The Cultivation of Mycorrhizal Mushrooms - Success and Failure

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Abstract: Edible ectomycorrhizal mushrooms such as the truffles and matsutake can retail for several thousands of dollars per kilogram but their total world market is just a fraction of that for saprobic mushrooms. This is primarily because it has only been possible to cultivate a few species and consequently for many species we are reliant on what can be harvested from areas where they grow naturally, there are significant problems with the cultivation of edible ectomycorrhizal mushrooms on their host plants, and there are difficulties delivering quality products to the consumer. Over the past 100 years there have also been catastrophic declines in harvests of some species of edible ectomycorrhizal mushrooms and this includes the cultivated species. This paper will outline science, industry and governments' response to this challenge, their successes and some reasons for failures, the current state of our knowledge and will suggest a vision for the future.

Key words: Edible mushrooms, truffle, mycorrhiza, *Tuber* spp, *Tricholoma matsutake*, cultivation problems

1 Introduction

Edible mushrooms fall into three trophic groups: the saprobes that grow on animal and/or plant wastes, pathogens which parasitize living plants or occasionally animals, and those that live in a mutually beneficial symbiotic relationship with the roots of suitable host trees. The last of these are the edible ectomycorrhizal mushrooms (EEMM). Wang et al. (Appendix 1) list 189 EEMM although many more are eaten in developing countries that largely go unnoticed by international science and commerce.[1-4]

While some EEMM have potential medicinal properties[5-8] most are consumed for their culinary attributes. Amongst the EEMM are some of the world's most expensive foods with the Périgord black truffle (*Tuber melanosporum*) and Italian white truffle (*Tuber magnatum*) typically retailing for in excess of US$1000 / kg and occasionally much higher.[9] Others fetch lower prices but the trade in them can be significant with the international market for chanterelles alone having been estimated at US$1.62 billion.[10]

2 Structure and Function of Ectomycorrhizas

In an ectomycorrhiza the fungal partner wraps the tips of the fine lateral roots in a layer of fungal tissue several cells deep, a structure first observed by Hartig,[11] given the name mycorrhiza by Frank[12] and subsequently ectomycorrhiza by Peyronel *et al.*[13, 14] This structure is the mantle and from it hyphae radiate out into the soil where they access nutrients, in particular phosphorus and nitrogen, and transport them back to the plant.[15] From the inside of the mantle fungal projections penetrate between the outer layers of the cortical cells (the Hartig net) where they act as the gateway between the plant and the fungus. This three dimensional network of hyphae, the Hartig net, can be visualised as being the mortar between the bricks in a brick chimney. In exchange for the nutrients from the soil the plant provides the obligate mycorrhizal fungus with a place to live and metabolites.[15]

3 Declining Harvests of Edible Ectomycorrhizal Mushrooms

At the beginning of the 20th century, the combined harvests of the winter truffle (*Tuber brumale*) and Périgord black truffle in France was about 1000 tonnes but now, even in a good year, French production is rarely more than 50 tonnes[16] (Figure 1) and the official figures for the combined annual harvests for France, Italy and Spain has been over 100 tonnes just once between 1990 and 2002 (Table 1).

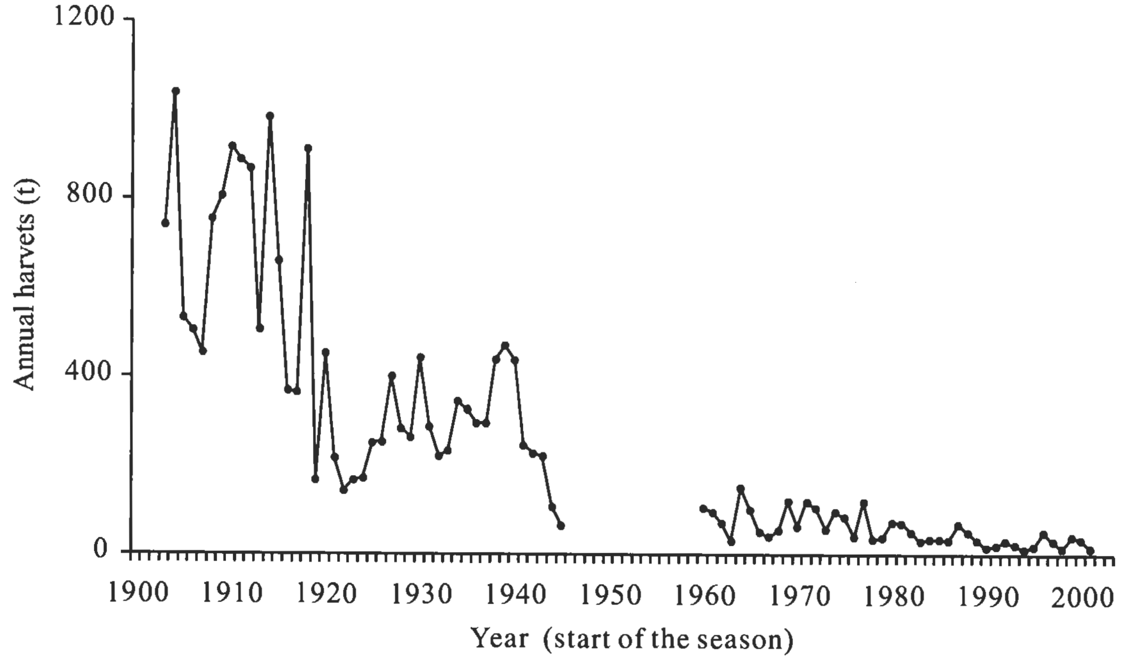

Figure 1. Combined French production of Périgord black truffle (*Tuber melanosporum*) and winter truffle (*Tuber brumale*) between 1903 and 2001

Table 1. Official figures for French, Italian and Spanish combined production of Périgord black truffle (*Tuber melanosporum*) and winter truffle (*Tuber brumale*) between 1990 and 2002 (Courvoisier, pers. comm.)

Year	France	Italy	Spain	Total
1990/91	17	5	30	52
1991/92	20	5	10	35
1992/93	31	3	23	57
1993/94	22	2	9	33
1994/95	12	30	4	46
1995/96	19	25	20	64
1996/97	50	20	25	95
1997/98	30	24	80	134
1998/99	14	4	7	25
1999/00	40	10	35	85
2000/01	35	4	6	45
2001/02	15	5	20	40

This is mirrored by falls in matsutake harvests in Japan (Figure 2) and other EEMM in Europe. [17, 18] These falls are exacerbated by our inability to cultivate matsutake (*Tricholoma matsutake*) along with most other EEMM, so that supplies are restricted to what can be harvested from the wild during the Northern Hemisphere autumn and winter, a situation that has sometimes necessitated the introduction of rules or regulations to control over picking.[19-21]

