

Comparison of Characteristics of *Ganoderma lucidum* According to Geographical Origins : Consideration of Morphological Characteristics (II)

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Nine species of genus *Ganoderma* different in cultural characteristics each other were separated by histo-anatomical differences. Differences among the species and geographic distribution of *G. lucidum* were also analyzed to provide the criteria for the classification of Korean cultivation or wild type strains. Korean cultivation and wild type strains were quite different from other species as well as Taiwan and North American *G. lucidum* strains in histo-anatomical traits of *Ganoderma*. Pore color of Korean *G. lucidum* strains was less brown than those of Taiwan and North American strains. Shapes of pores were round or circular in Korean strains but ellipsoidal or angular in Taiwan or North American strains. Pore numbers of Korean strains were more than those (4-6/mm) of Taiwan or North American strains. Hardness of the pileus of Korean strains was much more than that of Taiwan or North American strains. Such characteristics of Korean strains were different from those of other species of *Ganoderma*. Korean *G. lucidum* strains could be classified into the other group because they had many different traits in growth characteristics of fruiting bodies and histo-anatomical characteristics from those of Taiwan or North American *G. lucidum* and other species of *G. lucidum* complex.

KEYWORDS: Histo-anatomical characteristics, Korean *Ganoderma lucidum*, Classification

Genus *Ganoderma* including *G. lucidum* is world wide distributed in tropical, subtropical, and temperate regions. Nine species were reported in U.S.A. (Gilbertson and Ryvarden, 1986), 5 species in Japan (Imazeki *et al.*, 1988), 13 species in Taiwan (Chang and Chen, 1984), 64 species in China (Zhao, 1989), and four species in Korea (Jung, 1994).

The classification of *Ganoderma* has been based morphological characteristics of fruiting bodies such as the existence of stipes, shape of pleus, length or thickness of stipes, size or shape of pores, color of fruiting body, mycelial types, and host range (Ito, 1955). However, there are many different points of view among researchers, because there is no regulated type species. The classification study of *Ganoderma*, thus, was very complicated, because it was conducted in restricted areas and studied for a small number of samples. Practically, 386 species listed in the Ganodermataceae (Moncalvo and Ryvarden, 1997) might have been given to many different isolates in spite of same species.

On the other hand, many researches and cultivating have been conducted using *G. lucidum*. However, it could be verified that these fungi were not the same under the experiments of researchers (Kim, 1998). There have not been any deposition of *Ganoderma* isolates at ATCC and the internationally known institute, so *G. lucidum* strains used in Korea can be said uncertain. The fruiting body of *Ganoderma* species is produced easily using sawdust medium. However, systematic studies for *Ganoderma*

have not conducted in terms of cultivation yet. This study was done to compare and to analyze the histo-anatomical characteristics of Korean *G. lucidum* for clarifying more accurate systematic system.

Materials and Methods

Materials. Strains used in this study were 9 species of *G. applanatum*, *G. lucidum*, *G. meredithae*, *G. microsporium*, *G. oerstedii*, *G. oregonense*, *G. pfeifferi*, *G. resinaceum*, and *G. subamboinens*, described in the previous research (Kim *et al.*, 2001).

Cultivation. Inoculum was prepared using the method shown in the previous paper. Oak sawdust and wheat bran were mixed (8 : 2, v/v). Water was added to be 65% of total volume. The mixed medium was put into 250 ml flask or 2000 ml plastic bottle for the bottle cultivation. The medium containing flask or bottle was sterilized at 121°C for 60 minutes and cooled to 20°C afterwards. The medium was inoculated with each strain and cultured in an incubator at 21 to 22°C. The standard cultivating method (Cha *et al.*, 1989; Kim, 1995) was used thereafter.

