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Current status of global *Ganoderma* cultivation, products, industry and market

Hapuarachchi KK [1,2,3], Elkhateeb WA[4], Karunarathna SC[5], Cheng CR[6], Bandara AR[2,3,5], Kakumyan P[3], Hyde KD[2,3,5], Daba GM[4] and Wen TC[1*]

[1]The Engineering Research Center of Southwest Bio–Pharmaceutical Resources, Ministry of Education, Guizhou University, Guiyang 550025, Guizhou Province, China
[2]Center of Excellence in Fungal Research, Mae Fah Luang University, Chiang Rai 57100, Thailand
[3]School of Science, Mae Fah Luang University, Chiang Rai 57100, Thailand
[4]Department of Chemistry of Microbial Natural Products, National Research Center, Tahrir Street, 12311, Dokki, Giza, Egypt.
[5]Key Laboratory for Plant Diversity and Biogeography of East Asia, Kunming Institute of Botany, Chinese Academy of Sciences, 132 Lanhei Road, Kunming 650201, China
[6] School of Chemical Engineering, Institute of Pharmaceutical Engineering Technology and Application, Sichuan University of Science & Engineering, Zigong 643000, Sichuan Province, China

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Abstract

Among many traditional medicines, *Ganoderma* has been used in Asian countries for over two millennia as a traditional medicine for maintaining vivacity and longevity. Research on various metabolic activities of *Ganoderma* have been performed both *in vitro* and *in vivo* studies. However, it is debatable whether *Ganoderma* is a food supplement for health maintenance or a therapeutic "drug" for medical purposes. Over the past two decades, the *Ganoderma* industry has developed greatly and today offers thousands of products to the markets. Despite the large market, there are problems with the industry which prevent it from establishing an effective market. This paper describes the current status of the world *Ganoderma* cultivation, products, industry and provides suggestions for facilitating further research.

Key words – lingzhi – secondary metabolites – traditional medicine

Introduction

Ganodermataceae is a large family of polypores with seven accepted genera: *Amauroderma*, *Foraminispora*, *Furtadoa*, *Ganoderma*, *Haddowia*, *Humphreya* and *Polyporopsis* (Richter et al. 2015, Costa–Rezende et al. 2017) and 592 epithets, of which most species are classified in the genus *Ganoderma* (www.indexfungorum.org, accessed 18 September 2018). Members of Ganodermataceae are cosmopolitan basidiomycetes (Cao & Yuan 2013) and are distinct from other families of polypores in having a peculiar type of double-walled basidiospores (Adaskaveg & Gilbertson 1988). The genus *Ganoderma* was established by Karsten (1881) with *Ganoderma lucidum* (Curtis) P. Karst. as the type species (Moncalvo & Ryvarden 1997). *Ganoderma* species are distributed worldwide (Pilotti 2005) and the fruiting bodies of *Ganoderma* grow from living, or more commonly, from dead trunks or branches of trees. They grow as facultative parasites that can

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Corresponding Author: Ting-Chi Wen – e-mail – tingchiwen@yahoo.com

live as saprobes on decaying wood (Turner 1981). Two types of fruiting bodies are produced, depending on the species: a laccate fruiting body with a shiny upper surface, or a non-laccate fruiting body with a dull upper surface (Smith & Sivasithamparam 2000, Pilotti et al. 2004). *Ganoderma* species are not classified as edible mushrooms, since they have a bitter taste and hardness in their fruiting bodies and do not have the fleshy texture characteristic of true edible mushrooms (Jong & Birmingham 1992). The double walled basidiospores with interwall pillars are a key diagnostic feature for the genus (Smith & Sivasithamparam 2000, Li et al. 2013). *Ganoderma* species have important economic value, due to their medicinal properties and pathogenicity (Dai et al. 2007, 2009). *Ganoderma* species cause white rot of hard woods by decomposing lignin, cellulose and related polysaccharides (Hepting 1971, Adaskaveg et al. 1991). *Ganoderma* is one of the mushroom genera, traditionally used as popular medicinal mushrooms particularly in China, Japan and Korea for millennia to improve longevity and health (Cao et al. 2012). Hence, *Ganoderma* has been used as a functional food to prevent and treat many immunological diseases (De Silva et al. 2013, Tan 2015). There are many publications which show the abundance and variety of biological actions initiated by the primary metabolites of *Ganoderma* such as polysaccharides, proteins and triterpenes (De Silva et al. 2012a, Hapuarachchi et al. 2016a). Hence, research and development of *Ganoderma* is a trending topic, since the high potential to use in biotechnology. In this study, we discuss the current status of the global *Ganoderma* industry, cultivation, products and market.

History of *Ganoderma* as a medicinal mushroom

Ganoderma is called "Lingzhi", Chi–zhi" or "Rui–zhi" (auspicious herb) in China, "Reishi" ('divine Mushroom'), "Munnertake" ('10,000 year old Mushroom') or "Sachitake" in Japan and "Youngzhi" in Korea (Wagner et al. 2003, Paterson 2006). Lingzhi is viewed as the "herb of spiritual potency", "mushroom of immortality" or "Celestial Herb" and symbolizes happiness, sanctity, success, goodness and longevity (Wasser 2005, Lin 2009, De Silva et al. 2012a). The Chinese name "Lingzhi" is mainly applied to *Ganoderma lucidum* (Curtis) P. Karst., a woody polypore (Basidiomycota) and it has played an important role as a medicinal mushroom in Chinese and Japanese culture for at least 2000 years (Sliva 2006). Images of this mushroom can be seen often portrayed in ancient, oriental art and depictions of this fungus proliferated through Chinese literature and art (McMeekin 2004, Pegler 2002). Although 'Lingzhi' is important traditional medicine in Chinese culture for over millennia, assertions have been made that the basic concept of Lingzhi originated in India, and was an expression of "Soma", a Vedic plant (*Soma-Haoma*) (Pegler 2002). Time has made changes in legends and myths, and however, the "Lingzhi" name was finally assigned to a mushroom (Pegler 2002). The idea of 'Lingzhi', a mushroom with magical powers first appeared in the Qin Dynasty (221 – 207 BCE). Lingzhi was recorded in the first book which was wholly devoted to the descriptions of herbs and their medicinal values, *Shen Nong Ben Cao Jing* written in Han Dynasty (206 BCE–220 CE) (Wachtel-Galor et al. 2005).