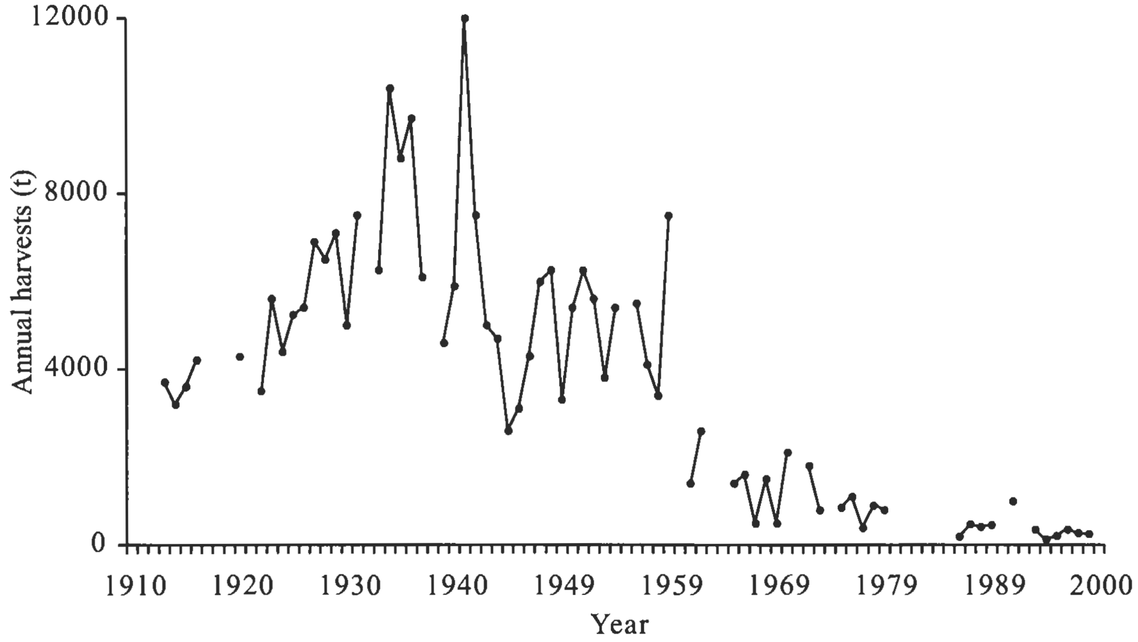

Figure 2. Japanese *Tricholoma matsutake* production between 1912 and 1998

For matsutake the fall in harvests can be linked to the decline of its primary host, the Japanese red pine (*Pinus densiflora*, Akahatsu). Some reasons for this are:

- Matsutake is found in Japanese red pine forests with about 75% canopy cover and relatively little undergrowth and maintaining forests in this state has been found to encourage production.[22] However, a reduction in the frequency of man made forest fires, a cessation of the removal of oaks to make charcoal and collecting kindling from forests has led to a dense undergrowth in pine forests and a gradual replacement of pines by oaks which are not hosts for matsutake.[22-26]
- Pine wilt disease caused by the nematode *Bursaphelenchus xylophilus* spread by the vector beetle *Monochamus alternatus*[24, 25, 27] has decimated Japanese red pine forests,
- Pollutants in particular SO_2 and NO_2 produce free radicals via photochemical reactions in dew on the leaves of Japanese red pine and this leads to defective stomatal opening, reduced photosynthesis and loss of vigour[28-30]
- Deforestation.

Additional possibilities advanced for the decline in harvests of EEMM in general are: [16, 18, 19, 22, 31-33]
- Reforestation with suitable host trees but with planting densities that suit timber production but not fruiting of EEMM,
- Replacement of forests that support EEMM with plantation forest trees that do not,
- Global climate change since the last ice age which has left host plants or the mycorrhizal fungi ill adapted to the new climatic conditions,
- The loss of land, forests and/or expertise through two World Wars-note the steep fall in harvests around 1918 and 1945 in Figure 1,
- Soil disturbance by harvesters who either compact the soil when looking for mushrooms or do severe damage to soil structure and surface feeder roots when they dig for species that fruit below the ground (e.g. truffles) or mushrooms that are in the best condition for the market before they break the soil surface (e.g. matsutake),
- Harvesting mushrooms before they have grown to full size-picking a small mushroom is better than leaving

it to grow larger for someone else to pick.[31, 34]

4 Nineteenth Century Cultivation of the Périgord Black Truffle - the First Cultivation of an Edible Ectomycorrhizal Mushroom

Early in the 1800s Joseph Talon in France found that if he transplanted self sown seedlings from under a truffle producing oak after a decade or so some of these seedlings would also produce truffles.[31, 34, 35] About the same time truffle infected plants were being produced in Italy by inoculating seedlings with pieces of truffle, a technique described in a letter of Giovio to Canonico Giacomo Sacchetti in 1807.[36] These early French and Italian workers had no conception of what was happening, this had to wait for the pioneering research of Frank, [12, 14] but these techniques worked and the use of Talon's technique, in particular, spread rapidly through France and Italy as an alternative source of income to those involved in the *Phylloxera*-ravaged wine industry of the 1860s [35] Simple though these techniques were during the golden age of truffles in the late 1800s perhaps as much as 2000 tonnes of black truffles were harvested each year in Europe and they remained the backbone of the truffle industry in Europe until the early 1970s.[35, 37]

5 "New" Techniques

By the 1960s a collapse of the European truffle industry, which had been hastened by two World Wars (Fig. 1), was well underway and new techniques were sought to reverse the decline. Talon's technique had its deficiencies because the seedlings were exposed to all organisms in the rooting zone of the donor plant, such as insect pests, nematodes and faster growing, contaminating ectomycorrhizal fungi. Consequently, alternative techniques for producing infected plants were developed that involved either inoculating non-mycorrhizal seedlings with sections of infected root,[38] or pureed truffle.[39, 40] More recently truffle infected plants have also been produced by inoculating non-mycorrhizal seedlings with sections of truffle-infected transformed roots.[41-43] Cultures have also been used experimentally[44, 45] but it has not been until recent developments that the barrier of their very slow rate of growth have been overcome.[46-48] These techniques offer the possibility of producing truffle infected plants free of contaminants and with strains adapted to particular combinations of soil, climate and host. However, inoculating plants with spores is still by far the most popular method for the commercial production of Périgord black truffle and Burgundy truffle (*Tuber aestivum or Tuber uncinatum*).[49-52] Infected plants with 300,000 to 450,000 Perigord black truffle inoculated seedlings produced in this way each year in France alone and many more produced in Spain and Italy[16, 32, 53]

Although commercial producers of infected plants such as Agri Truffe, Robin Pépinières and New Zealand Institute for Crop & Food Research remain tight lipped about the details they employ [54] the general methods that can be used for the Périgord black, Burgundy, bianchetto and desert truffles have been well documented over the past 20 years (e.g. [43, 46, 47, 51, 55-61]).

6 Field Cultivation of Truffles

The Périgord black truffle can be found growing naturally between 40°N and 47°N latitude in southern France, northern Italy, Croatia, parts of northeast Spain and to a small extent in Portugal and Bulgaria. It is found on agriculturally marginal land with calcareous soils from pH 7.5 to 8.3 and typically on hot, exposed slopes and plateaus.[35, 53, 62] The soils are invariably free draining, granular and well-aerated but varying from clayey to sandy or stony and characterized by moisture deficits in summer.[53, 63] Other truffles including the cultivated Burgundy truffle and bianchetto truffle (*Tuber borchii*) are also restricted to broad sets of climatic and edaphic conditions.[61, 64-68] Consequently, when selecting a site for a truffle plantation (a truffière) these requirements have to be met. Areas where there are competing ectomycorrhizal fungi on other ectomycorrhizal plants, such as beech, birch, hazelnut, oaks, pines, poplars and willows, should be avoided as these may actively compete and displace the truffle on the newly planted trees. An appropriate tree spacing is also an important consideration. Then once planted the husbandry of a truffière is aimed at maintaining the inoculant fungus on the roots-aeration of the ground in spring, judicious pruning, irrigating when there has been insufficient rain and controlling pests and diseases (e.g.[37, 59, 62, 69]).

Outside of Europe the Périgord black truffle has been cultivated in California (first harvested in 1991) and North Carolina (1993) and in the Southern Hemisphere (and out-of-season to the Northern Hemisphere) in Australia (1999) and New Zealand (1993). The majority of these truffières were established on naturally acidic or neutral soils that have been modified by the application of large amounts of lime, dolomite and/or hydrated lime-typically 2 tonnes or more per hectare for every 0.1 pH the pH has had to be raised.[37] For example, in New Zealand the Périgord black truffle has been successfully cultivated on a volcanic ash soil with a natural pH of 5. 3 through the application of more than 50 tonnes of lime per hectare.

Typical yields from cultivated Périgord black truffle truffières range from a few kilograms per hectare to about 100 kg[53] although one small truffière in New Zealand has produced several times this quantity.

