Isolation and Structure of a New Ceramide from the Basidiomycete *Hygrophorus eburnesus*

Yan Qu[a], Hong-Bin Zhang[b], and Ji-Kai Liu[a]

[a] Kunming Institute of Botany, Chinese Academy of Sciences, Kunming 650204, P.R. China
[b] Pharmacy School of Yunnan University, Kunming 650091, P.R. China

Reprint requests to Prof. Dr. Ji-Kai Liu. Tel.: +86-871-5216327. Fax: +86-871-5150227.
E-mail: jkliu@mail.kib.ac.cn

Z. Naturforsch. **59b,** 241 – 244 (2004); received July 4, 2003

A new ceramide, named hygrophamide (**1**), was isolated from the fruiting bodies of the basidiomycetes *Hygrophorus eburnesus* Fr.. The structure of the compound was elucidated as (2*S*, 3*S*, 4*R*, 2'*R*)-2-(2'-hydroxy-9'*Z*-ene-tetracosanoylamino)-octadecane- 1,3,4-triol (**1**) by spectral and chemical methods.

Key words: Hygrophorus eburnesus, Basidiomycete, (2*S*, 3*S*, 4*R*, 2'*R*)-2-(2'-Hydroxy-9'*Z*-ene-tetracosanoylamino)-octadecane-1,3,4-triol, Hygrophamide

Introduction

In recent years, renewed attention has been paid to constituents of higher, often edible mushrooms, *Basidiomycetes*, because of their possible medicinal usage [1]. Anti-viral, -biotic, -inflammatory, -hypoglycemic, -hypocholesterinemic and -hypotensive properties were ascribed to ingredients of such filamentous fungi [2]. It was assumed that, at least in part, observed therapeutic effects were due to a stimulation of the immune system [3 – 5]. On a chemical basis, the medical effects of basidiomycetes were attributed to glyproteins and proteoglycans [6]. Glycolipids of higher mushrooms have not yet been studied, except for an early, less detailed report [6, 7].

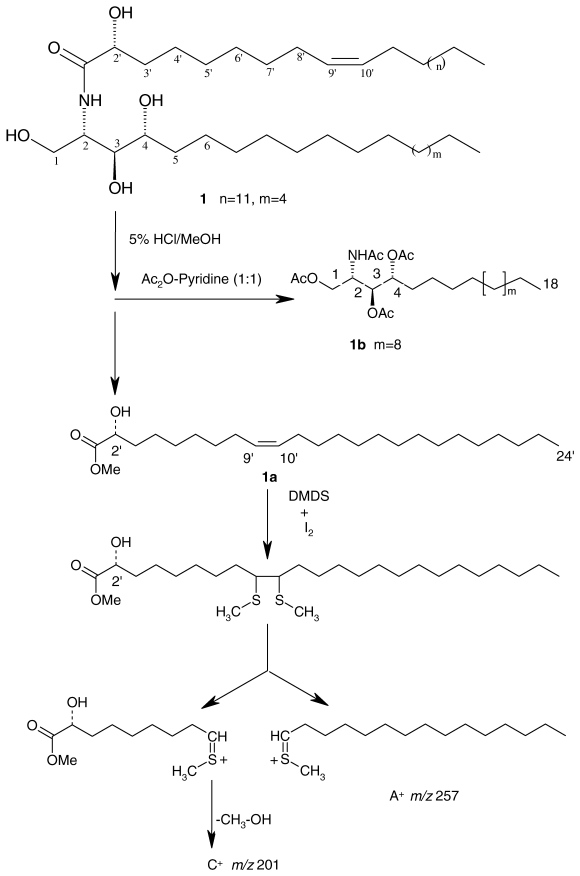
Sphingolipids, *e.g.*, ceramides, cerebrosides, glycosphingolipids (GSL), sphingomyelin and sphingosine derivatives or analogs are important constituents of cell membranes and are assumed to play important roles as antigens and receptors there [8]. Some showed anti-uncerogenic, -hepatotoxic, -tumor, immunostimulatory activities [9 – 11].

