# Chapter 2
# Edible Ectomycorrhizal Fungi and Their Cultivation in China

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## 2.1 Introduction

China is currently the largest producer of edible mushrooms in the world. Production of fresh mushrooms has reached 20 million tons annually, accounting for 70% of total world production; a value just behind those for cereals, cotton, oils, vegetables, and fruit (Chang and Miles 1997). More than 70 fungal species have been cultivated and approximately 50 commercialized (Mao 1998). The main cultivated varieties are *Lentinula edodes*, *Pleurotus ostreatus*, *Auricularia auricula-judae*, *Flammulina velutipes*, *Agaricus bisporus*, *Ganoderma linzhi* and *Auricularia polytricha*. *Volvariella volvacea*, *Tremella fuciformis*, *Pholiota nameko*, *Pleurotus citrinopileatus*, *Hericium erinaceus*, *Dictyophora* species, *Wolfiporia cocos*, and *Cordyceps militaris* are also commonly, commercially cultivated but with less production. Other species such as *Pleurotus eryngii*, *Agrocybe chashingu*, *Pleurotus nebrodensis*, *Tremella aurantialba*, *Agaricus blazei*, *Grifola frondosa*, *Coprinus comatus*,

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*Stropharia rugosoannulata*, *Ganoderma leucocontextum*, *Oudemansiella radicata* (Fig. 2.1), and *Morchella* species (Fig. 2.2, see also Chap. 6 by Yu et al.) are newly commercialized mushroom species, with future market potential.

China has a long history of mushroom cultivation and utilization. Several mushroom species, such as *Auricularia auricula-judae* (estimated cultivation date, 600 AD), *Flammulina velutipes* (800–900 AD), *Lentinula edodes* (1000–1100 AD), and *Volvariella volvacea* (1700 AD), were first successfully cultivated in China (Chang and Miles 1989). However, research into the cultivation of edible mycorrhizal mushrooms is not as advanced as for saprobic species, and also lags behind the Western world, despite China's richness in EMMs. Chinese research into EMMs has made great progress over the last 30 years. China has become the biggest exporter of matsutake (*Tricholoma matsutake*) and is newly emerging as a truffle-producing nation (Wang 1995; Wang et al. 1997, 2008, 2017; Wang and Hall 2006; Wang and Liu 2009). EMMs are gourmet foods and sources of livelihood in China (Wang and Hall 2004; Wang et al. 2008, 2017). Cash earnings from the harvesting of EMMs can make up 20–40% (or even 90%) of an annual family income (Wang and Hall 2004; Wang and Liu 2011b). Some EMMs, such as *Tuber indicum*, *Lactarius hatsudake*, and *Suillus luteus*, have been successfully cultivated. Efforts to protect wild truffles, matsutake, and other EMMs have been made (Wang and Chen 2014). Research into truffles, porcini, matsutake, and others has revealed that China has wide diversity of EMMs (Wang et al. 2006; Zang 2006; Yang 2015; Yu 2007; Tian et al. 2009; Zheng 2010; García-Montero et al. 2010; Wang and Liu 2011a, b; Zhang et al. 2013; Lin 2016). In 2007, the fifth International Workshop on Edible Mycorrhizal Mushrooms (IWEMM5) was successfully held in Yunnan. Truffle festivals, matsutake festivals, and wild edible mushroom festivals have recently been held in Panzhihua, Sichuan, and Diqing, Nanhua, Kunming, Yunnan (Fig. 2.3). We provide here a brief introduction to EMM research in China.

