International Food Research Journal 26(1): 11 - 31 (February 2019)

Journal homepage: http://www.ifrj.upm.edu.my

Review

Edible mushrooms from Malaysia; a literature review on their nutritional and medicinal properties

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Article history

Received: 21 May 2018
Received in revised form: 9 August 2018
Accepted: 16 August 2018

Keywords

Wild edible mushrooms, Cultivated edible mushrooms, Culinary mushrooms, Medicinal mushrooms, Nutritional and medicinal properties

Abstract

Mushrooms have been consumed by mankind for millennia. In Malaysia, there are many species of edible mushrooms which are either cultivated (*Agaricus* spp., *Auricularia* spp., *Pleurotus* spp.) or harvested in the wild (*Ganoderma* spp., *Polyporus* spp., *Termitomyces* spp.). With the advancement of technology, numerous discoveries have been made that elucidated the nutritional (high in fibres, proteins, vitamins; low in fats, cholesterols, sodium) and medicinal (anti-oxidative, anti-hypertensive, neuritogenesis) properties of edible mushrooms, all of which are highly beneficial for the maintenance of human health and well-being. This review thus compiles and documents the available literatures on edible mushrooms reported from Malaysia complete with scientific, English, and vernacular names for future references; provides a comprehensive and updated overview on the nutritional and medicinal properties edible mushrooms reported from Malaysia; and identifies the research gaps to promote further research and development on edible mushrooms reported from Malaysia. Overall, Malaysia is and remains a natural repository for wild and cultivated edible mushrooms. Deeper investigation on their nutritional and medicinal properties will certainly serve as an impetus for economic as well as scientific progress.

Introduction

Malaysia is a developing country located in Southeast Asia, and consists of Peninsular Malaysia and East Malaysia. Covering nearly 330 km^2 landmass, Malaysia is ranked the 67^{th} largest country by total land area. Of this, two-thirds are being covered in forest (Saw, 2007) with some of which are believed to be 130 million years old (Richmond *et al*., 2010). In 1998, Conservation International (www.conservation.org) has identified Malaysia as one of the 17 megadiverse countries which harbour the majority of the Earth's species of flora and fauna with high level of endemism (i.e., an ecological state whereby a species being unique to a defined geographic location and not found elsewhere). Malaysian ecosystems (e.g., forests, mountains, inland waters, marine and coastal, islands, agricultural) are home to a diverse array of species. According to the Malaysian Ministry of Natural Resources and Environment (2007), a considerably high number of terrestrial fungal species which includes micro- and macrofungi and also lichen-forming species have been reported from Malaysian ecosystems.

In Malaysia, the studies on microfungi usually concern the plant and animal pathogens, secondary metabolite production, and mycotoxin contamination of foods and feeds, while the studies on macrofungi usually involve the biodiversity, cultivation and health benefits of edible mushrooms. However, it has been noted that many sources of information and knowledge about the richness and diversity of fungi in Malaysia especially the macrofungi are either outdated or scattered in many different publications with many publications are not available locally (Lee *et al*., 2007) or already out of prints (Lee *et al*., 2012). Therefore, in 2007, the Mushroom Research Centre, University of Malaya, published a book entitled *Malaysian Fungal Diversity* (Jones *et al*., 2007) in an effort to compile available mycological research information while addressing the research gaps and overcoming the lack of centralised data.

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The Basidiomycota section of the book discussed in depth the occurrence and biodiversity of three orders; Boletales (*Boletus* spp.), Polyporales (*Ganoderma* spp., *Lentinus* spp., *Fomitopsis* spp.) and Agaricales (*Marasmius* spp.). Members from these orders represent the highest numbers of mushroom species discovered in Malaysia thus far.

Later in 2012, a more elaborate *Checklist of Fungi of Malaysia* jointly compiled by relevant authorities in mycological researches in Malaysia managed to list nearly 4,000 species of fungi (macro and micro) ever recorded from Malaysia in a single publication (Lee *et al*., 2012). Most of the listed species are the members of the phyla Ascomycota and Basidiomycota, though at present, both phyla have been poorly or only partially surveyed and reported in Malaysia. Earlier in 2007, Lee and co-workers estimated that 70% of macrofungi are yet to be described in Malaysia. Based on the published list, Basidiomycota in Malaysia counts for 1,820 species which belong to 358 genera and 90 families, and they are widespread in almost every terrestrial ecosystem (Lee *et al*., 2007). These basidiomycetes play pivotal functions as natural decomposers, pathogens, parasites and symbionts of both plants and animals. According to a 2008 estimate, there are over 64,000 species of Ascomycota, and 31,515 species of Basidiomycota recorded worldwide (Kirk *et al*., 2008).

Even though the checklist is almost comprehensive at the time of publication, it does not however discriminate between edible and non-edible mushrooms. In fact, it also lists several poisonous mushrooms simply because these mushrooms have been isolated from Malaysia such as *Entoloma rhodopolium* (wood pink gill) which is prevalent in Europe and Asia, and is frequently mistaken for the edible *E. sarcopum*; *Russula subnigricans* which causes rhabdomyolysis (muscle damage and pain; Takahashi *et al*., 1992); and *Scleroderma citrinum* (common earth ball) which causes gastrointestinal distress in humans and animals. As it is outside of the intended scope, the checklist also makes no mention whatsoever on the nutritional and medicinal properties of the mushroom species that are edible. Therefore, in a way, the present review can be regarded as an extension to the previous works mentioned earlier but with emphasis on the nutritional and medicinal properties of the edible mushrooms reported from Malaysia.

The edibility of mushrooms is primarily dictated by the absence of poisonous substances or effects on humans, and to a certain extent by the mushrooms' desirable aroma and taste, as well as the soft texture of their fruiting bodies (Mattila *et al*., 2000). Globally, the term "edible mushroom" is frequently and inter-changeably used with "culinary mushroom". Edible mushrooms were mainly consumed for their nutritional or dietary benefits such as high in fibres, proteins and vitamins, and low in fats, cholesterols and sodium. Over time however, as more and more researches were being conducted which discovered and shed more light and information on the medically-significant metabolites of the mushrooms, edible mushrooms then started to be consumed for their medicinal benefits such as anti-cancer, anti-microbial and anti-hypertensive (Wasser, 2002; Vikineswary *et al*., 2013). The terms "edible-medicinal mushroom" or "culinary-medicinal mushroom" therefore came into use to denote the edible and medicinal natures of such mushrooms. Nevertheless, it is also noteworthy that not all medicinal mushrooms are readily edible due to the hard texture of their fruiting bodies such as *Ganoderma* spp. or *Lignosus* spp. As a result, these mushrooms are usually consumed and commercially available in the form of powdered extract. In the present review, these types of mushrooms are also discussed.