Investigation of histo-anatomical characteristics. Color and shape of the basidiocarp were investigated by Corner's (1983) method. Thickness of pileus was checked by measuring the crossing point of width and length of the fruiting body. Color of pileus was compared using the color chart of Methuen (1983). Shape and number of pores were observed under a compound microscope (×30)

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Table 1. Strains of *Ganoderma* species used in this study

Strain	Species	Strain number ^a	Locality
G 1	<i>G. applanatum</i>	ATCC 44053	Japan
G 3	<i>G. lucidum</i>	ATCC 64251	Taiwan
G 6	<i>G. lucidum</i>	ASI 7002	Korea, Wild <i>Ganoderma</i>
G 8	<i>G. lucidum</i>	ASI 7004	Korea, Cultivated <i>Ganoderma</i>
G 9	<i>G. lucidum</i>	ASI 7071	Korea, Cultivated <i>Ganoderma</i>
G14	<i>G. lucidum</i>	MRI 5005	U.S.A.
G15	<i>G. lucidum</i>	MRI 5008	U.S.A.
G18	<i>G. lucidum</i>	MRI 5012	U.S.A.
G19	<i>G. meredithae</i>	ATCC 64490	U.S.A.
G20	<i>G. microsporum</i>	ATCC 76024	Taiwan
G23	<i>G. oerstedii</i>	ATCC 52411	Argentina
G24	<i>G. oregonense</i>	ATCC 64487	U.S.A.
G26	<i>G. pfeifferi</i>	CBS 747.84	Netherlands
G28	<i>G. resinaceum</i>	ATCC 52413	U.S.A.
G29	<i>G. subamboinense</i>	ATCC 52420	Argentina
G36	<i>Ganoderma</i> sp.	CNRDA 19	Korea, Cultivated <i>Ganoderma</i>
G39	<i>Ganoderma</i> sp.	CNRDA 24	Korea, Wild <i>Ganoderma</i>
G41	<i>Ganoderma</i> sp.	CNRDA 32	Korea, Wild <i>Ganoderma</i>
G43	<i>Ganoderma</i> sp.	CNRDA 34	Korea, Wild <i>Ganoderma</i>
G46	<i>Ganoderma</i> sp.	KNU 89	Korea, Wild <i>Ganoderma</i>

^aATCC : American Type Culture Collection. CBS : Centraalbureau voor Schimmelcultures, Netherlands, MRI : Mushroom Research Institute, University of Pennsylvania, U.S.A., CNRDA : Chungnam Rural Development Association, ASI : Institute of Agriculture Science, Korea. KNU : Kangwon National University.

and compared with the Classification of North American Polypores (Gilbertson and Ryvarden, 1987). Texture analyzer (TA-XT2) was used for measuring the hardness of pore or context of pileus.

Results and Discussion

Context. Thickness of context much varied with species, which ranged from 2.3 to 6.6 mm. Korean *G. luci-*

Table 2. Color of context, tubes and pores, thickness of context and tubes, number and shape of pores of *Ganoderma* species cultivated on oak sawdust medium

Group ^a	Strain	Species	Color ^b			Thickness (mm)		Pore (No/mm)	Shape ^c
			Context	Tubes	Pore	Context	Tubes		
I (3-4)	G26	<i>G. pfeifferi</i>	6E7, 5B3	7D5	-	4.5±1.9	7.5±1.5	3-4	A, R
II (4-5)	G1	<i>G. applanatum</i>	6D7, 5B3	7E6, 6D6	2B3	3.5±0.6	9.4±1.3	4-5	A, R
	G3	<i>G. lucidum</i>	6D6, 5A2	6E7	2C1	4.8±2.6	7.9±1.4	4-5	A, R
	G18	<i>G. lucidum</i>	6E7, 5B3	7E5	2B2	5.4±0.3	5.8±0.3	4-5	C
	G28	<i>G. resinaceum</i>	6D6, 5B3	6D6, 6E6	2B2	5.3±1.5	9.0±0.8	4-5	A, R
III (5-6)	G6	<i>G. lucidum</i>	6C5, 5A2	6D6	2B3	5.0±1.2	5.5±0.4	5-6	C
	G14	<i>G. lucidum</i>	6C4, 5A2	6D5	1C2	2.3±0.2	6.5±0.4	5-6	A, R
	G15	<i>G. lucidum</i>	6D6, 5A2	6E5, 6E8	3C2	2.9±0.6	7.5±1.2	5-6	A
	G23	<i>G. oerstedii</i>	6D6, 5A2	7E5	2B2	4.5±1.3	7.0±1.4	5-6	A, R
	G29	<i>G. subamboinense</i>	5B3, 5A2	6D6	2B4	3.3±0.5	3.5±0.4	5-6	A, R
IV (6-7)	G8	<i>G. lucidum</i>	6C5, 5A2	6D6	3B3	5.9±1.3	6.5±0.6	6-7	C
	G9	<i>G. lucidum</i>	5C5, 5A2	6D5	2B4	4.5±0.9	6.6±1.0	6-7	C
	G19	<i>G. meredithae</i>	6D6, 5A2	6D5	2B2	6.6±1.1	7.9±0.6	6-7	C
	G20	<i>G. microsporum</i>	6C5, 5A2	6D5	2C2	3.7±0.5	4.2±0.6	6-7	A, R
	G36	<i>Ganoderma</i> sp.	6C5, 5A2	6D6	3B3	4.0±0.0	6.1±0.6	6-7	C
	G39	<i>Ganoderma</i> sp.	6C5	6E5, 6D6	4C5	4.1±0.5	5.0±0.7	6-7	C
	G41	<i>Ganoderma</i> sp.	6C4, 5A2	6D6	3B4	4.0±0.0	5.8±0.9	6-7	C
	G43	<i>Ganoderma</i> sp.	6B3, 5A2	6E7	2B3	5.5±2.1	5.5±0.7	6-7	R
	G46	<i>Ganoderma</i> sp.	6C5, 5A2	7E5, 6D6	2B3	5.3±1.0	6.9±0.3	6-7	A, R

