Dietary Fiber Content and Composition of Some Cultivated Edible Mushroom Fruiting Bodies and Mycelia

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The mycelia and the caps and stalks of fruiting bodies of four edible mushrooms (*Lentinus edodes*, *Lycophyllum shimeji*, *Pleurotus sajor-caju*, and *Volvariella volvacea*) were analyzed for their total dietary fiber (TDF) content according to the Association of Official Analytical Chemists (AOAC) method and for TDF content and composition according to the Uppsala method. The nonprotein nitrogen attributable to chitin was corrected in the fiber residue obtained with the AOAC method. The TDF contents of all of the mushrooms as measured by the AOAC method were considerably greater than those determined by using the Uppsala method. Mushroom mycelia had higher TDF values than did the fruiting bodies as measured by both methods. The TDF composition of the mycelia and the TDF composition of the caps and stalks of the mushroom fruiting bodies were similar. Sugar composition reflected that β-glucans were the major fiber polysaccharide with chitin, hemicelluloses, and polyuronides as minor ones. Notably, one-third of the total sugar in the TDF of the mycelium of *L. shimeji* was galactose.

Keywords: *Edible mushrooms; fruiting bodies; mycelia; total dietary fiber; content; composition*

INTRODUCTION

Edible mushrooms, especially the Basidiomycetes, are widely utilized as human foods (Chang, 1980). However, attention is being paid at the present time to their use as a source of protein and flavoring materials. Fungal walls of Basidiomycetes contain chitin, which is a straight-chain $\beta(1-4)$-*N*-acetylglucosamine, and other hemicelluloses, such as β-glucans and mannans (Bartnicki-Garcia, 1968). Mushrooms are therefore a potential source of dietary fiber due to the presence of such nonstarch polysaccharides. Little information is available on the total dietary fiber (TDF) content and composition of edible mushrooms. Most literature values reported were based on the crude fiber or detergent fiber methods (Crisan and Sands, 1978; Kurasawa et al., 1982), which underestimated the TDF content of mushrooms. Traditionally, nutritional studies on edible mushrooms have focused on their fruiting bodies. Mushroom mycelia cultivated by submerged fermentation also have the potential to be used in human diet (Litchfield, 1967; El-Kattan et al., 1991). With regard to dietary fiber content and composition, there were even fewer data available on mushroom mycelia than mushroom fruiting bodies (Hadar and Cohen-Arazi, 1986).

Four cultivated edible mushrooms from the Basidiomycetes, namely *Lentinus edodes*, *Lycophyllum shimeji*, *Pleurotus sajor-caju*, and *Volvariella volvacea*, were selected for a detailed study of the fiber content and composition in both their fruiting bodies (separated into the cap and stalk tissues) and mycelia. Two methods of TDF analysis were used. First, the TDF was measured by using the AOAC enzymatic–gravimetric method (Prosky et al., 1988). However, when this method was applied to mushrooms (especially Basidiomycetes), the correction for residual protein based on the nitrogen content in the fiber residue was interfered with by the presence of nonprotein nitrogen originating from chitin. Measurement of the chitin content in the fiber residue is necessary to give accurate TDF results. Second, the TDF content and composition were measured by using the Uppsala method (Theander et al., 1994). This method, which is known as the enzymatic–chemical procedure, determines the dietary fiber composition in terms of monosaccharide composition and Klason lignin content. TDF values of the mushrooms obtained with the two methods are compared, and the significance of mushrooms as sources of dietary fiber is discussed.

