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Basic Composition and Amino Acid Contents of Mushrooms Cultivated in Finland

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The basic composition (moisture, total carbohydrates, dietary fiber, crude fat, ash, nitrogen, and protein) and amino acid contents were determined in the cultivated mushrooms *Agaricus bisporus*/white, *Agaricus bisporus*/brown, *Lentinula edodes,* and *Pleurotus ostreatus*. In addition, nitrogen-to-protein conversion factors were calculated for each species by dividing the sums of amino acid residues with total (Kjeldahl) nitrogen contents. The dry matter contents of mushrooms varied from 7.7% to 8.4%. The dry matter of mushrooms contained large amounts of carbohydrates, from 4.5 (*A. bisporus*/white) to 5.8 g/100 g fresh weight (*L. edodes*). *L. edodes* proved to be an especially good source of dietary fiber (3.3 g/100 g fresh weight); the other mushrooms contained 1.5−2.4 g/100 g fresh weight. Crude fat, ash, and protein (based on amino acid analysis) contents of the mushrooms varied 0.31−0.35, 0.49−0.78, and 1.8−2.09 g/100 g fresh weight, respectively. Mushrooms proved to be good sources of almost all essential amino acids when compared with common vegetables. The mean nitrogen-to-protein conversion factor analyzed in the present study was 4.7 ± 0.21. When using this factor, a very good estimation of protein contents could be obtained for the main species of mushrooms cultivated in Finland.

KEYWORDS: Mushrooms; basic composition; moisture; carbohydrates, dietary fiber; fat; ash; nitrogen; protein; amino acids

INTRODUCTION

Mushroom production has increased massively during recent years. In 1997 the annual world production of cultivated mushrooms was 6.34 million metric tons, compared with only 4.92 million metric tons in 1994 (*1*). In 1993 the countries producing the largest amounts of cultivated mushrooms were China, the United States, Japan, France, Holland, the United Kingdom, and Italy, in that order (*2*).

In Finland the commercial cultivation of mushrooms was begun in late 1940 with *Agaricus bisporus*. At present, mainly four mushroom cultivars are cultivated in Finland: two varieties of the button mushroom (*Agaricus bisporus*/white and *Agaricus bisporus*/brown), shiitake (*Lentinula edodes*), and the oyster mushroom (*Pleurotus ostreatus*). Mushroom production was 1 622 500 kg in 1999, which was 260 000 kg more than in the previous year (*3*).

From the available data it is known that mushrooms are nutritious foods. Compared with vegetables they are high in protein and have a good balance of vitamins and minerals. They contain little fat and digestible carbohydrate, making them suitable for low-calorie diets (*4*). However, the results of analyses vary widely for all constituents. This variation can be caused by differences in strain, substrate, and the developmental stage of the mushroom. Furthermore, cultivation, watering, fruiting, and storage conditions affect the contents of biologically active compounds (*2*, *5*, *6*). Because of developments in cultivation techniques, which in turn affect the nutrient contents in mushrooms, new data are needed. In addition, systematic nutrient analyses of Finnish mushrooms have not previously been performed.

The aim of the present study was to determine the basic composition of mushrooms commonly cultivated in Finland as well as the contents of amino acids. Another aim was to verify the protein determination methods used (Kjeldahl versus amino acid base analyses). The present study is a continuation of one previously published, dealing with vitamins, mineral elements, and phenolic compounds (*7*).

MATERIALS AND METHODS

Sampling. Samples of *P. ostreatus*, *A. bisporus*/brown, *A. bisporus*/white, and *L. edodes* were donated by major mushroom producers in Finland. Developmental stages of the mushrooms paralleled those of normal commercial products. Similarly, only pilei with very short stalks

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Table 1. Basic Composition of Cultivated Mushrooms (on Fresh Weight Basis)

mushroom	protein g/100 g	total carbohydrates g/100 g[a]	dietary fiber g/100 g	energy kcal/100 g[a]	crude fat g/100 g	ash g/100 g	dry matter %
Agaricus bisporus/white	2.09	4.5	1.5	27	0.33	0.78	7.7
Agaricus bisporus/brown	2.07	4.6	1.6	27	0.31	0.78	7.8
Pleurotus ostreatus	1.97	5.0	2.4	28	0.35	0.64	8.0
Lentinula edodes	1.8	5.8	3.3	30	0.31	0.49	8.4

[a] Calculated values.

were taken as samples. Each species (1.5 kg) was cut into 1-cm^3 cubes, mixed, packed into 300-mL plastic containers (each with 50−70 g), freeze-dried, and stored at −18 °C. Prior to every analysis the contents of 1−2 containers were homogenized. Analyses were performed from the freeze-dried samples in duplicate or triplicate. These samples were the same as those used in our previous study concerning other nutrient contents in mushrooms (*7*).