**Fig. 2.1** Cultivated *Oudemansiella radicata* in a plastic tunnel house, Yunnan

**Fig. 2.2** Cultivated *Morchella* sp., Kunming, Yunnan

**Fig. 2.3** Visiting a *Tuber indicum* forest of *Pinus yunnanensis* during the third International Panzhihua Truffle Festival, Sichuan, 2014

## 2.2 Diversity of Edible Ectomycorrhizal Mushrooms

China has some of the richest biodiversity on earth. There are more than 30,000 seed plants, among which 17,000 are endemic (Wang 1979). The plant flora has ancient origins and was conserved due to it being much less impacted by the continental glacier during the Quaternary ice age than some other parts of Eurasia. China's vast territory has great climatic variation, including boreal, temperate, warm-temperate, subtropical, and tropical zones, giving rise to various types of terrestrial ecosystems including boreal forests, temperate coniferous and broadleaf forests, warm temperate deciduous broadleaf forests, subtropical evergreen broadleaf forests, and tropical monsoon forests. Rainfall reduces from east to west in the north, and forests are replaced by meadow steppe, typical steppe, desert steppe, steppe desert, typical desert, and extremely arid desert. Such rich ecological diversity nourishes great fungal diversity including diversity of EMMs. There are estimated to be around 900 wild edible mushroom species in China, of which about 350 are EMMs (Mao 1998; Lin 2016). The most economically important EMMs, such as truffles, matsutake, porcini, chanterelles, shimeji (*Lyophyllum*), shoro (*Rhizopogon*), and closely related species, all grow in China. In addition, although most species of *Scleroderma* are poisonous or inedible, the unique and interesting *Scleroderma yunnanensis* (Fig. 2.4) is endemic to Yunnan and is a popular EMM locally. In *Thelephora*, the only edible species is *Thelephora ganbajun*; the most expensive delicacy at wild mushroom markets in SW China (Fig. 2.5).

**Fig. 2.4** *Scleroderma yunnanensis* at a wild mushroom market, Puwen, Yunnan

**Fig. 2.5** *Thelephora ganbajun* (left) and *Tricholoma matsutake* (right) at a wild mushroom market, Nanhua, Yunnan

粟殼蕈
寒氣至稠齊將盡粟殼色者則其續也尚有典刑焉
松蕈
生松陰採無時凡物松出無不可愛松葉與脂伏靈琥
珀皆松裔也昔之遁山服食求長年者實松焉伊人有
病瘦濁不禁者偶啜松下菌病良已此其效也
竹菌
生竹根味極甘嘗與筍通譜而菌爲北阮矣
麥蕈
多生溪邊沙壤鬆土中俗名麥丹蕈未詳味殊美絕類
北方蘑菇蕈品最優
玉蕈
生山中初寒時色潔皙可愛故謚爲玉然作羹微韌俗
名寒蒲蕈
黃蕈
叢生山中槐蟹黃色俗名黃纘蕈又有名黃竾者殊脆

**Fig. 2.6** *Rhizopogon* sp. recorded as “Wheat mushroom, growing on sandy soils” (circled in pencil)

## 2.2.1 Truffles

China has a long history of mushroom use, and a few of edible and medicinal species are recorded in ancient Chinese texts. Surprisingly, there are no comments about true truffles (*Tuber*). The only hypogeous basidiomycete of a *Rhizopogon* species was described in “Jun-Pu”, an ancient mushroom text (Chen 1245) (Fig. 2.6), and known as “mai-xun” (the mushroom that fruits during the wheat harvesting season). This species is also recorded in some ancient Japanese mushroom books (Kobayashi 1983) with the name “song-lu” (dew of pine). There has been a recent trend in many Chinese publications and websites to call truffles “song-lu” (Wang and Liu 2011b).

It was not until 1985 when *Tuber taiyuanense*, the first Chinese truffle species was scientifically reported by B. Liu. Since then, more than 40 truffle species have been reported, with more than 70% of these new to science, and more species will yet be described from China. Quite a few are good edibles and have been commercialized, including *T. indicum*, *T. pseudohimalayense*, *T. sinoaestivum*, and *T. panzhihuanense.* Since the 1990s, increasing quantities of Chinese black truffles have been sold in international and domestic markets, and the harvesting and trading of truffles is becoming a multimillion dollar industry. These developments indicate that China has much richer truffle diversity than previously expected and may be a centre of world truffle biodiversity (Jeandroz et al. 2008; García-Montero et al. 2010; Wang and Liu 2011b; Bonito et al. 2013). China is clearly a newly emerging truffle country (Wang and Liu 2009).

