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Nutritive value of popular wild edible mushrooms from northern Thailand

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Abstract

The nutritive (and market) value of sporocarps of edible wild ectomycorrhizal fungi from northern Thailand was determined. Protein, fat, crude fibre and carbohydrate concentrations were 14.0–24.2, 2.7–9.5, 8.3–16.8, and 41.6–65.1% dry weight, respectively. Mineral contents were: macronutrients (mg/g dry wt.) P 2.1–8.1, K 12.8–45.2, S 1.1–6.1, Ca 0.1–2.4, Mg 0.5–1.6; micronutrients (mg/kg dry wt.) Fe 162–3254, Zn 37.8–253, Mn 13.0–329, Cu 11.6–81.1, B 1.6–7.1, and Se 0–12.6. The main sporocarp sugars were D-glucose, D-fructose, trehalose, D-mannose, D-arabinose, D-xylose, D-fucose, L-rhamnose, and D-galactose. The sugar alcohol components were mannitol, glycerol, myo-inositol, meso-erythritol, D-arabitol, dulcitol, xylitol, and D-sorbitol.

Keywords: Wild mushrooms; Ectomycorrhizal fungi; Sugar; Sugar alcohols; Nutritive value; Minerals

1. Introduction

Mushrooms are traditionally used by many Asian communities for food and medicine. All of the studied mushrooms were collected from the wild where they form symbiotic associations (ectomycorrhizas) and fruit in association with indigenous tree families (Dipterocarpaceae, Fagaceae, Pinaceae and Ulmaceae) in the region. In general, cultivated mushrooms have higher protein contents than most vegetables, are rich in minerals, low in fat—the fat fraction is mainly composed of unsaturated fatty acids—and rich in the B vitamins, vitamin D, vitamin K, and sometimes vitamins A and C (Arora, 1986; Manzi, Aguzzi, & Pizzoferrato, 2001; Mattila et al., 2001; Yildiz, Karakaplan, & Aydin, 1998). Thus mushrooms are valuable food resources, providing dietary fibre but contributing few calories to the diet.

Unlike the cultivated, non-mycorrhizal mushrooms, such as *Volvariella* spp., *Lentinus edodes*, *Pleurotus* spp., *Auricularia* spp., and *Agaricus* spp., which are available throughout the year in markets of northern Thailand, edible wild mushrooms are common only in the wet season, which occurs from June to October. The ectomycorrhizal (ECM) fungi are collected by local people in remnant secondary stands of hillside forests and sold in road-side, local, and city markets. Although the edible wild mushrooms command higher prices than cultivated mushrooms (Dell et al., 2000), people prefer to consume them due to their flavour and texture. Although some wild species of *Russula* and *Lactarius* have a bitter flavour, people have developed local cuisine resulting in tasty dishes.

Although there are many studies on cultivated and wild edible mushrooms in the northern hemisphere and their nutritional value (Aletor, 1995; Dermirbaş, 2000; Latiff, Daran, & Mohamed, 1996; Manzi et al., 2001; Manzi, Gambelli, Marconi, Vivanti, & Pizzoferrato, 1999), there is little information available about the wild edible sub-tropical ECM fungi of Thailand. This is the first study on the nutritional quality of wild edible mushrooms collected from native forest in northern Thailand.

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2. Materials and methods

2.1. The cost of edible ECM fungi

The price of edible ECM fungi was surveyed in the Chiang Mai city market (Suthep), in road-side stalls of Amphur Weing Par Pao in Chiang Mai Province, and in the local market (Mae Tam Market) in Phayao Province during the wet season (June–September) in 2000.