^aGroups separated by the number of pores per mm.

^bColor : Methuen Handbooks of Colour(A. Komerup & J. H. Wanscher; 1983).

^cShape : A; Angular, C; Circular, R; Round.

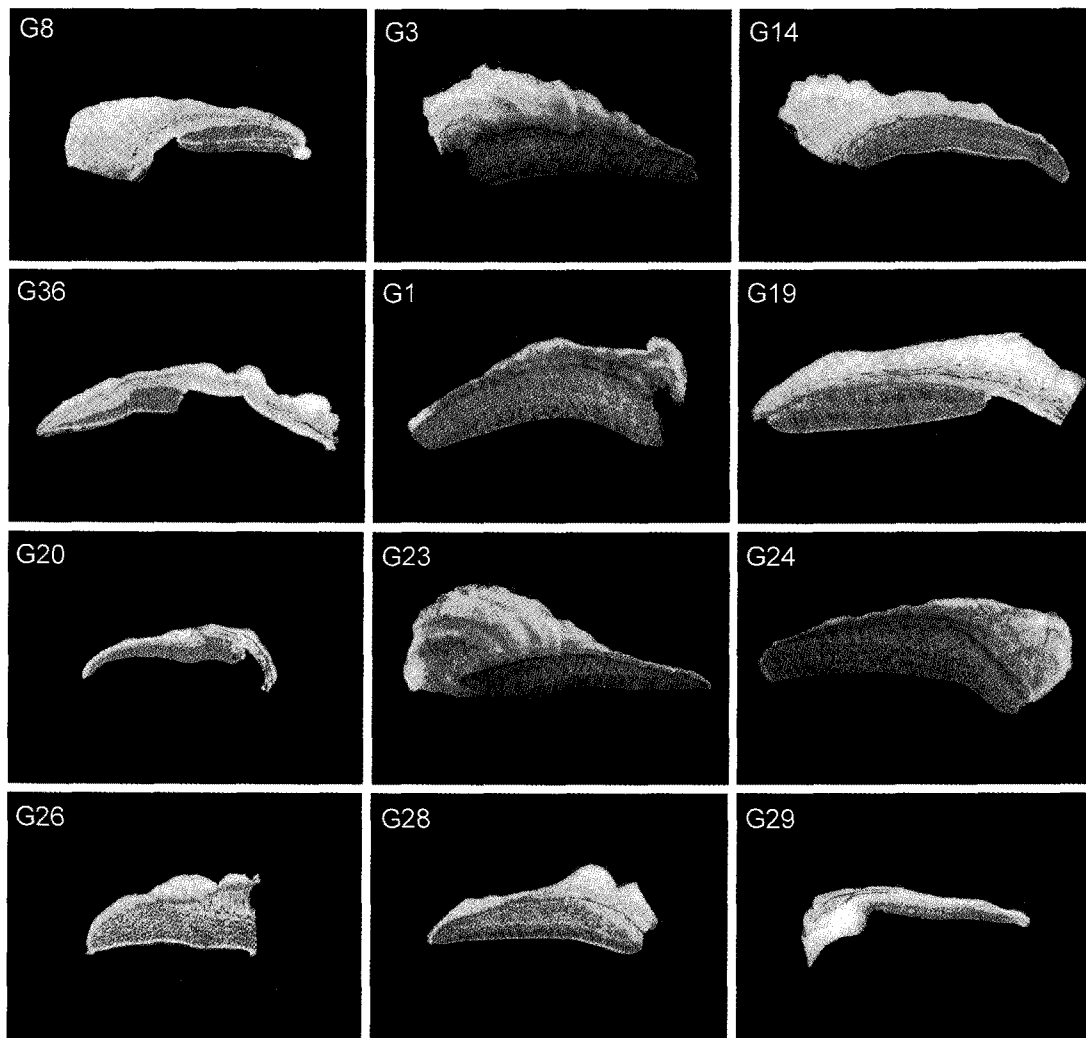


Fig. 1. Comparison of hyphal tube and context types between strains belonging to *Ganoderma* cultivated on oak sawdust medium. Strains are as follows : G8: *G. lucidum* (Korea), G3: *G. lucidum* (Taiwan), G14: *G. lucidum* (U.S.A.), G36: *G. lucidum* (Korea), G1: *G. applanatum* (Japan), G19: *G. meredithae* (U.S.A.), G20: *G. microsporum* (Taiwan), G23: *G. oerstedii* (Argentina), G24: *G. oregonense* (U.S.A.), G26: *G. pfeifferi* (Netherlands), G28: *G. resinaceum* (U.S.A.), G29: *G. subamboinense* (Argentina).

dum strains ranged from 4.1 to 5.9 mm, which were thicker than those of Taiwan or North American strains (G3, G14, and G15), which ranged from 2.3 to 4.8 mm (Table 2). Colors of context were mostly whitish orange and varied according to species. Korean strains were whitish orange near surface and brownish orange near pores. There were pale brownish tread-like tissues in the middle of context of Korean strains (G8, G36, G39, G41, and G46). These had a light orange color. Color of context were very stable characteristics on the classification of *Ganoderma* species. Zhao *et al.* (1979) classified the genus *Ganoderma* as Sect. *Ganoderma* and Sect. *Phaeonema*. There were two layers in the context color of Sect. *Ganoderma*: upper layer was pale to tan and lower layer was pale brown to brown. There were differences among *G. lucidum*, because Korean strains had thicker and brighter orange color than Taiwan or North Ameri-

can strains did.

Tube. Tube colors were differentiated into 3 groups (light brown, intermediate, and brown) in the artificial cultivation. Tube colors of *G. meredithae*, *G. pfeifferi*, *G. subamboinense*, *G. microsporum*, and Korean cultivation (G8, G9) or wild type strains were light brown. However, *G. oerstedii* and Taiwan or North American *G. lucidum* strains were brown (Table 2). Thickness of the tube varied within species, which ranged from 4.2 to 9.4 mm. Tube thickness of Taiwan and North American *G. lucidum* isolates ranged from 6.5 to 7.9 mm, which were thicker than that of Korean strain. Pore thickness of *G. applanatum* was 9.4 mm, the thickest among fungi used in this study (Table 2). Length, color, and separation of pores have been basic traits for the classification of species. For example, the tube of *G. annulare* is very long

