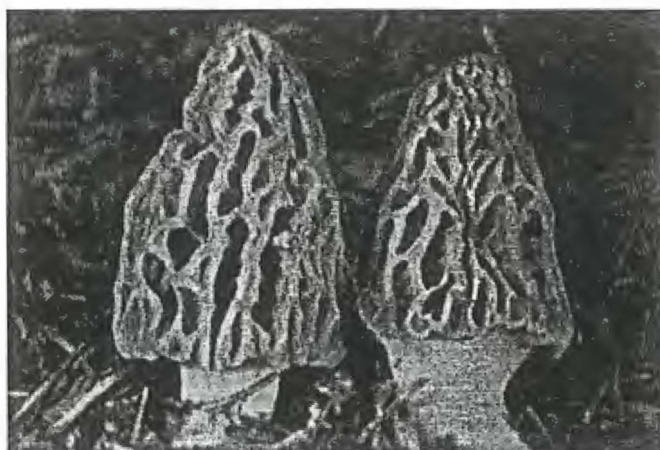




A business of the
Department of
Natural Resources
and Environment

Improved postharvest handling and storage of specialty mushrooms.

John Lopresti



RIRDC Project No.: DAV-123A

September 1997
Institute for Horticultural Development
Agriculture Victoria



**Improved postharvest handling and storage of
specialty mushrooms.**

John Lopresti

**Rural Industries Research and Development Corporation
Project No.: DAV-123A**

**Institute for Horticultural Development, Knoxfield
Private Bag 15
South Eastern Mail Centre
Victoria 3176**

Ph: (03) 9210 9222

Fax: (03) 9800 3521

Email: loprestij@knoxy.agvic.gov.au

©1997 Rural Industries Research and Development Corporation.
All rights reserved.

ISBN 0 7306 6224 1

"Improved postharvest handling and storage of specialty mushrooms"

The views expressed and the conclusions reached in this publication are those of the author/s and not necessarily those of persons consulted or the Rural Industries Research and Development Corporation. RIRDC shall not be responsible in any way whatsoever to any person who relies in whole, or in part, on the contents of this report unless authorised in writing by the Managing Director of RIRDC.

This publication is copyright. Apart from *any fair dealing for the purposes of research, study, criticism or review* as permitted under the Copyright Act 1968, no part may be *reproduced in any form, stored in a retrieval system or transmitted* without the *prior written permission* from the Rural Industries Research and Development Corporation. Requests and inquiries concerning reproduction should be directed to the Managing Director.

Researcher Contact Details

Mr. John Lopresti
Postharvest Technology
Institute for Horticultural Development
Private Bag 15
South Eastern Mail Centre
VICTORIA 3176

Phone: 03 9210 9222
Fax: 03 9800 3521
email: loprestij@knoxy.agvic.gov.au

RIRDC Contact Details

Rural Industries Research and Development Corporation
Level 1, AMA House
42 Macquarie Street
BARTON ACT 2600

PO Box 4776
KINGSTON ACT 2604

Phone: 06 272 4539
Fax: 06 272 5877
email: rirdc@netinfo.com.au
Internet: <http://www.dpie.gov.au/rirdc>

Disclaimer

This publication may be of assistance to you but the State of Victoria and its officers do not guarantee that the publication is without flaw of any kind or is wholly appropriate for your particular purposes and therefore disclaims all liability for any error, loss or other consequence which may arise from you relying on any information in this publication.

Published in September 1997

Foreward

Australian produced specialty mushrooms have high growth potential in the top-end domestic market, in replacing imported product and from export of this low-volume, high-value product to lucrative Asian markets.

Product handling, distribution, presentation and packaging have been identified as barriers to domestic and export market development.

This report reviews current industry practices and information relating to postharvest handling of specialty mushrooms with the aim of raising industry awareness, developing appropriate handling protocols and identifying research requirements.

Improved postharvest handling of specialty mushrooms will add value, reduce quality loss and increase their shelf-life, leading to a sustainable domestic market and lay foundations for export market development.

Executive Summary

The market in Australia for fresh specialty mushrooms has increased over recent years due to greater consumer awareness of specialty products and increased interest from retailers and the food service industry. Further growth in the domestic market is presently being constrained by poor postharvest handling practices and inappropriate packaging. Wastage on domestic markets, particularly at the retail level, is high due to poor handling and storage practices, and a lack of consumer information. Furthermore, the ability of growers to develop potential export markets is limited at present by variable product quality and lack of continuity of supply.