2.2. Sample collection

Sporocarps of ECM fungi were collected from Doi Suthep-Pui National Park, Amphur Sanpathong and Amphur Chiang Dao in Chiang Mai Province, Ban Maesard in Chiang Rai Province, or bought from the Suthep Market in Chiang Mai. The forest fungi were mainly collected under species of pines (*Pinus kesiya, P. merkusii*), dipterocarps (*Dipterocarpus, Shorea*) and oaks (*Castanopsis, Lithocarpus, Quercus*). Whole sporocarps (stipe and pileus) were taken for analysis. Herbarium specimens were lodged in the Chiang Mai University herbarium. Twelve ECM fungi were collected: *Astraeus hygrometricus* (Hed Phor), *Craterellus aureus* (Hed Kamin Laung Krob), *Craterellus odoratus* (Hed Kamin Nang), *Heimiella retispora* (Hed Pod Ma), *Heimiella* sp. (Hed Pod Ma), *Lactarius glaucescens* (Hed Khar), *Phaeogyroporus portentosus* (Hed Har), *Russula alboareolata* (Hed Num Paeng), *R. lepida* (Hed Daeng), *R. nigricans* (Hed Than Yai), *R. virescens* (Hed Lom Kra Keaw), and *R. xerampelina* (Hed Dang Luang).

2.3. Chemical analysis

The following components were determined on oven-dried material (98 °C) using AOAC (1990) methods: ash, from the incinerated residue obtained at 550 °C after 3 h (section 942.05); crude protein, by the Kjeldahl method (section 988.05) and a conversion factor of 4.38 was used to quantify the nitrogen percentage of the crude protein (Crisan & Sands, 1978); fat, by Soxhlet extraction with dichloromethane in place of petroleum ether (modified method, section 920.39); and crude fibre by the ceramic fibre filter method (section 962.09). The carbohydrate, or nitrogen-free extract (NFE), was calculated as % dry matter−(% ash + % crude protein + % fat + % crude fibre).

For mineral analysis, dried samples were ground to pass through a 1 mm sieve and mixed thoroughly. Samples (approx. 100 mg) were subjected to microwave nitric acid digestion (CEM Mars 5, USA), followed by elemental quantification using an inductively-coupled plasma-atomic emission spectrometer (ICP-OES).

For sugar and sugar alcohol analyses, 1 g dry weight of tissue was extracted with 100 ml water in an autoclave (120 °C for 1 h). The extract was first filtered through Whatman No. 52 paper, followed by passage through a 0.22 μm millipore filter. The sugar components from extracts were identified by high-performance liquid chromatography [HPLC, DIONEX (DX-500), CarboPac PA1]. Separation was achieved at 30 °C using H_2O and 0.1 M NaOH as the mobile phase (0–5 min, 80% H_2O:20% 0.1 M NaOH; 30 min, 20% H_2O:80% 0.1 M NaOH 20%) and a flow rate of 1.0 ml min^{-1}. The sugar alcohol components were identified by HPLC, DIONEX (DX-500), CarboPac Ma1. Separation was achieved at 30 °C using H_2O and 1 M NaOH as the mobile phase with gradient of H_2O:1 M NaOH (0–20 min, 50%: 50%; 30–45 min, 30%: 70%) and a flow rate of 4.0 ml min^{-1}.

3. Results and discussion

3.1. Retail value of ECM fungi

The price of edible ECM fungi ranged from 40 to 410 Bahts/kg, ca. US$ 1–10 (Table 1). *Astraeus hygrometricus* (Astraceae) had the highest value, up to 7 times more than some of the Amanitaceae and Boletaceae. Prices were higher in the city than the local or road-side markets. *Astraeus* is the most popular ECM fungus consumed in northern Thailand. It commands a high price because it is available early in the fungal fruiting season and is readily sold in the large cities. For the other genera eaten, the price of mushrooms also depends on the selling place, as wild edible mushrooms in the city markets were more expensive than in the road-side and the local markets. The latter markets occur in poorer socioeconomic areas and are closer to the collecting sites. Wild edible mushrooms were cheaper than cultivated mushrooms in 1994 (Jones, Whalley, & Hywel-Jones, 1994), but they are now more expensive than cultivated mushrooms (data not shown). Generally, the fungi collected are consumed fresh within the Provinces and only *Astraeus* is processed in cans for export. The fresh mushrooms command higher prices than most vegetables and rice. The wild mushroom collectors make skilful use of the knowledge transmitted down orally from their ancestors. In the city, the workers travel to the mountains for collecting mushrooms from early morning (03:00–04:00 h) until the afternoon (13:00–14:00 h). During this period, traders wait at designated locations and the collectors take the mushrooms from the forest to the traders at regular intervals. The traders transport the mushrooms to sale in the city market. In the rural areas, the collectors and the traders are often a single family, usually from one of the Hill Tribes in the region. Generally the husband is the collector and the wife conducts sales at the side of the road.