Lingzhi is mentioned in a 2000–years–old poem from the Han Dynasty and earlier descriptions of the 'Mushroom of Immortality' probably refer to this species (Money 2016). As early as 800 years ago in Yuan Dynasty (A.D. 1280 – 1368) "Lingzhi" has been represented in paintings, wood carvings, carvings of jade and deer's antlers, furniture, carpet designs, balustrades, jewelry, women's hair combs, perfumes, handicrafts and many more creative artworks (Wasser & Weis 1999). The first Chinese Pharmacopeia was written in Ming Dynasty (A.D. 1590) and Lingzhi has been recorded as a medicinal mushroom which claims several beneficial medicinal properties (Wachtel–Galor et al. 2011). This mushroom is popular in North America and Europe as one of the "artist's conk" fungi, but now it has been identified as *G. applanatum*. Furthermore, this has been used in the Orient as a talisman to protect a person or home against evil (Chang & Buswell 1999). The stipe of the fruiting bodies of *G. neojaponicum* were cut into bead-like pieces, strung and worn round the neck of children to treat epilepsy in Malaysia by ancient tribes (Tan 2015).

Taxonomic history and controversies

Traditional Chinese books classified *Ganoderma* into six species with reference to the colour of the fruiting body: *Sekishi* (red), *Shishi* (violaceous), *Kokushi* (black), *Oushi* (yellow), *Hakushi* (white) and *Seishi* (blue), and were assigned based on different triterpenoid patterns (Szedlay 2002) (Table 1). Liu (1974) compiled a monograph on Traditional Chinese Medicinal Fungi describing *G. lucidum* as "Lingzhi" in his book. Since then, *G. lucidum* was accepted as the scientific binomial of "Lingzhi" in many reports on Chinese edible and medicinal mushrooms (Ying et al. 1987, Mao 1998, Dai et al. 2009, Cao et al. 2012). Mycochemical and other studies reported different species numbers in the genus *Ganoderma* (Li et al. 2013, Yan et al. 2013, Peng et al. 2014). However, most of the species in *Ganoderma* have not been subjected to systematic studies (Baby et al. 2015). There are 445 records listed in Index Fungorum (2018) for *Ganoderma*, although Kirk et al. (2008) estimate that there are 80 species worldwide, but several are synonyms. The taxonomic situation within *Ganoderma* is unclear as the species and genus concepts are confused (Hapuarachchi et al. 2018), because morphologically similar members are found in *Fomes*, *Polyporus* and *Tomophagus* (Paterson 2006).

The traditional taxonomy of Ganodermataceae is based on its morphological traits, however, species identification has been unclear and taxonomic segregation of the genera has been controversial, since there are fundamentally different viewpoints among mycologists (Moncalvo et al. 1995, Moncalvo & Ryvarden 1997). Some *Ganoderma* collections and species have been misnamed because of the presence of heterogenic forms, taxonomic obstacles and variations in the way the genus has been subdivided (Mueller et al. 2007). Hence, most taxonomists regard the current nomenclatural situation of Ganodermataceae as chaotic and poorly studied (Ryvarden 1991, Smith & Sivasithamparam 2003, Hapuarachchi et al. 2015, Zhou et al. 2015, Thawthong et al. 2017). Accordingly, it is important to establish a combination of morphological, chemotaxonomic and molecular methods to develop a more stable taxonomy (Richter et al. 2015, Welti et al. 2015). The collections named as *G. lucidum* from different parts of the world are scattered in several separated lineages in phylogenetic analyses of the genus (Wang et al. 2012). The taxonomy of the *G. lucidum* complex has long been subjected to debate and even after many years of discussions, its taxonomy remains problematic due to many inconsistencies of phylogeny and morphology. Hence different opinions have been raised regarding the validity of its members (Yang & Feng 2013).

Ecological aspects

Ganoderma species have a worldwide distribution in green ecosystems both in tropical and temperate geographical regions in Asia, Africa, America and Europe (Wang et al. 2012). The species of *Ganoderma* have a wide host range, with more than 44 species from 34 genera of plants being identified as potential hosts (Venkatarayan 1936). Plant-pathogenic and wood decaying species (Fig. 1) of *Ganoderma* can cause severe diseases such as stem rot, butt rot and root rot in economically important trees and perennial crops, especially in tropical countries (Coetzee et al. 2015). *Ganoderma* species are white rot fungi and have ecological importance in the breakdown of woody plants for nutrient mobilization. They hold effective mechanisms of lignocellulose–decomposing enzymes useful for bioenergy production and bioremediation (Hepting 1971, Adaskaveg et al. 1991, Coetzee et al. 2015, Kües et al. 2015). Root and stem rots caused by *Ganoderma* species result in loss of forestry yields e.g. *Areca catechu* (betel nut) (Singh 1991), *Camillia sinensis* (tea), *Cocos nucifera* (coconut) (Kinge & Mih 2015), *Elaeis guineensis* (oil palm) (Glen et al. 2009) and *Hevea brasiliensis* (rubber) (Monkai et al. 2016) worldwide. Turner (1981) reported 15 species of *Ganoderma* from various parts of the world, such as Africa, India, Indonesia, Malaysia, North America, Papua New Guinea and Thailand as being associated with basal stem rot of oil palm, including *G. applanatum*, *G. boninense* (= *G. orbiforme*), *G. chalceum*, *G. cochlear*, *G. lucidum*, *G. miniatocinctum*, *G. pseudoferreum* (= *G. philippi*), *G. tornatum* (= *G. australe*), *G. tropicum* and *G. zonatum*. *Ganoderma boninense* is the most aggressive pathogen to cause the basal stem rot in oil palm (Turner 1981, Wong et al. 2012). Different species produce different features

and pathogenicity. Species identification in this genus is limited causing a crucial problem for disease management (Wong et al. 2012).