A review of current production and market trends has identified oyster, shiitake, swiss brown, wood ear and enoki mushrooms as the main mushroom varieties currently available in Australia. A number of Asian mushrooms such as shimeji are becoming available domestically and with increasing production will be potential export products.

The aim of this report was to identify current handling practices used through an industry survey, establish current marketing trends in mature mushroom markets, collate and review published information concerning the handling of specialty mushrooms and establish a preliminary postharvest handling protocol. The first section of the report details the results of a survey of the Australian specialty mushroom industry which identified the postharvest handling methods being used and the major postharvest factors limiting the development and sustainability of the industry.

The survey identified poor retailer and consumer knowledge, poor postharvest handling leading to physical injury and, poor temperature and humidity management during distribution and marketing as major factors leading to wastage and limiting market expansion. Current packaging systems have been found to be relatively unsuccessful in extending shelf life due to these poor handling practices and lack of information on packaging requirements for individual mushroom varieties. Based on the survey, industry believed these quality issues could be addressed if information regarding general handling requirements, grading and quality standards, and types of packaging was available. Analysis of more mature mushroom markets such as in the United States determined that growers placed strong emphasis on good postharvest handling and packaging. Cooperation between industry members has meant that resources are available for promotion and consumer education and has resulted in growers being able to directly influence the marketing and handling of mushrooms by retailers. The trend in these markets has been towards a consistent supply of prepacked mushrooms to large retailers that provide ample display space and who handle mushrooms carefully.

A critical and comprehensive review of industry and scientific literature has identified some information on how to address these issues that may be useful to some industry sectors. This information has been summarised in the report. In general, it was found that a lack of information exists in many areas concerning postharvest handling and packaging of specialty mushrooms. Studies have found that storage temperature is critical to mushroom quality and the beneficial effects of modified atmosphere storage in retarding deterioration have been demonstrated. Fundamental storage requirements such as optimum temperature, relative humidity and storage atmosphere are either unknown or the information is not readily available for many varieties.

A preliminary handling protocol for specialty mushrooms was developed based on the literature review and general horticultural handling principles. It has been prepared in a format suitable for growers, packers and retailers and provides practical handling information for the major specialty mushroom species. In the short term this protocol will make growers and retailers more aware of proper postharvest handling practices and enable some industry sectors to improve specialty mushroom handling through better temperature management and physical handling.

Assessment of the survey data and published literature has identified the priority research inputs required to address the problems faced by the specialty mushroom industry. Specific information appropriate to the local industry concerning correct handling and packaging methods, and quality and grading standards is not available and further research and extension activities are required to add value, reduce quality loss and increase shelf life of specialty mushrooms.

Contents

1. INTRODUCTION.....	1
2. OBJECTIVES	3
3. METHODOLOGY	3
4. COMMERCIAL FRESH SPECIALTY MUSHROOM VARIETIES	5
4.1 MAJOR CULTIVATED SPECIES.....	5
4.2 MAIN SPECIES BY DOMESTIC PRODUCTION	6
4.2.1 Cultivated mushrooms.....	6
4.2.2 Field-picked mushrooms	6
4.3 SPECIALTY MUSHROOM IMPORTS	7
4.4 EXPORT OPPORTUNITIES	7
5. SPECIALTY MUSHROOM DESCRIPTIONS	9
5.1 CULTIVATED VARIETIES	9
5.2 FIELD PICKED MUSHROOMS	11
5.3 ASIAN SPECIALTY MUSHROOMS.....	12
6. CONCEPT OF MUSHROOM QUALITY	13
7. SPECIALTY MUSHROOM INDUSTRY SURVEY	15
7.1 SURVEY PARTICIPATION AND METHODOLOGY	15
7.2 SPECIALTY MUSHROOM INDUSTRY STRUCTURE.....	15
7.3 SURVEY RESULTS	15
7.3.1 Varieties	16
7.3.2 Product cooling and storage.....	16
7.3.3 Grading and packaging	18
7.3.4 Distribution	19
7.3.5 Quality issues	20
8. OVERVIEW OF SPECIALTY MUSHROOM CULTIVATION.....	23
8.1 CULTIVAR SELECTION AND SPAWN PRODUCTION	23
8.2 COMMERCIAL MUSHROOM PRODUCTION	23
8.2.1 Oyster mushrooms.....	23
8.2.2 Shiitake.....	24
8.2.2.1 Cultivation on logs	24
8.2.2.2 Synthetic log production	24
8.2.3 Enoki	25
8.2.4 Agaricus spp.....	25
9. SPECIALTY MUSHROOM HANDLING AND MARKETING	27
9.1 DOMESTIC MARKETING	27
9.2 EXPORT MARKETS	29
9.3 MARKETING IN THE USA.....	29
9.3.1 Grading and packaging	29
9.3.2 Merchandising	30
9.3.3 Market comparisons.....	30
9.4 VALUE-ADDING OPPORTUNITIES.....	30