7 Cultivation of Epigeous Edible Ectomycorrizal Mushrooms

When compared with the truffles the cultivation of epigeous EEMM is still very much in its infancy as only three species have been cultivated in anything like commercial quantities-saffron milk cap (*Lactarius deliciosus*), shoro (*Rhizopogon rubescens*) and honshimeji (*Lyophyllum shimeji*).[70-72] Plants have also been infected with the chanterelle (*Cantharellus cibarius*)[73] *Suillus granulatus*[74] and *Tricholoma matsutake*.[21, 75] Infected plants were produced using similar methods to those that have been used for truffle-pure cultures prepared either from mycorrhizal root tips or fruiting bodies following methods devised for other ectomycorrhizal fungi,[76] sporal suspensions or infected root tips.[21, 73, 75, 77-81]

8 Pure Culture of Edible Ectomycorrhizal Mushrooms

Attempts to produce fruiting bodies of EEMM away from their hosts have generally been unsuccessful with only immature primordia developing in cultures of *Boletus badius, Boletus porosporus, Boletus subtomentosus, Suillus piperatus[82]* and porcini *Boletus edulis*.[83] A notable exception was the formation of fruiting bodies of *Lyophyllum shimeji* by[84, 85] where pure cultures that had produced primordia in preliminary studies[84] were grown in 500 ml bottles containing an autoclaved mixture of 80 g of barley grains, 8 g of *Fagus crenata* Blume sawdust, and 140 ml of a glucose-free synthetic supplement at 23°C and 8000 lux of fluorescent light for 16 h per day for 55-68 days.[85] Primordia were formed after reducing the temperature to 15°C and incubating for a further 26-35 days. After a further 10 days, lamellae with basidiospores developed in up to half of the bottles. While Ohta's results might point the way for future research the generally very slow growth of most EEMM in pure culture (e.g.[57, 81]) suggests that this might not be a particularly profitable line of research.

9 Production of Edible Ectomycorrhizal Mushrooms in the Southern Hemisphere

Most of the EEMM of commerce are not found south of the equator, only fruit for short periods during the year, are best eaten fresh and do not preserve well. There is, therefore, a golden opportunity to develop ways of cultivating these mushrooms in Southern Hemisphere countries to satisfy the out-of-season demand in the Northern Hemisphere.[86] There is also the possibility of developing IP that would enable the expansion of production in Northern Hemisphere countries to fill current shortfalls and generating new markets in countries south of the equator.

In New Zealand very large areas are free of ectomycorrhizal fungi that might compete with the Périgord black truffle. It would therefore have been negligent to have supplied potential growers with Périgord black truffle infected plants contaminated with other ectomycorrhizal fungi which is the norm in Europe. Consequently, the first author developed his own techniques for producing Périgord black truffle infected plants free of contamination. Over the past 20 years more than 120 Périgord black truffières have been established in New Zealand in areas ranging from climatically marginal to close to the ideal. Many of these have been established on naturally acidic soils to which very large quantities of lime have been applied.[67]

The first truffles to be harvested in New Zealand, the first in the Southern Hemisphere, were found in a truffière near Gisborne (38°S) in July 1993, five years after planting. Between May and early September 1997 this 0.5 ha truffière yielded 9 kg of truffles with many weighing between 250 g and 1000 g. A further 10 kg were harvested in the winter of 1998, 12 kg in 1999 and 65 kg in 2000. Between 1999 and 2004, Périgord black truffles were also found in truffières near Opotiki (38°S), Taumarunui (39°S), Paraparaumu (41°S), Nelson (41°S), North Canterbury (42°S) and Ashburton (41°S).

Other EEMM that have been cultivated in New Zealand are the saffron milk cap (*Lactarius deliciosus*) and the Japanese delicacy shoro (*Rhizopogon rubescens*).[21, 72, 87]

10 The Problems

Despite the introduction of the improved techniques for the production of truffle infected plants in the 1970s and the planting of more than half a million per year for more than a decade, the production of the Périgord black truffle has been at best static (Fig. 1). The quality of infected plants is certainly a problem and something that the industry is able to control through the implementation of standards that have been devised.[53, 88-90] However, poor seedling quality remains a significant problem for the industry[91, 92] and plants are still offered for sale that are poorly infected or not infected with the inoculant fungus, contaminated with other species of truffle with little commercial value or contaminated with ectomycorrhizal fungi that don't even produce EEMM. In Australia and New Zealand perhaps the consumer is better protected by legislation and two recent disputes over the quality of mycorrhized plants have been settled out of court.

Our understanding of how truffières should be managed, the complex interrelationship the fungus has with its host plants and environment and factor(s) induce fruiting also remains deficient.[67] In the absence of a sound understanding of how to cultivate truffles advisers, researchers and growers have fallen back on experience, intuition, opinion and speculation sometimes even when this flies in the face of sound scientific fact.

One might have thought that our lack of knowledge of the cultivation of EEMM would have spawned a rash of field based research at least for those species that can be cultivated. However, of 192 scientific articles on true truffles identified using the Web of Science database 5 were review papers, 13 were field surveys, 169 were laboratory studies-molecular work, biochemistry, taxonomy and the like-and just 5 were field experiments the majority of which were more than 10 years old. The situation is not quite as bad as this search might indicate because papers from three international conferences on EEMM[93-95] were not in the database and some significant work comparing truffle production from cloned truffle infected plants in France[96] and desert truffle cultivation in Spain[97] have yet to be fully reported. Even so publications on long term field studies are rare and we are left wondering if the responsibility lies in the assessment of scientists partly on how many papers they publish particularly in high impact factor journals, that long term field studies are unlikely to be attractive to high impact factor journals, and that long term studies produce few papers for the time invested. Long-term research also appears to be unattractive to funding bodies.

11 Outside the Square

After 100 years of research and with only half a dozen EEMM cultivated it is abundantly clear that science does not have the answers and we must speculate as to what the obstacles might be. Obviously before trying to

cultivate any EEMM it would be wise to fully understand its climatic, edaphic and biotic requirements. Regrettably apart from the Périgord black truffle, which is well covered with texts in French and Italian, there are few studies of this sort (e.g. [33, 65, 73, 98, 99]). Without such critical information we may make avoidable mistakes such as:

- Trying to grow an inoculated seedling on a greenhouse bench or in a bare patch of land in full sunlight where the surface soil temperatures may rise above 40°C that may be quite inappropriate for a fungus that inhabits cool, moist soils under a forest canopy,
- Growing a plant infected with an EEMM adapted to dry conditions in a moist, equitable climate under a forest canopy where there is intense competition from other better adapted ectomycorrhizal fungi,
- Failing to allow the development of a canopy, understorey or herbaceous layer which may be critical to the success of, for example, matsutake.[22]
- Failing to recognise critical soil chemical, organic content or porosity requirements.

Until recently it was assumed that there was little genetic variability in Périgord black truffle populations[100] which supported the continued use of any Périgord black truffle from any part of Europe for seedling production. However, another group of researchers using more sensitive molecular techniques[101] were able to detect ten different populations of Périgord black truffles in two major groups either side of the French Central Massif, a pattern that parallels differences in oaks and their northerly reclamation of land after the last age[102] Differences in populations are also know to occur in the Burgundy truffle with those from the island of Gotland to the east of Sweden different from Burgundy truffles from Denmark, the UK and France.[103] If these differences in the highly variable section of DNA[101, 103] used are reflected in even small differences in a gene, for example, that is associated with the temperature at which fruiting is triggered, then there would be major consequences not only for producers of Périgord black and Burgundy truffle infected plants but with the cultivation of EEMM generally.

Figure 3. *Boletus parasiticus* associated with *Scleroderma citrinum* (Hall)

Competing ectomycorrhizal fungi are an ever present danger (see above) first during the production of infected plants in the greenhouse and then in the field after transplanting. However, for many species of EEMM even if competing ectomycorrhizal are controlled we are still unable to get good mycorrhizal formation. For the Italian white truffle this has been partly attributed to poor spore germination[61] but even when infections are formed they are not vigorous with maybe only 1% of the root tips infected. With other species like porcini good infections on suitable host plants were achieved two decades ago (e.g. [104]) but this species has continued to defy cultivation. Similarly many attempts to cultivate matsutake by transplanting well infected plants to the field have also failed.[33, 34, 81]

Figure 4. An *Amanita excelsa* ectomycorrhiza with lighter coloured, rhizomorphs of *Boletus edulis* penetrating the mantle (Wang)

One possibility that has yet to be explored is the possible need for a third organism to produce a stable system. For example, some bacteria, termed mycorrhiza helper bacteria, and in particular *Pseudomonas*, appear to aid the infection process by mycorrhizal fungi, can have antimycotic activity and possibly have an effect on fruiting.[105-108] The routine association of Cytophaga-Flexibacter-Bacteroides bacteria with the mycelium of *Tuber* remains unknown.[109] Yeast also seem to be involved too.[110] It is also not too remotely possible that some EEMM fungi may gain at least some of their nutrition in a hyperparasitic way from other ectomycorrhizal fungi-a relationship that Boletus parasiticus appears to have with *Scleroderma citrinum* (Fig. 3). Alternatively dual ectomycorrhizas as formed by *Boletus edulis* and *Amanita muscaria* or *Amanita excelsa*[21, 34] (Fig. 4), might be mutually beneficial or even essential. While such speculation might seem just a little wild perhaps now is the time to think outside the square and to take a leaf from Sherlock Holmes, "Whenever you have eliminated the impossible, whatever remains, however improbable, must be true".