Figure 1 – Pathogenic and wood decaying *Ganoderma* species. a *Ganoderma applanatum* found in Chinese privet plant (*Ligustrum lucidum*) (GACP18032701). b *Ganoderma sinense* (GACP18032702). c *Ganoderma hoehnelianum* (GACP14080913). d *Ganoderma donkii* (GACP18032703). e *Ganoderma tropicum* (GACP18032704). f *Ganoderma brownii* (GACP18032705). (Photographs taken by TC Wen). *GACP – The Herbarium of Guizhou University (= the Original Herbarium of Guizhou Agricultural College)

Important uses of *Ganoderma*

Species of *Ganoderma* are widely researched, because of their highly prized medicinal value, since they contain many chemical constituents with potential nutritional and therapeutic values (Hapuarachchi et al. 2016b, 2017) (Fig. 4). *Ganoderma* and *Amauroderma* include several species which possess great economic and ecological importance (Correia de Lima et al. 2014). The fruiting bodies of *Ganoderma* species have gained wide popular use as dietary supplements in China, Japan, North America and other regions of the world (Paterson 2006). *Ganoderma* has been used as a functional food to prevent and treat immunological diseases (Wang et al. 2012). Several hundreds of metabolites have been obtained from the species of this family, including *G. lucidum*, which is the most sought after species of the genus (Dong & Han 2015). Polysaccharides, steroids and triterpenes as the major groups followed by alkaloids, fatty acids, glycoproteins, inorganic elements, lignin, nucleosides, nucleotides, peptides, phenols, proteins, sterols and vitamins were found in *G. lucidum* (Boh et al. 2007). The bioactive constituents (Table 2) are reported to be responsible for anti-cancer, anti-inflammatory, anti-tumor, anti-oxidant, immunomodulatory, immunodeficiency, anti-diabetic, anti-viral, anti-bacterial, anticonvulsant, anti-fungal, anti-hypertensive, anti-atherosclerotic, anti-aging, anti-androgenic, anti-hepatotoxic, radical scavenging property, neuroprotection, sleep promotion, cholesterol synthesis inhibition, hypoglycemia, inhibition of lipid peroxidation/oxidative DNA damage, hepatoprotective properties, maintenance of gut health, prevention of obesity, and stimulation of probiotics (Paterson 2006, Cao et al. 2012, De Silva et al. 2012a, b, 2013, Baby et al. 2015, Bishop et al. 2015, Liu et al. 2015b, Vyas et al. 2016).

Generally, *Ganoderma* species are a good source of anti-oxidant compounds (Mau et al. 2005a, b, Rawat et al. 2013), and such compounds can reduce oxidative damage by directly scavenging free radicals generated in the cell (Wong et al. 2004, Agarwal et al. 2012, Celık et al. 2014, Rajoriya et al. 2015, Obodai et al. 2017). The presence of phenolic compounds are also responsible for anti-oxidant properties in many mushrooms (Ferreira et al. 2009, Barros et al. 2008). The presence of flavonoids specifically may have detoxification, anti-inflammatory, and curing activities for various cardiovascular diseases (Le Marchand 2002). Many *Ganoderma* species exert remarkable anti-tumor activity (Jeong et al. 2008) due to the presence of many compounds such as triterpenes which can suppress growth and aggressiveness of cancer cells, polysaccharides that stimulate the anti-cancer response of immune cells and activate production of cytokines (Kuo et al. 2006, Sliva 2006, Smina et al. 2011), and flavonoids (Le Marchand 2002). An extract of *G. lucidum* inhibits distinct signalling pathways in different cancer cells (Aydemir 2002). *Ganoderma lucidum* has also strong activity against human prostate cancer cells since it induces apoptosis, inhibits cell proliferation, and suppresses cell migration (Stanley et al. 2005). *Ganoderma lucidum* showed activity against lymphoma, leukemia, and multiple myeloma cells (Muller et al. 2006). Furthermore, the methanolic extract of *G. applanatum* has an apoptotic anti-tumor activity in human colon cancer cell line (Caco–2) (Elkhateeb et al. 2018). Some *Ganoderma* metabolites showed also an anti-microbial activity against different pathogenic bacteria and fungi (Shikongo et al. 2013, Singh et al. 2014). Quereshi et al. (2010) reported the anti-bacterial activity of the acetone extract from fruiting bodies of *G. lucidum* against *Staphylococcus aureus* and against *Pseudomonas aeruginosa.* Polysaccharides extracted from *G. lucidum* exerted an anti-bacterial activity against *Micrococcus luteus* ATCC 10240 (Skalicka-Woźniak et al. 2012). Hleba et al. (2014) described the anti-microbial activity of the methanolic extracts of *G. lucidum* against *Saccharomyces cerevisiae*. Furthermore, ganodermin extracted from *Ganoderma lucidum* exhibited anti–fungal activity against *Botrytis cinerea*, *Fusarium oxysporum* and *Physalospora piricola* (Wang & Ng 2006). Polysaccharides extracted from *Ganoderma* species have been reported to have anti-tumor activity (Kim et al. 1980, Miyazaki & Nishijima 1981). Ganoderiol F and ganodermanontriol obtained from the methanol extract of the fruiting bodies of *G. lucidum* have anti–HIV–1 activity (El–Mekkawy et al. 1998). Eo et al. (1999) reported anti–viral activity of *G. lucidum* carpophores against herpes simplex virus type 2 (HSV–2) with low cytotoxicity to host cells *in vitro*. Li & Wang (2006) described ganoderic acid extracted from *G. lucidum* as an anti-

hepatitis B agent since it inhibited virus replication. Zhang et al. (2014) recorded the significant anti-viral activity of *G. lucidum* against enterovirus, which is the major cause of hand, foot and mouth diseases.