10. LITERATURE REVIEW.....	33
10.1 PREHARVEST FACTORS AFFECTING POSTHARVEST SHELF LIFE.....	33
10.1.1 Botany and morphology.....	33
10.1.2 Cultural factors.....	34
10.1.2.1 Growing temperature.....	35
10.1.2.2 Relative humidity.....	35
10.1.2.3 Carbon dioxide levels.....	36
10.1.2.4 Light and mushroom development.....	36
10.1.3 Harvest maturity.....	39
10.2 POSTHARVEST PHYSIOLOGY OF SPECIALTY MUSHROOMS.....	39
10.2.1 Metabolism and development.....	40
10.2.2 Enzymatic browning.....	41
10.2.3 Role of carbon dioxide and oxygen.....	41
10.3 POSTHARVEST HANDLING OF SPECIALTY MUSHROOMS.....	42
10.3.1 Harvesting and handling.....	42
10.3.2 Grading systems.....	42
10.3.3 Precooling systems and quality.....	44
10.3.4 Package design.....	45
10.3.5 Temperature management.....	45
10.3.6 Postharvest pathogens.....	46
10.4 ENVIRONMENTAL FACTORS INFLUENCING POSTHARVEST SHELF LIFE OF SPECIALTY MUSHROOMS.....	47
10.4.1 Temperature.....	47
10.4.1.1 Metabolism and respiration rate.....	47
10.4.1.2 Storage temperature.....	48
10.4.1.3 Freezing and chilling injury.....	51
10.4.2 Moisture loss and humidity.....	52
10.4.2.1 Structure and condition.....	52
10.4.2.2 Humidity and temperature effects.....	52
10.4.2.3 Control of moisture loss.....	53
10.4.3 Storage atmosphere.....	54
10.5 MODIFIED ATMOSPHERE PACKAGING OF SPECIALTY MUSHROOMS.....	56
10.5.1 Mushroom MAP requirements.....	56
10.5.2 MAP systems for specialty mushrooms.....	57
11. PROCESSED SPECIALTY MUSHROOMS.....	61
11.1 DRYING.....	61
11.2 MINIMAL PROCESSING.....	62
12. HANDLING PROTOCOLS.....	63
13. CONCLUSIONS.....	69
14. RECOMMENDATIONS.....	71
15. IMPLICATIONS FOR THE SPECIALTY MUSHROOM INDUSTRY.....	73
16. COMMUNICATIONS STRATEGY.....	73
17. GLOSSARY.....	75
18. LITERATURE CITED.....	77
19. APPENDICES.....	85
19.1 SPECIALTY MUSHROOM INDUSTRY SURVEY.....	85
19.2 SPECIALTY MUSHROOM SUPPLIERS.....	89

1. Introduction

Wider consumer acceptance and increasing production have led to a steady growth in the Australian fresh specialty mushroom market over the last five years. Production is currently estimated to exceed 400 tonnes which is valued at well in excess of \$4 million wholesale. Opportunities exist for continued growth of this industry in the top-end domestic market and in replacing imported product (Vinning, 1995). The current market value for imported canned and dried specialty mushrooms is over \$16 million and opportunities exist for sector substitution with locally grown fresh and processed (i.e. sliced) product. Mushroom handling, distribution, presentation and packaging have been identified as issues affecting domestic market development (Richards, 1995). Wastage on local markets, particularly at the retail level, is high due to poor handling and storage practices, and a lack of consumer information. All edible fungi are extremely perishable and each species will most likely have unique handling requirements that need to be identified and made available to industry and consumers.