#### 2.2.1.1 Black Truffles

There is a tradition of harvesting truffles for food in Huidong County and Panzhihua, Sichuan Province, although there are no written records. A black truffle species has been collected and traded locally in the Huidong region for a long time (Fig. 2.7).

Local names for truffle species include "wu-niang-tong" (fruit without mother), "songmao-fuling" (*Wolfiporia cocos*-like mushroom beneath pine needles), and "God's fruit". One of these was named as a new species, *T. sinense*, by Chinese mycologists in 1989 based on the collection from Huidong, Sichuan (Tao et al. 1989). Now the *T. sinense* has been considered as one of species in the *T. indicum* complex. *Tuber indicum* was named based on a collection from the small town of Mussoorie on the southwest slope of India's Himalayan foothills in 1892. *Tuber sinense* has been treated as a synonym of *T. indicum* by both Chinese and

**Fig. 2.7** A local truffle market in the Huidong region, Sichuan

international mycologists (Zhang et al. 2005; Wang et al. 2006; Chen 2007). However, *T. sinense* slightly differs morphologically from *T. indicum* in spore ornamentation and shape. Unfortunately, no DNA sequence was available from *T. indicum* at the time and then we could not firmly recognize whether *T. sinense* was a co-species of *T. indicum* or not. In 1987, Zhang and Minter re-examined the type collection of *T. indicum* and described a new species, *T. himalayense*, based on a part of this collection which has slightly different spore ornamentation. *Tuber formosanum* was initially reported from Taiwan but was not validly published due to the lack of a designated type. This species has been re-described with a lectotype (Qiao et al. 2013). *Tuber formosanum* is closely related to *T. indicum* but differs morphologically and phylogenetically (Huang et al. 2009; Qiao et al. 2013). Then, there are several names referring to the Chinese black truffles, including *T. indicum*, *T. sinense*, *T. formosanum*, and *T. himalayense*, but their morphological and phylogenetic relationships are not clear. It has been suggested that these should be referred to as "the *T. indicum* complex" (Wang et al. 2006; Chen 2007; Wang and Liu 2009). Species in this complex are mainly found in south-western China: Yunnan, Sichuan, and Tibet. Lately, however, it has been found in Beijing and Hebei Province of north China, Liaoning, and Heilongjiang Provinces of north-eastern China. The complex is also present in Japan and the Korean Peninsula (Fukiharu et al. 2006; Yamanaka et al. 2001). However, the phylogenetic relationships among these different populations from the south-west, north and north-east China need further research.

The *T. indicum* complex is closely related to *T. melanosporum* morphologically and phylogenetically (Song 2005; Zhang et al. 2005; Wang et al. 2006; Huang et al. 2009; Bonito et al. 2013; Qiao et al. 2013; Qiao et al. 2018) and they are comparable sibling species. However, the *T. indicum* complex has much more genetic and ecological diversity than *T. melanosporum*. Recent research into this complex has revealed that it has two pedigrees, ecotypes, subspecies or species: Lineages A and B (Bonito et al. 2013; Qiao et al. 2018). The *T. indicum* in Lineage A are found mainly on the Yunnan Plateau with its relatively cool and moist climate, while those in Lineage B are found in hot dry river valleys (Figs. 2.8 and 2.9). The *T. indicum* complex has mycorrhizal associations with both conifers and broadleaf trees, including those in the Pinaceae (*Pinus yunnanensis*, *P. armandii*, and another conifer *Keteleeria evelyniana*), the Fagaceae (*Quercus* spp., *Lythocarpus* spp., *Castanopsis* spp., *Castanea sativa*, and *Cyclobalanopsis delavayi*), the Corylaceae (*Corylus yunnanensis*), the Juglandaceae (*Platycarya strobilacea*) (Fig. 2.10), and the Salicaceae (*Populus yunnanensis*). This complex can adapt to a wide range of soils, from acid clay to calcareous (pH 6–8), with poor to rich organic matter. Soils that are calcareous or rich in organic matter have better production and better quality truffles (Fig. 2.11).