Table 1
The retail price of wild edible mushrooms sold in Chiang Mai and Pha Yao Provinces (Baht/kg).

Local name	Scientific name	Phayao Province	Chiang Mai Province	
		Amphur Muang (Mae Tam Market;[a] 27 May 2000)	Amphur Weing Par Pao (road side; 27 May 2000)	Amphur Muang (Suthep Market[b]; 17 May 2000)
Hed Kai Kao	*Amanita princeps*	50	50	150–200
Hed Kai Laung	*Amanita hemibapha*	50	50	150–200
Hed Phor	*Astraeus hygrometricus*	300	300	410 (24 April 2000)
Hed Mun Pu Yai	*Cantharellus cibarius*	–[c]	56	–
Hed Farn	*Lactarius volemus*	40	40	–
Hed Har	*Phaeogyroporus portentosus*	–	167	–
Hed Nar Moi	*Russula cyanoxantha*	40	40	150–200
Hed Than Lek	*Russula densifolia*	40	40	–
Hed Kor	*Russula senecis*	40	–	150–200
Hed Lom Kra Keaw	*Russula virescens*	60–130	56	150–200
Hed Lom Kao	*Russula* sp.	60–130	56	150–200
Hed Daeng	*Russula* sp.	40	40	150–200

Note US$1 = ca. 40 Baht
[a] The local market in 2000.
[b] The city market in 2000.
[c] Not reported.

3.2. Chemical composition

The ash content of young *Astraeus* was high (27.6%) while the other sporocarps ranged from 7–18% (Table 2). *P. portentosus* had the highest protein (24.2%) and *R. alboareolata* had the highest fat concentration (9.5%). Young *Astraeus* had the lowest fat (2.7%). The lowest crude fibre content was *C. odoratus* (8.3%), and the highest was *H. retispora* (16.8%). The carbohydrate contents ranged from 41.6% in *R. alboareolata* to 65.1% in *C. odoratus*.

Although sporocarp composition for the Thai fungi was generally in the range measured for sporocarps from other regions, there were some notable differences. The ash content of *Astreause* was 2–12 times higher than that of some other edible tropical and temperate basidiomes (Aletor, 1995; León-Guzmán, Silva, & López, 1997). The protein concentrations of six fungi (*P. portentosus, R. nigricans, R. xerampelina, R. alboareolata, H. retispora* and *R. virescens*) were within in range measured by Chang and Buswell (1996) who concluded that cultivated mushrooms normally contain 19–35% protein. *P. portentosus* had the highest protein content (24.2%), which is higher than that reported by León-Guzmán, Silva and López (1997) for wild edible mushrooms in Mexico. The fat levels in the Thai forest fungi are similar to levels in other wild ectomycorrhizal fungi in other regions, including *Amanita rubescens* (8.3%), *Boletus frostii* (3.7%), *Lactarius indigo* (4.3%), *Ramaria flava* (2.1%), *Tricholoma portentosum* (5.7%), and *T. terreum* (6.6%) (Díez & Alvarez, 2001; León-Guzmán, Silva, & López, 1997). Crude fibre contents of all thirteen mushrooms were lower than those reported by León-Guzmán, Silva, and López (1997).