Recent enquires by buyers and retailers in Japan and other South East Asian countries concerning locally produced specialty mushrooms have reinforced the export opportunities that exist. The ability of growers to develop these potential markets is constrained at present by variable product quality and lack of continuity of supply. Potential economic benefits from export are substantial as this low-volume, high-value specialty product is already well established in lucrative Asian markets. As an example of the export market potential for Australian-grown mushrooms, approximately 200,000 kg of shiitake mushrooms are imported into Japan annually with an average price of \$AU22/kg. This volume is likely to increase due to unstable local supplies and a decreasing number of logs suitable for shiitake production. Improved quality through better handling, storage and packaging practices will allow the realisation of these export opportunities for Australian specialty mushrooms.

The aim of this project is to reduce wastage and maintain quality of fresh specialty mushrooms during distribution and marketing by determining industry needs and reviewing relevant information. Industry use of information gathered, and protocols established in this report, will assist in reduction of quality loss and increase shelf-life of specialty mushrooms. These changes will lead to a sustainable domestic market and lay foundations for export market development.

The focus of this report is on the handling of fresh and minimally processed (e.g. sliced) specialty or 'exotic' mushrooms used for culinary purposes. Information on postharvest handling of the common white mushroom (*Agaricus bisporus*) will be used to establish general mushroom handling principles and in some cases supplement existing specialty mushroom information. This report has been compiled through extensive industry consultation and a literature review of industry and scientific information related to the marketing and handling of edible fungi. Some of the literature cited on specialty mushrooms includes sources unavailable in the English language.

248

249

250

2. Objectives

To increase the domestic and export market potential of Australian specialty mushrooms by developing improved postharvest handling, packaging and storage protocols for each stage of the distribution and marketing chain. Use an industry survey and desk-top review of existing literature to determine benchmarks and identify research priorities.

3. Methodology

1. Determine the major mushroom varieties marketed in Australia.
2. Identify current postharvest handling, packaging and storage practices used through an industry survey aimed at specialty mushroom growers, distributors and retailers.
3. Establish current marketing and packaging trends in mature mushroom markets that influence postharvest quality and shelf life of mushrooms.
4. Critically review published scientific and industry literature to obtain relevant handling information and determine knowledge gaps.
5. Establish improved postharvest handling, packaging and storage protocols from the information gathered.
6. Identify future research priorities to optimise postharvest handling and packaging of specialty mushrooms.

4. Commercial fresh specialty mushroom varieties

4.1 Major cultivated species

Through an industry survey (see Section 7) and a review of relevant reports such as Richards (1996) and Vinning (1995) the major cultivated specialty mushroom species currently available in Australia have been determined and are listed in Table 1. The market is supplied by both local producers and by distributors who import fresh product. Some of the species listed are grown locally in relatively small volumes.

Table 1. Main cultivated fresh specialty mushrooms available in Australia (1996).

Common name	Scientific name	Other names (including Japanese name)
Swiss brown	<i>Agaricus</i> spp.	Honey brown, Crimini
Wood ear*	<i>Aricularia</i> spp.	Black fungus, Jew's ear
Enoki	<i>Flammulina velutipes</i>	Enokitake
Shimeji	<i>Hypsizygus marmoreus</i>	Bunashimeji
Shiitake	<i>Lentinula edodes</i>	Forest, Oak mushroom
Oyster	<i>Pleurotus</i> spp.	Various, including abalone, golden, pink & white oyster, hiratake, tamogitake, ohritake
Jelly fungus*	<i>Tremella fuciformis</i>	White jelly fungus, Silver ear, Shirokikurage
Straw*	<i>Volvariella volvacea</i>	Paddy straw, Fukurotake
Portabella	<i>Agaricus</i> spp.	

*Not grown commercially in Australia

Industry discussion and the report by Richards (1996) has been used to estimate Australian specialty mushroom market size in 1996 (Table 2).

Table 2. Estimated market size for fresh specialty mushrooms in Australia (1996).

Mushroom variety	Estimated market volume (tonnes/year)
Oyster	280
Swiss Brown	50
Shiitake	70
Enoki	8
Shimeji	4
Other (Wood ear, Portabella etc.)	4
Total	416

The Australian market size is difficult to estimate due to a high number of producers entering and leaving the industry after relatively short periods. For example, in 1996 a large shiitake grower in Victoria entered the market and was producing over 1 tonne/week leading to a virtual doubling of fresh shiitake available at that time but production has since halted.

