	6.95	5.04	5.30	5.27	5.55
SER	5.56	5.83	4.97	3.49	5.03	5.07	5.00	5.98	8.43	5.96	5.57	6.13	5.70
GLU	14.97	14.76	16.63	13.25	14.45	13.14	13.36	14.46	18.68	12.89	12.76	13.42	20.91
PRO	4.32	3.80	3.78	4.58	4.50	4.79	4.70	3.55	6.42	3.77	3.49	3.38	3.85
GLY	4.38	4.48	4.61	4.53	4.55	4.68	4.81	4.43	6.25	4.52	4.65	4.62	4.66
ALA	5.97	6.26	7.51	7.66	7.80	8.07	8.27	6.00	9.46	6.24	5.99	6.01	5.27
VAL	4.38	4.39	4.75	4.94	5.15	4.80	4.88	4.28	5.74	4.51	4.00	3.79	3.81
MET	1.54	1.66	2.34	1.76	2.04	1.93	2.01	1.72	0.99	1.69	1.71	1.61	2.16
ILE	4.06	4.09	4.57	4.67	4.43	4.45	4.45	3.92	4.70	4.11	3.83	3.50	3.30
LEU	6.54	6.45	6.57	7.25	6.69	7.28	7.06	6.27	3.42	6.56	7.24	6.96	6.38
TYR	3.55	3.61	4.12	4.60	4.09	4.63	4.06	3.98	2.76	3.42	3.69	3.21	2.60
PHE	4.16	3.84	4.43	4.36	4.18	4.68	4.69	4.04	2.84	4.04	4.26	4.01	3.81
HIS	3.77	3.58	3.72	4.26	3.79	3.90	4.00	3.72	3.19	3.31	3.24	3.16	3.00
LYS	6.30	6.06	6.00	6.38	5.93	6.12	6.11	5.42	3.08	6.71	6.87	6.71	4.98
ARG	10.94	10.19	6.99	8.68	7.69	7.82	7.06	11.45	3.72	11.66	9.62	10.61	5.70
TRP	1.10	1.31	1.27	1.41	1.41	1.44	1.60	1.39	1.22	1.22	1.34	1.48	1.92
CYS	1.23	1.51	1.26	1.35	1.46	1.54	1.68	1.39	1.84	1.57	1.66	1.70	3.40
ORN	0.64	1.28	0.39	0.70	0.65	0.50	0.55	1.28	0.46	0.59	3.76	3.00	2.66
GABA	0.03	0.07	0.26	1.14	0.87	0.64	0.88	0.03	0.71	0.08	0.22	0.22	0.15

by performic acid to convert methionine into methionine sulphone and cysteine into cysteic acid (Schram, Moore & Bigwood, 1954). Tryptophan determination was carried out by isocratic reversed-phase high performance liquid chromatography and fluorescence detection after alkaline hydrolysis (Steven & Jorg, 1989). Protein chemical score and limiting aminoacids were evaluated using the FAO reference protein (FAO/WHO, 1991).

3. Results and discussion

In Table 1 the moisture content of the edible mushrooms studied is reported. The values range from 85.2 to 94.7%, confirming the high moisture content of these products (Breene, 1990). This variability is exclusively dependent on the mushroom species since other interfering parameters such as post-harvest period, temperature, relative humidity during growth (Bano & Rajarathnam, 1988) and storage have been standardised in this research.

In Table 2 nitrogen and protein contents on dry basis and on wet weight are reported. Total nitrogen varies from 3.47 to 7.93% (dry basis) and from 0.35 to 1.12% (wet weight) and, in particular, *L. edodes* shows the lowest nitrogen content. *P. ostreatus* samples reveal the largest variability ranging from 4.55 to 7.93% (dry basis), while in the *P. eryngii* samples more homogeneous values can be observed (5.23, 5.20 and 5.30%, dry basis). This large variability can be ascribed, as already reported in the literature (Crisan & Sands, 1978; Bano & Rajarathnam, 1988; Ragunathan, Gurusamy, Palariswamy, & Swaminathan, 1996), to the large genetic manipulation that *P.ostreatus* underwent.

A great variability can also be observed among the species of *P. ostreatus* in the protein contents, obtained from nitrogen using 4.38 as the conversion factor (Braaksma & Schaap, 1996). This factor, even if widely utilised, may not be accurate for all the species of mushroom and may be partially responsible for the fluctuations. In fact chitin, the nitrogen containing polysaccharide of the fungal cell walls, is present in different amounts in the various mushroom species and, as a consequence, the multiplicative factor may not be perfectly suitable for all the samples. A protein estimate can be obtained from the sum of the amount of each amino acid expressed as percentage of dry or wet sample. These last data are usually higher than the previous ones but *P. eryngii* samples show a good correspondence between the two values while, *P. pulmunarius* shows a level of protein calculated from nitrogen higher than that calculated from amino acids. The lack of mathematical proportionality among these results could be explained assuming a different amount of nitrogen-containing compounds in the studied samples. Actually, further studies now in progress bear evidence of chitin-chitosan levels considerably higher in *P. pulmunarius* and *P. eryngii* than in *P. ostreatus*.

