



Truffles & Other Edible Mycorrhizal Mushrooms

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Introduction

Among the most highly prized gourmet mushrooms in the world are edible mycorrhizal fungi. Included in this group are truffles, chanterelles, porcini (boletes), and morels. All of these mushrooms have complex life cycles that make them difficult to produce in cultivation. Despite the risk and challenges however, many have attempted to cultivate these valuable culinary delicacies. To date, only truffles are currently in widespread commercial production; they will be the focus of this profile. The artificial production of other fungi in this group will be discussed briefly.

Mycorrhizal Mushrooms

Mycorrhizal mushrooms differ from the more commonly commercially produced saprotrophic types (such as shiitake and button mushrooms) based on their food source. Saprotrophic mushrooms live and feed on dead organic matter, whereas mycorrhizal mushrooms grow in a close, symbiotic (mutually beneficial) relationship with the living roots of a tree. The mycorrhizae form a sheath or mantle of fungal tissue over the host's fine rootlets. In so doing, the mycorrhizal fungus can send out a network of fungal strands (hyphae) into the surrounding soil, well beyond the zone that the plant's roots could reach. These fungal strands absorb water and nutrients that benefit the tree, and, in turn, the tree provides the fungus with sugars and starches produced through photosynthesis. Because these mycorrhizae form on the outside (ecto) of the roots, they are technically called ectomycorrhizae. This association is so critical to



CHANTERELLES

the fungus that, with the exception of morels, mycorrhizal mushrooms will generally not fruit in the absence of the host.

CHANTERELLES

The golden chanterelle (*Cantharellus cibarius*) is the primary chanterelle species of commercial interest. This yellow to orange colored mushroom has a funnel-shaped cap with ridges (known as pseudo-gills), instead of gills, on its underside. *C. cibarius* is now thought to be a purely European species. Recent phylogenetic studies of North American chanterelles have indicated that there is much higher species diversity within this group than previously thought, and that it seems likely that none of the fungi we have been referring to as *C. cibarius* are this species. Currently, the naming and classification of chanterelles is undergoing an extensive reconstruction. In East-



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ern North America, California and the Pacific Northwest, chanterelles grow naturally in association with various softwood and hardwood trees. While their market value is not as great as truffles, chanterelles nevertheless can command a high price.

Not only do chanterelles require a mycorrhizal relationship with a host tree, but they also have a unique interdependence on other microorganisms that grow actively with the mushroom's fungal tissues. These additional symbiotic relationships have further complicated attempts at artificial cultivation. Nevertheless, in 1997 the chanterelle was cultivated for the first time in association with a potted Scots pine (*Pinus sylvestris*) in a greenhouse, the result of eight years of research. Subsequent efforts to build on this success to produce commercial quantities have been unsuccessful. A major obstacle has been the high cost of the complicated and labor-intensive production methods required.

MORELS

Known as “hickory chickens” in some parts of Kentucky, and also known as “dry land fish,” morels (*Morchella* spp.) have a conical-shaped cap that is covered with ridges. For many years, morels were thought to be exclusively saprobes, feeding on dead and dying organic matter. However, mycologists now believe that at least some species have the ability to form mycorrhizal relationships with living trees. This could be one of the reasons certain morels have been so notoriously difficult to cultivate.



Another complication to cultivation is related to the formation of sclerotia, structures that allow morel hyphae to survive adverse conditions in the soil. In the spring, these sclerotia form either new mycelia or fungal fruiting structures. Mycelia form readily; the difficulty lies in being able to force sclerotia to develop fruiting bodies instead.

Despite the complexity of the morel life cycle, patented techniques for indoor morel production have been developed and are currently being used for commercial production. Attempts by others to duplicate the methods outlined in the patents have failed, indicating that perhaps the instructions are incomplete or not sufficiently specific.