The present review was therefore aimed (a) to compile and document edible mushrooms reported from Malaysia complete with scientific, English, and vernacular names for future references; (b) to provide a comprehensive and updated overview on the nutritional and medicinal properties of edible mushrooms reported from Malaysia; and (c) to identify the research gaps and promote further research and development on edible mushrooms reported from Malaysia.

Methodology

A thorough literature search was performed electronically (e.g., Scopus, Science Direct, Google Scholar) for articles and reviews published in peer-reviewed journals. The search-phrase was narrowed down to "edible-mushroom-in-Malaysia" to obtain a more-focussed review scope with locally-obtained research inputs. The websites of relevant authorities particularly the Malaysian Ministry of Natural Resources and Environment (MNRE), Malaysian Ministry of Agriculture (MOA), Malaysian Agricultural Research and Development Institute (MARDI) and Forest Research Institute of Malaysia (FRIM) were also filtered to obtain essential information and statistical data. Over 400 publications including research articles, reviews, datasheets, statistics and checklists were obtained spanning almost 140 years' worth of mushroom researches conducted in Malaysia with the earliest document being a book in Latin about mushrooms in East Malaysia (Beccari and Cesati, 1879). The published and accessible information varied profoundly in terms of emphasis and niche areas (e.g., cultivated mushroom, wild mushroom, Peninsular Malaysia, East Malaysia, biodiversity, molecular identification, medicinal property, nutritional property, chemical composition, methods development, plant-pathogenicity). Although different, these niches were sometimes discussed and explained together, leading to overlap of information and interests. Therefore, careful screening and selection was exercised where necessary to ensure that the contents of the present review adhere to the intended scope. Two books namely *Checklist of Fungi of Malaysia* (Lee *et al*., 2012) and *Malaysian Fungal Diversity* (Jones *et al*., 2007) were the major sources for general information regarding Malaysian mushrooms especially those growing in the wild. List for cultivated mushroom species are often made available on the websites of local mushroom growers/companies. To our knowledge, this is the first attempt to compile the information and pictures of Malaysian edible mushrooms (wild and cultivated) with emphasis on their nutritional and medicinal properties.

Fungal taxonomy and terminology

Although the use of fungi by humans dates back to prehistory (Peintner *et al*., 1998), the study of Mycology only started to increase in prominence when the kingdom Fungi was re-assigned and hence separated from the kingdom Plantae in 1969 (Whittaker, 1969). Since then, its taxonomy has been revised several times with the advent of new technology such as molecular identification and biochemical characterisation. In 2007, an updated classification of the kingdom Fungi has been proposed by a large-scale research collaboration involving mycologists and other scientists working on fungal taxonomy worldwide (Hibbett *et al*., 2007). Seven phyla have thus been recognised namely Microsporidia (parasitic fungi infecting animals), Chytridiomycota (zoosporic fungi), Blastocladiomycota (zoosporic fungi), Neocallimastigomycota (anaerobic fungi in herbivores' digestive tracts), Glomeromycota (arbuscular mycorrhizal fungi), Ascomycota (sac fungi) and Basidiomycota (macrofungi). The phyla Ascomycota and Basidiomycota, or more commonly known as the "higher fungi", constitute the majority species of the kingdom Fungi. The phylum Basidiomycota is further divided into three sub-phyla (Kirk *et al*., 2008) namely Agaricomycotina, Pucciniomycotina (rust fungi), and Ustilaginomycotina (smut fungi). The sub-phyla Pucciniomycotina and Ustilaginomycotina have not been well studied in Malaysia with only a small number of species have been reported so far, in contrast to the sub-phylum Agaricomycotina which includes mushrooms, puffballs, stinkhorns, bracket fungi, polypores, jelly fungi, chanterelles, coral fungi and earth stars (Lee *et al*., 2012). Edible members of the sub-phylum Agaricomycotina reported from Malaysia are the main focus of the present review.

A mushroom or toadstool is the fleshy, spore-bearing fruiting body (*sporocarp*) of a fungus from the order Agaricales (agarics) which is typically produced above (epigeous) or below ground (*hypogeous*), or on a substrate (cultivated). Usually, it adopts the classic umbrella-like form which has a stem/stalk (*stipe)*, a cap (*pileus*), and gills (*lamellae*) on the underside of the cap. These gills produce microscopic spores for reproduction (*basidiospores*), hence the name "gilled fungi". The most common agarics reported from Malaysia include *Agaricus* spp., *Amanita* spp. and *Boletus* spp. among others. Figure 1 further illustrates the general anatomy of a mushroom. However, other members of the sub-phylum Agaricomycotina also adopt forms that deviate from the typical umbrella-like morphology but also with gills present such as the bracket fungi (*Trametes versicolor*, *Schizophyllum commune*), jelly fungi (*Auricularia auricula-judae*), and stinkhorns (*Phallus* spp.). Since layman understands "mushroom" as any visible fungal growth that includes a variety of gilled fungi, with or without the umbrella-like appearance, the term "mushroom" in the present review will remain as such to avoid confusion.