Ganoderma (as Lingzhi) was cultivated in a large-scale, successfully for the first time in 1969 in China (Yu & Shen 2003) and currently, the annual sale of products derived from *G. lucidum* is estimated to be more than US$ 2.5 billion in Asian countries, including China (Figs 2, 3), Japan, and South Korea (Li et al. 2013). *Ganoderma sinense* and *G. lucidum* have been listed in Chinese Pharmacopeia to prevent and treat many diseases, and *Ganoderma* was included in American Herbal Pharmacopoeia and Therapeutic Compendium.

Table 1 The six types of traditional *Ganoderma* and their uses (Szedlay 2002, Wasser 2005).

Color	Taste	Chinese name	Japanese name	Uses
Blue	Sour	Seishi	Aoshiba	Improves eyesight and liver function, calms nerves
Red	Bitter	Sekishi	Akashiba	Supports internal organs; sharpens memory, enhances vitality
Yellow	Sweet	Oushi	Kishiba	Strengthens spleen function
White	Hot (or pungent)	Hakushi	Shiroshiba	Improves lung function, gives courage and strong will
Black	Salty	Kokushi	Kuroshiba	Protects kidneys

Table 2 Common therapeutic effects of different *Ganoderma* spp.

Therapeutic effects	*Ganoderma* spp.	Major bioactive compounds	References
Anti-cancer	*G. amboinense*	Ganoderic acid X, Lanostanoid triterpenes	Li et al. 2005**,** Hsu et al. 2008
	G. applanatum	Terpene (Presiccanochromenic acid, Myrocin C, Sphaeropsidin D, Deoxyherqueinone , Xylariacin B, Trichiol C, Comazaphilone D, Zeylasteral, Erinacine H, Applanoxidic acid C,D, E, F,G,H	Elkhateeb et al. 2018
	G. lucidum	Triterpenoids (Ganoderic acids, Lucidumol, Lucialdehyde, Lucidenic acids)	Yuen & Gohel 2005
		LZ-8 protein	Boh 2013
		Polysaccharides, GLP-2B	Zhang et al. 2011
		LZP-F3	Huang & Ning 2010
		GLIS	Zhang et al. 2010 Zhu et al. 2007
		GlPS	Cao & Lin 2006
		GlPP	
	G. tsugae	Crude extract of *G. tsugae*	Hsu et al. 2008

Table 2 Continued.

Therapeutic effects	*Ganoderma* spp.	Major bioactive compounds	References
Anti-diabetic effects	*G. applanatum*	Polysaccharides (PSG)	Jung et al. 2005
	G. atrum	Polysaccharides (PSG)	Zhu et al. 2013, 2016
	G. lucidum	Polysaccharides, proteoglycans, Proteins (LZ-8) and Triterpenoids	Ma et al. 2015
Anti-inflammatory	*G. applanatum*	Ganodermycin, polysaccharide components	Jung et al. 2011, Vazirian et al. 2014
	G. atrum	Polysaccharide (PSG-1)	Li et al. 2017
	G. capense	*G. capense* Glycopeptide (GCGP)	Zhou et al. 2014
	G. colossus	Colosolactones	El Dine et al. 2009
	G. lucidum	Ganoderic acids T-Q and lucideinic acids A, D2, E2, and P	Sliva et al. 2003
	G. sichuanense	Lingzhilactone B	Yan et al. 2015
	G. sinense	Triterpenoid-enriched lipids	Yue et al. 2008
	G. tsugae	Water soluble polysaccharides	Ko et al. 2008
Anti-oxidant activity	*G. atrum*	Polysaccharides (PSG-1)	Zhu et al. 2016
	G. applanatum	Exopolysaccharides	Liu et al. 2015a
	G. capense	Polysaccharide, designated as GCPB-1b	Jiang et al. 2016
	G. cochlear	(+)- and (-)-cochlearols	Dou et al. 2014
	G. hainanense	lanostane-type triterpenoids	Li et al. 2016b
	G. lucidum	Triterpenes, Polysaccharides, polysaccharide-peptide complex and phenolic component	Mehta 2014, Kana et al. 2015
	G. sichuanense	Lingzhilactone B	Yan et al. 2015
	G. tsugae	Polysaccharides	Tseng et al. 2008
Anti- Microbial Activity	*G. lucidum*	Polysaccharides	Mehta 2014
		Triterpenoids (Ganoderic acids, Ganodermin, Ganoderic acid A, Ganodermadiol, Ganodermanondiol, Lucidumol B, Ganodermanontriol, Ganoderic acid B and Ganolucidic acid A	Zhang et al. 2011, Isaka et al. 2013, Bisko & Mitropolskaya 1999,
	G. pfeifferi	Ganomycins A and B	Mothana et al. 2000
Cardiovascular problems	*G. lucidum*	Polysaccharides (Ganopoly)	Gao et al. 2004

Ganoderma tsugae is regarded as a health food by Chinese government (Chen et al. 2016). *Ganoderma lucidum* products, from different parts of its fruiting bodies, mycelia or spores, are sold in the form of coffee, powder, tea, dietary supplements, spore products, drinks, syrups, tooth pastes, soaps and lotions and have been commercialized as food and drug supplements (Fig. 5) which enhance the body's immune system and improve metabolic functions (Chang & Buswell 1999, Lai et al. 2004, Singh et al. 2013). *Ganoderma lucidum* was used as Bonsai products to decorate gardens, ornaments and many other art products. Awareness of *Ganoderma* has improved from fundamental level to artificial cultivation, large-scale cultivation and isolation of bioactive components.

Figure 2 – Cultivated *Ganoderma lingzhi* species in Yunnan Province, China (GACP16091002). a Upper surface. b Lower surface. c Cut surface. d–g Spores (100×). h Generative hyphae (100×). i Skeletal hyphae (100×). j Binding hyphae (100×). Scale bars: d–g = 10 μm, h–j = 5 μm. *GACP – The Herbarium of Guizhou University (= The Original Herbarium of Guizhou Agricultural College).