Acknowledgements

We are grateful to Wang Yun, Peter Buchanan and Ian Hall for permission to use the Appendix.

References

[1] Boa E. How do local people make use of wild edible fungi? Personal narratives from Malawi. In I.R. Hall, Y. Wang, E. Danell & A. Zambonelli (eds), Edible mycorrhizal mushrooms and their cultivation. Proc. Second Int. Conf. on Edible Mycorrhizal Mushrooms, Christchurch, 3-5 July 2001, CD-ROM. Christchurch: New Zealand Institute for Crop & Food Research Limited. 2002.

[2] Ducousso M, Bâ AM, Thoen D. Ectomycorrhizal fungi associated with native and planted tree species in West Africa: a potential

source of edible mushrooms. (see ref. 1).

[3] FAO Wild edible fungi a global overview of their use and importance to people. Non-wood forest products 17. Rome: FAO. http://www.fao.org/documents/ 2004.

[4] Flores R, Bran MC, Honrubia M. Edible mycorrhizal mushrooms of the west highland of Guatemala. (see ref. 1).

[5] Baute MA, Deffieux G, Vercauteren J, *et al.* Enzymic activity degrading 1,4-á-D-glucans to ascopyrones P and T in Pezizales and Tuberales. Phytochemistry 1993, 33, 41-45.

[6] Hobbs C. Medicinal mushrooms. Santa Cruz: Botanica Press, 1995.

[7] Wasser SP, Weis AL. Medicinal properties of substances occurring in higher basidiomycetes: current perspectives. Int. J. Med. Mush. 1999, 1: 31-62.

[8] Xu JT. Chinese Medicinal Mycology. Beijing: Coalition Press of Beijing Medicinal University & Chinese Xiehe Medicinal University, 1997.

[9] Associated Press London restaurant pays $52,000 for a truffle: 2.4 lb delicacy fetches top dollar at charity auction in Tuscany. 22 November, 2004. http://www.msnbc.msn.com/id/6561846

[10] Baker H. Gourmet mushrooms for all. New Scientist 1997, 153:2066.

[11] Hartig T. Vollständige naturgeschichte der forstlichen culturpflanzen Deutschlands. förstnersche ver lagsbuchhandlung. Berlin. 1840

[12] Frank AB. Ueber die auf Wurzelsymbiose beruhende Ernährung gewisser Bäume durch unterirdische Pilze. Bericht der Deutschen botanischen Gesellschaft, 1885, 3:128-145. [English translation in Mycorrhiza 15: in press.]

[13] Peyronel B, Fassi B, Fontana A, *et al.* 1969. Terminology of mycorrhizae. Mycologia, 61:410-411.

[14] Trappe JM. A.B. Frank and mycorrhizae: the challenge to evolutionary and ecologic theory. Mycorrhiza. In press.

[15] Smith SE, Read DJ. Mycorrhizal symbiosis. London: Academic Press, 1997.

[16] Olivier JM. Progress in the cultivation of truffles. In L.J.L.D. Van Griensven (ed.), Mushroom science XV: Science and cultivation of edible fungi, Vol. 2. Rotterdam: Balkema, 2000.

[17] Arnold E. Decline of ectomycorrhizal fungi in Europe. Agric. Ecosystem Environ. 1991, 35:209-244.

[18] Cherfas J. Disappearing mushrooms: another mass extinction? Science 1991, 254:1458.

[19] Gong MQ, Chen Y, Wang FZ, *et al.* Song rong. Kunming:Yunnan Science and Technology Press, 1999.

[20] Pilz D, Norvell L, Danell E, *et al.* Ecology and management of commercially harvested chanterelle mushrooms. General technical report PNW-GTR-567. Portland: Pacific Northwest Research Station, USDA Forest Service, 2003.

[21] Wang Y, Hall IR. Edible ectomycorrhizal mushrooms: challenges and achievements. Can. J. Bot. 2004, 82:1063-1073.

[22] Ogawa M. Biology of matsutake mushroom. Tokyo:Tsukiji Shokan, 1978.

[23] Fujiha M. Changes in the stand structure of a pine forest after rapid growth of *Quercus serrata* Thunb. Forest Ecol.Management 2002, 170:55-56.

[24] Hosford D, Pilz D, Molina R, *et al.* Ecology and management of commercially harvested American matsutake mushroom. General Technical Report PNW-GTR-412. US Department of Agriculture Forest Service, Pacific Northwest Research Station. 1997.

[25] Kamada M, Nakagoshi N. Landscape structure and the disturbance regime at three rural regions in Hiroshima Prefecture, Japan. *Landscape Ecology* 1996, 11:15-25. http://landscape.forest.wisc.edu/landscapeecology/articles/v11i01p015.pdf

[26] Yamanaka T, Iizuka S, Tanaka T. An isotope-ecohydrological study on water use strategy of plants in a suburban secondary forest. Abstracts of the Western Pacific geophysics meeting, Honolulu, 16-20 August 2004. http://www.agu.org/meetings/wp04/wp04-sessions/wp04_B12A.html 2004.

[27] Anon. Diagnostic protocols for regulated pests *Bursaphelenchus xylophilus*. European and Mediterranean plant protection organization. http://www.eppo.org/QUARANTINE/nematodes/Bursaphelenchus_xylophilus/BURSXY_protocol.pdf 2000.

[28] Fujii H. Tree decline and leaf color change in Japan. Botanical Electronic News 151: http://www.ou.edu/cas/botany-micro/ben/ben151.html Original articles in Jap.Forestry Soc. 1996, 105: 417-422, 423-428 and 106:389-390.

[29] Kume A, Nakane K, Sakugawa H. Complex environmental factors affect the decline of *Pinus densiflora* in the Seto inland sea area of western Japan. Phyton, 2005, in press.

[30] Nakaji T, Fukami M, Dokiya Y, *et al.* Effects of high nitrogen load on growth, photosynthesis and nutrient status of *Cryptomeria japonica* and *Pinus densiflora* seedlings. Trees 2001, 15:453-461.

[31] Hall IR, Stephenson S, Buchanan P, *et al.* Edible and poisonous mushrooms of the world. Portland:Timber Press, 2003.

[32] Lefevre C, Hall IR. The global status of truffle cultivation. In S.A. Mehlenbacher (ed.), Fifth Intern. Cong. Hazelnut, Corvallis, August 2000, Acta Horticulturae 2001, 556:513-520.

[33] Wang Y, Hall IR, Evans L. Ectomycorrhizal fungi with edible fruiting bodies. 1. *Tricholoma matsutake* and allied fungi. Econ. Bot. 1997, 51:311-327.

[34] Hall IR, Wang Y, Amicucci A. Cultivation of edible ectomycorrhizal mushrooms. Trends Biotechnol. 2003, 21:433-438.

[35] Olivier JM, Savignac JC, Sourzat P. Truffe et trufficulture. Perigueux: Fanla, 2002.

[36] Bruni F. Tartufi. Milano:Hoepli, 1891.

[37] Hall IR, Brown G, Byars J. The black truffle: its history, uses and cultivation. Reprint of second edition on cd rom plus booklet. Christchurch:New Zealand Institute for Crop & Food Research Limited, 2001.