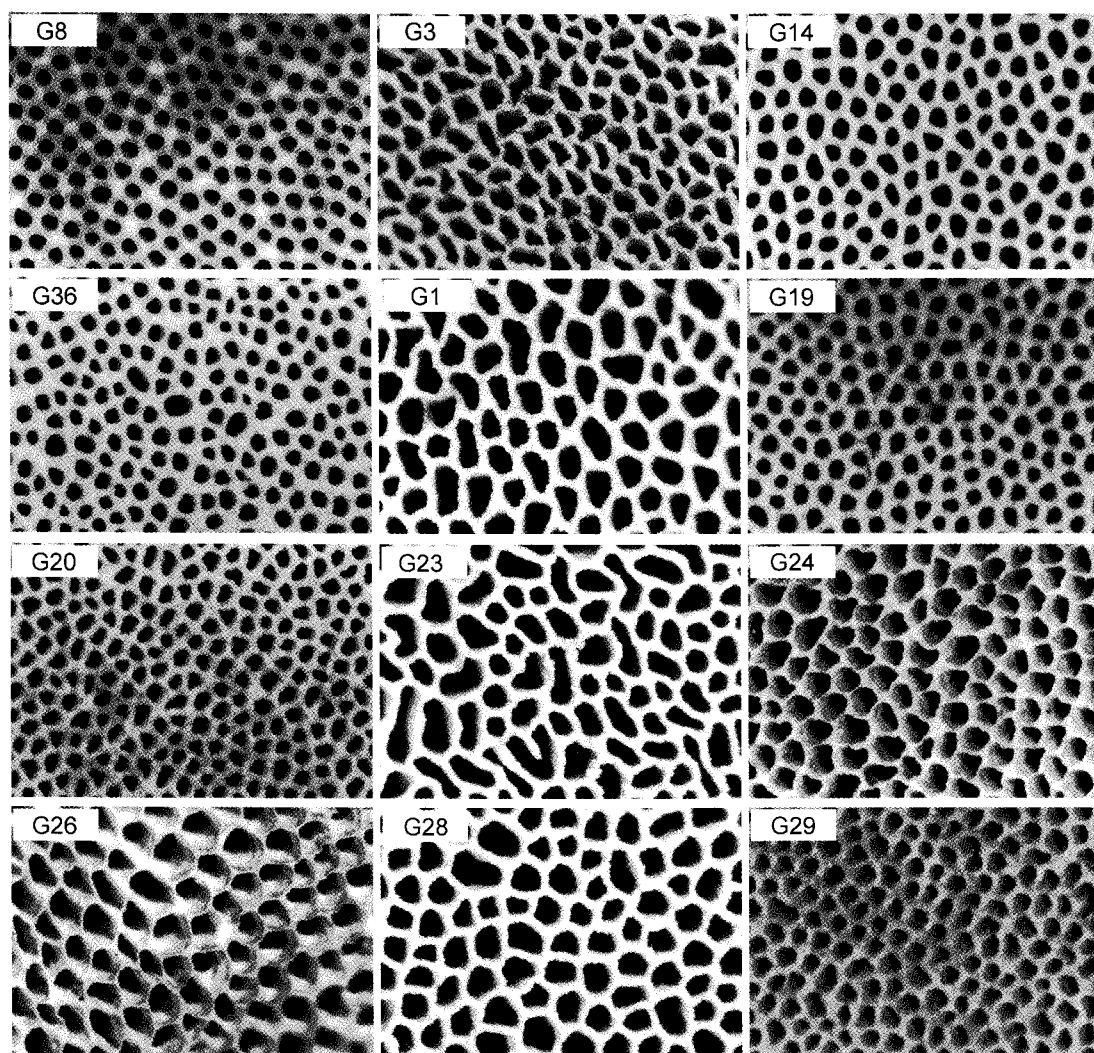


Fig. 2. Patterns of hymenial pores of *Ganoderma* species cultivated on oak sawdust medium. Strains are as followings : G8: *G. lucidum* (Korea), G3: *G. lucidum* (Taiwan), G14: *G. lucidum* (U.S.A.), G36: *G. lucidum* (Korea), G1: *G. applanatum* (Japan), G19: *G. meredithae* (U.S.A.), G20: *G. microsporum* (Taiwan), G23: *G. oerstedii* (Argentina), G24: *G. oregonense* (U.S.A.), G26: *G. pfeifferi* (Netherlands), G28: *G. resinaceum* (U.S.A.), G29: *G. subamboinense* (Argentina).

reaching to crust and tissues are very thin to almost none. Surface color of pore is the other characteristics and the color of basidiocarp of same isolates changed depending on growth stages. However, in this study, color of basidiocarp was an inherent trait, because fungi were cultivated under the same cultivating condition (Fig. 1). Lower pileus color of Korean strains was yellow, while those of Taiwan or North American strains was grey. Thus, colors of fruiting body varied according to locality though they are belong to same species by present classification system. Number of pores varied from 4 to 7 per 1 mm. The pore number of Korean cultivation (G8, G9) or wild type isolates were 6 or 7, while those of Taiwan (G3) or North American (G14, G15) *G. lucidum* strains and *G. resinaceum* (G28) were 4 or 5 (Table 2). They were similar to that of Zhao's (1989) report in which pore number of *Ganoderma* species were 4 or 5 per mm, while 1 in larger

pore-sized strains and 6 or 7 in smaller pore-sized one. Shapes of pore varied from angular to circular (Fig. 2). Shapes of Korean isolates were circular while those of Taiwan or North American strains were circular or angular. Thus, Korean *G. lucidum* strains had differences in all items concerning tube such as the color of pore or context and number or shape of pore compare to those of Taiwan or North American isolates.