Figure 3 – *Ganoderma* cultivation in China. (Photographs taken by TC Wen)

Cosmetic products based on *Ganoderma*

Ganoderma is a part of several cosmetics produced mainly in China, Korea, USA and some other Asian and European countries, many being used for skin lightening (Jiang 2015). Tyrosinase enzyme is a key enzyme in the melanin formation and *Ganoderma lucidum* has shown tyrosinase inhibition activity (Chien et al. 2008). Hence, many facial mask cosmetics in the market contain *Ganoderma* extracts which helps in skin whitening (Hyde et al. 2010). *Ganoderma lucidum* combined with three other plants and zinc to stimulate hair growth in human males by lowering dihydrotestosterone or prostatic hyperplasia levels (Meehan 2015). Table 3 lists common cosmetic products containing *Ganoderma lucidum* extracts.

Traditional Chinese Medicine

In ancient China, it was believed that *Ganoderma* had the power to enhance longevity and vivacity. Royalty considered it as a valuable mushroom and they used it when they were meditating (Ulbricht et al. 2010). In Traditional Chinese Medicine (TCM), *Ganoderma* is claimed "to replenish the energy, ease the mind, and relieve cough and asthma" (Wachtel-Galor et al. 2011). In herbal medicine, *Ganoderma* is used to increase energy, resist stress, or as a liver tonic (Wachtel-Galor et al. 2011). Modern studies associated with animal models and molecular-based research techniques have demonstrated numerous pharmacological effects supporting these claims (Hapuarachchi et al. 2016a, b, 2017). Inappropriate claims involving the efficacy of TCM are frequently made (Hui 1997). Jiaogulan (*Gynostemm pentaphyllum*) is mixed with *G. lucidum* and make "Lingzhi Jiaogulan oral liquid" which helps in relieving palpitation, shortness of breath, and insomnia (Yan 2015). There are nearly 200 medicines and compounded medicines containing *Ganoderma* available within China (Chen et al. 2016). Modern research revealed that triterpenoids and polysaccharides were responsible for the pharmacological effects mentioned above. However, due to the difficulty in obtaining large amounts of the pure triterpenoids and polysaccharides, double-blind clinical data of the active components are limited. No natural products or extracts from *Ganoderma* have been reported to enter clinical trial (Cheng et al. 2013, Hapuarachchi et al. 2017).

Medicated foods and dietary supplements

The total number of publications on *Ganoderma* in the world has exceeded 10,000 with 7,000 related patents. Over 1,000 *Ganoderma* health food products are certified by Chinese government (Chen et al. 2016). *Ganoderma lucidum* is used as the material of functional food in daily life such as soup, tea, wine and yoghourt (Dong & Han 2015). This species is used with ginseng (*Panax ginseng*) to make soups. These soups are useful for soothing the nerves, relieving asthma, and strengthening the immune system (Zhao 2015). *Ganoderma lucidum* is mixed with sanqi (*Panax nostoginseng*) to make herbal *Sanqi* wine which helps to promote blood circulation and soothe nerves (Zhao 2015). *Ganoderma lucidum* alone or combined with other herbs such as Chinese yam (*Dioscorea opposite*), magnolia berry (*Schisandra chinensis*), and desert-broomrape (*Cistanche deserticola*) can be used in herbal wine for balancing the body and anti-aging process (Dong & Han 2015). Tea is prepared by *G. lucidum* alone or mixed with other herbs such as Japanese honeysuckle (*Lonicera japonica*), Chinese hawberry (*Crataegus pinnatifida)* and wolfberry (*Lycium barbarum*) which helps in modulating immunity to keep the body in balance (Dong & Han 2015).

Cultivation

Commercial cultivation of *Ganoderma* has been introduced worldwide, especially in tropical Asian countries to meet the gradually increasing demand of the mushroom as a natural medicine (Wachtel-Galor et al. 2011). Wild *Ganoderma* is difficult to collect and to maintain its quality. In ancient times, *Ganoderma* was collected from the wild and consumed only by wealthy people, but a large proportion is cultivated today for the general population. Artificial cultivation of *Ganoderma* was attempted in 1937 (Perumal 2009). However, the first successful cultivation of

Ganoderma was performed in 1969 with the use of a spore separation cultivation method by a Chinese technician in the Institute of Microbiology, Chinese Academy of Sciences, Beijing (Yu & Shen 2003). Since then, the cultivation of *Ganoderma* has been popular in China and other Asian countries, such as Japan and Korea (Li et al. 2016a). Traditional cultivation (since 1969) was based on inoculating one meter long natural logs without sterilization, which were then buried in a shallow trough (Pegler 2002). Most broad-leaf hardwoods can be used to cultivate *Ganoderma* species and logs are cut from living trees (Chen 2002). Fruiting bodies took 6-24 months to emerge, but cropping could continue for five years (Pegler 2002). Since late 1980s, new methods have been developed that use short logs (15 cm or less) (Chen 2002). Today, this method is followed by most *Ganoderma* natural-log growers in China, Japan and Korea (Chen & Chen 2004). As it takes several months to produce the fruiting body, mycelia-based and culture broth-based products have been considered as methods to ensure quality control and for continuous production throughout the year (Sanodiya et al. 2009).

Different species of *Ganoderma* need different conditions for growth and cultivation (Mayzumi et al. 1997). There are several other methods that have been trialed to cultivate *Ganoderma* such as basswood cultivation (Zhang et al. 2004), sawdust cultivation and substituted cultivation. Artificial cultivation of *G. lucidum* has been achieved using substrates such as grain, sawdust, wood logs (Chang & Buswell 1999, Wasser 2005, Boh et al. 2007), tea waste (Peksen & Yakupoglu 2009), cotton seed husk, or residues of farm crops (Zhang & Wang 2010), cork residues (Riu et al. 1997), sunflower seed hull (González–Matute et al. 2002), corn cobs (Ueitele et al. 2004), olive oil press cakes (Gregori & Pohleven 2014) and wheat straw (Khajuria & Batra 2014). Various ornamental growth forms, including antler-like structures, can be produced by altering the growing conditions, especially temperature and the carbon dioxide volume (Pegler 2002). Current methods involved in commercial production of *Ganoderma*, include wood log, short basswood segment, tree stump, sawdust bag, and bottle procedures (Mayzumi et al. 1997, Lin & Zhou 1999, Erkel 2009, Chen 1999, Han et al. 2008). Natural log cultivation produces *Ganoderma* mushrooms with superior quality and gets best prices in the markets of Southeast Asia. However, the yield could be lower, and the production time could be little more extended than sawdust synthetic log cultivation (Chen & Chao 1997). It is important to conserve the forests where logs are collected, and this is of significant environmental concern (Chen & Chen 2004). Nowadays *G. lucidum* is not the only species in this genus grown for a commercial purpose worldwide, but also *G. applanatum*, *G. capense*, *G. sinense*, *G. tsugae* (Chen & Chen 2004) and *G. neojaponicum* (Tan 2015) are cultivated in farms.