Wild versus cultivated edible mushrooms

In Malaysia at present, a wide variety of edible mushrooms that are either harvested wild (e.g., *Grifola frondosa*, *Lentinus squarrosulus*, *S. commune*) or cultivated (e.g., *A. auricula-judae*, *Flammulina velutipes*, *Pleurotus ostreatus*) are commercially available at the supermarkets. However, although the cultivated mushrooms are receiving well-established consumer acceptance, mass media reports on deaths or food poisonings caused by consuming wild mushrooms are among the reasons as to why the latter are generally avoided. Furthermore, since the wild mushrooms are mostly collected by a select few who are knowledgeable in the field (e.g., traditional mushroom collectors, experienced mycologists), and that the harvests are usually for personal or family consumption, the occurrence of wild edible mushrooms commercially in Malaysia is therefore

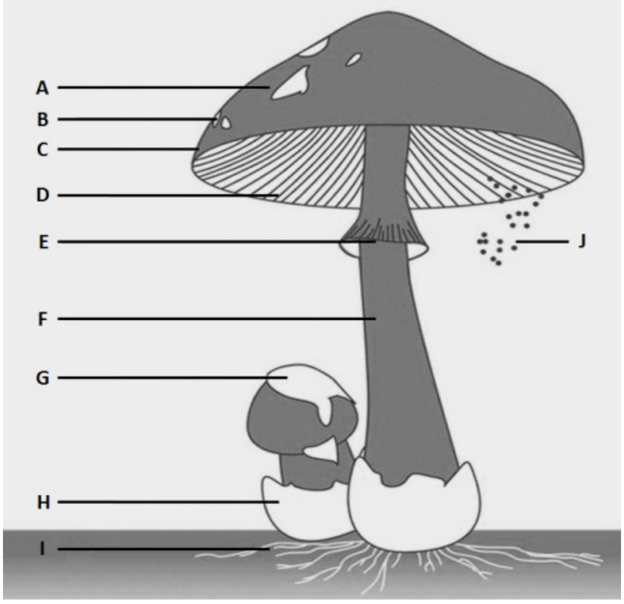

Figure 1. The general anatomy of a complete common mushroom. (A) *pileus* or cap; (B) scales or warts, which are remnants of the universal veil; (C) margin or edge, which is the outer perimeter of the cap; (D) *hymenium* or *lamellae* or gills, which is for the spore dispersal; (E) annulus or ring, which is the remnant of the partial veil following rupture thus exposing the gills; (F) *stipe* or stalk or stem, which is composed of sterile hyphal tissue; (G) universal veil, which is a temporary membranous tissue that envelops and protects the immature fruiting bodies; (H) *volva* or base or bulb, which is the cuplike remnant of the universal veil; (I) *rhizomorph* or mycelial cords or hyphal tissue, which are the below ground structures for nutrient transfer; and (J) *basidiospores*, which are the reproductive spores developed on specialised microscopic club-shaped cells called *basidium* found on the gills.

still comparatively lower than the cultivated ones. In addition, it has also been noted that the mushroom collector as a profession is almost non-existent in Malaysia (Abdullah and Rusea, 2009). Occasionally however, very common species of wild mushrooms, such as *S. commune* and *Termitomyces* spp., could be found in local weekend and farmers' markets (Chang and Lee, 2004). Nevertheless, the collection of wild edible mushrooms for consumption and trade, however small, is still vital for rural livelihoods in local communities (Boa, 2004).

Table 1 lists the scientific, English and vernacular names for wild mushroom species recorded from Malaysia. The scientific names were cross-referenced with Index Fungorum to obtain accurate authority names (www.indexfungorum.org), while the species names were cross-referenced with the Basidiomycota list provided by Lee *et al*. (2012). It should be noted that the species reported in the present review which do not appear in the 2012 list are marked with asterisk (*) and can be treated as newly discovered species since it has been duly emphasised that not all fungi (micro- and macro-) have been included in the 2012 list (Lee *et al*., 2012).

Mushroom cultivation (i.e., fungiculture) has a long history that involves the improvement of the artificial conditions (e.g., well-defined substrate, full climatisation) in which the mushrooms are grown (Kozarski *et al*., 2015a). Mushroom cultivation is steadily expanding with China emerges as the biggest producer around the world (Valverde *et al*., 2015). In Malaysia, cultivated mushrooms are one of the high-value crops; with the land area for cultivation will be increased from 78 ha in 2010 to 340 ha in 2020 with the government supports in order to meet the increasing demand for the commodity (Haimid *et al*., 2013). In 2010, the daily demand for fresh mushrooms was estimated to be approximately 50,000 kg, and the figure was projected to increase annually. In 2013 survey, there were more than 300 mushroom growers registered in Peninsular Malaysia. Of this number, 5% were considered large-scale (>500 kg daily), 20% medium-scale (50-500 kg daily), and 75% small-scale (<50 kg daily) growers/companies (Haimid *et al*., 2013). Data for East Malaysia are being compiled and hence not available at the time of publication of the present review.

Table 2 lists the scientific, English and vernacular names for cultivated mushroom species recorded from Malaysia. According to the websites of most local mushroom growers/companies, members of the genus *Pleurotus* are among the major species selected for commercial cultivation. Not only in Malaysia, but *Pleurotus* spp. are also among the most commonly cultivated edible mushrooms globally, probably due to the fact that they are highly adaptable to the tropical and temperate climates throughout the world (Miles and Chang, 2004). Figure 2 depicts several members of the soft-flesh genus *Pleurotus* which are being cultivated in Malaysia. Figure 3 depicts the hard-flesh polypores *Ganoderma lucidum* and *Lignosus rhinocerotis* which are usually found in the wild in Malaysia. With the advancement of technology, it is now possible to cultivate *G. lucidum* as has been long practiced by many mushroom cultivators in Malaysia and abroad. Following the successful domestication of *L. rhinocerotis* (Abdullah *et al*., 2013), mushroom cultivators in Malaysia have also started to cultivate this wild mushroom at commercial scale.

Mushrooms as food with nutritional properties

Mycophagy (i.e., the act of consuming mushrooms) dates back to ancient times when the upper class of early civilisations such as the Chinese, Romans and Greeks used wide variety of edible