Analytical Methods. *Moisture.* To obtain moisture contents, samples of the mushrooms were weighed before and after freeze-drying. The residual moisture was determined by drying at 105 °C overnight (17 h).

Nitrogen. The nitrogen contents of the samples were determined as a boric acid application using a Kjeltec Auto 1030 analyzer according to the Association of Official Analytical Chemists (AOAC) method (*8*).

Crude Fat. The fat content of the samples was determined with the Twisselman method, using diethyl ether as a solvent (*8*).

Total Carbohydrates. The content of total carbohydrates was calculated with the following formula: total carbohydrates (%/fresh weight (FW)) = 100 − moisture (%) − protein content (%/FW) − crude fat (%/FW) − ash (%/FW) = total carbohydrates (g/100 g FW).

Ash. The ash content was analyzed by weighing the samples before and after burning at 500 °C overnight (17 h).

Energy. The energy content was calculated with the following factors: protein 4.0 kcal/g; fat 8.37 kcal/g; and carbohydrates 3.48 kcal/g (*9*).

Dietary Fiber. The total dietary fiber from the mushrooms was determined according to Lee et al. (*10*).

Amino Acids. The total protein amino acids were analyzed according to the method established by the European Commission (*11*). Amino acids were determined by reaction with ninhydrin using a Biochrom 20 amino acid analyzer (Pharmacia Biotech, Cambridge, England) equipped with a 90 × 4.6 mm PEEK sodium pre-wash column and 250 × 4.6 mm Bio PEEK sodium high performance column (Pharmacia Biotech, Cambridge, England) after acid hydrolysis (6 M HCl, 110 °C, 24 h). The sulfur-containing amino acids cyst(e)ine and methionine were oxidized with performic acid (0 °C, 16 h) to cysteic acid and methionine sulfone prior to acid hydrolysis and calculated as cystine and methionine, respectively. The hydrolysis acid contained 1 mg of phenol/mL of acid to protect labile amino acids, especially tyrosine and phenylalanine, both of which were determined in hydrolysates of unoxidized samples. Other amino acids were determined as mean values of the oxidized and unoxidized samples. Tryptophan is all but destroyed in acid hydrolysis, and was not determined in this study.

The net protein contents of *P. ostreatus*, *A. bisporus*/brown, *A. bisporus*/white, and L. *edodes* were evaluated by summing the amino acid residues of each species. In addition, nitrogen-to-protein (NP) conversion factors were calculated for each species by dividing the sums of amino acid residues with the total (Kjeldahl) nitrogen contents.

RESULTS AND DISCUSSION

Moisture. When the nutritional value of mushrooms is evaluated, perhaps the most important factor is their dry matter/moisture content, which directly affects the nutrient contents of mushrooms. For example, the moisture content of *A. bisporus* varied in one study from 87.2% to 93.5%, a difference of 6.3%. This may seem of little significance; however, the dry matter varied from 6.5% to 12.5%. Hence, the latter will contain 1.97 times as much nutrients as the other (*4*).

As shown in **Table 1** there was very low variation in the dry matter contents of the mushrooms analyzed in this study (from 7.7% for *A. bisporus*/white to 8.4% for *L. edodes*). These figures are in accordance with earlier-published data: according to Kurzman (*4*), Crisan and Sands (*9*), Bano and Rajaratham (*12*), and Manzi et al. (*13*) fresh mushrooms contained 5−15% dry matter. Variation in water contents could be caused by different factors; e.g., Laborde and Delpech (*6*) concluded that dry matter content is strain-related in *A. bisporus* and varies during the cropping period. In addition, heavy watering had a reducing effect on the mushroom dry weight. Furthermore, the moisture content can be affected by environmental factors such as temperature and relative humidity during growth and storage, as well as by the relative amount of metabolic water that may be produced (or utilized) during storage (*9*).

Energy. Mushrooms are low-energy foods, and their energy values varied from 27 to 30 kcal/100 g (**Table 1**). The energy value of a food can be estimated based on its content of crude protein (N × 6.25), fat, and carbohydrate using Atwater factors of 4.0, 9.1, and 4.2 kcal/g per component, respectively. In mushrooms, however, these components are not 100% digestible, and conversion factors of 2.62, 8.37, and 3.48 kcal/g are usually used to correct for the reduced digestibility of protein (70%), fat (90%), and carbohydrate (85%) (*9*). Because the protein results in the present study were net protein values instead of crude protein, 4.0 kcal/g of protein is used here.

