

SHIITAKE GROWERS HANDBOOK

**The
Art and Science
of
Mushroom
Cultivation**

**by
Paul Przybylowicz
John Donoghue**



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The Art and Science of Mushroom Cultivation

Shiitake is the second most widely cultivated mushroom in the world and has grown to become a worldwide multi-billion dollar industry.

"The market for shiitake is increasing steadily as more and more people learn about the great taste and other qualities of this excellent, exotic mushroom . . . This book is one of the first items that a person interested in growing shiitake should buy . . . Dr. Paul Przybyłowicz, and John Donoghue have brought nearly all the useful knowledge and available practical experience together in this book . . . Even the experienced grower will find a lot of very useful information in this carefully written and well illustrated book."—*Pieter J. D. Vedder, Vice-President Training & Development, Campbell's Mushroom Division.*

This definitive sourcebook clearly describes the underlying scientific principles governing the behavior of shiitake and presents detailed practical mushroom cultivation techniques.

- Understandable descriptions of shiitake biology.
- Traditional and year-round production on logs.
- New methods of shiitake cultivation on sawdust substrates.
- Effective pest and disease controls.
- Informative review of marketing and of health benefits.
- The most comprehensive shiitake bibliography available.



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Shiitake Growers Handbook

The Art and Science of
Mushroom Cultivation

Paul Przybylowicz
John Donoghue

Northwest Mycological Consultants, Inc.



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Foreword

Shiitake belongs, in my opinion, to a very small group of the overall best and most delicious edible fungi, which also includes the fruiting bodies of *Tuber melanosporum*, *Amanita caesarea*, *Cantharellus cibarius*, *Pleurotus nameko* and perhaps a few more. We know from historical documents, literature, and old paintings, that a great number of Asian people have known and cultivated shiitake for centuries.

Researchers at institutes in several countries are working on the development of growing techniques for other well-known and highly appreciated mushrooms. So far, only a few species from the aforementioned group have been successfully cultivated.

Although shiitake has been grown in Asian countries for ages, the big interest there and also in the Western world came after World War II, especially in the last 10 to 15 years. At present, the biggest part of the more than 300,000 metric tons of shiitake produced annually is grown in China and Japan. However, every year a growing number of people in the United States and Europe are trying to make a living by growing this product for a market that is increasing steadily as more and more people learn about the great taste and other qualities of this excellent, exotic mushroom.

There are several similarities between the situation in the shiitake growing business now and in the button mushroom (*Agaricus*) industry of, let's say, 50 years ago. Lured by quite often unprofessional stories about easy money-making and high market prices, a number of people tried to go into this business, completely unprepared, with far too high expectations and, therefore, a very high failure rate. It is amazing how easily so many people can step into such a new business, with hardly any knowledge or experience—and lose their money.

The yearly production of *Agaricus* mushrooms has risen in the last 40 years by more than 10 times: from approximately 100,000 metric tons to the present 1.2 million metric tons. The key for the survivors in the white button mushroom industry is, and always has been, a combination of sufficient knowledge, hard work, and good marketing. I can't see any reason why this should be different for the shiitake business.

It is therefore a very good idea that John Donoghue and my good mushroom friend, Dr. Paul Frybylowicz, have brought nearly all the useful knowledge and available practical experience together in this book.

A book like this is one of the first items that a person interested in growing shiitake should buy. After studying the book intensively, some readers may come to the conclusion that it is not as simple as they had thought and therefore, not the right place for them to put their money. For the group which, after reading, is still convinced that growing shiitake, though perhaps not easy, could be a very fascinating hobby or even a good oppor-

tunity to make a living, this book will be a great help. Even the experienced grower will find a lot of very useful information in this carefully written and well-illustrated book.

Spring, 1988

Pieter J.C. Vedder
Vice-President
Training & Development
Campbell's Mushroom Division

Preface

Shiitake is the second most widely cultivated mushroom in the world. In the past four decades, shiitake cultivation has grown to become a worldwide, multi-billion dollar industry.