Table 1. List of wild edible mushroom species recorded from Malaysia

Scientific Name	English Name	Vernacular Name	References
Auricularia auricula-judae (Bull.) Quél. (1886)	Jew's ear / jelly ear mushroom	*Cendawan telinga kera*	Abdullah and Rusea, 2009
*Auricularia fuscosuccinea (*Mont.) Henn. (1893)*		*Cendawan bibir*	Abdullah and Rusea, 2009
Auricularia polytricha (Mont.) Sacc. (1885)	Cloud ear / black jelly mushroom	*Cendawan gelememeh*	Abdullah and Rusea, 2009
Boletus griseipurpureus Corner (1972)*		*Cendawan gelam*	Muniandy et al., 2016
Calostoma fuscum (Berk.) Massee (1888)		*Cendawan mata babi*	Abdullah and Rusea, 2009
Calvatia cyathiformis (Bosc) Morgan (1890)*	Purple-spored puffball	*Cendawan kumbul*	Abdullah and Rusea, 2009
Dictyophora indusiata (Vent.) Desv. (1809)	Long-net stinkhorn / bamboo mushroom		Chang and Lee, 2004
Ganoderma lucidum (Curtis) P. Karst. (1881)	Lingzhi mushroom	*Cendawan lingzhi*	Chang and Lee, 2004
Hygrocybe similis (Petch) Pegler	Waxcap mushroom	*Cendawan kuning*	Abdullah and Rusea, 2009
Hygrocybe conica (Schaeff.) P. Kumm. (1871)	Witch's hat mushroom		Wong and Chye, 2009
Lentinus sajor-caju (Fries) Fries (1838)		*Cendawan gelang*	Abdullah and Rusea, 2009
Lentinus squarrosulus Mont. (1842)		*Cendawan burak*	Abdullah and Rusea, 2009
Pleurocybella porrigens (Pers.) Singer (1947)	Angel's wing mushroom		Wong and Chye, 2009
Polyporus tenuiculus (P. Beauv.) Fries (1821)			Wong and Chye, 2009
Polyporus umbellatus (Pers.) Fries (1821)*	Umbrella polypore		Chang and Lee, 2004
*Schizophyllum commune F*ries (1815)	Split gill mushroom	*Cendawan sisir*	Abdullah and Rusea, 2009
Termitomyces aurantiacus (R. Heim) R. Heim (1977)*	Termite mushroom	*Cendawan tahun*	Abdullah and Rusea, 2009
Termitomyces clypeatus R. Heim (1951)	Termite mushroom	*Cendawan kaki pelanduk*	Abdullah and Rusea, 2009
Termitomyces heimii Natarajan (1979)	Termite mushroom	*Cendawan busut*	Abdullah and Rusea, 2009
Termitomyces microcarpus (Berk. & Broome) R. Heim (1942)	Termite mushroom	*Cendawan tali*	Abdullah and Rusea, 2009
Tremella fuciformis Berk. (1856)	Snow / white jelly mushroom		Chang and Lee, 2004
Xerula furfuracea (Peck) Redhead, Ginns & Shoemaker (1987)*	Rooted oude mushroom		Wong and Chye, 2009

*not found in the 2012 list of Malaysian basidiomycetes mushrooms for culinary purposes (Boa, 2004). At present, mushroom consumption continues in households of many parts of the world including Malaysia. In some communities in Europe, mushrooms form a prized component of the diet such as morels (*Morchella* spp.) and truffles (*Tuber* spp.), though in other parts, mushrooms are perceived only as the vegetable component of the diet which can be readily replaced by easier alternatives (Abdullah and Rusea, 2009). Basically, the edibility of mushrooms is based on criteria such as non-poisonous, desirable taste and aroma (Mattila *et al*., 2000), and unique texture (Kalač, 2013). Nowadays however, the true nutritive potentials of mushrooms are gaining recognition not only fro m the scientific community, but also from the general consumers (Chang and Wasser, 2012). Edible mushrooms have been widely reported to contain high levels of functional proteins and polyunsaturated fatty acids, and low levels of fats and cholesterols which render them well suited for low calorie diets (Kozarski *et al*., 2015a). Besides providing high content of vitamins (Mattila *et al*., 2001; Kozarski *et al*., 2015b), they also have low glycaemic index which is beneficial for diabetic patients, and low natrium content which is beneficial for hypertensive patients (Chang and Wasser, 2012). Excellent reviews on chemical compositions of wild and cultivated mushrooms have been provided by Kalač (2009 and 2013) for European countries, and Wang *et al*. (2014) for China.

Carbohydrates and fibres

In mushrooms, carbohydrate is the prevailing component (Kalač, 2009 and 2013). Carbohydrates in foods provide energy (Westman, 2002), and mushrooms provide both digestible (e.g., mannitol, glucose, glycogen, trehalose) and non-digestible carbohydrates (e.g., chitin, β-glucans, mannans) with the latter forming the larger portion of the total carbohydrates found in mushrooms (Wang *et al*., 2014) since chitin and β-glucans are the major components of fungal cell walls (Wasser and Weis, 1999). It is interesting to note that while mushrooms are closer to plant in physiology, they contain glycogen and chitin which are the polysaccharides typical in animals instead of starch and cellulose which are typical in plants (Kalač, 2013). Crude fibre is another group of non-digestible carbohydrate found in mushrooms. In humans, fibre is not hydrolysed since the digestive system lacks the necessary enzymes to split the glycosidic bonds. Instead, they absorb water as they move through the digestive system and ease defecation, hence the importance of fibre in human daily dietary requirements (Eastwood and Kritchevsky, 2005; Anderson *et al*., 2009). While the contents of monosaccharides in mushrooms are comparatively low, and glycogen's low intake from mushrooms is mainly compensated by meat consumption (Kalač, 2009 and 2013), many studies have instead been focussed on mushrooms' β-glucans (Wasser, 2002; Rop *et al*., 2009). β-glucans are polysaccharides of D-glucose monomers linked by β-(1→3) and β-(1→6) bonds. According to Zekovic *et al*. (2005), mushrooms' β-glucans have been reported to exhibit different effects (e.g., anti-tumour, immune-booster) when compared with β-glucan from oats and barley (e.g., lowering cholesterol and blood sugar). Often, the β-glucans produced by specific mushroom species have specific names such as ganoderan (Ganodema lucidum), grifolan (*Grifola fondosa*), lentinan (*Lentinus edodes*), pleuran (*Pleurotus ostreatus*) and schizophylan (*Schizophyllum commune*) (Zhu *et al*., 2015). Apart from the immunomodulatory properties reported, mushrooms' β-glucans have also been documented to have anti-bacterial (Rasmy *et al*., 2010), anti-viral (Minari *et al*., 2011) and radioprotective (Pillai and Devi, 2013) activities.