Oyster, swiss brown and shiitake are seen by retailers and consumers as the main specialty mushroom types. Oyster mushrooms are the most popular of the exotic varieties due to a relatively high level of customer exposure and competitive pricing (Richards, 1996). Approximately five species are currently cultivated, the most common variety being *Pleurotus ostreatus* (white oyster) but pink, yellow and golden oyster mushrooms are also becoming available. Shiitake mushrooms are also gaining in popularity due to increasing customer awareness but a large proportion of the product being marketed is imported from China and has been found to be of very poor quality. An excellent opportunity exists for domestic shiitake producers to supply a fresh, high quality product which can replace imported mushrooms.

4.2 Main species by domestic production

At present the local specialty mushroom industry is made up of approximately 12 growers based mainly in eastern Australia with a similar number of wholesalers and distributors who specialise in *Agaricus* and exotic mushrooms.

4.2.1 Cultivated mushrooms

There are virtually no published statistics on specialty mushroom production in Australia. An industry survey has established that most producers either grow oyster or swiss brown mushrooms while a few are cultivating shiitake. These varieties account for more than 90% of specialty mushroom production in Australia at present. Oyster mushrooms are relatively simple to cultivate while swiss browns are grown in a similar fashion to the common white mushroom. As local expertise in specialty mushroom production increases it is likely that commercial scale cultivation of shiitake, enoki and shimeji will increase substantially.

4.2.2 Field-picked mushrooms

A number of producers field pick and pack wild mushrooms for niche markets such as restaurants. The supply is seasonal (usually March-November) and inconsistent. It is difficult to determine total production each season but it is estimated at approximately 2,500-3,000 kg. The majority of these edible fungi are harvested from areas such as the Dandenong Ranges near Melbourne and the NSW highlands. Table 3 lists the main wild mushroom varieties available in Australia.

Table 3. Main field picked specialty mushrooms available in Australia (1996).

Common name	Scientific name	Common name	Scientific name
Morels	<i>Morchella esculenta</i>	Parasol	<i>Lepiota procera</i>
Ceps	<i>Boletus edulis</i>	Shaggy Parasol	<i>Lepiota rhacodes</i>
Wood Blewits	<i>Lepista nuda</i>	Chantarelle	<i>Cantharellus cibarius</i>
Blewits	<i>Lepista saevum</i>	Slippery Jack	<i>Suillus luteus</i>
Ink cap	<i>Coprinus</i> spp.	Saffron Milk cap	<i>Lactarius deliciosus</i>
Shaggy Ink cap	<i>Coprinus comatus</i>	Field mushroom	<i>Psalliota campestris</i>
Pine	<i>Armillaria ponderosa</i>	White Coral fungus	<i>Clavulina cristata</i>

4.3 Specialty mushroom imports

There is little information available on import volumes of specialty mushrooms into Australia. It has been estimated that imports accounted for 8 percent of total sales in 1992/93 (Richards, 1996). Industry evaluation has established that this figure could currently be as high as 20%, with imports mainly comprising of shiitake, enoki and black fungus from China and other South-East Asian countries. In general, it has been found that although these mushrooms are competitively priced due to low production costs in the exporting countries, the quality is very poor in comparison to locally grown product. This is most likely due to poor postharvest handling as overseas strains are usually regarded by Australian growers as superior to those currently available in Australia, although objective evidence to demonstrate this is not available.

4.4 Export opportunities

A number of specialty mushrooms have been identified as having an expanding market world wide as well as providing potential export products for Australian producers (Brown, 1996). These are listed in Table 4. Many of these mushrooms are either harvested from the wild or grown on natural logs, and are highly favoured in countries such as Japan. They also have a relatively high wholesale and retail price, for example, matsutake mushrooms have achieved prices of \$AU500/kg wholesale in some markets (Vinning, 1995).

Research funded by the Rural Industries Research and Development Corporation (RIRDC) is currently examining the cultivation of maitake, bunashimeji and the hedgehog mushroom on artificial logs. Studies have been completed to determine the most suitable shiitake strain and substrate to obtain commercial yields under local conditions (Chung, 1994). Improving production techniques is an ongoing process for shiitake growers in Australia.

Table 4. Asian specialty mushrooms with high export potential.