For centuries, this mushroom has been grown in Asia using traditional methods. Today, a steadily increasing market for fresh shiitake outside of Asia has created a demand for localized shiitake production in many new areas. By adapting traditional methods and developing new ones, growers around the world are successfully producing shiitake at many different scales, from back-yard hobbyists to part-time farmers to large corporate endeavors.

There are many manuals that describe specific methods for growing shiitake on logs, although the majority of these are not available in English. However, for the most part these publications neglect the underlying biological principles which govern the cultivation process. A thorough understanding of these principles demystifies the process of shiitake cultivation, allowing the grower to successfully adapt and develop cultivation methods as needed.

In this book, we have avoided a “cookbook” approach by first presenting the underlying scientific principles governing the behavior of shiitake, then describing their practical applications to the art of mushroom cultivation. In this context, we have covered the entire range of shiitake cultivation methods currently in use. These include:

- Traditional methods for seasonal production on logs.
- Techniques for year-round mushroom production on logs.
- New methods of cultivation on sawdust substrates.

We have also included an extensive discussion of shiitake pests and diseases, and effective management measures for their control.

Our involvement in the scientific community and in the mushroom industry has afforded us the opportunity to study shiitake from both scientific and applied viewpoints. We have drawn on this experience and have incorporated both approaches in this book; we hope that it will be useful to anyone with an interest in mushrooms. We have attempted to clearly explain and illustrate the underlying principles that are basic to successful shiitake cultivation. In addition, we have drawn extensively from scientific literature and have included a comprehensive bibliography for readers who want additional information.

Because of the wide range of shiitake cultivation techniques and scientific research presented herein, we feel this book will serve as both a handbook and a reference for growers and others interested in the art and science of mushroom cultivation.

We would like to thank Dr. William Denison and Northwest Mycological Consultants, Inc. for providing us the opportunity to pursue our research interests in shiitake. This sponsorship enabled us to visit the major shiitake research and production centers of the world to observe many different systems of shiitake cultivation, including the latest scientific advances.

We would also like to thank our editors, Margo Denison and Maia Fischler, for their unflagging enthusiasm and sharp eyes, Lisa Ellingson for her wonderful illustrations, Al Bob Hollister for his fine photographs, Annette Simonson for assistance in our research endeavors, and the many mushroom growers and researchers who have, throughout the years, so readily shared their experiences, problems and solutions. Finally, we would like to thank Shannon, Ellen and Cas for putting up with us during this project.

Paul Przybylowicz
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Northwest Mycological Consultants, Inc.
702 NW 4th St.
Corvallis, Oregon
1 April, 1988

Dedication

In memory of Jim Roberts (1931 to 1990)

Jim's open, insightful and often humorous nature catalyzed the establishment of the US shiitake industry. He fashioned a global network of people, ideas and resources that continues to be the fabric of this industry. His contributions will provide perspective and inspiration far into the future.

Introduction

"Art is science in the flesh"

— Joan Cooreau

An ancient mushroom is enjoying a recent upsurge in popularity. This mushroom is consumed widely in Asia, where it is prized for its flavor and health-promoting benefits. For centuries, it has been cultivated in China, where it is known as "Shiang-gu" or "Hoang-mo." The Japanese name, "Shiitake," is taken from the *Shii* tree, one of the many tree species that it grows on in nature, and "take," a Japanese word for mushroom. Because Japan is the world leader in production, this mushroom is now widely known as shiitake.

Shiitake's popularity has spread to the West, where it is also known as the "Black Forest Mushroom." Previously available only in its dried form, fresh shiitake has found increasing acceptance with Western consumers due to its distinctive flavor and texture.

This increasing demand for fresh shiitake has resulted in the expansion of cultivation to areas outside its natural habitat. This has created a need to adapt and modify traditional cultivation techniques in order to develop new methods for growing shiitake in new situations. To do this successfully, the grower must be able to distinguish between methods based solely on tradition and those founded on the fundamental relationships between the mushroom and its environment. Thus, the grower must thoroughly understand not only mushroom biology and its response to the environment, but also the various techniques of cultivation. The grower then has a framework within which to adapt—rather than adopt—techniques appropriate for local conditions.