In Malaysia, a study on β-glucan isolated from several wild mushrooms [tiger's milk mushroom (*Lignosus rhinocerotis*), termite mushroom (*Termitomyces heimii*)] and cultivated mushrooms [button mushroom (*Agaricus bisporus*), shiitake mushroom (*Lentinus edodes*), and oyster mushroom (*Pleurotus ostreatus*)] has demonstrated that alkaline solution (1.25 M NaOH) has improved the extract yields as compared to the hot water (Mohd-Jamil *et al*., 2013). However, later in 2015, the determination of β-glucan from local isolate of *Ganoderma neojaponicum* collected in the wild by hot water extraction yielded 30-40% β-glucan from both dried mycelia and dried broth (Ubaidillah *et al*., 2015). Although species difference is noted on the variation of β-glucan levels, both studies were aimed at exploring the immunomodulatory properties of the compounds extracted from Malaysian mushrooms.

Proteins and amino acids

The nutritional values of mushrooms are closely linked to their high protein contents (Wang *et al*., 2014). Mushroom proteins are thought to have higher nutritional quality than that of plant (Belitz and Grosch, 1999). The protein contents of mushrooms do not solely depend on environmental factors or maturity stages, but also on species (Colak *et al*., 2009). Further, the amino acid composition of mushrooms is similar to, if not better than, that of soy proteins, and several mushroom species have been

Table 2. List of cultivated edible mushroom species recorded from Malaysia

Scientific Name	English Name	Vernacular Name
Agaricus bisporus (J.E. Lange) Imbach (1946)	Button / common mushroom	Cendawan butang (putih)
Agaricus blazei Murrill (1945)*	Almond mushroom / royal sun *agaricus* (*himematsutake*)	Cendawan butang (perang)
Agaricus campestris Schwein. (1822)*	Field / meadow mushroom	*Cendawan padang*
Auricularia auricula-judae (Bull.) Quél. (1886)	Jew's ear / jelly ear mushroom	*Cendawan telinga kera*
Auricularia polytricha (Mont.) Sacc. (1885)	Cloud ear / black jelly mushroom	*Cendawan gelememeh*
Flammulina velutipes (Curtis) Singer (1951)	Golden needle / winter mushroom (*enokitake*)	*Cendawan jarum*
Ganoderma lucidum (Curtis) P. Karst. (1881)	Lingzhi mushroom (*mannentake*)	*Cendawan lingzhi*
Ganoderma neo-japonicum Imazeki*	Lingzhi mushroom (*mannentake*)	*Cendawan lingzhi*
Grifola frondosa (Dicks.) Gray (1821)	Hen-of-the-woods / ram's head mushroom (*maitake*)	*Cendawan maitake*
Hericium erinaceus (Bull.) Pers. (1797)*	Monkey's head / lion's mane mushroom (*yamabushitake*)	*Cendawan kepala kera*
Lentinula edodes (Berk.) Pegler (1976)*	Oakwood / black mushroom (*shiitake*)	*Cendawan shiitake*
Pleurotus citrinopileatus Singer (1942)*	Yellow / golden oyster mushroom (*tamogitake*)	*Cendawan tiram kuning*
Pleurotus cystidiosus O.K. Mill. (1969)*	Abalone mushroom	*Cendawan abalone*
Pleurotus djamor (Rumph. ex Fries) Boedijn (1959)	Pink oyster mushroom	*Cendawan tiram merah jambu*
Pleurotus eryngii (DC.) Quél. (1872)*	King trumpet / king oyster mushroom	*Cendawan tiram raja*
Pleurotus flabellatus Sacc. (1887)*	Pink oyster mushroom	*Cendawan tiram merah jambu*
Pleurotus floridanus Singer (1948)	White oyster mushroom	*Cendawan tiram putih*
*Pleurotus giganteus (*Berk.) Karun. & K.D. Hyde (2011)	Swine's stomach mushroom	*Cendawan seri pagi*
Pleurotus ostreatus (Jacq.) P. Kumm. (1871)	Pearl oyster mushroom (*hiratake*)	*Cendawan tiram mutiara*
Pleurotus ostreatus var. columbinus (Quél.) Quél. (1886)*	Blue oyster mushroom	*Cendawan tiram biru*
Pleurotus pulmonarius (Fries) Quél. (1872)*	Indian / Italian oyster mushroom	*Cendawan tiram india*
Pleurotus sajor-caju (Fries) Singer (1951)	Grey oyster mushroom	*Cendawan tiram kelabu*
Pleurotus tuber-regium (Fries) Singer (1951)*	King *tuber* mushroom	no local name
Schizophyllum commune Fries (1815)	Split gill mushroom	*Cendawan sisir*
Volvariella volvacea (Bull.) Singer (1951)*	Paddy straw mushroom	*Cendawan jerami*

*not found in the 2012 list of Malaysian basidiomycetes

Figure 2. Several members of the genus *Pleurotus* which are being cultivated in Malaysia. (a) *P. citrinopileatus* (yellow oyster mushroom), (b) *P. cystidiosus* (abalone mushroom), (c) *P. djamor* (pink oyster mushroom), (d) *P. eryngii* (king oyster mushroom), (e) *P. floridanus* (white oyster mushroom), (f) P. *ostreatus* (pearl oyster mushroom), (g) *P. ostreatus* var. columbinus (blue oyster mushroom), (h) *P. pulmonarius* (Indian oyster mushroom), (i) *P. sajor-caju* (grey oyster mushroom).

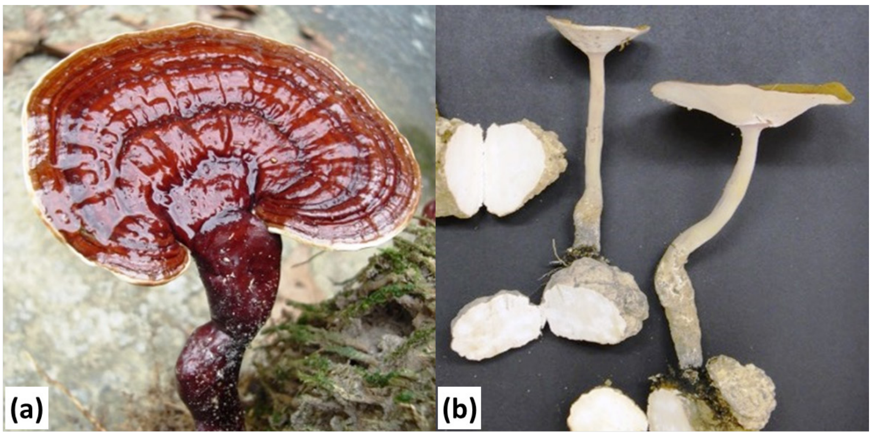

Figure 3. The hard-flesh polypores *Ganoderma lucidum* (lingzhi mushroom) and *Lignosus rhinocerotis* (tiger's milk mushroom) found in the wild in Malaysia.

shown to have similar amino acid composition of a hen's egg (Yin and Zhou, 2008). In addition, essential amino acids that cannot be synthesised by humans *de novo* (i.e., from scratch) can also be supplied by mushrooms (Wang *et al*., 2014). Among the amino acids, aspartic and glutamic acids, which give the characteristic umami taste of mushrooms (Tsai *et al*., 2008), were detected at high concentrations on several species of mushrooms (Sun *et al*., 2012). However, even though mushrooms are generally consumed for its high protein content, information on changes of protein and amino acid composition during mushroom preservation and cooking remain limited including in Malaysia. Interestingly, the relatively high protein content and low dry matter are in fact the main reasons for short shelf life of mushrooms (Kalač, 2013).