PORCINI (KING BOLETE)

PORCINI

Also known as the king bolete, porcini mushrooms (*Boletus edulis*), are highly regarded as a gourmet mushroom. The light brown to reddish brown cap is supported on a thick, club-shaped stipe (stem) that is rather large in comparison to the cap. The underside of the cap is covered with pores instead of gills. Porcini grow symbiotically with conifers. While successful associations between porcini mycorrhizae with host trees were first established at least 20 years ago, this mushroom has defied cultivation. This mushroom does not grow in our region and, much like the golden chanterelle, true king bolete mushrooms most likely occur only in Europe. The mushrooms we call king bolete in North America are most likely very morphologically similar, yet genetically distinct, members of the genus.



TRUFFLES

These lumpy, irregularly shaped underground mush-



PÉRIGORD BLACK TRUFFLE

rooms often resemble clods of dirt. While their appearance may be unassuming, some species of European truffles have sold for hundreds or even thousands of dollars per pound. The most highly valued truffle species are native to Europe: the Périgord black truffle (*Tuber melanosporum*) and the Italian white (*T. magnatum*) dominate the market. Of lesser value is the Burgundy truffle (*T. aestivum*), also native to Europe. Oregon white truffles (*T. oregonense* and *T. gibbosum*), which are native to the U.S. Pacific Northwest and Canada, are also gaining favor in some markets. Pecan truffles (*T. lyonii*) grow in association with pecan trees in the southern U.S. Once discarded by pecan farmers, these truffles show promise as a culinary commodity.

Plantations of trees where truffles are cultivated, as well as natural truffle forests, are known as truffières. The following information relates to establishing a truffière in the United States.

Marketing

Truffles may be sold to fine restaurants, especially those specializing in French, Spanish, northern Italian, and Greek cooking. Upscale hotels, celebrated chefs, and private kitchens may also purchase truffles. Additionally, established truffle growers may purchase a quality product from other producers to help meet their supply demands.

Production of a specialty crop harvested in the winter (such as truffles) could be a way for farms to generate

off-season income by developing a holiday market, as well as a means of providing occasional income from a farm's woodlots and forests.

Market Outlook

The scarcity of truffles, once fairly available to the masses, has made them a rare and expensive delicacy. World War I, industrialization and a shrinking rural population are often blamed for the loss of many European natural truffle habitats, as well as the decline in mass production. Although artificial truffle production in Europe and other parts of the world has resurged since the 1980s, truffle production has yet to rebound to the peak levels of the past.

Truffle orchards in the U.S. range in size from less than one-half acre to several acres with more than 12,000 inoculated trees. Large commercial truffières are in North Carolina, Oregon, Virginia, and Tennessee. In addition to selling truffles, many of the successful truffle producers also sell inoculated planting stock.

The possibility of high returns has lured many to invest in truffle production, but it can be a risky endeavor with a high rate of failure. Land preparation can be costly and time-consuming, inoculated planting stock may fail to establish, and orchards may experience losses due to environmental conditions. Producers should carefully weigh the financial and production risks for truffles, realizing that markets are highly volatile and dominated by experienced producers. Exploring partnerships or apprenticeships with existing producers could be one way to reduce risks associated with production.

Production Considerations

There are no established, tried and true methods for truffle cultivation. Even successful truffle producers may not be able to identify exactly why their truffière has thrived. Additionally, growers may not be willing to share the secrets of their success (if they know what they are) because they want to protect their investment. Thus, each new truffle venture can be viewed as an experiment, which may or may not yield positive results.

The following summary is provided to give interested producers a general idea of what can be involved in truffle production. Prospective growers need to get

as much information as they can about all aspects of truffle production before beginning this high-risk enterprise.

Species selection

There are about 60 species of true truffles, but only about a dozen of these are sought after for their culinary uses. Commercial growers have had the most success cultivating black Périgord and Burgundy truffles. Other truffle species are either considered of inferior quality, and therefore of lesser value, or they have yet to be successfully cultivated on a large scale.