This book explores the biology of shiitake and the underlying concepts basic to all methods of shiitake cultivation. Detailed examples of specific management practices are presented to illustrate applications of these concepts.

The reader should view the examples in the context of these governing principles, and use them as a resource to develop a successful system for shiitake production. The reader is encouraged to use the extensive bibliography as an additional resource.

Section I provides historical and background information on shiitake cultivation, the biology of shiitake, and important environmental factors. Traditionally, shiitake has been grown on logs, and more recently, on sterilized sawdust substrates. Section II covers cultivation on logs, from simple outdoor management to intensive indoor production. Section III presents techniques for shiitake cultivation on sawdust and other particulate substrates. Each of these sections includes a detailed discussion of diseases and pests.

Finally, Section IV discusses harvesting, storage and marketing. It then details the nutritional and health benefits of shiitake.

Section I General Information



Successful shiitake cultivation depends upon thoroughly understanding mushroom biology and how the environment influences fungal growth and development. The response of shiitake to the environment is the same, regardless of the cultivation method. The grower applies this information to control the environment in order to provide optimum conditions for each phase of shiitake cultivation.

This first section provides necessary background information about shiitake and its environment. The basic principles of mushroom cultivation are discussed, with emphasis on shiitake cultivation, followed by an in-depth look at the shiitake fungus and at the process of wood decay by which shiitake obtains nutrients. Special terms pertaining to fungi are explained. Finally, important physical and chemical factors which can be manipulated to control the shiitake life cycle are examined.

Introduction to Shiitake Cultivation

This chapter explains the basic principles of mushroom cultivation, briefly reviews the history of shiitake cultivation, describes several methods of growing shiitake, and reports on worldwide trends in its production and consumption.

Principles of Mushroom Cultivation

Mushroom cultivation is both a science and an art. Science has investigated basic mushroom biology and determined how environmental factors influence it. It is an art to apply this information to the business of growing a successful mushroom crop.

Shiitake cultivation should not be a haphazard process. Constant attention is required to maintain the competitive edge necessary for economic success. The basic steps in mushroom cultivation are:

1. Creating a selective nutrient base for the mushroom;
2. Introducing the mushroom of choice;
3. Managing the environment to favor mushroom growth and development.

Shiitake grows and produces mushrooms by decaying wood. Materials which serve as both a food supply and habitat are referred to as substrate. Shiitake can be commercially cultivated on one of two types of substrate: logs or a medium (plural, media) consisting mostly of sawdust.

History

The earliest written record of shiitake dates back to 159 A.D. Japanese historical documents recorded that Emperor Chuai praised the shiitake given him by the natives of Kyushu (182). Probably, these shiitake were gathered from the wild.

Actual cultivation of shiitake originated in China during the Sung Dynasty (960-1127). Both history and legend credit Wu San Kwong as the originator of shiitake cultivation. Almost every mushroom-growing village in China has a temple in his honor (22).

Wu San Kwung lived in Lung-Shyr village in Lung-Chyuan county in southwest Chekiang Province. While collecting wild mushrooms in the high mountains, he found "nice-smelling mushrooms" (shiitake) growing on broken trees which had fallen to the ground. He later discovered that slashing the bark of these logs and bearing them vigorously caused more mushrooms to appear.

In 1313, Chinese author Wang Cheng recorded shiitake-growing techniques in his *Book of Agriculture* (22). Wang Cheng described how to select a suitable site, choose appropriate trees and cut them down. He outlined basic cultivation methods as follows: cut the bark with a hatchet and cover the logs with soil. After one year, cover the decayed logs with branches, leaves and soil and water frequently. Beat the logs with a wooden club to stimulate mushroom production and mushrooms will appear after a rain. Chinese farmers introduced cultivation techniques into Japan between 1500 and 1600 A.D. (174, 182). Since that time, the Japanese have been the leaders in developing techniques for shiitake cultivation on logs.