Hardness of basidiocarp. Hardness of basidiocarp was differentiated into 4 groups. Basidiocarps of Korean *G. lucidum* cultivation strains (G8) and wild types were harder (15,000–20,000 kg/cm²) than those of other strains (Table 3). Taiwan (G3) or North American strains (G15, G18) of *G. lucidum*, *G. oerstedii* (G23), *G. oregonense* (G24), *G. resinaceum* (G28), *G. pfeifferi* (G26), and *G. subamboinens* (G29) were in Group I (below 10,000 kg/

Table 3. Hardness of basidiocarps of *Ganoderma* species grown on oak sawdust medium

Group ^a	Strain	Species	Hardness (kg/cm ²) ^b		Locality
			Pore	Contex	
I (<10,000)	G1	<i>G. applanatum</i>	6773	5559	Japan
	G3	<i>G. lucidum</i>	7695	4722	Taiwan
	G15	<i>G. lucidum</i>	6946	5952	U.S.A.
	G18	<i>G. lucidum</i>	7549	5552	U.S.A.
	G23	<i>G. oerstedii</i>	6395	3179	Argentina
	G24	<i>G. oregonense</i>	5633	3855	U.S.A.
	G26	<i>G. pfeifferi</i>	7698	5605	Netherlands
	G28	<i>G. resinaceum</i>	5722	3530	U.S.A.
	G29	<i>G. subamboinense</i>	9406	6395	Argentina
II (10,000~15,000)	G14	<i>G. lucidum</i>	10077	6263	U.S.A.
	G19	<i>G. meredithae</i>	11405	6339	U.S.A.
	G20	<i>G. microsporum</i>	14299	11782	Taiwan
	G43	<i>Ganoderma</i> sp.	11710	5924	Korea, Wild <i>Ganoderma</i>
III (15,000~20,000)	G6	<i>G. lucidum</i>	15358	9694	Korea, Wild <i>Ganoderma</i>
	G8	<i>G. lucidum</i>	15904	10617	Korea, Cultivated <i>Ganoderma</i>
	G36	<i>Ganoderma</i> sp.	16522	11004	Korea, Cultivated <i>Ganoderma</i>
	G39	<i>Ganoderma</i> sp.	17012	9377	Korea, Wild <i>Ganoderma</i>
	G41	<i>Ganoderma</i> sp.	17094	10450	Korea, Wild <i>Ganoderma</i>
	G46	<i>Ganoderma</i> sp.	18229	11659	Korea, Wild <i>Ganoderma</i>
IV (>20,000)	G9	<i>G. lucidum</i>	21226	17179	Korea, Cultivated <i>Ganoderma</i> ,

^aGroups separated by hardness of pore.

^bConditions for the determination of hardness : Speed; 5.0 mm/sec, Distance; 0.5 mm.

cm²). *G. meredithae* (G19) and *G. microsporum* (G20) were in Group II (10,000~15,000 kg/cm²). Hardness was closely related with the number of pores. Harder strains may be due to more number and smaller size of pores. Hardness of pileus surface may also related with the wrinkles of pileus surface. Korean strains did not have wrinkles however, North American strains had wrinkles because of thin pileus surface and soft tissues. Therefore, Korean strains of *G. lucidum* were very different in hardness than those of Taiwan or North American strains, which had different geographical origin. Such differences can be a criterion for the classification of *Ganoderma* species, including *G. lucidum*, *G. lucidum* complex, and be a key to differentiate species.

Because *G. lucidum* in Korea showed great differences to genus *Ganoderma* or *Ganoderma lucidum* complex which have different geographical origins, such as Taiwan and North America on various morphological characters, it is proposed that Korean cultures should be classified into the other species in genus *Ganoderma*.

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