In Malaysia, most proteomic researches on edible mushrooms have been conducted in search of novel angiotensin I-converting enzyme inhibitory peptides which are further discussed in sub-Section medicinal properties below. In 2012, a proteomic analysis on selected local edible mushrooms (e.g., *Pleurotus cystidiosus*, *Agaricus bisporus*) reported high anti-hypertensive activities from the extracted proteins (Lau *et al*., 2012). Later in 2013, a study on the protein and amino acid composition of the local tiger's milk mushroom (*Lignosus rhinocerotis*) from different developmental stages (e.g., the fruit body, sclerotium, mycelium) collected in the wild revealed moderate protein levels with all essential amino acids (e.g., phenylalanine, valine, threonine, methionine, leucine, isoleucine, lysine, histidine) were present except tryptophan (Lau *et al*., 2013). The investigation was the first of its kind, and aimed to highlight scientifically the nutritional contents and bioactive constituents of the widely regarded traditional medicinal mushroom. The nine amino acids that are essential in the human diet were first established in the 1950's. It was noted that the symptoms such as nervousness, exhaustion and dizziness were encountered whenever human subjects were deprived of any one of the essential amino acids (McCoy *et al*., 1935; Rose *et al*., 1951; Simoni *et al*., 2002).

Lipids

Lipids are a group of naturally occurring molecules whose main biological functions include storing energy and acting as structural components of cell membranes (Subramaniam *et al*., 2011). In mushrooms, the overall content of lipids (crude fat) usually varies according to species (Kalač, 2009 and 2013; Wang *et al*., 2014). In a study conducted to profile the lipid components of fresh Malaysian termite mushrooms (*Termitomyces heimii*) collected in the wild, 28 compounds were extracted with ergosterol and linoleic acid being the major fractions (Malek *et al*., 2012). Ergosterol is a type of sterol predominantly found in fungal cell membranes (Weete *et al*., 2010). It serves many similar functions as does cholesterol in animal cells. It is named after the ergot mushroom (Claviceps spp.) from which the compound was first isolated (Dupont *et al*., 2012). Even though mushrooms are generally deficient in vitamin $D_{2,}$ they have high levels of ergosterol which can act as a biological precursor to vitamin D_2 (Keegan *et al*., 2013) which in turn indirectly making mushrooms as an excellent source for vitamin D_2. In mushrooms, ergosterol can transform into viosterol by ultraviolet light, irradiation temperature and moisture, which is then converted to vitamin D_2 (Jasinghe *et al*., 2007; Simon *et al*., 2013). In humans, vitamin D_2 (ergocalciferol; obtained through diets or supplements) and vitamin D_3 (cholecalciferol; obtained through dermal synthesis from sunlight) are important for enhancing intestinal absorption of calcium (Ca), iron (Fe), magnesium (Mg), phosphate (PO_4^{3-}) and zinc (Zn) (Holick, 2006). Although vitamin D3 (through sunlight exposure) is the primary source for vitamin D for majority of the population as compared to vitamin D_2 (through diets and supplements) (Calvo *et al*., 2005), recent research has pointed out that vitamin D_2 is indeed equally effective (Borel *et al*., 2015).

Linoleic acid is a poly-unsaturated fatty acid (fatty acid that contains more than one double bond in their backbone), and is a member of the group of essential fatty acids. Essential fatty acids are fatty acids that cannot be synthesised within an organism from other components by any known chemical pathways; therefore, they must be obtained from the diet (Wang *et al*., 2014). According to Ellie and Rolfes (2008), only two fatty acids are known to be essential for humans namely the α-linolenic acid (C18:3; omega-3 fatty acid) and linoleic acid (C18:2; omega-6 fatty acid). Linoleic acid is the raw material for the synthesis of several compounds vital for health (e.g., arachidonic acid, prostaglandins, leukotrienes, thromboxane). Linoleic acid is also important for the proper growth and development of infants. When they were discovered in 1923, α-linolenic acid and linoleic acid were termed as vitamin F until a research on rats showed that they were better classified as fats rather than vitamins (Egmond *et al*., 1996). Other works have also corroborated the importance of mushrooms as natural sources for linoleic acid (Kalač, 2009 and 2013).