Mineral nutrient concentrations varied with fungal species (Table 3). For example, the P concentration ranged from 2.1 in *C. odoratus* to 8.1 mg/g in *P. portentosus*, K from 12.8 in mature *Astraeus* to 45.2 mg/g in *C. aureus*, and S from 1.1 in *R. nigricans* to 6.1 mg/g in *L. glaucescens*. Mature *Astraeus* had the highest concentrations of Ca and Mg. The higher levels of K and P were within the range usually associated with sporocarps of wood-decomposing fungi (Clinton, Buchanan, & Allen, 1999; Harmon, Sexton, Caldwell, & Carpenter, 1994; Vogt, Edmonds, & Grier, 1981). Vogt and Edmonds (1980) observed that sporocarps on the forest floor tended to have lower concentrations of N, P and K than sporocarps formed on wood. Calcium concentrations were low compared to host plant tissues (data not shown), which is typical for ectomycorrhizal fungi.

The mean micronutrient concentrations across all fungi were in the order Fe > Zn > Mn > Cu > B > Se. There was a 20-fold difference in Fe concentration between *Astraeus* and *Heimiella* sp. The zinc concentration ranged from 37.8 in *C. odoratus* to 253 mg/kg in *L. glaucescens*. The manganese concentration was high in mature *Astraeus* (329.4 mg/kg) compared to young *Astraeus* and most other fungi. The concentration of copper ranged form 11.6 in *Heimiella* sp. to 81.1 mg/kg in *R. nigricans*. *Russula lepida* had the highest level of boron (7.1 mg/kg). Selenium was detected in three fungi: *R. virescens*, *H. retispora* and *Heimiella* sp. The highest level of Se was measured in *R. virescens* (12.6 mg/kg). Selenium concentrations from 1 to 20 mg/kg dry matter have been recorded in some wild edible fungi (Quinche, 1983).

In general, the micronutrient concentrations of the Thai ECM fungi were within the same order of magnitude as

Table 2
Proximate composition[a] (% dry wt.) of edible ectomycorrhizal fungi

Local name	Scientific name	Ash	Crude protein	Fat	Crude fibre	Carbohydrate[b]
Hed Phor (mature)	*Astraeus hygrometricus*	14.2±0.45	14.7±0.08	4.4±0.18	12.3±0.28	54.4
Hed Phor (young)	*Astraeus hygrometricus*	27.6±0.29	14.0±0.28	2.7±0.05	10.8±0.16	44.9
Hed Kamin Laung Krob	*Craterellus aureus*	12.9±0.04	18.3±0.07	2.9±0.03	8.9±0.32	57.0
Hed Kamin Nang	*Craterellus odoratus*	8.1±0.10	15.5±0.06	3.0±0.04	8.3±0.51	65.1
Hed Pod Ma	*Heimiella retispora*	11.6±0.28	21.1±0.04	6.0±0.10	16.8±0.76	44.5
Hed Pod Ma	*Heimiella* sp.	7.6±0.11	16.3±0.03	3.7±0.12	14.7±0.12	57.7
Hed Khar	*Lactarius glaucescens*	8.5±0.33	18.6±0.09	9.2±0.30	10.8±0.50	52.9
Hed Har	*Phaeogyroporus portentosus*	17.8±0.16	24.2±0.03	2.8±0.15	8.8±0.56	46.4
Hed Num Paeng	*Russula alboareolata*	17.6±0.33	21.2±0.13	9.5±0.08	10.1±0.10	41.6
Hed Daeng	*Russula lepida*	7.6±0.61	18.3±0.85	5.6±0.04	8.4±0.22	60.1
Hed Than Yai	*Russula nigricans*	6.7±0.11	22.6±0.78	4.8±0.14	9.6±0.09	56.3
Hed Lom Kra Keaw	*Russula virescens*	11.3±0.04	20.0±0.09	4.3±0.11	9.7±0.66	54.7
Hed Daeng Luang	*Russula xerampelina*	6.7±0.10	22.4±0.06	4.5±0.05	10.6±0.09	55.8

[a] Mean values and standard deviation.
[b] Nitrogen free extract.