Since the 1990s, increasing quantities of Chinese black truffles of the *T. indicum* complex have been exported to Europe. One export problem has been the bad impression given by the sale of immature or degenerated Chinese truffles at European markets following a 1–2 month delay in arrival. However, members of the *T. indicum* complex are almost as delicious as *T. melanosporum*. These sister species share almost the same volatile organic compounds dominated by alcohols

**Fig. 2.8** A *Tuber indicum* forest of *Keteleeria evelyniana* in a dry-hot valley in Yunnan

(48–57%), aldehydes (4–27%), and aromatics (9–30%). However, *T. indicum* contains a lower quantity of sulfur compounds (Splivallo et al. 2011; Fang et al. 2013). Recently it was discovered that the quantities of volatile organic compounds especially sulfur compounds and ketones, increase, while aldehydes decrease, with increasing maturity. Only mature fruit bodies of the *T. indicum* complex contained 2-methyl-1-propanol (up to 19%), a very important component of truffle flavor.

**Fig. 2.9** A *Tuber indicum* forest of *Pinus armandii*, Yunnan Plateau, Yunnan

**Fig. 2.10** *Platycarya strobilacea*

Unfortunately, the harvest of Chinese black truffles starts as early as August when they are not mature, with no or very little aroma (Fig. 2.12) (Wang unpublished).

*Tuber sinoaestivum* is another Chinese black truffle species (Fig. 2.13) which is closely related to the European summer truffle, *T. aestivum* (Zhang et al. 2011). It has been found in Huidong of Sichuan Province and in Gongshan, Baoshan, and

**Fig. 2.11** *Tuber indicum* produced in soils with rich organic matter, Gongshan, Yunnan

**Fig. 2.12** Immature *Tuber indicum* harvested in September

Dongchuan of Yunnan Province. It grows in habitats moister than the *T. indicum* complex. The *T. indicum* complex can share the same forests as *T. sinoaestivum*; however, the former has a much wider distribution. *Tuber sinoaestivum* is harvested from August to early the following year, but is not ripe until November. *Tuber pseudoexcavatum* is another, but less valuable, edible black truffle species in China (Fig. 2.14). It also often grows in the same habitats as the *T. indicum* complex. A recently published new black truffle species, *Tuber pseudobrumale*, was found closely related to *T. pseudoexcavatum* and *T. brumale* (Li et al. 2014).

**Fig. 2.13** *Tuber sinoaestivum*

**Fig. 2.14** *Tuber pseudoexcavatum*

#### 2.2.1.2 White Truffles

Over the last 30 years, a greater number of white truffle species have been reported from China compared to black ones; more than 30 white truffles have been discovered, and over 80% are new to science. All are edible but only a few have commercial value. *Tuber panzhihuanense* is a recently discovered and commercialized Chinese white truffle with large fruit bodies and good aroma (Fig. 2.15). *Tuber liyuanum* (Fig. 2.16) is another newly described white truffle species with commercial potential (Fan and Cao 2012). These species are found under pine forests in Yunnan and Sichuan. White truffles are better adapted to arid climates than black species in China. In the last 5–6 years, the climate has become drier due to much less rainfall in Yunnan and Sichuan, and the yield of the *T. indicum* complex has reduced dramatically, while more white truffles have been discovered.

**Fig. 2.15** *Tuber panzhihuanense*

**Fig. 2.16** *Tuber liyuanum*

#### 2.2.1.3 Cuisine

With growing awareness of truffles by everyone in China, a whole new truffle cuisine has developed. It ranges from simple stir-fried or sautéed truffles to hot-pots with meats and vegetables, to variations in combinations of both Chinese and Western style cooking (Figs. 2.17 and 2.18). However, it will take time to understand the essence of truffle cooking.

With this new passion for processing truffles, the Chinese truffle industry has developed many different products, including truffle wines, sliced, dried, or frozen truffles, and frozen fresh truffles. The truffle wines, in particular, are considered mysterious beverages and are available in various brands (Fig. 2.19). Improved methods of storage, packaging, and transportation are needed to preserve the quality of harvested truffles.