[38] Chevalier G, Grente J. Propagation de la mycorhization par la truffe à partir de racines excisées et de plantes inséminateurs. Annales de Phytopathologie 1973, 5:317-318.

[39] Fontana A, Bonfante Fasolo P. Sintesi micorrizica di *Tuber brumale* Vitt. con *Pinus nigra* Arnold. Allionia, 1971, 17:15-18.

[40] Grente J, Chevalier G, Pollacsek A. La germination de l'ascospore de *Tuber melanosporum* et la synthèse sporale des mycorhizes. Comptes Rendus Hebdomadaires des Seances de l'Academie des Sciences, Serie D, 1972, 275:743-746.

[41] Bustan A, Ventura Y, Kagan-Zur V, *et al.* Optimizing growing conditions towards intensive cultivation of Périgord black truffles. In S. Berch (ed.) Proc. Third Intern. Meet. Ecol., Physiol. Cult. Edible Mycorrhizal Mushrooms, Victoria, 16-22 August 2003. (2

x CDs). Victoria: University of Victoria, 2003.
[42] Dubé SL. Vitro truffle mycorrhized hazels and oaks for the establishment of truffle orchards are unrestrained travellers. (see ref. 41).
[43] Kagan-Zur V, Wenkart S, Mills D, *et al.* *Tuber melanosporum* research in Israel. (see ref. 1).
[44] Morte A, Lovisolo C, Schubert A. Effect of drought stress on growth and water relations of the mycorrhizal association *Helianthemum almeriense-Terfezia claveryi*. Mycorrhiza 2000, 10:115-119.
[45] Palenzona M, Chevalier G, Fontana A. Sintesi micorrizica tra i miceli in coltura di *Tuber brumale, T. melanosporum, T. rufum* e semezali di conifere e latifoglie. Allionia 1972, 18:41-52.
[46] Sisti D, Giomaro G, Rossi I, *et al.* In vitro mycorrhizal synthesis of micropropagated *Tilia platyphyllos* Scop. plantlets with *Tuber borchii* Vittad. mycelium in pure culture. Acta Horticulturae, 1998, 3:457-460.
[47] Sisti D, Giomaro G, Cecchini M, *et al.* Two genetically related strains of *Tuber borchii* produce *Tilia* mycorrhizas with different morphological traits. Mycorrhiza, 2003, 13:107-115.
[48] Zambonelli A, Iotti M. The pure culture of *Tuber* mycelia and their use in the cultivation of the truffles. Le Primier Symposium sur les Champignons Hypogés du Bassin Méditerranéen, Rabat, 6-8 April 2004. In press.
[49] Paccioni G, Frizzi G, Miranda M, *et al.* Genetics of a *Tuber aestivum* population (Ascomycotina, Tuberales). Mycotaxon, 1993, 47: 93-100.
[50] Paolocci F, Rubini A, Riccioni C, *et al.* *Tuber aestivum* and *Tuber uncinatum*: two morphotypes or two species? FEMS Microbiol. Lett. 2004, 235:109-115.
[51] Wedén C. Black truffles of Sweden: systematics, population studies, ecology and cultivation of *Tuber aestivum* syn. *T. uncinatum*. PhD thesis. University of Uppsala, 2004.
[52] Wedén C, Danell E, Tibell L. Species recognition in the truffle genus *Tuber* - the synonyms *T. aestivum* and *T. uncinatum*. J. Environ. Microbiol. In press.
[53] Chevalier G. The truffle cultivation in France: assessment of the situation after 25 years of intensive use of mycorrhizal seedlings. In E. Danell (ed.), Proc. First Intern. Meet. Ecol., Physiol. Cult. Edible Mycorrhizal Mushrooms, Uppsala, 3-4 July 1998. http://www.mykopat.slu.se/mycorrhiza/edible/proceed/chevalier.html 1998.
[54] Pacioni G, Comandini O.. Tuber. In J.W.G, Cairney & S.M. Chambers (eds.), Ectomycorrhizal fungi: key genera in profile. New York: Springer-Verlag, 2000.
[55] Bencivenga M. Alcune metodiche di micorrizazione do piante forestali con il tartufo nero pregiato di Norcia o di Spoleto (*Tuber melanosporum* Vitt.). Informatore Agrario 1982, 38: 21155-21163.
[56] Gutierrez A. Caracterización, micorrización y cultivo en Campo de las trufas de desierto, PhD Thesis, University of Murcia, 2002.
[57] Iotti M, Amicucci A, Stocchi V, *et al.* Morphological and molecular characterization of mycelia of some *Tuber*. New Phytologist, 2002, 155:499-505.
[58] Pinkas Y, Maimon M, Shabi E, *et al.* Inoculation, isolation and identification of *Tuber melanosporum* from old and new oak hosts in Israel. Mycol. Res. 2000, 104:472-477.
[59] Tibiletti E, Zambonelli A. I tartufi della provincial di Forlì-Cesena. Bologna:Pàtron, 1999.
[60] Tocci A. Tartuficoltura: elementi per una razionale coltivaziona. Agricoltura e Ricerca, 1982, 18:48-55.
[61] Zambonelli A, Di Munno R. Indagine sulla possibilità di diffusione dei rimboschimenti con specie tartufigene: aspetti tecnico-colturali ed economici. Rome: Ministero dell'Agricoltura e delle Foreste, Ecoplanning, 1992.
[62] Ricard J.-M, Bergounoux F, Callot G, *et al.* La truffe: guide technique de trufficulture. Paris: Centre technique interprofessionnel des fruits et legumes, 2003.
[63] Giovannetti G, Roth-Bejerano N, Zanini E, *et al.* Truffles and their cultivation. Hort. Rev. 1994, 16:71-107.
[64] Bencivenga M, Urbani G. Produzione di tartufo bianchetto in una tartufaia coltivata di tre anni. Informatore Agrario 1996, 52:25-26.
[65] Chevalier G, Frochot H. La truffe de Bourgogne, *Tuber uncinatum* Chatin. Levallois-Perret: Pètrarque, 1997.
[66] Chevalier G, Gregori G, Frochot H, *et al.* The cultivation of the Burgundy truffle. (see ref. 1).
[67] Hall IR, Dixon CA, Parmenter GA, *et al.* 2002a. Factors affecting fruiting of the Périgord black truffle: a comparison of productive and non-productive *Tuber melanosporum* truffières in New Zealand. Crop & Food Research Confidential Report No. 768 on CD ROM. Christchurch: New Zealand Institute for Crop & Food Research Limited.
[68] Zambonelli A, Iotti M, Giomaro G, *et al.* *T. borchii* cultivation: an interesting perspective. (see ref. 1).
[69] Reyna S. Trufa, truficultura y selvicultura trufera. Madrid: Mundi-Prensa, 2000.
[70] Anon. Kyoto scientists grow hon-shimeji mushrooms. http://www.kippo.or.jp/KansaiWindowhtml/News/1996-e/19961119_NEWS.HTML 1996.
[71] Fujita H, Fujita T, Ito T. Study on cultivation technique of *Lyophyllum shimeji* using infected tree seedling. Annual report of the forestry experimental station, Kyoto prefecture. 1990. (In Japanese.)
[72] Wang Y, Hall IR, Dixon C, *et al.* Potential for the cultivation of *Lactarius deliciosus* (saffron milk cap) and *Rhizopogon rubescens* (shoro) in New Zealand. (see ref. 1).
[73] Danell E. Cantharellus. In J.W.G. Cairney & S.M. Chambers (eds.) Ectomycorrhizal fungi: Key genera in profile. Heidelberg: Springer-Verlag, 2000.
[74] Poitou N, Mamoun M, Ducamp M, *et al.* Mycorrhization controlée et culture expérimentale du champ de Boletus (=*Suillus*) *granulatus*et *Lactarius deliciosus*. In Proceedings of the 12th Int. Congr. on the Science and Cultivation of Edible Fungi 1987. Braunschweig, 1989.
[75] Guerin-Laguette A, Shindo K, Matsushita N, *et al.* The mycorrhizal fungus *Tricholoma matsutake* stimulates *Pinus densiflora* seedling growth in vitro. Mycorrhiza, 2004, 14:397-400.
[76] Molina R, Palmer JG. Isolation, maintenance, and pure culture manipulation of ectomycorrhizal fungi. In Schenck NC (ed.)