Table 3
Mineral concentration of edible ectomycorrhizal fungi (dry wt.)

	Macronutrients (mg/g dry wt)					Micronutrients (mg/kg dry wt)					
	P	K	S	Ca	Mg	Fe	Zn	Mn	Cu	B	Se
Astraeus hygrometricus (mature)	2.2	12.8	1.7	2.4	1.6	3254	203	329	16.5	2.4	nd[a]
Astraeus hygrometricus (young)	5.7	26.1	5.0	0.8	1.2	2059	105	81.7	25.2	2.4	nd
Craterellus aureus	4.2	45.2	1.2	0.3	1.2	452	107	36.8	17.1	2.1	nd
Craterellus odoratus	2.1	26.1	2.5	0.2	0.5	623	37.8	22.1	48.7	6.0	nd
Heimiella retispora	6.0	37.0	3.0	0.2	1.2	187	117	17.7	26.9	1.6	1.2
Heimiella sp.	3.3	25.7	2.2	0.2	0.8	162	81.0	13.0	11.6	1.8	0.3
Lactarius glaucescens	5.3	28.1	6.1	0.1	0.8	962	253	20.6	68.0	1.9	nd
Phaeogyroporus portentosus	8.1	33.3	2.6	0.3	1.2	2422	93.2	139	63.7	2.2	nd
Russula alboareolata	6.6	36.2	3.9	0.2	1.3	3118	135	66.1	71.8	4.2	nd
Russula lepida	4.1	35.3	1.8	0.1	0.7	228	108	24.2	52.8	7.1	nd
Russula nigricans	3.4	25.3	1.1	0.2	0.6	208	61.9	13.7	81.1	2.4	nd
Russula virescens	5.1	27.6	5.3	0.1	0.8	283	131	18.4	41.3	2.1	12.6
Russula xerampelina	3.3	28.9	1.4	0.1	0.6	193	94.1	17.4	48.0	4.2	nd

[a] nd, not detected.

measured in fungi from more temperate regions and from a range of substrates (Harmon, Sexton, Caldwell, & Carpenter, 1994; Hinneri, 1975). Sporocarp B concentrations were 2–10 times lower than in vegetables (Huett, Maier, Sparrow, & Piggott, 1997). The low B concentrations may reflect a lack of requirement for B for hyphal growth in the higher fungi. By contrast, concentrations of Zn and Cu were higher in fruit bodies than in many plant tissues. This suggests that the sporocarps may selectively accumulate some essential minerals.

Copper concentrations, considerably higher than those in vegetables, should be considered as a nutritional source of the element. Nevertheless, for man, bioavailability from mushrooms was reported to be low, due to limited absorption from the small intestine (Işıoğlu, Yılmaz, & Merdivan, 2001).

The sugar composition varied with fungal taxa. D-glucose, D-fructose, D-mannose, D-ribose, and D-arabinose were present in all species but only some fungi contained trehalose, D-xylose or D-fucose. Furthermore, L-rhamnose and D-galactose were only detected in *L. glaucescens* and *C. odoratus*, respectively (Table 4). Galactose has previously been measured in *A. hygrometricus* (Amar, Syed, & Pramanik, 2000), but could not be detected in this study. The sugars of highest concentrations were D-fructose and trehalose in *Lactarius*. The sugar alcohols mannitol, glycerol, and myo-inositol were also found in all species of edible ECM fungi (Table 5). Most fungi had high mannitol concentrations (15.0–21.8 mg/g). Xylitol and D-sorbitol were only detected in *Craterellus*.

Mono- and disaccharides are usually present in low concentrations in fungi, with the exception of certain storage carbohydrates (Wannet, Hermans, van Der Drift, & Op Den Camp, 2000). Trehalose is a common sugar component of most immature sporocarps and it may function as a reserve which is metabolised when the

Table 4
Sugar composition of edible ectomycorrhizal fungi (mg/g dry wt.)