Total Carbohydrates. The dry matter of mushrooms contains large amounts of carbohydrate, which, according to the present and previously published data, constitutes the major part of mushroom nutrients. The carbohydrates in mushrooms include polysaccharides such as glucans, mono- and disaccharides, sugar alcohols, glycogen, and chitin (*4*). According to data compiled by Walker (*14*) and Beelman and Edwards (*15*), *A. bisporus* contained 46−60% carbohydrates in dry matter or 2.45−5.75 g/100 g fresh mushrooms, respectively. The carbohydrate contents of *L. edodes* varied 67.5−78% on a dry weight basis (*9*, *12*) and that of *P. ostreatus* varied 46.6−81.8% (*12*, *16*, *17*). Generally, our results were in accordance with earlier-published data; the lowest carbohydrate contents were found in *A. bisporus* (4.5 g/100 g FW or 58% of dry matter), and highest carbohydrate content was found in *L. edodes* (5.8 g/100 g FW or 69% of dry matter; **Table 1**).

Dietary Fiber. The dietary fiber in mushrooms is primarily composed of chitin. Chitin is a polymercomprising *N*-acetyl-glucosamine units and is a constituent of cell walls of most fungi (*2*). Chitin is a relatively unusual dietary material, and studies of its dietary effects have been limited (*4*). It may, however, have important physiological properties with respect to human health (*18*). Furthermore, some dietary fiber substances, e.g., beta-glucans, have shown powerful antitumor,

Table 2. Calculated Protein (P), Net Protein (NP), and Nitrogen (N) Contents of Mushrooms (g/100 g Fresh Weight), Calculated Nitrogen-to-Protein Factors (NP Factor), and Percentage Difference between Calculated and Net Protein Contents (difference %; P − NP)

mushroom	P (N × 4.7)	NP	NP factor	N	difference % (P − NP)
P. ostreatus	1.87	1.97	4.97	0.40	5.1
A. bisporus, brown	2.13	2.07	4.55	0.45	2.9
A. bisporus, white	2.09	2.09	4.70	0.45	0
L. edodes	1.88	1.80	4.50	0.40	4.4

antimutagenic, and anticancer activity through their stimulatory effects on the immune system (*19, 20*).

According to previously published data the variation in dietary fiber results are large, and much of this variation is caused by the analytical methodology used. Both the AOAC enzymatic−gravimetric and Uppsala methods are frequently used to determine dietary fiber contents in foods. However, when the AOAC method is applied for mushrooms, the correction for residual protein based on the nitrogen content in the fiber residue is interfered with by the presence of nonprotein nitrogen originating from chitin (*18, 21*). If a chitin correction is not applied the dietary fiber results would be approximately 10% lower than that obtained when applying the chitin correction (as calculated from the data of Cheung; *18, 21*).

According to the present study performed with the AOAC method (without chitin correction), *P. ostreatus* (2.4 g/100 g FW; 30% of dry matter) and especially *L. edodes* (3.3 g/100 g FW; 39.3% of dry matter) proved to be moderately good sources of dietary fiber, whereas *A. bisporus*/white and *A. bisporus*/brown contained lower levels, 1.5 (19% of dry matter) and 1.6 g/100 g FW (21% of dry matter), respectively (**Table 1**). Cheung (*18, 21*) obtained similar results for *L. edodes* and *A. bisporus* using the AOAC method (with chitin correction); the caps of these mushrooms contained 36.6% and 18.2% dietary fiber in dry matter, respectively. With the Uppsala method the results were somewhat lower: 32.4% (*L. edodes*) and 13.2% (*A. bisporus*) of dry matter.

Fat. Crude fat in mushrooms includes representatives of all classes of lipid compounds, including free fatty acids, mono-, di-, and triglycerides, sterols, sterol esters, and phospholipids (*9*). Of the sterols, various species are especially high in ergosterol, which is the precursor of vitamin D_2 (ergocalciferol; *22*).

There was low variation in crude fat contents in the mushrooms analyzed. The contents expressed as g/100 g FW varied from 0.31 to 0.35 (**Table 1**), and on a dry matter basis the variation was from 3.7% to 4.4%. These figures are very similar to earlier-reported values: according to Huang et al. (*23*) and Beelman and Edwards (*15*) *A. bisporus* contained 3.1% fat in dry matter and 0.19−0.7% of FW, respectively. Previous results for *L. edodes* have varied from 1.3% to 8.0% of dry weight (*9, 23, 24*), *and* previous fat results for *P. ostreatus* have varied from 1.6% to 5.0% on a dry matter basis (*9, 16, 17*).

Ash. Ash contents varied from 0.48 g (*L. edodes*) to 0.78 g/100 g FW (*Agaricus* varieties; **Table 1**). The main constituents in the ash were K and P, whose combined percentage was about 60% (*7*). Our results agreed well with earlier-published data (*4, 9, 17*).