MATERIALS AND METHODS

Materials. All edible mushroom species used in this study were obtained from the Departmental Mushroom Culture Collection. Mature fruiting bodies of the mushroom species were grown on regular lignocellulosic compost (sawdust for *L. edodes* and wheat straw for the rest). The cap tissue (pileus) and the stalk tissue (stipe) of the fruiting bodies were separated and thoroughly cleaned to remove any residual compost and then freeze-dried separately. Mycelia of these mushroom species were grown in flasks containing 300 mL of medium inoculated with 30 mL of homogenate of mycelia previously subcultured on potato dextrose agar plates. Cultures were incubated in a rotary shaker (New Brunswick Scientific, Edison, NJ) at 25 °C, pH 7, and 200 rpm for 7 days. The medium used in all fermentation experiments contained the following reagents (per liter): 24 g of potato dextrose broth (Difco Laboratory, Detroit, MI), 0.4 g of KH_2PO_4, 1 g of K_2HPO_4, 0.5 g of $MgSO_4$, and 2 g of asparagine. The mycelium was harvested by filtration through a glass fiber filter, washed with distilled water, and freeze-dried. All dried samples of mushroom mycelia and fruiting bodies were ground in a Cyclotech mill (Tecator, Hoganas, Sweden) and passed through a sieve of 0.5 mm. Samples were extracted prior to fiber analysis using petroleum ether (50 mL/g × 2; 15 min) with stirring if they contained more than 5% fat.

Dietary Fiber Analysis. Each of the four replicates of mushroom samples was analyzed using the AOAC TDF method (Prosky et al., 1988) to provide duplicate samples for nitrogen and ash determination. In brief, aliquots of samples (1 g of dry matter) were treated with two amylases, a heat stable α-amylase (EC 3.2.1.1, catalog no. A3306, Sigma Chemical Co., St. Louis, MO) for 15 min in a boiling water bath and an amyloglucosidase (EC 3.2.1.3, from *Aspergillus niger*, catalog no. A3513, Sigma) for 1 h at 60 °C to remove glycogen, and a protease (catalog no. P3910, Sigma) to solubilize protein. The amylase enzymes used had been tested to

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Table 1. Correction for Nonprotein Nitrogen from Chitin in the Fiber Residue Obtained by the AOAC Method Expressed as Percent of Dry Matter of Fiber Residue

					undigested protein	
mushroom species	chitin content[a]	chitin N[b]	total N[c]	net protein N[d]	in fiber residue[e]	in mushrooms[f]
L. edodes						
fb[g] caps (82.4)[h]	19.0	1.31	2.44	1.13	7.06	3.17
fb stalks (17.6)	17.3	1.19	2.07	0.88	5.50	2.90
mycelia	21.8	1.50	2.53	1.03	6.44	3.78
L. shimeji						
fb caps (30.3)	8.25	0.57	1.78	1.21	7.56	3.33
fb stalks (69.7)	9.02	0.62	1.39	0.77	4.81	1.89
mycelia	5.51	0.38	1.17	0.79	4.94	3.57
P. sajor-caju						
fb caps (88.5)	13.8	0.95	2.50	1.55	9.69	4.13
fb stalks (11.5)	11.9	0.82	1.55	0.73	4.56	1.92
mycelia	10.9	0.75	1.55	0.80	5.00	2.56
V. volvacea						
fb caps (63.4)	17.3	1.19	2.54	1.35	8.44	2.94
fb stalks (36.6)	17.0	1.17	2.03	0.86	5.38	1.84
mycelia	17.1	1.18	2.01	0.83	5.19	3.05

[a] Mean value of two measurements. [b] Chitin content divided by 14.5. [c] Kjeldahl nitrogen content of fiber residue. [d] Net protein N = total N − chitin N. [e] Net protein × 6.25. [f] Undigested protein expressed as percent of dry matter of mushrooms. [g] fb, fruiting bodies. [h] Expressed as percent of dry matter of fruiting bodies.

be free of β-glucanase. After a 78% ethanol precipitation, the ethanol-insoluble residue recovered by filtration was dried and weighed, and the weight was corrected for ash and residual protein content. The amount of chitin in the fiber residue was measured as glucosamine according to the colorimetric method of Ride and Drysdale (1972). The nonprotein nitrogen content in the fiber residue was determined by dividing the percentage of chitin by a factor of 14.5 based on the fact that there is 6.9% N in the natural chitin. Residual protein was calculated from the corrected nitrogen content multiplied by a factor of 6.25.