**Fig. 2.17** Crevettes grillées à la truffe [Grilled shrimps with truffle]

**Fig. 2.18** Truffle rice

#### 2.2.1.4 Conservation and Cultivation

The price of Chinese black truffles has soared from a few US dollars to US$150/kg as international and domestic demands have increased every year since 1990s. Commercial interests have resulted in large-scale exploitation involving unrestricted plundering of truffles. This has severely damaged truffle habitats and truffle resources (Figs. 2.20 and 2.21). Truffle production has recently declined so much that truffles in early exploited regions have become extinct. Management, restoration, and conservation of truffle resources in China are becoming urgent. The recent use of trained truffle dogs for harvest is a positive strategy. The establishment of natural reserves for truffles has begun. Recently, experimental plots for restoration of *T. indicum* resources have been established at the truffle exploited areas of Luliang, Yunnan. After only 2 years of efforts with re-inoculation and conservation, brûlés are recovering (Figs. 2.22 and 2.23) and the production of *T. indicum* increased dramatically (unpublished data).


**Fig. 2.19** One of the truffle wines made with *Tuber indicum*

**Fig. 2.20** A severely damaged *Tuber sinoaestivum* woodland of *Pinus armandii* in Huidong, Sichuan

The establishment of plantations of truffle-inoculated mycorrhizal trees has been successful. One plantation with *T. formosanum* in Taiwan and another four with *T. indicum* in Guizhou, Sichuan, and Yunnan have produced truffles (Fig. 2.24). A few more plantations are waiting for production (Fig. 2.25).

**Fig. 2.21** *Populus yunnanensis* plantation in Luliang, Yunnan, before its conservation

**Fig. 2.22** *Populus yunnanensis* plantation in Luliang, Yunnan, after its conservation

**Fig. 2.23** Brûlés recovering after conservation of a *Populus yunnanensis* plantation, Luliang, Yunnan

**Fig. 2.24** A *Tuber indicum* plantation with pine, chestnut and oak trees in Shilin, Yunnan

Both native and foreign tree species have been successfully mycorrhized by *T. indicum*, and the mycorrhizal seedlings have been planted out. The Chinese tree species are *Pinus yunnanensis*, *P. armandii*, *Keteleeria evelyniana*, *Cyclobalanopsis glauca*, *Quercus franchetii*, *Castanopsis delavay*, *Castanea molissima*, *Platycarya*

**Fig. 2.25** A clear brûlé developed around planted, 3 years old *Castanea mollisima* tree inoculated with *T. indicum*, Panzhihua, Sichuan

*strobilacea*, *Corylus yunnanensis*, and *Populus yunnanensis.* The introduced trees are *Quercus robur*, *Corylus avellana*, and *Carya illinoensis*. Pine and broadleaf trees mycorrhized by *T. panzhihuanense* and *T. borchii* were also produced and out-planted in plantations. Production from seedlings inoculated with *T. melanosporum* and *T. aestivum* is in progress. Compared with the rapid deterioration of truffle environments, it is clear that these efforts are not enough to protect truffle resources.

## *2.2.2 Desert Truffles and Other Hypogeous Fungi*

### 2.2.2.1 Desert Truffles

Five desert truffle species have been recorded in Chinese literature. Actually, only two species, *Mattirolomyces terfezioides* and *Terfezia parvocarpus*, are present in China (Tao 1988; Zhang 1990). *Mattirolomyces terfezioides* grows under pine trees and on farm soils. *Terfezia parvocarpus* has been found in Mount Wulingshan, Xinglong County, Hebei, growing with *Salix wallichiana* trees. However, the mycorrhizal status of these species needs further research. China has a large area of desert and semi-desert, and these have not been searched for desert truffles. It is quite possible that truffles occur in these areas. More than 100 other hypogeous species in 40 genera and 23 families have been reported in China (Li et al. unpublished data). Shoro and others are often found at mushroom markets.