In Table 3 the amino acid content is reported as the percentage of the sum of amino acids. The most abundant compounds are glutamic acid, aspartic acid, and arginine, even if in the samples of *P. pulmunarius* and *L. edodes* the percentages of arginine are not as high as in the other mushrooms. The largest variability among the amino acids can be observed in the *P. ostreatus* samples, while *P. eryngii* (SMR 172, 173, 133) seem to be more constant in composition.

In Table 4 the contents of two unusual amino acids, γ-amino butyric acid (GABA) and ornithine, are shown. Both compounds are characterised by a peculiar physiological activity: GABA is a non essential amino acid that functions as a neurotransmitter in the central nervous system by decreasing neuron activity, while ornithine is a precursor in the synthesis of arginine. All the analysed samples contain these amino acids, but in

Table 4
Contents of unusual amino acid in edible mushrooms (mg/100 g). Data are means of triplicates ± standard deviation

Edible mushrooms		GABA		ORN	
		d.w.	w.w	d.w.	w.w
P. ostreatus	(SMR 122)	14.3 ± 2.4	2.1 ± 0.4	251.7 ± 23.2	37.1 ± 3.4
P. ostreatus	(SMR 125)	19.1 ± 7.3	2.2 ± 0.8	391.8 ± 53.8	44.4 ± 6.1
P. ostreatus	(SMR 127)	60.6 ± 7.8	5.2 ± 0.7	88.7 ± 14.8	7.6 ± 1.3
P. ostreatus	(SMR 128)	391.3 ± 4.0	27.3 ± 0.3	273.6 ± 17.5	16.6 ± 1.2
P. ostreatus	(SMR 129)	280.8 ± 29.1	18.3 ± 1.9	211.9 ± 23.7	13.8 ± 1.6
P. ostreatus	(SMR 131)	189.8 ± 7.7	14.3 ± 0.6	153.4 ± 2.3	11.5 ± 0.2
P. ostreatus	(SMR 132)	205.8 ± 13.2	10.9 ± 0.7	131.0 ± 15.4	6.9 ± 0.8
P. ostreatus	(SMR 138)	10.2 ± 2.3	1.3 ± 0.3	383.5 ± 27.7	51.7 ± 3.7
P. pulmunarius	(SMR 126)	165.4 ± 25.6	20.4 ± 2.9	111.1 ± 26.1	13.7 ± 3.2
P. eryngii	(SMR 172)	53.3 ± 10.8	4.4 ± 0.9	844.8 ± 68.3	70.2 ± 5.7
P. eryngii	(SMR 173)	54.6 ± 8.1	4.7 ± 0.7	666.5 ± 60.3	56.9 ± 5.2
P. eryngii ferulae	(SMR 133)	16.3 ± 3.0	1.9 ± 0.4	154.0 ± 12.8	18.3 ± 1.5
L. edodes	(SMR 90)	21.2 ± 0.9	2.1 ± 0.8	359.3 ± 26.4	35.0 ± 2.6

d.w. = dry weight; w.w = wet weight.

different amount and, apparently, without any correlation with mushroom species.

In order to obtain a nutritional evaluation of the quality of proteins from mushroom, a comparison between the fungal essential amino acids and the human requirements was performed. The levels of essential amino acid in *P. ostreatus* and in the other mushrooms studied, calculated as percentage of the relevant levels of the FAO pattern, are reported in Figs. 1 and 2, respectively. The limiting amino acid, i.e. the amino acid less effective in providing the amount stated by the FAO reference pattern, is leucine and/or lysine in *P. ostreatus* samples, leucine in *P. eryngii* and *P. pulmunarius* and lysine in *L. edodes*. However, the protein chemical score, i.e. the percentage of the FAO recommended level provided by the limiting amino acid, is generally high and varies from 110 to 96% in *P. ostreatus* and from 111 to 102% in *P. eryngii* confirming the good biological value of fungal proteins. On the other hand, a low chemical score (53%) can be calculated for the protein of *P. pulmunarius* but the limited number of samples studied does not allow us to generalise this result.