Methods and principles of mycorrhizal research. St Paul: American Phytopathological Society, 1982.
[77] Colgan W, Claridge AW. Mycorrhizal effectiveness of *Rhizopogon* spores recovered from faecal pellets of small forest-dwelling mammals. Mycol.Res. 2002, 106:314-320.
[78] Hall IR, Wang Y. Methods for cultivating edible ectomycorrhizal mushrooms. In A. Varma (ed.), Mycorrhiza manual. Heidelberg: Springer Verlag, 1998.
[79] Parladé J, Pera J, Alvarez IF. Inoculation of containerized *Pseudotsuga menziesii* and *Pinus pinaster* seedlings with spores of five species of ectomycorrhizal fungi. Mycorrhiza, 1996, 6: 237-245.
[80] Parladé J, Pera J, Luque J. Evaluation of mycelial inocula of edible *Lactarius* species for the production of *Pinus pinaster* and P. *sylvestris* mycorrhizal seedlings under greenhouse conditions. Mycorrhiza, 2004, 14:171-176.
[81] Wang Y. *Tricholoma matsutake*. PhD Thesis, University of Otago, 1995.
[82] Giltrap NJ. Formation of primordia and immature fruiting bodies by ectomycorrhizal fungi in culture. Trans. Brit. Mycol. Soc. 1981, 77:204-205.
[83] Wang Y, Hall IR, Sinclair L, *et al.* *Boletus edulis* sensu lato: A new record for New Zealand. NZ J. Crop Hort. Sci. 1995, 23:227-231.
[84] Ohta A. Some cultural characteristics of mycelia of a mycorrhizal fungus, *Lyophyllum shimeji*. Mycoscience, 1994, 35:83-87.
[85] Ohta A. Production of fruit-bodies of a mycorrhizal fungus, *Lyophyllum shimeji*, in pure culture. Mycoscience, 1994, 35:147-151.
[86] Hall IR. Potential for the production of high-priced edible symbiotic fungi in New Zealand. In: Combined Proceedings of the International Plant Propagators Society 1990, 39:281-284.
[87] Bruce, D. Mushrooming success excites team. Otago Daily Times: 26 February 2003.
[88] Fischer C, Colinas C. Methodology for certification of *Quercus ilex* seedlings inoculated with *Tuber melanosporum* for commercial application. http//:labpatfor.udl.es/docs/tubing.html 1996.
[89] Govi G, Bencivenga M, Granetti B, *et al.* Metodo basato sulla caratterizzazione morfologica delle micorrize. In Regione Toscana (ed.). Il tartufo. Florence: Centro Stampa Giunta Regionale, 1997.
[90] Reyna S, Boronat J, Palomar E. Quality control of plants mycorrhized with *Tuber melanosporum* Vitt. (see ref. 1).
[91] Bencivenga M. Ecology and cultivation of *Tuber magnatum* Pico. In E. Danell (ed.), Proc. First Int. Meet. Ecol., Physiol. Cult. Edible Mycorrhizal Mushrooms, Uppsala, 3-4 July, 1998. www.mykopat.slu.se/mycorrhiza/edible/proceed/bencivenga.html 1998.
[92] Gregori G. Problems and expectations with the cultivation of *Tuber magnatum*. (see ref. 1).
[93] Danell E. (ed.) Proc. First Int. Meet. Ecol., Physiol. Cult. Edible Mycorrhizal Mushrooms, Uppsala, 3-4 July 1998. http://www.mykopat.slu.se/mycorrhiza/edible/proceed/ 1998.
[94] Hall IR, Wang Y, Danell E, *et al.* (see ref. 1).
[95] Berch S. (ed.). Proc. Third Intern. Meet. Ecol., Physiol. Cult. Edible Mycorrhizal Mushrooms, Victoria, 16-22 August 2003. (2 x CDs). Victoria: University of Victoria. 2004.
[96] Mamoun M, Olivier J.-M. Mycorrhizal inoculation of cloned hazels by *Tuber melanosporum*: effect of soil disinfestation and co-culture with *Festuca ovina*. Plant and Soil, 1996, 188:221-226.
[97] Honrubia M, Gutiérrez A, Morte A. Desert truffle plantation from south-east Spain. (see ref. 1).
[98] Hall IR, Lyon AJE, Wang Y, et al. Ectomycorrhizal fungi with edible fruiting bodies. 2. *Boletus edulis*. Econ. Bot. 1998, 52:44-56.
[99] Hall IR, Zambonelli A, Primavera F. Ectomycorrhizal fungi with edible fruiting bodies. 3. *Tuber magnatum*. Econ. Bot. 1998, 52: 192-200.
[100] Bertault G, Raymond M, Berthomieu A, *et al.* Trifling variation in truffles. Nature 1998, 394:734.
[101] Murat C, Díez J, Luis P, *et al.* Polymorphism at the ribosomal DNA ITS and its relation to postglacial re-colonization routes of the Périgord truffle *Tuber melanosporum*. New Phytologist, 2004, 164:401-411.
[102] Petit RJ, Brewer S, Bordacs S, *et al.* Identification of refugia and post-glacial colonisation routes of European white oaks based on chloroplast DNA and fossil pollen evidence. For. Ecol. Management, 2002, 156:49-74.
[103] Wedén C, Danell E, Camacho FJ, *et al.* The population of the hypogeous fungus *Tuber aestivum syn. T. uncinatum* on the island of Gotland. Mycorrhiza, 2004, 14:19-23.
[104] Ceruti A, Tozzi M, Reitano G. Micorrize di sintesi tra *Boletus edulis, Pinus silvestris* e *Picea excelsa*. Allionia, 1987, 28:117-124.
[105] Founoune H, Duponnois R, Ba AM, *et al.* Mycorrhiza helper bacteria stimulated ectomycorrhizal symbiosis of *Acacia holosericea* with *Pisolithus alba*. New Phytologist, 2002, 153:81-89.
[106] Garbaye J. Helper bacteria: a new dimension to the mycorrhizal symbiosis. Tansley Review no. 76. New Phytologist, 1994, 128: 197-210.
[107] Sbrana C, Agnolucci M, Bedini S, *et al.*. Diversity of culturable bacterial populations associated to *Tuber borchii* ectomycorrhizas and their activity on *T. borchii* mycelial growth. FEMS Microbiol. Lett. 2002, 211:195-201.
[108] Sbrana C, Bagnoli G, Bedini S. Adhesion to hyphal matrix and antifungal activity of *Pseudomonas* strains isolated from *Tuber borchii* ascocarps. Can. J. Microbiol.2000, 46:259-68.
[109] Barbieri E, Riccioni G, Pisano A, *et al.* Competitive PCR for quantification of a Cytophaga-Flexibacter-Bacteroides phylum bacterium associated with *Tuber borchii* Vittad. mycelium. Appl. Environ. Microbiol. 2002, 68:6421-6424.
[110] Zacchi L, Vaughan-Martini A, Angelini P. Yeast distribution in a truffle-field ecosystem. Ann. Microbiol. 2003, 53:275-282.