Each mushroom sample was analyzed in duplicate using a modified Uppsala procedure (Theander et al., 1994). In short, the sample (250−500 mg of dry matter) was pretreated with 78% ethanol to remove soluble free sugars. The ethanol-insoluble residue was incubated with thermostable α-amylase (EC 3.2.1.1, catalog no. A3306, Sigma) for 1 h in a boiling water bath and amyloglucosidase (EC 3.2.1.3, from *A. niger*, catalog no. A3513, Sigma) for 4 h at 60 °C to remove glycogen in a manner similar to the AOAC method but with longer incubation times and without the protease treatment. The residue recovered by filtration of 78% ethanol-insoluble precipitate was dried and subjected to sequential acid hydrolysis (12 M sulfuric acid for 1 h, 30 °C, and then 0.41 M sulfuric acid for 1 h at 125 °C by autoclaving). The hydrolysate was filtered through a Pyrex fritted disk glass crucible (pore size 40 μm), and the amount of insoluble residue was determined gravimetrically as Klason lignin after ashing. Alditol acetates of the neutral and amino sugars in the hydrolysate were prepared according to the method described by Blakeney et al. (1983) with β-D-allose as the internal standard. Alditol acetates were quantified by an HP5890 Series II gas chromatograph using an Alltech DB-225 capillary column (15 m × 0.25 mm i.d., 0.25 μm film) and the following oven temperature program: initial temperature, 180 °C; 2 °C/min to 210 °C; 5 °C/min to 220 °C; and 220 °C for 20 min. The carrier gas was hydrogen, and detection was by flame ionization. Individual sugars were corrected for losses during hydrolysis and derivatization and for the response on the GLC. The values for monosaccharides were expressed as polysaccharide residues (anhydrosugars) by multiplying the amounts of pentoses and deoxypentoses by a factor of 0.88 and of hexoses by a factor of 0.90. The uronic acid content was determined colorimetrically using *m*-hydroxydiphenyl with D-galacturonic acid monohydrate as the standard and expressed as a polysaccharide residue by multiplying by a factor of 0.91 (Blumenkrantz and Asboe-Hansen, 1973) instead of the original decarboxylation procedure. TDF was calculated as the sum of neutral and aminopolysaccharide residues, uronic acid residues, and Klason lignin.

RESULTS AND DISCUSSION

Since the fat content of the mushroom samples was less than 5% dry matter (data not shown), no defatting procedure was required. The relative proportions of the caps and stalks of the mushroom fruiting bodies are shown in Table 1. With the exception of *L. shimeji*, the caps constituted more than 60% of the fruiting bodies in all mushroom species.

Correction of Nonprotein Nitrogen. The TDF content measured by using the AOAC method requires correction for the ash and undigested protein that remain in the fiber residue. In mushrooms, the amounts of nonprotein nitrogen from chitin need to be subtracted from the total nitrogen in the fiber residue. Table 1 shows the calculations of such correction. The chitin contents of the fruiting bodies and mycelia within each mushroom species were similar except in *L. shimeji*, in which the mycelia had only half the amount of chitin (5.5%) compared to its fruiting bodies. The relative amounts of chitin N present in the total N of the fiber residue ranged from 32% in the caps of the fruiting body of *L. shimeji* to 59.3% in the mycelia of *L. edodes*. The results suggested that fungal chitin contributes significantly to the nonprotein nitrogen present in the fiber residue. The amounts of undigested protein after chitin N correction varied between 4.6% and 9.7% and between 1.7% and 3.7% of the fiber residue and mushroom sample, respectively.

TDF Content Determined According to the AOAC Method. Table 2 shows the TDF content of the mushrooms obtained by using the AOAC method after correction of undigested protein, ash, and reagent blank (Prosky et al., 1988). Generally, the contributions of ash content were less than 10% of the fiber residue, except in the caps of the fruiting bodies of *V. volvacea* (18.9%). The reagent blank accounted for less than 3% of the fiber residue. The AOAC TDF content varied from 24.03% in the caps of the fruiting bodies of *V. volvacea* to 62.51% in the mycelia of *L. shimeji*. All mushroom mycelia had consistently higher TDF values than their corresponding fruiting bodies. There was little difference in the TDF content between the caps and stalks of the mushroom fruiting bodies except in *L. edodes*, of which the stalks of the fruiting bodies had larger amounts of TDF than the caps.