Mushrooms produce spores, minute reproductive structures which are dispersed by air currents. Early cultivation methods depended on spores to transfer the shiitake to new logs. Shiitake growers gathered logs bearing mushrooms and placed them near freshly cut logs, relying on airborne spores to "infect" the new logs (182).

Methods of inoculation, the process of introducing shiitake to new logs, were improved over the years. Cutting the bark of the new logs increased colonization by the shiitake spores. Another advance was introducing spores directly into the wood, either by inserting spore-covered pieces of paper or by pouring suspensions of spores in water into the cuts. These primitive methods of infecting new logs were unreliable, and when the logs did produce mushrooms, yields were variable.

Shiitake colonizes logs by permeating and penetrating the wood with small, thread-like hyphae (singular, hypha). Collectively, hyphae are referred to as mycelium (plural, mycelia) which appears as a white cottony mass.

All mycelia in a shiitake colony contain the same genetic information, but the genes are reshuffled during spore production. Thus, colonies which start from spores are different from the parent mushroom(s), whereas colonies resulting from the transfer of mycelium are genetically identical to the parent mycelium.

Early cultivation methods that used spores for propagation were inherently variable. Desired mushroom characteristics, such as higher yields, could not be reliably transferred to new logs. Some growers solved this problem by using pieces of logs which had produced many high quality mushrooms to "infect" fresh logs (182).

In the 1920's, K. Kitayama developed pure culture spawn, consisting of genetically uniform mycelium growing on a suitable material (182). This made it possible to select and propagate shiitake mycelium with improved vigor and higher yields.

In 1943, K. Mori introduced sterilized wooden wedges which were colonized by pure cultures of shiitake (129). These wedges were inserted into ax cuts in the logs. Using this method, logs could be rapidly inoculated, and successful colonization of new logs was greatly increased. The higher and more reliable yields that resulted from this innovation allowed the commercial shiitake industry to develop and expand rapidly (17). A later development was the use of colonized wooden dowels or plugs which were inserted into holes drilled in the logs. This further decreased inoculation time and increased successful inoculations.

A recent development in log inoculation technology employs thin half-moon shaped wafers of colonized wood which are inserted into deep saw cuts in the log. These wafers distribute the shiitake more evenly in the log, decreasing the time needed to completely colonize the log and producing mushrooms more rapidly (47).

Originally, shiitake production was seasonal. Fruiting occurred during the spring and fall when rainfall and temperature were conducive. Most mushrooms were dried, for consumption throughout the year. As demand for fresh mushrooms increased, Japanese growers developed methods to achieve year-round mushroom production by inducing shiitake to fruit under controlled conditions. This technique, referred to as forcing or forced fruiting, is now used in most shiitake-producing areas.

As logs have become scarce in some areas, alternative substrates for shiitake cultivation have been sought. Shiitake produced on heat-treated substrates was first reported in 1933, when it was grown on blocks of wood in glass cylinders (156). In 1935, cultivation on sawdust was reported as a means of testing shiitake mycelium for genetic characteristics (144).

Commercial cultivation of shiitake on sawdust and other cellulose-containing materials is increasing worldwide. Most sawdust-grown mushrooms are cultivated on sterilized substrates. However, a method developed by Dutch growers produces shiitake on pasteurized substrates on beds in standard button mushroom houses.

As the availability of raw materials fluctuates, and as economic, political and marketing factors shift, shiitake growers develop new techniques to cope with changing conditions. Thus, there is no one ideal method of cultivation, but rather a wide range of methods developed under different constraints. New innovations continually emerge as the balance between these factors shifts and as understanding and technology improve.

Overview of Techniques

Cultivation on Logs

Traditionally, shiitake has been cultivated on freshly cut logs, usually from the oak family. Live trees are cut during the dormant season when their sugar content is high. Within one or two months, the logs are inoculated with

actively growing pure culture spawn. This spawn usually consists of sawdust or wooden plugs which have been permeated by shiitake mycelium.