The basidiomycete *Hygrophorus eburnesus* belongs to the family Hygrophoraceae. This edible mushroom grows in symbiosis with trees [12]. By literature search, there have been no reports on the chemical analysis of constituents of fungi for the genus *Hygrophorus*. In continuation of our studies on basidiomycete-derived bioactive secondary metabolites [13 – 17], the chemical constituents of the mushroom *Hygrophorus eburnesus* were investigated. This report describes the structure elucidation of a new cerebroside (2*S*, 3*S*, 4*R*, 2'*R*)-2-(2'-hydroxy-9'*Z*-ene-tetracosanoylamino)-octadecane-1,3,4-triol (**1**).

Results and Discussion

Hygrophamide (**1**), $C_{42}H_{83}NO_5$ (high resolution FAB-MS showed $[M-1]^-$ *m/z* 680.6168 calcd. for $C_{42}H_{82}NO_5$ 680.6189), was obtained as white powder. Its IR spectrum exhibited strong hydroxyl absorption bands at 3435 cm^{-1} and bands at 1651, 1540, 1261 cm^{-1} due to an amide group. EI-MS showed the characteristic fragments ion at *m/z* 682 $[M+1]^+$, 664 $[M+1\text{-}H_2O]^+$, 357 $[M+1\text{-}H_2O\text{-}C_{22}H_{43}]^+$, 300 $[C_{18}H_{36}O_3]^+$. In its ^{13}C NMR (DEPT) spectrum, the signals at δ 130.3 ($CH\times2$) showed the presence of one double bond group which was also revealed by the signals at δ 5.49 (2H, bs) in its ^1H NMR spectrum. The signals at δ_C 14.3 ($CH_3 \times 2$), δ_H 0.86 (6H, t, $J = 6.7$ Hz) were assigned to be the two straight chain terminal methyl groups. At δ 1.21 – 1.45 ppm in ^{1} H NMR and δ 23.0 – 35.8 ppm in ^{13}C NMR the overlapped signals of methylenes suggested the existence of two long aliphatic chains. In addition, ^1H NMR spectrum also presented a characteristic amide NH doublet at δ 8.57 (1H, *d*, $J = 8.8$ Hz; exchangeable with D_2O) and ^{13}C NMR (DEPT) spectrum of **1** showed the presence of an amide functionality at δ 175.3 (C-1') and δ 53.0 (C-2). These evidences

0932–0776 / 04 / 0200–0241 $ 06.00



Scheme 1. Structure of **1** and related derivatives.

led to the conclusion that compound **1** was a ceramide.

To determine the length of fatty acid (FA) and long-chain base (LCB), the compound **1** was treated with methanolic hydrochloric acid to yield a mixture of fatty acid methyl ester (FAME, **1a**) and long-chain base (LCB). The EI-MS of **1a** displayed the molecular ion at *m/z* 396 $[M]^+$ and prominent fragment ion 337 $[M\text{-}COOCH_3]^+$. The optical rotation of **1a** ($[\alpha]_D^{20}$ $-3.3°$, c 0.02, $CHCl_3$), which was very close to those of methyl esters of 2-(*R*)-hydroxy fatty acids reported earlier [18], identified fatty acid methyl as the *R*-isomer.

1a (5 mg) was treated in 0.5 ml of CS_2 by addition of 0.5 ml DMDS and 2 mg I_2. The reaction was carried out in a 10 ml flask closed with a Teflon-lined cap and kept 40 h at 60°. Samples were treated with $Na_2S_2O_3$ solution (5% in distilled water) and twice extracted with petroleum ether. The organic extract was conducted to EI-MS analysis immediately. The MS

Table 1. ^1H and ^{13}C NMR (pyridine-D_5) data of hygrophamide **(1)**.