Vitamins and minerals

Analyses of vitamins A (β-carotene), E (α-tocopherol and γ-tocopherol), C (ascorbic acid), B_1 (thiamine) and B_2 (riboflavin), and major and trace minerals on wild edible mushrooms collected in East Malaysia (e.g., *Pleurotus* sp., *Hygrocybe* sp., *Hygrophorus* sp., *Schizophyllum commune*, *Polyporus tenuiculus*) provided interesting findings (Chye *et al*., 2008). It was found that *S. commune* contained the highest vitamin A (2711.30 mg/g fresh weight) followed by *Hygrocybe* sp. (2129.04 mg/g fresh weight) when compared to the control *P. floridanus* (7.24 mg/g fresh weight). In humans, vitamin A plays important role in maintaining growth and development, immune system and good vision (Thompson and Gal, 2003; Tanumihardjo, 2011). *S. commune* was also found to contain the highest amount of vitamin E (85.08 mg/g fresh weight). Vitamin E has multiple biological functions such as anti-oxidative (Bell, 1987; Traber and Stevens, 2011), enzymatic activity regulator (Schneider, 2005), in gene expression (Azzi and Stocker, 2000; Devaraj *et al*., 2001; Villacorta *et al*., 2003), in neurological functions (Muller, 2010), in the inhibition of platelet coagulation (Dowd and Zheng, 1995; Brigelius-Flohé and Davies, 2007; Atkinson *et al*., 2008), and in lipid protection and prevention of oxidation of polyunsaturated fatty acids (Whitney and Rolfes, 2011). However, the results further showed that the other wild mushrooms tested were not good sources of vitamins C, B_1 and B_2 except *Pleurotus* sp. It was also found that *Hygrocybe* sp. contained the highest potassium (K), iron (Fe) and copper (Cu) at 47.89, 175.64, and 8.12 mg/100 g dry weight respectively. According to Kalač (2013), K is the prevailing element in edible mushrooms. It is also noteworthy that K is unevenly distributed within the mushroom fruit bodies in the order of cap > stipe > spore-forming part > spores. Since K is highly accumulative, its levels in mushroom fruit bodies are usually 20 to 40-fold higher than in the substrate (Kalač, 2013). Magnesium (Mg) was found to be the second major mineral after potassium in the edible wild mushrooms tested, with the highest in *S. commune* (144.7 mg/100 g dry weight). In nature, *S. commune* grows on wood and this enables them to accumulate minerals in their fruit bodies from the substrate (Baldrian, 2003). In addition to Mg, *S. commune* was also high in zinc (Zn, 139.06 mg/g dry weight). Mendil *et al*. (2004) has stated the biological significance of these mushrooms as Zn accumulators. *Hygrophorus* sp. contained moderate amount of other major minerals, with the highest being calcium (Ca; 81.70 mg/100 g dry weight). As major elements (macronutrients) essential in human diets, K functions as a systemic electrolyte and is essential in co-regulating the ATP with sodium in human body (Drewnowski, 2010); Ca is required to maintain the health of muscle, heart and digestive system, to build bones, and to support the synthesis and functions of blood cells; and Mg is required for the processing of ATP, and also for the bones (Larsson *et al*., 2008). As trace elements (micronutrients) in human diets, Zn is required for several enzymes (carboxypeptidase, liver alcohol dehydrogenase, carbonic anhydrase); Fe is required for many proteins such as haemoglobin and enzymes, and also to prevent anaemia (Janz *et al*., 2013); and Cu is required for the proper functioning of organs and metabolic processes, and also as component of many reduction-oxidation enzymes such as cytochrome-c-oxidase (Stern *et al*., 2007). Sodium (Na) concentrations were the lowest among all minerals in the mushroom species tested including the control, ranging between 0.280 and 0.880 mg/100 g dry weight. This is in agreement with the works of Manzi *et al*. (1999) and Vetter (2003) which also stated that the low Na levels found in mushrooms could be of great nutritional potential to hypertensive consumers.

Another studies conducted on ten wild edible mushrooms collected in East Malaysia (e.g., *Lentinellus omphallodes*, *Lentinus cilliatus*, *Pleurotus* spp., *S. commune*, *Hygrocybe* sp., *Volvariella* sp., *Auricularia auricula-judae*, *Trametes* sp.) revealed almost similar results in which K was found as the most abundant mineral, followed by Mg and Ca, while Na was found at the lowest concentrations in all the wild mushrooms tested (Shin *et al*., 2007). Overall, the trace element concentrations across all the wild mushrooms tested were in the order of Fe > Zn > Mn > Cu > Cr. Manganese (Mn) is an element important in human development, metabolism, and the anti-oxidative system with many enzymes having Mn as cofactors (oxidoreductases, transferases, hydrolases, lyases, isomerases, ligases, lectins, integrins) (Emsley, 2001). The biological roles of chromium (Cr) as micronutrient essential to human health are conflicting, with some maintained Cr as an essential trace element required in human diets (Anderson, 1997), while more recent studies disregarded its importance in mammals (Di Bona *et al*., 2011).

Mushrooms as food with medicinal properties

Apart from the nutritional benefits, edible mushrooms are also being consumed for their medicinal properties in promoting health and vigour. Many therapeutic values of mushrooms traditionally mentioned in folklores of many countries including Malaysia are being scientifically corroborated, and have been found to stem from numerous biologically-active and health-promoting metabolites that the mushrooms produce. These mycochemicals have been shown to demonstrate a broad spectrum of healing activities such as anti-asthmatic, anti-atherosclerotic, anti-cholestrolemic, anti-diabetic, anti-fungal, anti-hypertensive, anti-inflammatory, anti-obesity, anti-oxidative, anti-tumour, anti-ulcer and anti-viral.

Table 3 lists the medicinal properties of edible mushroom species recorded from Malaysia, from which, it is apparent that anti-oxidative is one of the primary health functions of edible mushrooms as also mentioned by Chang and Wasser (2012). The radical-scavenging anti-oxidative activities of edible mushrooms come from an array of biomolecules from the carotenoid and polyphenol groups. A comprehensive review on the anti-oxidative mechanisms of edible mushroom is provided by Kozarski *et al*. (2015a).

Research gaps

In Malaysia, mushroom is considered an industrial crop alongside coconut (*Cocos nucifera*), coffee (*Coffea* sp.), nipa palm (*Nypa fruticans*), areca nut (*Areca catechu*), roselle (*Hibiscus sabdariffa*), sago (*Metroxylon sagu*) and tea (*Camellia sinensis*). The country's cultivated mushroom production saw a 23.32% increase from 3,916.8 metric tonnes in 2015 to 4,830.2 metric tonnes in 2016 (DOA 2015; 2016), and is projected to steadily increase in the coming years due to its growing demand among the population. The surge in interest and awareness in mushroom consumption and cultivation opens up to various areas previously lacking in information.