After inoculation, the logs are placed in stacks and are managed to create favorable conditions for the mycelium to colonize the wood (*spawn run* or *incubation*). The spawn run can occur naturally, in a forest, or under controlled conditions in special structures with irrigation. This process takes from 6 to 18 months depending on the amount of spawn used, the shiitake variety and the conditions during incubation.

After the logs are fully colonized, they are induced to produce mushrooms. Outdoors, seasonal rains will induce mushroom formation. However, to obtain a steady supply of mushrooms, the time of fruiting must be controlled by the grower. Logs can be forced to fruit by soaking or irrigating them with water, either outdoors or in special houses (Fig. 1-1). Depending on their size and the number of fruitings per year, logs can produce mushrooms periodically for two to five years after they have been colonized by shiitake.

Log farms vary widely in size, from households growing a dozen logs as a hobby, to corporate farms with over 500,000 logs.

Much of the dried shiitake produced in Asia is produced by small family farms with 3,000 or fewer logs (8). Small-scale, seasonal production needs a relatively low investment and can generate part-time income.

Year-round production requires investment in special fruiting structures and can be a full-time occupation. The long cropping cycle yields a long-term return comparable to growing orchard crops.

Cultivation on Sawdust

Heat-treated substrates for shiitake cultivation usually consist of a mixture of sawdust and/or other cellulose-containing materials supplemented with grain, bran or other sources of carbohydrates and nitrogen. The mixture is placed in heat-resistant containers and sterilized to kill competitors. After cooling, the substrate is inoculated with shiitake and is incubated for 30 to 180 days. During incubation, the shiitake fungus permeates and degrades the substrate; the shiitake mycelium virtually knits the sawdust medium together. Then, fruiting is initiated by moving the substrate to a cooler, humid environment and exposing all or part of its surface. Mushrooms can be produced periodically for three to six months (Fig. 1-2).

In addition to the need for structures, a sawdust farm requires considerable investment in equipment for sterilization, air filtration and environmental control. Sawdust farms are usually large and require a year-round labor force. The entire cropping cycle is much shorter than in log cultivation. This results in a more rapid cash flow. In addition, these operations can react more rapidly to changing market demands.