Common name	Scientific name	Other names
Maitake	<i>Grifola frondosa</i>	Hen of woods
Bunashimeji	<i>Hypsizygus marmoreus</i>	Shimeji, beech mushroom
Matsutake	<i>Tricholoma matsutake</i>	Pine mushroom
Reishi	<i>Ganoderma lucidum</i>	Ling-zhi
Nameko	<i>Pholiota nameko</i>	
Shiitake	<i>Lentinula edodes</i>	Forest, oak mushroom

5. Specialty mushroom descriptions

In this section, pictures and descriptions are given of the main specialty mushroom types available in Australia including wild varieties and Asian mushrooms with potential for export market development.

5.1 Cultivated varieties

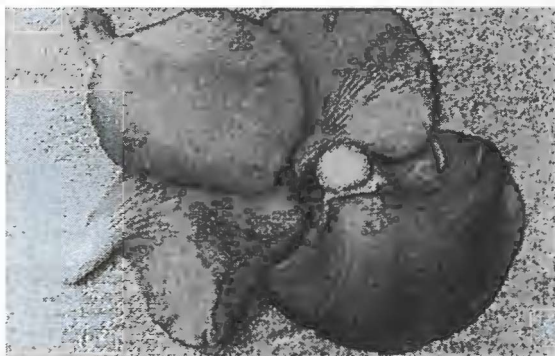


Plate 1. Oyster mushroom (*Pleurotus* spp.). Short stemmed with a large, delicate, fluted cap. Colour can vary between species from white, grey to golden. Mild flavour and delicate texture.



Plate 2. Shiitake (*Lentinus edodes*). Large mushroom ranging in colour from tan to dark brown with broad, umbrella-shaped caps, wide open veils and tan gills. Caps have a soft sponge texture while the stem is tough and inedible. Rich and woody flavour with a meaty texture when cooked.



Plate 3. Swiss Brown (*Agaricus* spp.). Similar in appearance to the common white mushroom (*Agaricus bisporus*). Has a naturally light tan to rich brown cap and a very firm texture. Deeper, denser and an earthier flavour than *A. bisporus*.

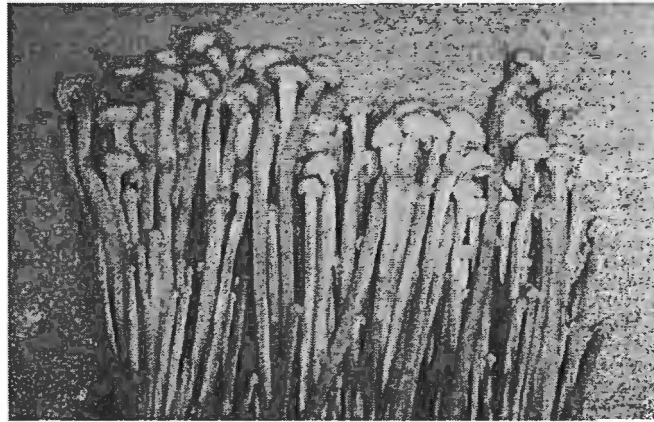


Plate 4. Enoki (*Flammulina velutipes*). Fragile, flower-like creamy white mushroom with a long, slender stem and small round cap that grows in clusters. Light flavour with a slight crunch.



Plate 5. Wood ear (*Auricularia* spp.). Black, leathery fungus with a floppy cap, short stem and distinctive flavour.



Plate 6. White jelly fungus (*Tremella fuciformis*). Gelatinous, pure white fungus with leaf-like blades and mushroom-type flavour.

5.2 Field picked mushrooms



Plate 7. Morel (*Morchella esculenta*). Rounded, egg-shaped with a honeycomb-like arrangement of ridges and pits, 6-12 cm high. Colour ranges from pale yellow to black. Flesh is rough and fibrous.



Plate 8. Pine (*Armillaria ponderosa*). Closely related to Matsutake. Tawny, convex cap 8-20 cm wide. Flesh is white, thick and firm. Taste is agreeably spicy.



Plate 9. Ceps (*Boletus edulis*). Brownish to dark cap colour, whitish at first, 6-20 cm wide. Tastes sweet and nutty, smells pleasant and high in protein. Soft, white flesh.

5.3 Asian specialty mushrooms



Plate 10. Nameko (*Pholiota nameko*). Smooth cap, 2-15 cm in diameter, bay-brown at the centre becoming slightly paler in colour near the margin. Cap covered with glutinous mucilage.