Site selection and site preparation

One of the major challenges of truffle production is competition with native ectomycorrhizal fungi that can displace the truffle fungus on the host roots. Proper site selection and preparation are crucial steps to providing truffles with a competitive advantage over these other fungi.

The ideal site is open with a slight slope, a southern exposure, free of trees and tree roots, and can be irrigated. If possible, avoid sites in or near forested areas that could support undesirable truffles or competing ectomycorrhizae. Trees of particular concern include birch, beech, hazelnut, oaks, poplars, willows, and conifers. Most fruit trees, maples, and vineyards generally do not support competing ectomycorrhizae, and thus present less of a problem. Truffles may also follow cultivated crops, flowering plants, grasses, and clover.

While various soil types are suitable, the soil must be well-drained. European truffles prefer soils high in calcium with a pH of 7.5 to 8.3. Most Kentucky soils will require applications of lime to raise the soil pH to the desired level prior to planting. This can be a costly and slow process and should be taken into consideration when planning the truffle plantation. Naturally occurring mycorrhizae will generally be adapted to Kentucky's more acidic soils; therefore, maintaining an alkaline soil pH helps favor the growth of the European truffle mycorrhizae.

In addition to liming, nutrient deficiencies should be corrected prior to planting. Landowners should consider soil testing for pH and nutrient deficiencies prior to site preparation. Land preparation also involves removing large rocks, clearing out vegetation, and

plowing. Existing trees, along with their root systems, must be removed and carted off at least one year in advance of planting. Pasture lands should be mowed or grazed and then killed with an herbicide prior to plowing. Drip irrigation lines should be installed before planting the truffle orchard.

Inoculation of trees

Broadcasting spawn or a slurry of truffle spores and mycorrhizae into the root zone of potential host trees is one inoculation technique. Prior work with Oregon white truffles in the Pacific Northwest has shown that this method does increase truffle production in natural sites where these mushrooms are already growing. While this method is perhaps the least costly in terms of effort, time, and expense, success is also highly unpredictable in establishing a new planting.

A breakthrough in truffle cultivation occurred when techniques were developed to inoculate the roots of host tree seedlings in large numbers under controlled conditions in the nursery. Once the roots become colonized by truffle mycelium, trees are then planted into the truffière. A number of companies sell pre-inoculated trees; however, it is important to select a reputable nursery that sells trees acclimated to the production region of the grower. The 2-year-old host stock should be sturdy, healthy, and container-grown. Be sure trees were inoculated at least six months to one year prior to purchase. A certificate or written guarantee stating that the roots are infected with the desired truffle species and are free of contaminants should accompany the purchase. It is also prudent to request information on the percent of roots infected with mycorrhizae. Independent labs are available to test for truffle DNA on infected roots should there be any question.

Host selection and planting

European filberts (*Corylus avellana*), also known as hazelnuts, are most commonly used as the host stock for truffles in the United States. Various oak species may also be used, including holly leaved oak (*Quercus ilex*), English oaks (*Q. robur*, *Q. pedunculata*), and downy oak (*Q. pubescens*). Oaks, which can take longer than filberts for truffle formation, are often interplanted with filberts to optimize long-term fruiting.

Container-grown trees are planted with the surrounding potting soil intact around the roots. Optimal tree density is much debated, with planting sizes ranging

from 100 (or fewer) trees per acre to as many as 1,000 trees per acre. The area around each tree should be maintained weed-free during establishment. Various organic mulches (such as straw or leaves), as well as polyethylene film, can be helpful in managing weeds and conserving soil moisture. The repeated use of glyphosate herbicides is discouraged.

Maintenance

Trees should be irrigated as needed during establishment to provide the soil moisture necessary for both host and truffle growth. As the host trees grow, they may need to be thinned and pruned to permit light penetration to the soil surface. Because the build-up of fallen leaves and nuts tends to acidify the soil, this debris should be removed as necessary.