#### 2.2.2.2 Shoro

The "shoro" (*Rhizopogon roseolus*) was the fourth most commonly consumed mushroom in Japan, around 200 years ago (Okumura 1989), and it is recorded in ancient fungal books (Kobayashi 1983). Chinese shoro is known as "ji-yaozi" (chicken kidney) and is commonly collected and traded in Yunnan and Sichuan (Fig. 2.26). Its previous Latin name was *R. rubescens*, but it was found that Chinese shoro consists of three new species *Rhizopogon jiyaozi*, *R. flavidus*, and *R. sinoalbidus* (Li et al. 2016).

#### 2.2.2.3 *Choiromyces*

*Choiromyces* aff. *meandriformis* is one of the edible ones, commonly found in Shanxi, Xinjiang, and the Inner Mongolian Region (Fig. 2.27). It was previously reported as *C. vinosus* and *C. alveolatus* (Tao 1988; Zhang 1990). The taxonomy of the Chinese *Choiromyces* species awaits further research. They are found mainly with *Picea* trees such as *P. schrenkiana* and *P. crassifolia*.

**Fig. 2.26** *Rhizopogon jiyaozi*

**Fig. 2.27** *Choiromyces* aff. *meandriformis*

**Fig. 2.28** Yang-yanjing (*Astraeus hygrometricus)* sold at a mushroom market, Shidian, Yunnan

#### 2.2.2.4 Yang-Yanjing (*Astraeus hygrometricus*)

*Astraeus hygrometricus* is another edible hypogeous species, which is known as "Yang-Yanjing" (Sheep's eye) or "Potato mushroom" and sold at local mushroom markets in Yunnan and Sichuan Provinces (Fig. 2.28). It grows with *Pinus yunnanensis* or *Castanea mollissima.* The outer layer, the exoperidium, is thick and initially inseparable from the inner layer (endoperidium). At maturity, the exoperidium bursts open into several pointed "rays" when moistened, but the rays are closed over the exoperidium when dry. When the exoperidium opens up, the spores are blown away. However, when the rays are closed, the spores are dispersed by insects. The insects can eat the gleba through opening up a hole (Fig. 2.29) from the bottom of fruiting body where there is a peridium gap (Fig. 2.30). There is another similar edible species, *Astraeus asiaticus*, in the north of Thailand (Phosri et al. 2004).

**Fig. 2.29** A gleba of *Astraeus hygrometricus* eaten by insects through a hole

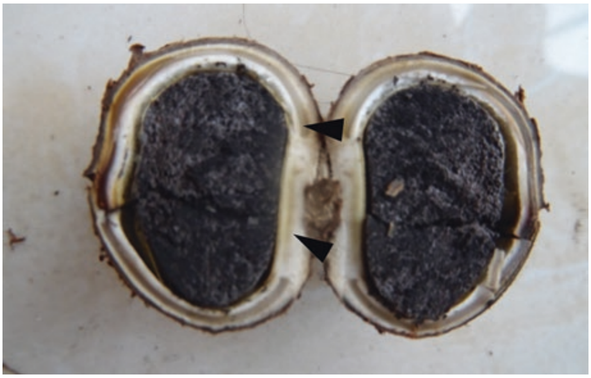

**Fig. 2.30** *Astraeus hygrometricus*: Note the peridium gap (arrowheads) at the fruiting body bottom

### *2.2.3 Porcini and Related Edible Mycorrhizal Mushrooms*

China has rich resources of edible boletes with hundreds of species (Li and Song 2001). *Boletus edulis* (porcini) and closely related species are the most important species for export in the form of sliced and dried or brined mushrooms. Annually, 50,000 tons of edible boletes are harvested and sold on domestic and international markets. Wild porcini and related boletes are found all over China, especially in the north-east, south, and south-west.

*Boletus* aff. *edulis* is one of the most popular edible mycorrhizal mushrooms in China and is called "white bolete" in Yunnan (Fig. 2.31). It grows with pine or oak or in mixed pine-oak forests and fruit from June to August. *Leccinum extremiorientale* is another good edible mycorrhizal fungus. As delicious as *B. edulis*, it gives large yields with great commercial value.