	δC	δH	^1H-^1HCOSY selected	HMBC selected
1(CH_2)	62.1	4.51(dd, 10.5, 4.1)	H-2	H-3
		4.42(dd, 10.5, 4.7)		
2(CH)	53.0	5.11(m)	NH,H-1, 3	H-4
3(CH)	76.8	4.36(dd, 6.5, 4.0)	H-2, 4	H-1
4(CH)	73.0	4.28(m)	H-3, 5	H-2, 5
5(CH_2)	34.2	1.91(m)		H-3
6(CH_2)	25.9	1.71(m)		
7 ∼	29.6 ∼	1.21 ∼		
17(CH_2)	32.4	1.45		
18(CH_3)	14.3	0.86(t, 6.7)		
1’	175.3			H-2
2’(CH)	72.5	4.62(dd, 7.7, 3.8)	H-3’	
3’(CH_2)	35.8	2.03(m)	H-2’, 4’	
4’(CH_2)	34.6	2.26(m)	H-3’, 5’	
5’(CH_2)	27.6	1.96(m)		
6’(CH_2)	23.0	1.75(m)		
7’(CH_2)	23.0	1.25(m)		H-9’
8’(CH_2)	26.8	2.11(m)	H-9’	H-10’
9’(CH)	130.3	5.49(bs)	H-8’, 11’	H-7’,8’,11’
10’(CH)	130.3	5.49(bs)	H-8’, 11’	H-8’
11’(CH_2)	26.8	2.11(m)		H-9’
12’∼	29.6 ∼	1.21 ∼		
23’(CH_2)	32.4	1.45		
24’(CH_3)	14.3	0.86(t, 6.7)		
NH		8.57(d, 8.8)	H-2	

spectrum gave remarkable fragment-ion peaks at *m/z* 257 for A and 201 for C due to cleavage of the bond between the carbons bearing a methylthio group. These data indicated that the double bond in the fatty acid is located at C-9’ [19]. Combined the above facts it revealed **1a** as methyl 2-hydroxy-9-ene-tetracosanoate.

The geometry of the C-9’/C10’ double bond was determined to be *cis Z* on the basis of the ^{13}C NMR chemical shift of the methylene carbon adjacent to the olefinic carbon, which is observed at δ 26.8 (C-8’), 26.8 (C-11’) in (*Z*) isomer (at $\delta \approx 32$ if in *E* isomers) [19, 20], as also evidenced by the triplet-like signals of olefinic protons (H-9’ and H-10’) that appear at δ 5.49 in the ^1H NMR of **1** [21].

On the other hand, the LCB component was reacted with acetic anhydride/pyridine (1:1, v/v) to afford peracetate of the LCB (**1b**). EI-MS of peracetyl LCB (**1b**) displayed the molecular ion at *m/z* 485 $[M]^+$ and prominent fragment ions at *m/z* 443 $[M\text{-}Ac]^+$, 425 $[M\text{-}CH_3COOH]^+$, 365 $[M\text{-}2CH_3COOH]^+$. It suggested the LCB part of **1** to be 2-amino-1, 3, 4-trihydroxyloctadecane.

Comparing the chemical shifts and coupling constants of C-1, C-2, C-3, C-4 with those of

phytosphingosine-type LCB possessing (2*S*, 3*S*, 4*R*) configuration [14, 22 – 24], the relative configurations of C-2, C-3, C-4 were predicted to be *S*, *S*, *R*, respectively. The ^{1}H NMR signals of the basic structure of 1 (Table 1) are in good agreement with those of the known ceramides, which is composed of (2*S*, 3*S*, 4*R*)-sphingosine and 2'*R*-fatty acid. These results led us to establish the structure of compound 1 as (2*S*, 3*S*, 4*R*, 2'*R*)-2-(2'-hydroxy-9'*Z*-ene-tetracosanoylamino)-octadecane-1,3,4-triol.

Experimental Section

General

Melting point was obtained on an XRC-1 apparatus (Sichuan, P.R. China) and is uncorrected. Optical rotation was taken on a Horiba Sepa-300 polarimeter (Horiba, Tokyo, Japan). ^{1}H, ^{13}C NMR and two-dimensional NMR spectra were recorded on Bruker DRX-500 (Karlsruhe, Germany) at 500 MHz for ^{1}H and 125 MHz for ^{13}C NMR, chemical shifts δ in ppm to TMS as internal standard and coupling constants in Hz. Mass spectra were measured with a VG Autospec 3000 mass spectrometer (VG, England). Infrared (IR) spectra were obtained on a Bio-Rad FTS-135 infrared spectrophotometer (Bio-Rad, Richmond, CA, USA) in KBr pellets. GC-MS was performed on a Finnigan 4510 GC-MS spectrometer (San Jose, CA, USA) employing the EI mode (ionizing potential 70eV) and a capillary column (30 m×0.25 mm) packed with 5% phenyl and 95% methylsilicone on 5% phenyl-dimethylsilicone (HP-5) (Hewlett-Packard, Palo Alto, CA, USA). Helium was used as carrier gas, column temperature was varied from 160 to 240 °C with rate of 5 °C/min.