Global Marketing

Ganoderma based products have attracted a great deal of attention during the last decade in Europe, Malaysia, North America and Singapore. China, Japan and Korea are the main producers and suppliers of *Ganoderma* based products (Chang & Mills 2004) (Table 4). The total *Ganoderma* production of Japan during 1995 was estimated approximately 500 MT. In 1997, the worldwide *G. lucidum* production was 4300 MT, and 3000 MT were from China, while 1500 MT were exported to Japan, Korea, Singapore and Taiwan. The remaining 1300 MT were produced mainly in Korea, Taiwan, Japan, Thailand, US, Malaysia, Vietnam, Indonesia and Sri Lanka (Zhou & Gao 2002). The DXN Group in Malaysia produced 70 MT of *Ganoderma* and accounted for 1% of the global production in 2001 (DXN Holdings' IPO listing Reports).

The total world market for *Ganoderma* based natural health care products was 1628 million US dollars in 1995 (Chang & Buswell 1999). In 2004, *Ganoderma lucidum* worldwide production was approximately 5000-6000 MT and more than half was produced by China (Rai 2003, Lai et al. 2004). The China Edible Fungi Association recorded that *Ganoderma* production in China was 36700 and 49200 MT in 2002 and 2003, respectively (Banuelos & Lin 2009). However, there are some problems with *Ganoderma* based products because of low reproducibility and poor quality control. Various reasons such as seasonal variations, different soil conditions and stage of fruiting body development weaken the product quality. Hence, it is important to develop acceptable and

Figure 4 – Medicinally important *Ganoderma* species. a *Ganoderma sinense* (GACP14081236). b *Ganoderma calidophilum* (GACP15081036). c *Ganoderma orbiforme* (GACP1706211). d *Ganoderma flexipes* (GACP17102301). e *Ganoderma resinaceum* (GACP HNU58). f *Ganoderma multiplicatum* (GACP14081328). *GACP – The Herbarium of Guizhou University (= the Original Herbarium of Guizhou Agricultural College)

Figure 5 – *Ganoderma* products used as drugs and food supplements in China. a *Ganoderma lucidum* compound capsules (Chongqing Taiji Industry (Group) Co. Ltd). b *Ganoderma lucidum* syrups (Guizhou Shunjian Pharmaceutical Co. Ltd). c *Ganoderma lucidum* spore powder capsules enriched with Se (Guizhou Lingkangshi Biological Technology Co. Ltd). d *Ganoderma lucidum* spore powder (Yunnan Xianghui Pharmaceutical Co. Ltd). e Broken *G. lucidum* spore powder oil capsules (FGTZ Biotechnology Company). f Broken *G. lucidum* spore powder (Chengdu Dujiangyan Chunsheng Chinese Herbal Pieces Co. Ltd). g *Ganoderma lucidum* fruiting body slices (Sichuan Zibo Pharmaceutical Co. Ltd) (Photographs taken by TC Wen).

Table 3 Cosmetic products containing *Ganoderma lucidum* extract and their functions.

Product Name	Function	Reference
CV Skinlabs Body Repair Lotion, U.S.	Wound-healing and anti-inflammatory properties	Wu et al. 2016
Dr. Andrew Weil for Origins Mega-Mushroom, Skin Relief Face Mask, U.S.	Anti-inflammatory properties	Wu et al. 2016
Dr. Andrew Weil for Origins Mega-Mushroom, Moisturizing body Cream, U.S.	Skin anti-aging	Taofiq et al. 2016
DXN Ganozhi E Deep Cleansing Cream, UK	Deeply removes impurities and dead cells without drying skin and revitalize the skin	www.ganodermalucidumproducts.com
DXN Ganozhi E Nourishing Night Cream, UK	Improve firmness whilst strengthening the skin's structure	www.ganodermalucidumproducts.com
DXN Ganozhi E Hydrosoft Toner, UK	cleanses and minimizes pores, penetrates and tones skin	www.ganodermalucidumproducts.com
DXN Ganozhi E UV defense Day Cream, UK	Hydrates, firms and moisturize and protects against UV rays	www.ganodermalucidumproducts.com
DXN Ganozhi Moisturizing Micro Emulsion, Malaysia	Hydrate and nourish the skin	www.dxnmalaysia.com
DXN Ganozhi Lipstick, Malaysia	Hydrating lips with a natural, subtle shine	www.lifeganodermaen.dxnseo.com
DXN Ganozhi Liquid Cleanser, Malaysia	Cleanses skin deep into the pores and refreshed	www.lifeganodermaen.dxnseo.com
DXN Ganozhi Toner, Malaysia	Minimize skin pores while leaving the skin soft and hydrated	www.lifeganodermaen.dxnseo.com
Estée Lauder, Re-Nutriv Sun Supreme Rescue Serum sun care product, U.S	Triple-action repair technology to enhance the skin's own natural defenses against the visible effects of sun exposure and sun-stressed skin	Taofiq et al. 2016
Guangzhou Maycare cosmetics, Collagen crystal facial mask, China	Skin revitalizing and whitening	www.may-care.com
Guangzhou Bocaly Bio-Tec., *Ganoderma* Cells Repairing Anti-aging Face Mask, China	Anti-wrinkle, firming, lightening, moisturizer, nourishing, pigmentation correctors, pore cleaner and whitening.	www.vegamebeljepara.com

Table 3 Continued.