Appendix 1. Scientific, English and Chinese names of some edible ectomycorrhizal mushrooms
*Pinyin formulated by Wang Yun. Chinese names of mushrooms in alphabetical order based on pinyin can be found in [31].
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Scientific name	Some common names	Chinese common names in Pinyin	Chinese names
Amanita caesarea (Scop.: Fr.) Quél.	Caesar's mushroom	chenggai egao	橙盖鹅膏
	Latin bolete		
	oronge		
Amanita calyptrata Peck	coccora, coccoli		
Amanita citrina Schaeff. Pers. = *Amanita mappa* (Batsch) Quél.	False death cap	chenghuang egao	橙黄鹅膏
Amanita crocea (Quélet) Singer		hehuang egao	褐黄鹅膏
Amanita hemibapha (Berk. et Br.) Sacc. subsp. *hemibapha*		honggai egao *	红盖鹅膏
Amanita fulva (Schaeff.) Secr.	tawny grisette	chihe egao	赤褐鹅膏
Amanita rubescens Pers.	the blusher	zhegai egao	赭盖鹅膏
Amanita vaginata (Bull.: Fr.) Vitt.	grisette	huiegao	灰鹅膏
Amanita velosa (Peck) Lloyd	springtime amanita		
Boletellus russellii (Frost) Gilb.		lengbing tiaobaoniugangjun	棱柄条孢牛肝菌
Boletinus appendiculatus Peck	butter bolete		
Boletopsis leucomelas (Pers.) Fayod	kurokao	heininiugajun *	灰拟牛肝菌
Boletopsis subsquamosa (Fr.) Kotl. et Pouz.	kurokawa		
Boletus aereus Bull.: Fr.	cep	tongse niuganjun	铜色牛肝菌
Boletus badius Fr.	bay boletus	heniuganjun *	褐牛肝菌
Boletus barrowsii Thiers et A.H. Smith	white king bolete		
Boletus bicolor Peck	red and yellow bolete	shuangce niuganjun	双色牛肝菌
Boletus chrysenteron Fr.	red-cracked bolete	hong ronggai niuganjun	红绒盖牛肝菌
Boletus dryophilus Thiers	oak-loving bolete		
Boletus edulis Bull.: Fr.	cep	meiwei niuganjun	美味牛肝菌
Boletus fechtneri Ryman et Holmåsen			
Boletus fibrillosus Thiers			
Boletus frostii Russell	apple bolete		
Boletus mirabilis Murr.	admirable bolete	ronggai tiaobao niuganjun	绒盖条孢牛肝菌
Boletus ornatipes Peck		cu wangbing niuganjun	粗网柄牛肝菌
Boletus pallidus Frost		tuhe niuganjun	土褐牛肝菌
Boletus pinicola (Vitt.) A. Venturi = *Boletus pinophilus* Pilát & Dermek	cep	songniuganjun *	松牛肝菌
Boletus pulverulentus Opat.			
Boletus regius Krombh .	butter bolete	taohong niuganjun	桃红牛肝菌
Boletus reticulatus Schaeff. = *Boletus aestivalis* Fr.	cep	wangbing niuganjun *	网柄牛肝菌
Boletus speciosus Frost		huamei niuganjun	华美牛肝菌

Boletus subtomentosus L.: Fr.	yellow cracked bolete		
Boletus variipes Peck		wuhe niuganjun	乌褐牛肝菌
Boletus violaceofuscus Chiu		ziniuganjun	紫牛肝菌
Cantharellus cibarius Fr.	chanterelle	jiyoujun	鸡油菌
Cantharellus cinnabarinus (Schwein.) Schwein.	red chanterelle	Hongjiyoujun	红鸡油菌
Cantharellus formosus Corner			
Cantharellus lateritius (Berk.) Singer		bo huangjiyoujun	薄黄鸡油菌
Cantharellus luteocomus Bigelow		huangjiyoujun *	黄鸡油菌
Cantharellus minor Peck		Xiaojiyoujun	小鸡油菌
Cantharellus pallens Pilát			
Cantharellus subalbidus A.H. Smith et Morse	white chanterelle	baijiyoujun *	白鸡油菌
Catathelasma imperiale (Fr.) Sing.	imperial cap	darutoumo *	大乳头蘑
Choiromyces aboriginum Trappe	Australian native truffle	auzhou zhukuaijun *	澳洲猪块菌
Choiromyces meandriformis Vitt. = *Choiromyces venosus* (Fr.) Th. Fr.	white truffle	baizhukuaijun *	白猪块菌
Clitocybe clavipes (Pers.: Fr.) Kummer	club-foot clitocybe	bangbing beisan	棒柄杯伞
Cortinarius armillatus (Fr.: Fr.) Fr.	bracelet cortinarius	mihuan simojun	蜜环丝膜菌
Cortinarius claricolor (Fr.) Fr. var. *turmalis* (Fr.) Moser		huangsimojun	黄丝膜菌
Cortinarius collinitus (Sow.: Fr.) Fr.		nianbing simojun	粘柄丝膜菌
Cortinarius elatiọ Fr.		gaosimojun	高丝膜菌
Cortinarius pseudosalor J. Lange		nilanzisimojun *	拟兰紫丝膜菌
Cortinarius praestans (Corda) Sacc.		yuanwen simojun	缘纹丝膜菌
Cortinarius purpurascens (Fr.) Fr.		zisesimojun	紫色丝膜菌
Cortinarius tenuipes (Hongo) Hongo		xibing simojun *	细柄丝膜菌
Cortinarius violaceus (L.: Fr.) Fr	violet cortinarius	zirong simojun	紫绒丝膜菌
Cortinarius xiphidius Moser et Horak			
Craterellus cinereus (Fr.) Quél.	black chanterelle		
Craterellus cornucopioides (L.: Fr.) Pers.	horn of plenty	labajun	喇叭菌
Craterellus tubaeformis (Fr.) Quél. = *Cantharellus infundibuliformis* Fr.	winter chanterelle		
Entoloma clypeatum (L.: Fr.) Kumm.	roman shield entoloma	hongdun chizhegu	红盾赤褶菇
Fuscoboletinus paluster (Peck) Pomerleau		xiaonuganjun	小牛肝菌
Fuscoboletinus serotinus (Frost) A.H. Smith et Thiers			
Geopora cooperi Harkness	fuzzy truffle		
Gomphidius oregonensis Peck			
Gomphidius glutinosus (Schaeff.: Fr.) Fr.		nianmodinggu	粘铆钉菇
Gomphus clavatus (Pers.: Fr.) S.F. Gray	pig's ears	tuoluojun	陀螺菌
Gyroporus castaneus (Fr.) Quél.	chestnut bolete	heyuanbao niuganjun	褐圆孢牛肝菌
Gyroporus cyanescens (Fr.) Quél.		lanyuanbao niuganjun	兰圆孢牛肝菌
Hydnum repandum L.: Fr.	hedgehog fungus	juanyuan chijun	卷缘齿菌
	wood hedgehog		

Hydnum rufescens Schaeff. : Fr.		bianhong cijun	扁红齿菌
Hygrocybe coccinea (Schaeff.: Fr.) Kummer		feihong lagu *	绯红蜡菇
Hygrophorus arbustivus Fr.		shuzhuang lasan	树桩蜡伞
Hygrophorus borealis Peck			
Hygrophorus camarophyllus (Alb. & Schw. : Fr.) Dumèe			
Hygrophorus eburneus (Fr.) Fr.	ivory waxy cap	bailasan	白蜡伞
Hygrophorus gliocyclus Fr.	glutinous waxy cap		
Hygrophorus hypothejus (Fr.: Fr.) Fr.		qinghuanglasan	青黄蜡伞
Hygrophorus lucorum Kalchbr.		ningmeng lasan *	柠檬蜡伞
Hygrophorus purpurascens (Fr.) Fr.			
Hygrophorus roseibrunneus Murr.	rosy-brown waxy cap		
Hygrophorus russula (Schaeff.: Fr.) Quél.	russula-like waxy cap	honggu lasan	红菇蜡伞
Laccaria amethystea Cooke	amethyst deceiver	zilamo	紫蜡蘑
Laccaria laccata (Scop.: Fr.) Berk. et Br.	deceiver	honglamo	红蜡蘑
Lactarius akahatsu Tanaka		chenghongrugu	橙红乳菇
Lactarius camphoratus (Fr.) Fr.	candy cap	xiangrugu	鲜乳菇
Lactarius deliciosus (L.: Fr.) S.F. Gray	saffron milk cap	meiwui rugu	美味乳菇
Lactarius deterrimus Gröger			
Lactarius fragilis (Burlingham) Hesler et A.H. Smith	candy cap		
Lactarius hatsudake Tanaka	hatsudake	hongzhi rugu	红汁乳菇
Lactarius indigo (Schwein.) Fr.	indigo milk cap	lanlurugu	兰绿乳菇
Lactarius lactifluus (L.) Burlingham			
Lactarius laeticolorus (Imai) Imaz.		yanrugu *	艳乳菇
Lactarius quietus (Fr.) Fr.	oak milk cap	youwei rugu	油味乳菇
	southern milk-cap		
Lactarius rubrilacteus Hesler et A.H. Smith	bleeding milk cap		
Lactarius rufulus Peck	candy cap		
Lactarius sanguifluus Fr.	bloody milk cap	xuehong rugu	血红乳菇
Lactarius volemus (Fr.) Fr.	fryling milk cap	duozhi rugu	多汁乳菇
	orange-brown lactarius		
	weeping milk cap		
Leccinum extremiorientale (L. Vass.) Singer		yuandong youbing niuganjun *	远东疣柄牛肝菌
Leccinum fibrillosum A.H. Smith, Thiers et Watling			
Leccinum insigne A.H. Smith,Thiers et Watling	aspen bolete		
Leccinum manzanitae Thiers	manzanita bolete		
Leccinum scabrum (Fr.) S.F. Gray	brown birch bolete	heyoubing niuganjun	褐疣柄牛肝菌
Leccinum versipelle (Fr. et Hök.) Snell	orange birch bolete	chengyoubing niuganjun *	橙疣柄牛肝菌
Lycoperdon perlatum Pers.: Pers.	common puff-ball	wangwen huibao	网纹灰包
	gem-studded puff-ball		