Material

Column chromatography was carried out on silica gel (200 – 300 mesh) and TLC was carried out on plates precoated with silical gel F_{254} (Qingdao Marine Chemical Ltd., Qingdao, People's Republic of China). RP-8 (LiChroprep, 40 – 63 μm, Merck, Germany).

Fungal material

The fresh fruiting bodies of *Hygrophorus eburnesus* were collected at Lijiang of Yunnan Privence in July 2002 and identified by Ms X. H. Wang at Kunming Institute of Botany, Chinese Academy of Sciences, Kunming, Yunnan, People's Republic of China. A voucher specimen has been deposited at the Herbarium of Kunming Institute of Botany, Chinese Academy of Sciences, People's Republic of China (HKAS 39214).

Extraction and isolation

The fresh fruiting bodies of *H. eburnesus* were extracted with 95% ethanol at room temperature (×3, total 15 l), followed with chloroform/methanol (1:1, v/v, 1l×3) and methanol (1l×3) at 20 °C. The combined extracts were concentrated *in vacuo* to give a crude extract, which was partitioned between H_2O and chloroform to provide chloroform extract (26 g). The mushroom residue after extraction was dried and weighed (135 g). The chloroform soluble fraction was subjected to column chromatography eluting with mixture solvent of chloroform/methanol from 100:0 (v/v) to 90:10 (v/v) to give 20 fractions. The fractions eluted by chloroform/methanol (98:2 and 95:5, v/v) were concentrated to small volume and then a white solid was precipitated from the solution. Then the solid was washed with acetone repeatedly, and **1** (190 mg) was obtained as white powders.

*Methanolysis of **1***. Compound **1** (15 mg) was refluxed with 3 ml 5% hydrochloride-methanol at 60 °C for 6 h. 10 ml cold water was poured into the reaction mixture, which was extracted with *n*-hexane for three times (5 ml×3). The combined organic layer was dried over anhydrous Na_2SO_4 and concentrated under reduced pressure. The residue **1a** of the hexane phase was analyzed by GC-MS directly. The result showed that **1a** displayed major ion peak at *m/z* 396 $[M]^+$, 337 $[M\text{-}COOCH_3]^+$, its retention time was 41.4 min.

*Derivatization of **1a***. **1a** (5 mg) was treated in 0.5 ml CS_2 by addition of 0.5 ml DMDS and 2 mg I_2. The reaction was carried out in a 10 ml flask closed with a Teflon-lined cap and kept 40 h at 60 °C. Samples were treated with $Na_2S_2O_3$ solution (5% in distilled water) and extracted with petroleum ether for two times. The two organic extracts were combined and concentrated. Immediate EI-MS analysis gave fragments at A^+ (*m/z* 257), C^+ (*m/z* 201) in the MS spectrum.

2-Acetoamino-1,3,4-triacetoxy-octadecane (**1b**). The aqueous methanol layer was neutralized with saturated Na_2CO_3, concentrated to dryness, and extracted with ether. The ether phase was dried over anhydrous Na_2SO_4 and evaporated *in vacuo* to afford long chain base (LCB), which was reacted with acetic anhydride/pyridine (1:1, v/v) at room temperature in 0.5 ml acetone overnight. The reaction mixture was diluted with water and then extracted with ethyl acetate. The residue of organic phase was subjected to silica gel column chromatography using petroleum ether/ethyl acetate (9:1, v/v) as eluent to produce a tetraacetate of LCB (**1b**, 3 mg). MS (EI, 70 eV) *m/z* (%): 485 (10) $[M]^+$, 443 (12) $[M\text{-}Ac]^+$, 425 (7) $[M\text{-}CH_3COOH]^+$.