Product Name	Function	Reference
Guangzhou Ocean Cosmetic Beauty, *Ganoderma* Moisturizing Cream, China	Acne treatment, anti-aging, anti-wrinkle, dark circles, firming, lightening, moisturizer, nourishing, skin revitalizer, sunscreen, whitening.	www.vegamebeljepara.com
Hankook Sansim Firming Cream (Tan Ryuk SANG), Korea	Make skin tight and vitalized	Hyde et al. 2010
Julie Levin Organic skin Care, Green Tea Reishi Face Serum, US	Nourish and invigorate the skin	www.leafpeople.com
Kat Burki Form Control Marine Collagen, Gel, U.K.	Boost collagen, improve elasticity and provide hydration	Wu et al. 2016
MAVEX, 24 hrs. Intensive Cream, Hong Kong	Stimulates cell turnover formation of collagen and elastin, Skin anti-aging	www.dazzlinggroup.com
MAVEX, Rejuvenating Treatment, Hong Kong	Anti-oxidant action and deep cellular renewal. Fights degenerative processes and the negative action of free radicals.	www.dazzlinggroup.com
MAVEX, Hyaluronic Lifting Serum, Hong Kong	Stimulates collagen synthesis and keeps the skin toned, hydrated and luminous, skin anti-aging	www.dazzlinggroup.com
MAVEX, Beauty Secret Eye Contour, Hong Kong	skin anti-aging, Anti-oedema, prevents and reduces oedemas, fights the formation of wrinkles	www.dazzlinggroup.com
MAVEX, 2 in 1 Cleansing Milk & Tonic, Hong Kong	Effectively removes impurities and residues of make-up, deeply purifies, deeply protects and moisturize the skin	www.dazzlinggroup.com
MAVEX, AHA/BHA Peeling, Hong Kong	Effective exfoliating, keratolytic and bio-stimulating properties, skin anti-aging and revitalized	www.dazzlinggroup.com
Menard Embellir, Night cream, Japan	Eliminate toxins and help repair skin damage associated with over exposure to UV radiation and free radicals	Taofiq et al. 2016

Table 3 Continued.

Product Name	Function	Reference
Paris Skin Institute, Derma Sublime, **Luxurious Revitalizing crème, France**	Intensely hydrate and comfort dry and sensitive skin	www.parisskininstitute.com
Paris Skin Institute, Derma Sublime, **La Crème Supreme, France**	Nurtured skin and enhanced regenerating performance, moist and intense hydration.	www.parisskininstitute.com
Paris Skin Institute, Derma Sublime, Eye Crème Suprême, **France**	An intense rejuvenating effect while reducing the appearance of dark circles, lines and puffiness of eyes	www.parisskininstitute.com
Paris Skin Institute, Derma Sublime, Le Sérum Lifting Concentrate, **France**	Skin anti-aging	www.parisskininstitute.com
Pureology NanoWorks Shineluxe, France	Anti-aging and anti-fading	Hyde et al. 2010
Shenzhen Hai Li Xuan Technology, HailiCare Skin Whitening Cream, China	Removing freckle speckle and whitening	www.vegamebeljepara.com
Tela Beauty Organics Encore Styling, Cream, U.K	Provide hair with sun protection and prevent color fading	Wu et al. 2016
Yves Saint Laurent Temps Majeur Elixir De Nuit, France	Anti-aging	Hyde et al. 2010
Nanjing Zhongke Pharmaceuticals, *Ganoderma* Face Cream Set (Day/night cream and eye gel set), China	Immune & anti-fatigue	www.vegamebeljepara.com

reproducible protocols for manufacturing processes to ensure high quality, standard and safe *Ganoderma* products (Chang & Mills 2004). Good laboratory, agriculture, manufacturing, production and clinical practices are essential to achieve quality *Ganoderma* products (Chang & Mills 2004).

Ganoderma products are divided into three types; developmental products based on *Ganoderma* fruiting bodies (Wasser 2011), mycelia (He 2000), and spore powder (Xie et al. 2002). A variety of *Ganoderma* products have been commercialized and it is estimated that at least 100 brands and over 780 products are sold in the world markets (Lai et al. 2004, Li et al. 2016a). USA is the largest market for *Ganoderma* and related products (Perumal 2009). Li et al. (2016a) showed China is the largest producer and exporter with a capacity over 110,000 MT/year of fruiting bodies, slices, and spore powders as most popular products among consumers. Even though China accounts for 70% of the world's production, it exports less than 5% of total production. Most manufacturing facilities in China do not possess internationally recognized GMP (Good Manufacturing Practice)

certifications for acceptance in international markets (Pang 2002). There are more than 100 research institutes that specialize in the study of *Ganoderma*, and more than 200 factories involved in the production of drugs and nutraceuticals in China. Furthermore, many patented products have been marketed upon the preparation of anti-tumor, liver function accelerant, lowering of blood pressure, hypoglycemic activity, lowering of cholesterol levels, treatment of chronic bronchitis, immunomodulator, lysozyme as antibiotic and shampoo and body shampoo (Xie et al. 2002). In the early 1980s, there were some *Ganoderma* based products on the international market, such as decoction, syrup, tablet, and injection liquid. In the early 1990s, 90 brands of *Ganoderma* products were registered and marketed internationally (Lin 2000). However, today it varies from drugs, health liquor, and *Ganoderma* dietary supplements to cosmetology products. These products are sold as prescription drugs in some Asian countries, however, mostly they are advertised as dietary supplements globally (Lai et al. 2004). Global consumption is estimated at several thousand tonnes, and the demand is growing swiftly (Wachtel-Galor et al. 2011). Numerous *G. lucidum* products, prepared from different parts of the mushroom, are currently available on the market (Chang & Buswell 2008). However, these products do not yet fulfill the customer satisfaction.