After three to five years, some truffles form a brûle (a “burned” area free of vegetation) underneath the trees; this is an indication that truffle formation has begun; however, it will still be a few more years before the truffles are mature. Opinion is divided as to the best course of maintenance once the brûle forms. The two primary approaches are the Tanguy and Pallier methods. The low intensity Tanguy system allows nature to take its course by providing only minimal maintenance, such as mowing for weed management. The more intensive Pallier method involves irrigating, light tillage twice a year to control weeds and aerate the soil, fertilization, and pruning trees to an inverted cone. While this more intensive management scheme is believed to produce truffles sooner, there is a danger of damaging roots and disrupting truffle production during the soil management operations.

Pest management

Disease and insect problems that affect the host will depend on the species of tree planted. Both filberts and oaks can be affected by a long list of diseases, which include anthracnose, fungal cankers, phytophthora, leaf spots, and Armillaria root rot. When using filberts, select stock that is immune or highly resistant to Eastern filbert blight, a disease that can cause devastating losses to this host. Disease management strategies will include planting healthy, disease-free stock; removal and destruction of fallen foliage; and following good cultural practices. Maintaining tree health is paramount to promoting truffle formation. Some of the fungicides used to manage foliar diseases can have a negative impact on truffle formation if the

runoff seeps into the soil.

Oak and filbert are the hosts to a number of insects. For example, twig and stem galls, borers, leaf galls, and tent caterpillars occur on oak. However, these and most other pests would not pose a serious threat to tree health.

Young trees should be protected from browsing by deer and rabbits until the trees are large enough to withstand the damage. Fencing can be erected to prevent livestock and wildlife from wandering through the truffière.

Insect pests that can attack the truffles include truffle beetles, truffle flies, and slugs. Bacteria entering through insect feeding sites may result in rot. As truffles mature, they emit a strong odor that may attract small animals foraging for food. In addition to these potential problems, human theft will be a major concern.

Harvest and storage

Truffles can mature anywhere from four to 12 years after planting inoculated trees. Harvest season for truffles is typically during the winter and early spring. Mounds of soil with cracks radiating from the centers are indicative of expanding truffles that will be ready for harvest a few months later. At full production, yields can vary from 25 pounds to more than 100 pounds per acre depending on the host, weather conditions, age of planting, number of trees, and how well the truffière is managed.

Mature truffles are at the peak of ripeness for a limited period and must be harvested in a timely manner. Because the truffles form 6 inches below ground, it is necessary to use some type of detection system to determine where the ripe truffles are located. Fortunately, mature truffles give off a strong, telltale odor that can be sensed by some animals. Historically pigs (truffle hogs) were used to identify the specific locations where mature truffles had formed. Today trained dogs are the more popular choice. Because of their rather short shelf life, truffles should be marketed or used soon after digging.

Truffles are brushed clean for fresh market sales; washing is only done just prior to use since water can hasten decay. Truffles can be stored for the short term

in uncooked rice or microporous containers. Bottling, canning, freezing, vacuum sealing, and processing truffles are methods that have been used by various companies to preserve truffles for off-season sales. Most truffle oils do not contain any truffles; they are made from synthesizing some of the aromatic chemicals found in real truffles.

Labor requirements

Because truffle production can vary between specific geography and farm situations, it is difficult to estimate hours required for production. Producers considering commercial production of truffles should realize that time for establishing, producing, and harvesting the crop will vary considerably.

Economic Considerations

Initial investments include land preparation, purchase of inoculated seedlings, and installation of an irrigation system. Additional startup costs can include mulch and fencing around the perimeter of the planting. Those contemplating growing truffles should carefully consider the potentially substantial initial investment involved, coupled with the potentially long wait period (5 - 12 years on average) until harvest and sale. Harvest costs could be significant and will include time spent locating and harvesting the truffles, as well as preparing them for market.

Prices of truffles are reported to peak at the Christmas season. Prices can also fluctuate wildly based on variety, quality, supply, and demand. Because of the volatile nature of a market for a specialty item such as truffles, economic considerations should be developed based on a producer's intended market. As with any crop, it is unwise to begin production without a specific plan outlining where and how the crop will be marketed.