**Fig. 2.31** *Boletus* aff. *edulis* sold at a wild mushroom market in Kunming, Yunnan

**Fig. 2.32** One of "Jianshouqing" boletes, *Boletus speciosus*

*Boletus bicolor*, *B. speciosus*, *B. magnificus*, *B. subsplendidus*, and other similar species (Fig. 2.32), known as "jian-shou-qing" (turning blue when bruised or cut), are likeable boletes and are even more popular than *B.* aff. *edulis* in Yunnan. Members of this "jian-shou-qing" group can cause hallucinogenic reactions and even death, but the local people continue to enjoy them. Five poisonous boletes have been detected commonly mixed with commercial edible ones in Yunnan mushroom markets. These are *Tylopilus eximius*, *T. microsporus*, *Pulveroboletus ravenelii*, *Chiua virens*, and *Heimioporus retisporus* (Li et al. 2011).

Research into the taxonomy, ecology, and processing of Chinese boletes is a huge task due to their diversity. Conservation and cultivation has begun, but without any sound progress at the moment.

*Suillus luteus* and closely related species are very common EMMs all over China. They are commonly dried and kept for winter consumption. *Suillus luteus* has been

**Fig. 2.33** *Phlebopus portentosus*

successfully cultivated by mycorrhization of *Pinus massoniana* in the Lishui region, Zhejiang (Han and Ren 2016).

*Phlebopus portentosus* is an edible mushroom in the Boletinellaceae (Fig. 2.33). It has been considered a facultative mycorrhizal fungus (Kumla et al. 2012). However, based on over 10 years of our research, this fungus shouldn't be considered ectomycorrhizal and can be cultivated using methods for saprophytic mushrooms (Ji et al. 2011; Zhang et al. 2017).

## *2.2.4 Russulaceae*

There are many edible mycorrhizal *Lactarius* species in China. Hundreds and even thousands of kilograms of edible *Lactarius* mushrooms change hands daily at wild mushroom markets. *Lactarius deliciosus*, *L. hatsudake*, *L. volemus*, *L. vividus*, and *L. hygrophoroides* are important edible mycorrhizal species in China. *Lactarius hatsudake* is the most favorable edible mushroom in Hunan Province, and it is known as "Hanjun" (chill or cold season mushroom). Seedlings of *Pinus massoniana* mycorrhized by *L. hatsudake* in Hunan have produced fruit bodies 3–4 years after planting in plantations in 2001 and now give an average yearly production of 670 kg/ha (Tan et al. 2008; Wang et al. 2013). Research into the production of mycorrhizal trees inoculated with *Lactarius* species from the section *Deliciosi* has been a successful and recent focus in Yunnan (Wang et al. 2019, see also Chap. 6 by Yu et al.).

*Russula virescens*, known as "qingtou-jun" (green head mushroom), is a popular edible species in south-western China. Another favorable and expensive edible *Russula* is *R. griseocarnosa*; it was previously misidentified as *R. virosa* (Wang et al. 2009) and is called "dahong-jun" (bright red mushroom) by the local people (Fig. 2.34). Consumers believe that this mushroom is beneficial to human health,

**Fig. 2.34** *Russula griseocarnosa*

especially for pregnant women, and there is scientific evidence to support the claim (Wang et al. 2009). Dried dahong-jun can be sold for over 800 Chinese yuan/kg (around US$130/kg). This species is found under evergreen oaks in tropical and sub-tropical China.

The yield of *L. volemus* and "dahong-jun" has been increased by the use of *L. volemus* spores as inocula in natural habitats in Yunnan (see also Chap. 6 by Yu et al.).

### *2.2.5 Shimeji*

*Lyophyllum shimeji* (Honshimeji, true-shimeji) is a well-known edible ectomycorrhizal fungus, as famous as matsutake in Japan. *Lyophyllum shimeji* and its closely related species are also considered one of most delicious mushrooms in China, especially in south-western and north-eastern China (Fig. 2.35). It is widely distributed in East Asia and northern Europe. Nineteen *Lyophyllum* species have been reported from China, including *L. shimeji*, which is mainly associated with pines. It grows with *Pinus yunnanenis* and *P. kesiya* var. *langbianensis* at lower elevations, but can be associated with *Quercus aquifolioides* and *Pinus densata* at higher elevations (over 3000 m). Other edible *Lyophyllum* species, such as *L. decastes* and *L. fumosum*, are also present in China. Based on research by Japanese mycologists, it has two genotypes: mycorrhizal and saprophytic and can be cultivated using mycorrhizal or saprophytic methods (Ohta 1994, 1998). Meanwhile, *Lyophyllum shimeji* is not a typical ectomycorrhizal fungus as it produces a very thin and unstructured mantle in the mycorrhizae.