Table 5 shows the ash and mineral contents of the samples analysed. The total ash contents range from 6.9 to 10.5% on a dry basis and from 0.52 to 1.15% on wet weight. As regards the mineral constituents, in

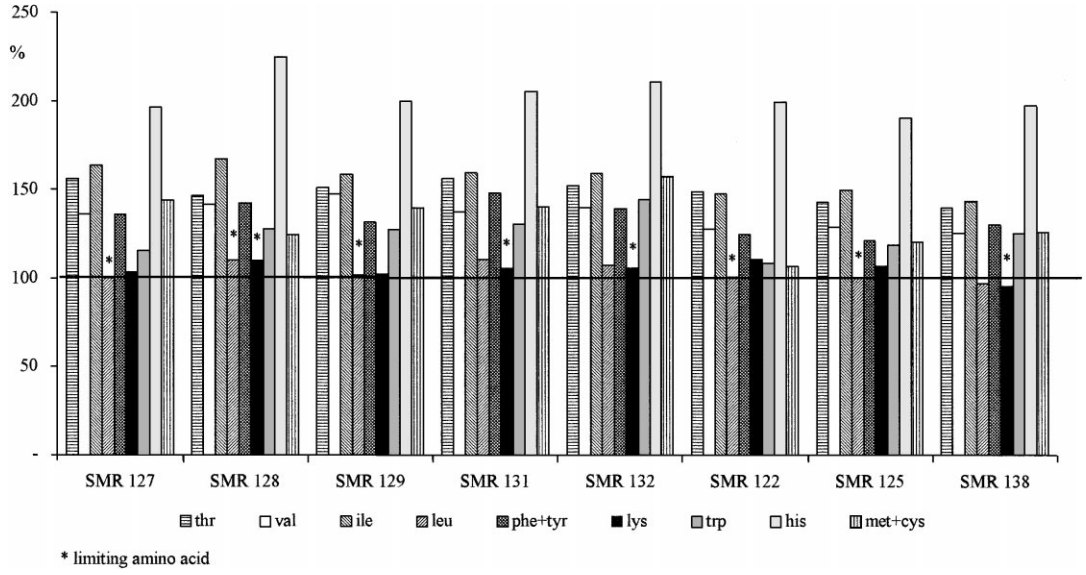

Fig. 1. Levels of essential amino acids calculated as % of the relevant levels of FAO pattern in *P. ostreatus*.

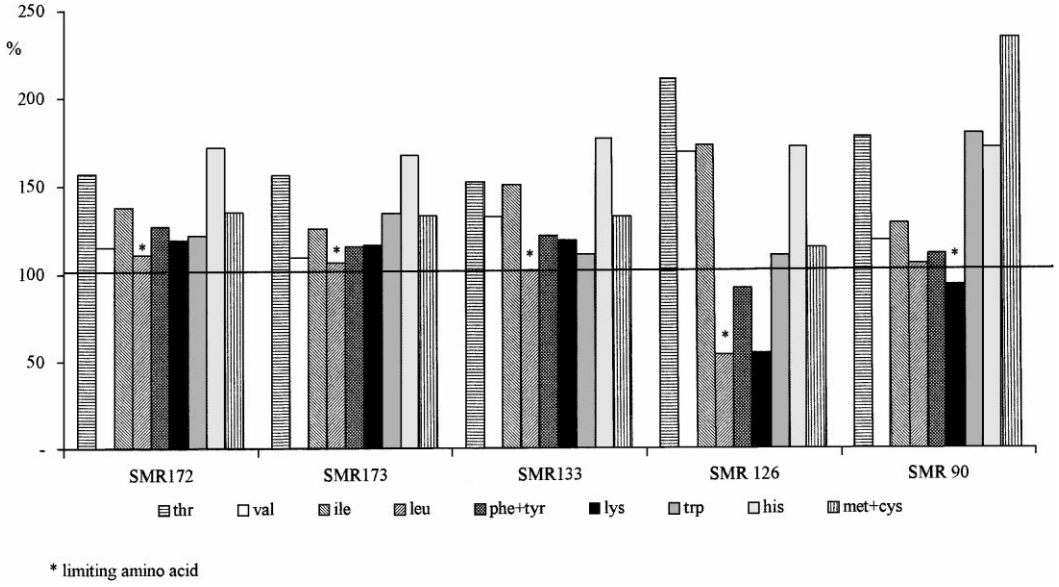

Fig. 2. Levels of essential amino acids calculated as % of the relevant levels of FAO pattern in *P. eryngii* (SMR 172, SMR 173, SMR 133), *P. pulmunarius* (SMR 126) and *L. edodes* (SMR 90).