Draw backs and future trends

A number of challenges have to be addressed regarding this industry. The systematics and taxonomy of *Ganoderma* species needs to be studied and confirmed. Homogeneity of products, lack of highly value-added products, poor quality and high prices are also major problems (Li et al. 2016a). The quality standard of the fungus and management of *Ganoderma* products must be improved and include the identification and control of the bioactive components, any hazardous and noxious substances such as heavy metals and residual pesticides and, moreover, trials are needed to develop new product formulations (Zhou et al. 2011, Hobbs 2017). Recently, a group of researchers showed that most of the *Ganoderma* products in USA lacked characteristic triterpenoids and contained a starch like – polysaccharide profile that was inconsistent with *G. lucidum* (Wu et al. 2017). Furthermore, it was suggested that the quality consistency of *G. lucidum* dietary supplements collected in USA was extremely poor and requires careful investigation (Wu et al. 2017). All companies manufacturing *Ganoderma* based products should be accredited according to international standards. There has been a trend and significant increase in developing natural drugs to prevent and treat many immunological diseases over the last few decades. There have been some reports of human trials using *Ganoderma* as a direct control agent for various diseases but scientific evidence is inconclusive (Gao et al. 2003a, b, Zhao et al. 2011, Zhou et al. 2014, Baby et al. 2015). Clinical trials were successful most of the time together with *Ganoderma* preparation, but more in-depth investigation and accurate scientific evidence are still required, especially for double–blind clinical data. Factors like small sample size, lack of a placebo control group, lack of information regarding long term treatment of the drug, age, patient's gender and side effects, standard method of extraction of *Ganoderma*, standard dosage, and number of patients treated weaken the validity of the results (Hapuarachchi et al. 2017). However, well-designed *in vivo* tests and randomized controlled clinical studies with *Ganoderma* can provide statistically significant results to confirm the efficacy and safety of *Ganoderma* preparations in order to incorporate *Ganoderma* as an integrative therapy. Clarification of active ingredients, isolation and purification of individual compounds should be carried out and this will enable the active ingredients within nutriceutical products to be measured and to understand whether the beneficial compounds in *Ganoderma* act synergistically or independently. Hence, it will help to explain potential synergistic effects and establish safe and beneficial dose ranges of active ingredients for each disease type. Further, standardization and quality control of *Ganoderma* strains, cultivation processes, extracts and commercial formulations, are needed for wide acceptance of *Ganoderma* as a natural product for use in the prevention and treatment of various diseases (Hapuarachchi et al. 2016b).

Breeding of new *Ganoderma* strains will enhance the development of strains with higher yield and resistance to diseases, which in turn will increase productivity and reduce the use of chemicals for pest control. Modern engineering technologies, such as computerized control systems

to control environmental parameters, techniques for the production of mushrooms in new substrates, new methods for substrate sterilization and spawn preparation, will also increase the productivity of mushroom culture (Zhou et al. 2011). *Ganoderma* development and research helps to prevent and control environmental pollution since the production of *Ganoderma* creates a great amount of waste which can be consumed as animal feed, soil conditioner, mushroom recultivation, and bioremediation. Furthermore, *Ganoderma* cultivation is a biotechnological process that recycles lignocellulosic wastes and converts agricultural and forest wastes into useful biomass and reduces environmental pollution (Zhou et al. 2011). Effective market research on global *Ganoderma* industry should be carried out with information such as company profiles, product picture and specification, capacity, production, price, cost, revenue and contact information. This will help to provide current market trends and future growth expectations with respect to value and volume, technological advancement, macro economical and governing factors in the market.

Table 4 List of major *Ganoderma* producing companies.

***Ganoderma* Company**	**Country of origin**	**Company Website**
ALPHAY	China	http://www.alphayglobal.com/
AMAX NUTRASOURCE	USA	http://www.amaxnutrasource.com
BIO-BOTANICA	USA	http://www.bio-botanica.com
BRISTOL BOTANICALS	UK	http://www.bristolbotanicals.co.uk
DXN	Malaysia	https://www.dxn2u.com/
DRAGON HERBS	USA	http://www.dragonherbs.com
GANO EXCEL	Malaysia	http://www.ganoexcel.com.my/
GANOLIFE	USA	http://www.ganolife.us/
GUXIN	China	http://www.gubaolz.com
HANGZHOU	China	http://johnsun.en.alibaba.com
HOKKAIDO REISHI	Japan	http://www.hokkaido-reishi.com/
HUAHERNHANFANG	China	http://www.hhhf.com.cn
HUACHENGBIO	China	http://www.huachengbio.com
JIABAO	China	http://www.lqjiabao.com
LINKANGSHI	China	http://www.gzlzzp.com/
MUSHROOM SCIENCE	USA	https://mushroomscience.com
NATUREPLUS	China	http://www.gonatureplus.com
NAMMEX	Canada	http://www.nammex.com
ORGANO GOLD	Canada	https://www.organogold.com/en/
QINGDAO DACON	China	http://www.cccme.org.cn
RUIZHI	China	http://www.rzswkj.com
SANLIAN	China	http://www.cn-lingzhi.com
SERENIGY	USA	https://sites.google.com/site/serenigycoffeebusiness/home
SHOUXIANGU	China	http://www.sxg1909.com
SHUANG HOR	China	http://www.shuanghor.com.my/select_country.jsp
TOTAL LIFE CHNAGES	USA	https://totallifechanges.com/
XIANKELAI	China	http://www.xkl-cn.com
XI'AN GREENA BIOTECH	China	http://www.greena-bio.com
XIANPAILINGZHI	China	http://www.shinpire.com

Table 4 Continued.

Ganoderma Company	Country of origin	Company Website
XI'AN SOST	China	http://www.xasost.com
XIANZHILOU	China	www.xianzhilou.com
XIAN YUENSUN	China	http://www.yuensunshine.com
XUCHANG YUANHUA	China	http://www.yamasuan.com
YUEWEI	China	http://www.gdyuewei.cn
YUNLE	China	http://www.hsyllz.com
ZHENGXIN	China	http://www.taishanlingzhi.net
ZHONGKE	China	http://www.zhongke.com

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