Hygrophamide (**1**). M.p. 121 ∼ 123 °C. $[\alpha]_D^{22} + 7.65°$ (c 0.3, pyridine). – UV (MeOH) λ_{max} $(\log\varepsilon) = 205$ nm (3.43), 194 nm (3.09). – IR (KBr): $\nu = 3435$ (OH), 2921, 2849, 1651, 1540, 1468, 1261, 1077 cm^{-1}. HR-FABMS: *m/z* 680.6168 $[(M\text{-}1)^-$, calcd. for $C_{46}H_{82}NO_5$ 680.6189]. MS (EI, 70 eV): *m/z* (%) = 682 (35) $[M+1]^+$, 664 (55) [M+1-

$H_2O]^+$, 455 (20), 437 (18), 424 (25), 382 (28), 357 (50), 325 (15), 300 (28), 272 (12), 225 (8), 97 (38). ^1H and ^{13}C NMR (pyridine-D_5) see Table 1.

Acknowledgement

We wish to acknowledge the financial support from the National Natural Science Foundation of China (30225048).

[1] S. P. Wasser, A. L. Weis, Crit. Rev. Immunol. **19**, 65 (1999).
[2] A. T. Borchers, J. S. Stern, R. M. Hackman, C. L. Keen, M. E. Gershwin, Proc. Soc. Exp. Biol. Med. **221**, 281 (1999).
[3] H. X. Wang, T. B. Ng, V. E. Ooi, W. K. Liu, S. T. Chang, Biochem. Cell. Biol. **74**, 95 (1996).
[4] H. Ito, K. Shimura, H. Itoh, M. Kawade, Anticancer Res. **17**, 277 (1997).
[5] X. L. Mao: Economic Fungi of China, Sciences Press, Beijing, P14 (1998).
[6] R. Jennemann, R. Geyer, R. Sandhoff, R. M. Gschwind, S. B. Levery, H. J. Groene, H. Wiegandt, Eur. J. Biochem. **268**, 1190 (2001).
[7] P. F. Byrne, P. J. Brennan, J. Gen. Microbiol. **89**, 2455 (1975).
[8] T. Kolter, K. Sandhoff, Angew. Chem. Int. Ed. **38**, 1532 (1999).
[9] E. Okuyama, M. Yamazaki, Chem. Pharm. Bull. **31**, 2209 (1983).
[10] S. Y. Kim, Y. H. Choi, H. Huh, J. Kim, Y. C. Kim, H. S. Lee, J. Nat. Prod. **60**, 274 (1997).
[11] T. Natori, M. Morida, K. Akimoto, Y. Koezuka, Tetrahedron **50**, 2771 (1994).
[12] T. Mao, J. Van de Water, C. L. Keen, J. S. Stern, R. Hackman, M. E. Gerswin, Int. J. Immunotherapy **15**, 13 (1999).
[13] J. K. Liu, Heterocycles, **57**, 157 (2002).
[14] J. M. Gao, Z. J. Dong, J. K. Liu, Lipids **36**, 175 (2001).
[15] Z. H. Ding, J. P. Li, J. K. Liu, Y. Lu, C. Wang, Q. T. Zheng, Helv. Chim. Acta **85**, 882 (2002).
[16] J. W. Tan, Z. J. Dong, J. K. Liu, Lipids, **38**, 81 (2003).
[17] L. Hu, J. K. Liu, Z. Naturforsch. **58c**, 452 (2003).
[18] V. Costantino, E. Fattorusso, A. Mangoni, Liebigs Ann. 2133 (1995).
[19] K. Yamada, E. Hara, T. Miyamoto, R. Higuchi, R. Isobe, S. Honda, Eur. J. Org. Chem. 371 (1998).
[20] N. Fusetani, K. Yasumoto, S. Matsunaga, H. Hirota, Tetrahedron Lett. **30**, 6891 (1989).
[21] R. Higuchi, M. Inagaki, K. Togawa, T. Miyamoto, T. Komori, Liebigs Ann. Chem. 653 (1994).
[22] G. S. Garg, S. Agrawal, J. Nat. Prod. **58**, 442 (1995).
[23] M. Inagaki, R. Isobe, Y. Kawano, T. Miyamoto, T. Komori, R. Higuchi, Eur. J. Org. Chem. 129 (1998).
[24] S. Sugiyama, M. Honda, R. Higuchi, T. Komori, Liebigs Ann. Chem. 349 (1991).