Nitrogen, Protein, and Amino Acids. In the present study the amount of nitrogen was 0.45 and 0.45 g/100 g for white and brown *A. bisporus*, respectively, 0.40 g/100 g for *P. ostreatus*, and 0.40 g/100 g for *L. edodes* (**Table 2**). Kurtzman (*4*) found wide variation in the nitrogen contents within different mushroom species and in some cases in mushrooms of the same species. In *A. bisporus* the amount of nitrogen varied from 0.43 to 0.79 g/100 g, but in *P. ostreatus* and *L. edodes* the variations were smaller: 0.25−0.34 g and 0.49−0.52 g/100 g, respectively (*4*).

Table 3. Amino Acid Contents of Mushrooms (mg/100 g Fresh Weight)

amino acid	*P. ostreatus*	*A. bisporus*/ brown	*A. bisporus*/ white	*L. edodes*
cystine	28	23	23	24
methionine	35	30	33	29
aspartic acid	293	270	275	190
threonine	106	102	111	98
serine	110	110	108	103
glutamic acid	364	478	431	355
proline	93	103	104	90
glycine	97	97	106	91
alanine	124	158	159	104
valine	112	120	121	124
isoleucine	82	85	91	79
leucine	139	142	153	133
histidine	65	54	58	56
lysine	126	127	143	122
arginine	179	108	116	127
tyrosine	219	292	283	265
phenylalanine	111	97	107	91

Table 4. Contents of Essential Amino Acids except Tryptophan (mg/100 g fresh weight) in Some Vegetables (*30*) and in Mushrooms Studied

amino acid	potato	carrot	cauliflower	mushrooms
isoleucine	77	29	88	79–82
leucine	110	38	130	133–153
lysine	120	35	120	122–143
methionine	29	9	31	29–35
cystine	17	1	15	23–28
phenylalanine	84	26	84	91–111
tyrosine	40	14	52	219–292
threonine	71	26	84	98–111
valine	120	43	140	112–124

Using analyzed nitrogen amounts in calculating protein contents in foods is very complicated. The protein content of a product is highly affected by the NP conversion factor used. In the fungi, relatively large amounts of nonprotein nitrogen are present, largely in the chitin of the cell walls as well as in free amino acids and in nucleic acids (*2*). Only 60−77% of the nitrogen in mushrooms is found in proteins (*2, 25, 26*), hence, the universally used NP factor of 6.25 is too high for mushrooms and should not be used. In the present study, NP conversion factors of 4.55 and 4.70 for *A. bisporus* (brown and white, respectively), 4.97 for *P. ostreatus*, and 4.50 for *L. edodes* were obtained (**Table 2**). The factor 4.50 for *L. edodes* is nearly the same as the 4.44 obtained by Fujihara et al. (*26*) for Japanese mushrooms; for *P. ostreatus* they obtained a factor of 4.15, which is remarkably lower than the 4.97 found in our study. Kurtzman (*4*) recommended a factor of 5.0 for *A. bisporus*, *P. ostreatus*, and *L. edodes*, which is somewhat higher than the value obtained here.

As described above, NP conversion factors are very specific for each species and the use of a single factor may lead to errors in protein values. However, the mean NP conversion factor for mushrooms analyzed in the present study was 4.7 ± 0.21. When using this factor, very good estimation of protein contents could be obtained for the main species of mushrooms cultivated in Finland. When comparing protein values obtained using this

factor with net protein values (sum of amino acid residues), which are probably nearest to the true values, differences were ≤ 5% (**Table 2**). Previously, somewhat lower universal NP conversion factors, 4.38 (70% N × 6.25; *2*, *9*) and 4.17 (*27*) were introduced for mushrooms.

Mushrooms proved to be good sources of protein compared with vegetables (**Tables 1** and **2**). The protein contents (net protein) of *A. bisporus*/white and *A. bisporus*/brown were 2.09 and 2.07 g/100 g, respectively, which were of the same magnitude as that found by Braaksma and Schaap (*28*), 2.04 g/100 g. For *P. ostreatus* a net protein content of 1.97 g/100 g was obtained. Fujihara et al. (*26*) and Tshinyangu and Hennebert (*29*) found widely varying protein values for *P. ostreatus*: 2.3 g/100 and 1.7 g/100 g, respectively. In the present study a protein value of 1.8 g/100 g was obtained for *L. edodes*, whereas Fujihara et al. (*26*) announced somewhat lower contents of 1.6 g/100 g.

The amino acid contents of the mushrooms studied (**Table 3**) were quite similar to those of Møller et al. (*30*), although slightly higher. Similarities were also found in the results of Haytowitz and Matthews (*31*), although the isoleucine, leucine, and lysine contents were somewhat lower and the tyrosine and cystine results were somewhat higher than those found in the present study. However, compared with common vegetables used in the Nordic countries such as potatoes, carrots, or cauliflower, mushrooms proved to be good sources of almost all essential amino acids. For instance, the amounts of the sulfur-containing amino acids threonine, tyrosine, and arginine are much higher in fungi than in the above-mentioned vegetables (**Table 4**; *30*).

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