Table 2. Gravimetric Composition of Mushroom Fiber Residue and Corrected Values for TDF Expressed as Percent of Dry Matter of Mushrooms

mushroom species	gravimetric fiber residue[a]	undigested protein[b]	ash[c]	blank[d]	TDF[e]
L. edodes					
fb caps	44.9	3.17	4.04	1.01	36.6
fb stalks	52.7	2.90	3.77	1.01	45.0
mycelia	58.8	3.78	4.05	1.01	49.9
L. shimeji					
fb caps	44.0	3.33	3.47	1.13	36.1
fb stalks	39.2	1.89	3.60	1.13	32.6
mycelia	72.2	3.57	4.97	1.13	62.5
P. sajor-caju					
fb caps	42.6	4.13	4.44	0.95	33.1
fb stalks	42.2	1.92	3.79	0.95	35.5
mycelia	51.3	2.56	3.02	0.95	44.7
V. volvacea					
fb caps	34.9	2.94	6.60	1.11	24.2
fb stalks	34.2	1.84	3.02	1.11	28.2
mycelia	58.8	3.05	4.75	1.11	49.9

[a] Mean values of four measurements. [b] From the last column of Table 1. [c] Average of two measurements. [d] Blanks were run along each mushroom species in quadruplicate. [e] TDF = fiber residue − protein − ash − blank.

Table 3. Chemical Composition of TDF Obtained by the Uppsala Method of Mushrooms Expressed as Percent of Dry Matter

mushroom species	neutral and amino sugars[a]	uronic acids[a]	Klason lignin[a]	TDF by Uppsala[b]	TDF by AOAC[c]
L. edodes					
fb caps	30.1	0.49	1.83	32.4	36.6
fb stalks	37.1	0.72	2.13	40.0	45.0
mycelia	41.9	0.35	2.11	44.4	49.9
L. shimeji					
fb caps	28.9	0.85	1.69	31.5	36.1
fb stalks	26.8	0.59	1.98	29.3	32.6
mycelia	50.2	0.32	2.03	52.5	62.5
P. sajor-caju					
fb caps	25.6	0.66	2.76	29.1	33.1
fb stalks	27.0	0.84	3.11	30.9	35.5
mycelia	36.3	0.69	2.97	40.0	44.7
V. volvacea					
fb caps	20.3	0.45	2.11	22.8	24.2
fb stalks	21.4	0.37	2.53	24.3	28.2
mycelia	42.8	0.43	2.19	45.4	49.9

[a] Data are mean values of two measurements. [b] TDF = neutral/amino sugars + uronic acids + Klason lignin. [c] Data cited from Table 2 for comparison.

TDF Content Determined According to the Uppsala Method. The chemical composition of the TDF obtained by using the Uppsala method (Theander et al., 1944) is shown in Table 3. Neutral and amino sugars were the predominant sugar components found in the mushroom TDF and ranged from 88.1% in the stalks of the fruiting bodies of *V. volvacea* to 95.5% in the mycelia of *L. shimeji*. The contribution of Klason lignin to fiber residue ranged from 3.9% in the mycelia of *L. shimeji* to 10.4% in the stalks of the fruiting bodies of *V. volvacea*. Uronic acids constituted a very minor component in the TDF (less than 3% dry matter of fiber residue). Similar to the AOAC results, all mushroom mycelia analyzed with the Uppsala method had higher TDF values than did the fruiting bodies whose caps and stalks differed only slightly in the TDF content.