**Fig. 2.35** *Lyophylum shimejii*

**Fig. 2.36** A species from the *Amanita hemibapha* complex, Diqing, Yunnan

## *2.2.6 Amanita*

"Caesar's mushroom" is a yellow–orange *Amanita* species that was once called *A. caesarea* in China, but has now been properly identified as one member of the *Amanita hemibapha* complex (Fig. 2.36). It grows in moist areas of China, especially the south-west, and has large genetic variation. Another good edible *Amanita* species is *A. vaginata.* These edible *Amanita* species are harvested for food and are traded locally. Some poisonous ones are sometimes also collected and sold at local markets. Unfortunately, poisoning incidents caused by *Amanita* species occur every mushroom season in China.

### 2.2.7 Chanterelles and Craterellus

The *Cantharellus cibarius* complex and related species, and *Craterellus cornucopioides* and its related species, are some of the most popular EMMs in the world and are very common at wild mushroom markets in China (Fig. 2.37). *Cantharellus cinnabarinus* is one of the most common species in Yunnan but is less appreciated. At least 15 species of *Cantharellus* have been recorded from southwestern China; 7 of these are new to science. They grow with many conifers (*Abies*, *Picea*, and *Pinus*) and broadleaf trees (*Quercus*, *Carpinus*, and *Castanea*) in alpine and subalpine regions. In southwestern China, they are the main group of EMMs associated with pine forests, such as *P. yunnanensis*, *P. massoniana*, *P. kesiya* var. *langbianensis*, *P. densata*, and exotic pines. The *Cantharellus cibarius* complex includes some of the most important EMMs exported to Europe from China (Tian et al. 2009). Despite its economic and ecological importance, its cultivation has not been studied in China.

### 2.2.8 Albatrellus

Nineteen species of *Albatrellus* have been recorded in China with several species new to science. A few have been examined for their biotrophic status in the field and the laboratory, and they have been found to be ectomycorrhizal (Zheng 2010). However, further research is needed to confirm their mycorrhizal status and features. Some, such as *Albatrellus elisii* known as “yellow huzhang-jun” (yellow tiger-paw mushroom), are collected for food and are traded locally (Fig. 2.38). See also Chap. 6 by Yu et al. for more details about this genus.

**Fig. 2.37** *Cratarellus aureus* at a market in Puer, Yunnan

**Fig. 2.38** *Albatrellus elisii* sold at a mushroom market, Yunnan

**Fig. 2.39** *Thelephora ganbanjun* growing at a forest of *Pinus yunnanensis*, Yunnan

## *2.2.9 Unique Edible Mycorrhizal Mushrooms*

*Thelephora ganbajun* (Fig. 2.39) and closely related species (2–3 species) are the most expensive and highly favored edible mycorrhizal fungi in Yunnan (see also Chap. 6 by Yu et al.). Research into cultivation has made good progress. Ganbajun produces sclerotia that plays an important role in its life circle (Fig. 2.40). Mycelial isolates have been made (unpublished data). Environment management and habitat improvements are known to increase mushroom yield.

*Scleroderma* species are widespread and common from tropical to boreal regions and are described as inedible or poisonous in mushroom books and scientific papers. Very interestingly, Yunnan has one edible and sought after new species *S. yunnanense* (Fig. 2.41) (see Chap. 6 by Yu et al. for more details).

**Fig. 2.40** Sclerotia of *Thelephora ganbanjun*

**Fig. 2.41** *Scleroderma yunnanense* collected from a *Pinus yunnanensis* forest, Yunnan

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