	warted puff-ball		
Lyophyllum decastes (Fr.: Fr.) Singer	fried-chicken mushroom	heye lizhesan	荷叶离褶伞
	hatakeshimeji		
Lyophyllum shimeji (Kawam.) Hongo	hon-shimeji	yuxun lizhesan *	玉蕈离褶伞
Phaeangium lefebvrei (Pat.) Maire	desert truffle	niaohedijun *	鸟褐地菌
Ramaria botrytis (Pers.) Ricken	red-tipped clavaria	putaozhuang zhihujun	葡萄状枝瑚菌
Ramaria obtusissima (Peck) Corner		guangbao huangzhihujun	光孢黄枝瑚菌
Ramaria patagonica (Speg.) Corner			
Ramaria rasilispora Marr et Stuntz	yellow coral mushroom		
Rhizopogon parksii Smith	false truffle		
Rhizopogon rubescens (Tul.) Tul.	shoro	hongxufujun	红须腹菌
	red false truffle		
Rhizopogon vinicolor Zeller & Dodge	false truffle		
Rozites caperatus (Pers.: Fr.) P. Karst.	gypsy mushroom	zhougai luolinsan	皱盖罗鳞伞
Russula alutacea (Pers.) Fr.		gezhi honggu	革质红菇
Russula cyanoxantha (Schaeff.) Fr.	charcoal burner	lanhuang honggu	兰黄红菇
Russula delica Fr.	milk-white russula	meiwui honggu	美味红菇
Russula vesca Fr.	bare-toothed russula	linghonggu	菱红菇
Russula virescens (Schaeff.) Fr.	cracked green russula	bianlu honggu	变绿红菇
	green russula		
Russula xerampelina Fr.	shrimp russula	huangbaohonggu	黄孢红菇
Sarcodon aspratus (Berk.) S. Ito		xiangrouchijun	香肉齿菌
Sarcodon imbricatum (L.: Fr.) P. Karst.		qiaolin rouchijun	翘鳞肉齿菌
Strobilomyces floccopus (Vahl: Fr.) P. Karst.	old man of the woods	rongbing songtaniuganjun	绒柄松塔牛肝菌
Suillus albidipes (Peck) Sing.		baibing runiuganjun	白柄乳牛肝菌
Suillus albivelatus A.H. Smith, Thiers et O.K. Miller			
Suillus bovinus (L.: Fr.) Kuntze	shallow-pored boletus	runiuganjun	乳牛肝菌
Suillus brevipes (Peck) Kuntze		duanbing runiugangjun	短柄乳牛肝菌
Suillus cavipes (Opat.) A.H. Smith et Thiers		kongbing runiuganjun	空柄乳牛肝菌
Suillus granulatus (L.: Fr.) Kuntze	granulated boletus	dianbing runiuganjun	点柄乳牛肝菌
Suillus grevillei (Klotsch) Singer	larch bolete	houhuan runiuganjun	厚环乳牛肝菌
Suillus luteus (L.: Fr.) S.F. Gray	slippery jack	hehuan runiuganjun	褐环乳牛肝菌
Suillus pictus (Peck) A.H. Smith et Thiers			
Suillus variegatus (Swartz: Fr) O. Kuntze			
Terfezia arenaria (Moris) Trappe	desert truffle	shasheng digu *	沙生地菇
Terfezia elaveryi Chatin	yellow truffle	bangdigu *	棒地菇
Terfezia pfeilii Henn.		nanfi digu *	南非地菇
Tirmania africana Chatin	desert truffle	feizhou dimo *	非洲地蘑
Tirmania pinoyi (Maire) Malençon		huangdimo *	黄地蘑

Tricholoma bakamatsutake Hongo	bakamatsutake	shasongrong	傻松茸
Tricholoma caligatum (Viv.) Ricken	European matsutake	ouzhou songrong	欧洲松茸
Tricholoma flavovirens (Pers.: Fr.) Lund.	firewood agaric	youkoumo	油口蘑
Tricholoma columbetta (Fr.) Kumm.		baimao koumo	白毛口蘑
Tricholoma fusipes Horak	yellow night fungus		
Tricholoma japonicum Kawam.		ribenkoumo *	
Tricholoma magnivelare (Peck) Redhead	North American matsutake	meizhou songrong	美洲松茸
	white matsutake		
Tricholoma matsutake (S. Ito et Imai) Sing.	matsutake	song rong	松茸
= *Tricholoma nauseosum* Blytt	pine mushroom	song koumo	松口蘑
Tricholoma muscarium A. Kawam. et Hongo		puying koumo *	扑蝇口蘑
Tricholoma portentosum (Fr.) Quél.	dingy agaric	huikoumo	灰口蘑
Tricholoma robustum (Alb. et Schwein.: Fr.) Ricken (sensu Imaz.)		cuzhuangkoumo	粗壮口蘑
Tricholoma saponaceum (Fr.) Kummer	soapy tricholoma	zaoni koumo	皂腻口蘑
Tricholoma sejunctum (Sow.: Fr.) Quél.	separating tricholoma	sikoumo	丝口蘑
Tricholoma terreum (Schaeff.: Fr.) Kummer		zonghui koumo	棕灰口蘑
Tuber aestivum Vitt.	summer truffle	xiakuaijun	小块菌
Tuber aestivum Vitt. var. *uncinatum* Chatin	Burgundy truffle	bogandi kuajun *	波甘地块菌
Tuber borchii Vitt.	bianchetto o marzuolo	baikuijun *	白块菌
Tuber brumale Vitt.	winter truffle	dongkuajun	冬块菌
Tuber brumale Vitt. var. *moschatum* Ferry		modongkuaijun *	摩冬块菌
Tuber californicum Harkn.	California truffle	jiazhou kuaijun *	加洲块菌
Tuber gibbosum Harkn.	Oregon white truffle	elegang baikuaijun *	俄勒冈白块菌
Tuber hiemalbum Chatin	white winter truffle	baidongkuaijun *	白冬块菌
Tuber magnatum Pico	Italian white truffle	yidali baikuijun *	意大利白块菌
	Piedmont white truffle	pitemongte baikuijun *	皮特蒙特白块菌
Tuber melanosporum Vitt.	Périgord black truffle	heibao kuaijun *	黑孢块菌
	French black truffle	peiruigaode heikuaijun *	佩瑞高得黑块菌
Tuber mesentericum Vitt.	bagnoli truffle	bogenuoli kuaijun *	波哥诺利块菌
Tuber rufum Pico	cinnamon truffle	zonghong kuaijun	棕红块菌
Tuber separans Gilkey	acorn truffle		
Tuber sinense K. Tao et Liou	Chinese truffle	zhonghua kuaijun	中华块菌
Tylopilus chromapes (Frost) A.H. Smith et Thiers	chrome-footed bolete		