Comparison of the TDF Values Obtained with the AOAC and Uppsala Methods. The TDF values of all of the mushroom samples determined according to the AOAC method were higher than those of the Uppsala method (within 20% limit) as shown in Table 3. Such discrepancies ranged from 5.4% in the mycelium of *V. volvacea* to 19.0% in the mycelium of *L. shimeji*. The consistently higher TDF values obtained with the AOAC method may be due to two reasons. First, free sugars, such as trehalose, mannitol, and glucose (Birch, 1976; Holtz, 1971), were coprecipitated with the fiber polysaccharides when ethanol was used to recover the fiber residue. The 78% ethanol extraction in the modified Uppsala method eliminated the interference of these free sugars. Second, incomplete hydrolysis of glycogen may contribute to the higher AOAC TDF values. The use of relatively shorter incubation times for α-amylase and amyloglucosidase in the AOAC procedure (15 min and 1 h, respectively) compared to the Uppsala method (1 and 4 h, respectively) may not be long enough for complete removal of the glycogen. Previous studies on mushroom fiber content were very limited, and the methods used were either the crude fiber procedure (Crisan and Sands, 1978) or the detergent fiber method (Kurasawa et al., 1982). For the fruiting bodies of *L. edodes*, crude fiber content ranged from 6.5% to 14.7% dry matter (Crisan and Sands, 1978), and neutral detergent fiber content varied from 34.8% to 44.8% dry matter (Kurasawa et al., 1982). Literature data on the fiber content of mushroom mycelia were not available. With regard to TDF content of the fruiting bodies and mycelia, *V. volvacea* and *P. sajor-caju* had the least amounts, respectively.

TDF Composition According to the Uppsala

Table 4. Monosaccharide Composition of TDF Determined by the Uppsala Method of Mushrooms Expressed as Percent of Total Polysaccharide Sugars[a]

mushroom species	rhamnose	xylose	mannose	galactose	glucose	glucosamine	uronic acids
L. edodes							
fb caps	nd[b]	1.92	5.21	3.30	70.8	15.0	3.75
fb stalks	0.65	1.47	5.23	1.77	73.9	13.9	3.12
mycelia	1.72	3.71	6.30	8.09	60.2	17.7	2.32
L. shimeji							
fb caps	1.28	5.18	5.38	3.16	71.6	7.66	5.72
fb stalks	1.41	3.17	4.40	3.43	73.2	9.23	5.19
mycelia	nd	nd	nd	32.6	60.1	5.89	1.35
P. sajor-caju							
fb caps	nd	1.14	5.12	3.47	78.2	7.90	4.17
fb stalks	nd	0.62	3.77	2.01	82.8	6.50	4.34
mycelia	nd	1.06	4.15	1.88	84.8	4.73	3.34
V. volvacea							
fb caps	nd	nd	6.22	4.48	70.5	13.9	4.91
fb stalks	nd	nd	6.01	4.11	72.0	13.1	4.73
mycelia	nd	nd	2.69	4.95	79.9	11.0	1.43

[a] Data are mean values of two measurements. [b] nd, not detected.

Method. The monosaccharide composition of the mushroom TDF obtained by using the Uppsala method is shown in Table 4. Glucose was the most predominant sugar (ranging from 60% to 85%) in all of the mushroom samples, and this reflected β-glucans as the most abundant cell wall polysaccharide. The presence of other sugars, such as xylose, mannose, galactose, uronic acids, and rhamnose, reflected hemicelluloses, such as glucuronoxylomannan, polyuronides, and mannogalactan (Misaki et al., 1986). The sugar compositions of the caps and stalks of the fruiting bodies in each mushroom species were very similar. There were some variations in the sugar composition of the mushroom mycelia compared to their fruiting bodies. The galactose contents in the mycelia of *L. shimeji* and *L. edodes* were 32% and 8%, respectively, which were much higher than the amounts found in their fruiting bodies. On the other hand, the glucose content in their mycelia was significantly lower than that of the fruiting bodies. The amounts of chitin (as reflected from glucosamine content) in *L. edodes* and *V. volvacea* were greater than those of *L. shimeji* and *P. sajor-caju*.

The above results showed that both mushroom fruiting bodies and mycelia were rich in dietary fiber. Work is now being carried out to isolate, characterize, and evaluate the dietary fiber component of these mushrooms.

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