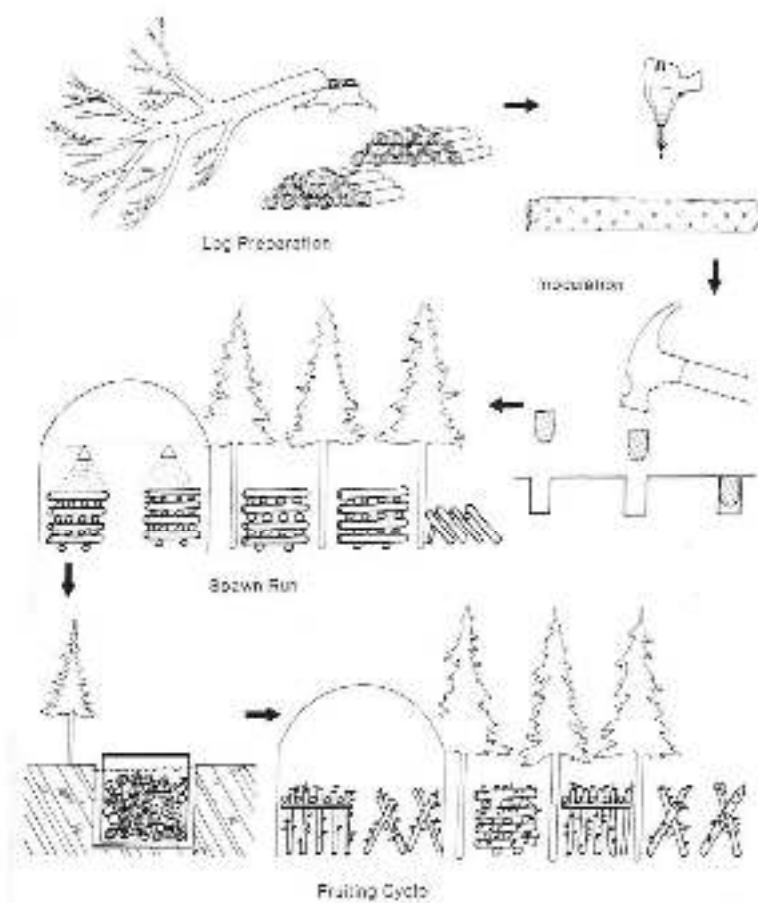


Figure 1-1. Overview of shiitake cultivation on logs.

Trends in Shiitake Production and Consumption

Shiitake ranks second after the button mushroom (*Agaricus*) in total world mushroom production. Worldwide, shiitake production has increased from less than 10,000 metric tons (mt) in 1946 to over 300,000 mt in 1986. During this same period, *Agaricus* production increased from 100,000 mt to 1,226,640 mt (20, 171).

Japan is still the leading producer of shiitake, but its share of the world production has dropped from 83% in 1983 (171) to 51% in 1986 (20)

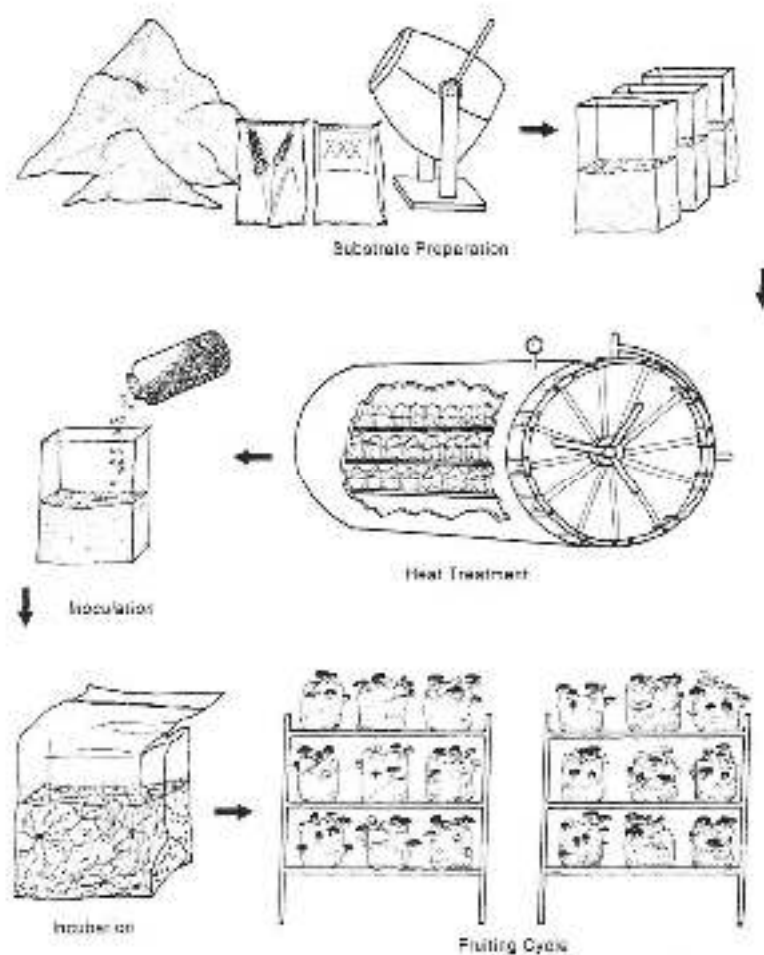


Figure 1-2. Overview of shiitake cultivation on sawdust.

(Table 1-1). Approximately 80% of the world production is dried, and 20% is sold fresh (17). Most international trade is in dried shiitake, while most fresh production is consumed domestically. Virtually all Japanese production is on logs, but both sawdust and log farms are found in other countries.

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