A detailed budget estimate for black truffle production in Oregon's Willamette Valley was published in 2001 as an undergraduate thesis at Oregon State University. The detailed but hypothetical production budgets indicated that, in 2001 dollars, a producer would have accumulated establishment costs of about \$35,000 per acre before beginning to generate positive returns. About half these costs were for the purchase of trees plus the irrigation and electricity required for establishing the trees; a substantial portion of the estimated establishment expense was interest expense.

The estimated annual profit to the producer for a fully producing orchard was \$9,678 per acre annually. This amount was realized only after the third or fourth year of production, which was estimated at 10 years after establishment. The cost for orchard establishment in Oregon, as of 2015/16, had reportedly declined somewhat from that estimate. Likely establishment costs would be similar to perennial tree fruit, between \$15,000 and \$20,000 per acre.

Selected Resources

Internet resources

- Black Perigord Truffles in NC (N.C. State University 2022) <https://newcropsorganics.ces.ncsu.edu/specialty-crops/black-truffle-project/>
- Black truffle economics: Evaluating the costs and returns of establishing and producing *Tuber melanosporum* in the Willamette Valley, Oregon. Heather E. Alvis graduate thesis (Oregon State University, 2001) http://ir.library.oregonstate.edu/xmlui/bitstream/handle/1957/7314/Alvis_Hea.pdf?sequence=1
- Burgundy Black Truffle Cultivation in an Agroforestry Practice (University of Missouri, 2012) <https://extension.missouri.edu/publications/af1015>
- Growing Morel Mushrooms: 3 Popular Techniques (Mushroom Appreciation, 2022) <http://www.mushroom-appreciation.com/growing-morel-mushrooms.html>
- Diversity, Ecology, and Conservation of Truffle Fungi in Forests of the Pacific Northwest (USDA Forest Service, 2009) 3 MB file <https://www.fs.usda.gov/research/treesearch/32697>
- Ecology and Management of Commercially Harvested Chanterelle Mushrooms (USDA FS, 2003) 1.81 MB file <https://www.fs.usda.gov/research/treesearch/5298>
- Ecology and Management of Morels Harvested From the Forests of Western North America (USDA FS, 2007) 1.48 MB file <https://www.fs.usda.gov/research/treesearch/26906>
- Growing Morels: Tips and Techniques (Mushroom Appreciation, 2022) <http://www.mushroom-appreciation.com/growing-morels.html>
- Growing Truffles in Canada (Duckett Truffieres, Canada, no year) http://www.ducketttruffieres.com/growing_truffles.htm
- Morel Mushrooms (Mushroom Appreciation, 2022) <https://www.mushroom-appreciation.com/morel>
- The Morel Life Cycle (University of Wisconsin,

2008) http://botit.botany.wisc.edu/toms_fungi/mo-rel.html

- Mushroom Cultivation and Marketing (AT-TRA, 2004) <https://attra.ncat.org/wp-content/uploads/2019/05/mushroom.pdf>
- North American Truffle Growers Association <http://www.trufflegrowers.com>
- The Pecan Truffle (*Tuber lyonii*): A Gourmet Truffle Native to the Southeastern U.S. (University of Florida, 2019) <https://edis.ifas.ufl.edu/pdffiles/PP/PP33000.pdf>
- Truffle Cultivation (New World Truffières, Inc., no year) <http://www.truffletree.com/cultivation/>

Books in print

- Growing Gourmet and Medicinal Mushrooms. Paul Stamets. 3rd ed. 2000. Ten Speed Press: Berkley. 574 pp.
- Taming the Truffle: The History, Lore, and Science of the Ultimate Mushroom. Ian R. Hall, Gordon T. Brown, and Alessandra Zambonelli. 2007. Timber Press: Portland, Oregon. 304pp.

Note: *The inclusion of a commercial website as a resource does not represent an endorsement of the company or its products by the University of Kentucky.*

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