Utilisation of agro-residues as edible mushroom growth substrates

Common practice of mushroom cultivation usually involves substrate consisting of sawdust and wheat bran. An experiment to investigate the efficiency of other agro-residues (e.g., corn cob, corn straw, paddy straw, soybean straw) as a substrate in *G. frondosa* cultivation in China showed a 40% increase in the average yield by using corn cob (Song *et al*., 2018). In Malaysia, corn residues are an abundant agricultural waste which is conveniently and readily available all year round. In 2016, 64,867.34 metric tonnes of corn was produced in Malaysia (DOA, 2016b). For every 1 kg of corn grains produced, approximately 0.15 kg of cobs is produced and subsequently turns to waste (Zhang *et al*., 2012). Therefore, the utilisation of corn cobs as mushroom growth substrate will certainly reduce the amount of annual corn waste production. The utilisation of agro-residues as mushroom growth substrates in Malaysia is not yet well investigated. Based on available literature, only five papers described the utilisation of palm oil mesocarp fibre in the cultivation of *Pleurotus* spp. (Saidu *et al*., 2011); paddy straw, palm empty fruit bunches, and palm-pressed fibre in the cultivation of *F. velutipes* (Harith *et al*., 2014); oil palm empty fruit bunch and sago waste in the cultivation of *Auricularia polytricha* (Lau *et al*., 2014b); oil palm frond in the cultivation of *Pleurotus* sp. (Ibrahim *et al*., 2015); and rice husk ash in the cultivation of *P. sajor-caju* (Fasehah and Shah, 2015).

Domestication of wild edible mushrooms

For reasons already described earlier in sub-Section wild versus cultivated edible mushrooms, the availability of wild edible mushrooms in the markets is still comparatively lower than that of their cultivated counterparts. However, in terms of nutritional and medicinal attributes, both wild and cultivated mushrooms are nevertheless comparable to an appreciable degree. Therefore, to mitigate the scarcity of wild edible mushrooms in the markets, domestication is the answer. However, domestication of wild edible mushrooms is not an easy task. In Malaysia to date, very few species of wild edible mushroom have been successfully domesticated such as *Lignosus rhinocerotis* (Abdullah *et al*., 2013), and *Ganoderma neo-japonicum* (Tan *et al*., 2015). The domestication of these two wild edible mushrooms is primarily driven by the superior contents of biologically active substances found in their sclerotia such as polysaccharides, polysaccharides-protein complexes and β-glucan (Lau *et al*., 2015) which exhibit numerous medicinal properties as listed in Table 3. Besides maintaining a steady supply of wild edible mushrooms throughout the year (which are otherwise seasonal), their domestication could also supplement the livelihood of farmers.

Mycosynthesis of nanomaterials

Nanoparticles, nanosheets and nanocomposites are nanomaterials often used in microfabrication technology in the industrial and medical lines which best employ the unique optical, electronic, and mechanical properties of the nanomaterials. The mycosynthesis of nanomaterials (otherwise known as green or biological synthesis) using edible mushrooms is drawing attention over conventional physical and chemical methods because it is more manageable, low-cost and rapid. In Malaysia however, the area is

Table 3. Medicinal properties of edible mushroom species recorded from Malaysia

Medicinal Properties	References
Anti-asthmatic	Johnathan *et al*., 2016; Lee *et al*., 2018
Anti-atherosclerotic	Rahman *et al*., 2014
Anti-cholestrolemic	Choong *et al*., 2007; Keong *et al*., 2010
Anti-diabetic	Rushita *et al*., 2013; Wahab *et al*., 2014; Ng *et al*., 2015; Paravamsivam *et al*., 2016; Nyam *et al*., 2017; Yap *et al*., 2018
Anti-fungal	Phan *et al*., 2013b
Anti-hypertensive	Abdullah *et al*., 2012a; Lau *et al*., 2012; Fadzil *et al*., 2013; Lau *et al*., 2013a,b,c; Lau *et al*., 2014a; Ibadallah *et al*., 2015
Anti-inflammatory	Lee *et al*., 2014
Anti-obesity	Kanagasabapathy *et al*., 2013
Anti-oxidative	Chye *et al*., 2008; Kuppusamy *et al*., 2009; Wong *et al*., 2009a; Wong and Chye, 2009; Sasidharan *et al*., 2010; Yim *et al*., 2010; Yim *et al*., 2011; Yim *et al*., 2012; Lim and Yim, 2012; Gan *et al*., 2013; Rajalingam *et al*., 2013; Wong *et al*., 2013a; Yap *et al*., 2013; Yim *et al*., 2013; Chong *et al*., 2014; Phan *et al*., 2014b; Subramaniam *et al*., 2014; Yap *et al*., 2014; Omar *et al*., 2015; Rahman *et al*., 2015; Tan *et al*., 2015a,b; Abidin *et al*., 2016; Kong *et al*., 2016; Mohd Rashidi and Yang, 2016; Nallathamby *et al*., 2016; Ng and Tan, 2017; Sim *et al*., 2017
Anti-tumour	Choong *et al*., 2008; Lim *et al*., 2010; Lee *et al*., 2012; Lau *et al*., 2013; Fauzi *et al*., 2015; Yap *et al*., 2015
Anti-ulcer	Abdulla *et al*., 2008; Abdullah *et al*., 2012b; Wong *et al*., 2013b; Nyam *et al*., 2016
Anti-viral	Lai *et al*., 2010
Hepatoprotective	Wong *et al*., 2012
Neuritogenesis	Wong *et al*., 2007; Wong *et al*., 2009b; Sabaratnam *et al*., 2011; Eik *et al*., 2012; Phan *et al*., 2012; John *et al*., 2013; Lai *et al*., 2013; Phan *et al*., 2013a,c; Seow *et al*., 2013; Phan *et al*., 2014a; Phan *et al*., 2015; Samberkar *et al*., 2015; Seow *et al*., 2015; Wong *et al*., 2015; Wong *et al*., 2016
Wound-healing	Abdulla *et al*., 2011; Cheng *et al*., 2013

not yet receiving the appropriate attention it deserves with the first available report on it was only published very recently in 2015 describing the use of the edible *Pleurotus djamor* var. *roseus* in the synthesis of silver nanoparticles (Raman *et al*., 2015). To our knowledge thus far, only handful publications are available from Malaysia (Muthoosamy *et al*., 2015; Owaid *et al*., 2015; Geetha Bai *et al*., 2016; Al-Bahrani *et al*., 2017: Musa *et al*., 2018) reporting mycosynthesis, with all the publications only used *Pleurotus* spp. and *Ganoderma* spp.

Conclusion

In conclusion, Malaysia is and remains a natural repository for wild and cultivated edible mushrooms with numerous nutritional and health benefits. The search for novel and undiscovered species must be continued. And for the species that are already discovered, deeper investigation on their nutritional and medicinal properties as well as the research gaps presented are warranted. The information and knowledge gathered thereof will certainly serve as an impetus for economic as well as scientific progress.

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