Table 5
Ash (g/100 g) and mineral (mg/100 g) contents of edible mushrooms. Data are means of triplicates ± standard deviations

Edible mushrooms		ASH		Na		K		Mg		Ca	
		d.w.	w.w.	d.w.	w.w.	d.w.	w.w.	d.w.	w.w.	d.w.	w.w.
P. ostreatus	(SMR 122)	7.80 ± 0.74	1.15 ± 0.11	136.0 ± 4.6	20.1 ± 0.7	2682.3 ± 53.0	395.9 ± 7.8	166.1 ± 2.3	24.5 ± 0.3	23.5 ± 1.8	3.5 ± 0.3
P. ostreatus	(SMR 125)	7.99 ± 0.87	0.91 ± 0.10	84.9 ± 12.8	9.6 ± 1.5	2338.2 ± 45.2	270.8 ± 5.1	177.9 ± 5.6	20.2 ± 0.6	34.3 ± 1.1	3.9 ± 0.1
P. ostreatus	(SMR 127)	8.49 ± 1.40	0.73 ± 0.12	53.5 ± 0.2	4.6 ± 0.1	2965.2 ± 143.0	253.8 ± 12.3	166.4 ± 1.3	14.2 ± 0.1	23.6 ± 0.4	2.0 ± 0.1
P. ostreatus	(SMR 129)	9.13 ± 0.65	0.60 ± 0.04	57.4 ± 0.5	3.7 ± 0.1	3365.0 ± 73.0	219.0 ± 48.0	203.2 ± 1.4	13.2 ± 0.1	48.6 ± 1.5	3.2 ± 0.1
P. ostreatus	(SMR 132)	9.70 ± 1.30	0.52 ± 0.07	25.2 ± 5.7	1.3 ± 0.3	3443.8 ± 109.0	182.5 ± 5.8	161.4 ± 10.0	8.6 ± 0.5	25.9 ± 7.5	1.4 ± 0.4
P. ostreatus	(SMR 138)	6.89 ± 0.72	0.93 ± 0.10	48.3 ± 3.2	6.5 ± 0.4	2184.6 ± 67.0	284.5 ± 9.0	165.3 ± 3.1	22.3 ± 0.4	23.6 ± 8.2	3.2 ± 1.1
P. pulmunarius	(SMR 126)	8.35 ± 0.77	1.03 ± 0.09	103.4 ± 2.1	12.7 ± 0.3	2818.9 ± 36.0	346.7 ± 4.4	183.8 ± 2.0	22.6 ± 0.3	19.1 ± 2.1	2.3 ± 0.3
P. eryngii ferulae	(SMR 133)	8.61 ± 0.17	1.00 ± 0.02	44.1 ± 6.2	5.2 ± 0.7	2611.0 ± 87.0	309.0 ± 10.3	134.5 ± 7.0	16.0 ± 0.8	28.4 ± 12.1	3.7 ± 1.5
P. eryngii	(SMR 172)	9.16 ± 0.26	0.76 ± 0.02	50.4 ± 1.1	4.2 ± 0.1	3095.0 ± 40.0	257.3 ± 3.4	144.4 ± 15.6	12.0 ± 0.3	33.7 ± 0.4	2.8 ± 0.1
P. eryngii	(SMR 173)	10.55 ± 0.31	0.90 ± 0.03	76.6 ± 2.8	6.5 ± 0.2	4054.3 ± 244.2	346.5 ± 20.9	187.2 ± 12.1	16.0 ± 1.0	35.3 ± 6.5	3.0 ± 0.4
L. edodes	(SMR 90)	7.08 ± 0.33	0.71 ± 0.03	100.6 ± 1.0	10.1 ± 0.1	2647.5 ± 5.2	264.7 ± 6.8	116.5 ± 5.2	11.6 ± 0.5	42.3 ± 1.8	4.2 ± 0.2

agreement with other literature data (Fasiki & Ekuere, 1993), the most abundant mineral element is potassium (ranging from 2185 to 3444 mg/100 g on dry weight) followed by magnesium, while the most variable mineral is sodium. Calcium levels are not so high in mushrooms (ranging from 19.1 to 48.6 mg/100 g dry weight) and in particular, in *P. pulmunarius* a very low level of calcium (19.1mg/100g dry basis) is evident, but a single sample does not allow an extrapolation of general validity for the species, even if the level of the sodium, magnesium and potassium seems to be in the range of variability of the other mushrooms.

The low concentration of sodium and the presence of a great amount of potassium suggest the utilisation of mushrooms in an anti-hypertensive diet, in fact potassium from fruit and vegetables can lower blood pressure. The content of potassium in mushrooms ranges from 182 to 395 mg/100 g on an "as is" basis while the recommended daily intake is 3100 mg/day (LARN, 1996). Because of this, the percent contribution of a 100g portion of mushrooms to the recommended daily intake of potassium can range from 6 to 13%.

In conclusion, mushrooms, in spite of the great variability observed among species, represent an interesting food item that can contribute to the formulation of a well-balanced diet.

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