Sugar	*Astraeus hygrometricus*	*Craterellus odoratus*	*Lactarius glaucescens*	*Phaeogyroporus portentosus*	*Russula alboareolata*	*Russula lepida*	*Russula virescens*
D-Glucose	0.88	0.11	0.66	0.67	0.16	0.70	0.59
D-Fructose	0.85	0.58	11.1	0.55	0.24	0.64	0.91
Trehalose	0.50	0.64	12.4	2.71	nd[a]	nd	nd
D-Mannose	0.26	0.35	0.06	0.27	0.06	0.40	0.13
D-Ribose	0.12	0.08	0.14	0.38	0.17	0.34	0.42
D-Arabinose	0.21	0.10	0.06	0.18	0.06	0.13	0.22
D-Xylose	0.03	0.26	nd	nd	nd	nd	nd
D-Fucose	0.10	0.02	nd	nd	0.03	0.02	nd
L-Rhamnose	nd	nd	0.02	nd	nd	nd	nd
D-Galactose	nd	0.01	nd	nd	nd	nd	nd

[a] nd, not detected.

Table 5
Sugar alcohol composition of edible ectomycorrhizal fungi (mg/g dry wt.)

Sugar alcohol	*Astraeus hygrometricus*	*Craterellus odoratus*	*Lactarius glaucescens*	*Phaeogyroporus portentosus*	*Russula alboareolata*	*Russula lepida*	*Russula virescens*
Mannitol	6.52	17.1	16.4	15.0	0.71	21.8	16.4
Glycerol	0.12	0.11	0.92	0.16	0.33	0.59	0.52
myo-Inositol	0.14	0.05	0.09	0.18	0.02	0.05	0.14
meso-Erythritol	0.02	nd[a]	0.02	nd	0.05	0.02	0.01
D-Arabitol	nd	0.01	0.04	0.49	nd	0.05	nd
Dulcitol	nd	0.11	nd	nd	nd	0.01	nd
Xylitol	nd	0.01	nd	nd	nd	nd	nd
D-Sorbitol	nd	0.02	nd	nd	nd	nd	nd

[a] nd, not detected.

sporocarps are maturing (Koide, Shumway, & Stevens, 2000). Mannitol is the most abundant polyol in the sporocarps of Basidiomycetes and Ascomycetes (Lewis & Smith, 1967) and is an energy store as well as an osmoticum (Hammond & Nichols, 1976). Because of their mannitol contents, mushrooms are useful for diabetic foods (Hamano, 1997).

4. Conclusion

Whilst the focus of this paper has been on fungi for human consumption, it is worth noting that sporocarps of the same species can also be food for forest animals. Mycophagy has been well documented for North America (Fogel & Trappe, 1978; North, Trappe, & Franklin, 1997) and Australasia (Johnson, 1996) but is little known in tropical regions. In Thai forests, some insects, snails, wild pigs and rats have been observed to eat forest fungi. The high mineral, complex carbohydrate and vitamin contents of many hypogeous sporocarps, such as the French black truffle, are considered to have high nutritional value for mammals. However, not all mammals are morphologically adapted to a fungi-dominated diet. Whereas much of the sporocarp N and carbohydrate in *Elaphomyces granulatus* is unavailable to the mycophagous ground squirrel (Cork & Kenagy, 1989), marsupials with an enlarged forestomach, in which microbial fermentation takes place (Claridge & Cork, 1994), are well-adapted to metabolise sporocarp tissues.

As the human population increases in Northern Thailand, the pressures on remnant vegetation and the conservation estate will become more severe. Potential damaging impacts of over-harvesting of fungi include soil erosion and loss of biodiversity (Dell et al., 2000). Research into the biology of edible ectomycorrhizal and other forest fungi is still in its infancy in Thailand. There is a need for ethnomycological and fungal conservation studies. In the long term, it is anticipated that some of the more valuable edible forest fungi will be able to be grown using suitable host trees in agroforestry systems. However, before this can be achieved, a small number of target fungi will need to be identified for commercialisation, and culture and inoculation systems developed for local conditions.

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