Plate 11. Bunashimeji (*Hypsizygus marmoreus*). Small, fragile mushroom with small, grey-white, flat caps that grow in clumps.



Plate 12. Matsutake (*Tricholoma matsutake*). Light brown to brown cap 8-18 cm wide. Mature cap resembles an umbrella. Fine, white flesh when young. Strong fragrance and rich flavour.

6. Concept of mushroom quality

The purpose of improving postharvest handling and packaging of mushrooms is to increase product quality at all stages of the distribution chain. Quality is defined as the degree to which a product meets the requirements of the buyer (Kramer & Twigg, 1970). At the end of the distribution chain it is the consumer that makes the final decision as to the extent to which growers, distributors and retailers have taken account of the concept of quality (Schaper *et al*, 1988).

The quality of the mushroom determines its saleability on the market. It is difficult to describe the concept of mushroom quality in one general sentence. A good quality mushroom must meet the expectations of the user in terms of:

- flavour, texture and odour
- colour, shape and size
- free from blemishes, defects or rots
- shelf life
- health and nutritional value

In general, a clean, wholesome product is required. That is, a mushroom free from substrate or soil residues, unblemished and without off-flavours. To a large extent these factors are influenced by production methods and by handling during harvesting, storage and marketing (Nichols, 1985). The consumer also considers other factors such as colour, turgor and developmental stage in determining the freshness and thus the apparent age of the mushroom.

As a result of handling and natural ageing, enzyme activity (e.g. reaction of tyrosinase) in mushrooms increases which leads to discolouration. These colour changes are recognisable, obvious signs of ageing. Consequently discolouration can be used as an indicator of freshness, but not necessarily as an indicator of acceptability to the consumer or of off-flavours. A consequence of water loss from harvested mushrooms is that the cap and stem wrinkle, toughen and contract (Nichols, 1985; Beelman, 1988). These are symptoms of dehydration and are associated with loss of freshness in much the same way as are changes in colour. Continued mushroom growth after harvest leads to cap opening, stem elongation and darkening of gills as spores develop and are eventually released. This development results in fragile mushrooms that are difficult to handle and have a reduced shelf life, and may also detract from the mushroom's appearance. Thus, postharvest methods of handling, storage and marketing are required to minimise the loss of quality brought about by these natural changes.

For the consumer to receive the freshest mushrooms possible, producers must grow mushrooms of the highest quality and every link in the marketing chain must ensure that the greatest care is taken in maintaining this initial quality.

14

7. Specialty mushroom industry survey

Current postharvest handling, packaging and storage practices used in the Australian fresh specialty mushroom industry were identified through an industry survey (Appendix 1). This survey was used to:

- Determine the main mushroom types grown and distributed, and grading standards used.
- Establish environmental conditions and packaging currently used during handling.
- Provide a forum for industry to address postharvest research and technology transfer issues.

7.1 Survey participation and methodology

Over a six month period between July and December 1996, 20 growers, packers and distributors throughout Australia were interviewed over the telephone after receiving a copy of the survey. It has been estimated that this industry group represented over 95% of specialty mushroom growers and over 80% of mushroom distributors at the time. More detailed information was gathered from personal interviews of some growers and farm visits and is included in the report where appropriate. Although the local specialty mushroom industry is fragmented and highly competitive, the majority of growers and distributors were very cooperative in supplying the required information.

7.2 Specialty mushroom industry structure

As part of the surveying process information was gathered on the size and structure of the local specialty mushroom industry. Approximately 12 growers are presently cultivating specialty mushrooms while several others specialize in field picking wild mushrooms. Only 2 or 3 of this group can be considered large commercial growers. The majority of growers produce 250-1000 kg of mushrooms weekly. The number of growers in any year can vary dramatically as many have a short-term outlook and use the industry as an income source used to develop other businesses.

Around seven wholesalers either repack or distribute prepacked mushrooms to retailers and consumers while a few growers deal directly with retail chains. A number of these distributors also deal in other specialty items such as culinary and salad herbs. Wholesalers will source their product from growers or from importers if the product is unavailable locally. Imported shiitake is the only mushroom type in direct competition with domestically grown product.

It has been found that the market volume of specialty mushrooms available at any one time is highly variable, in many cases due to a lack of growing expertise and the fact that many growers are unable to consistently supply their customers with high-quality product. A number of businesses have failed by attempting to 'cash-in' on relatively good mushroom prices over the short-term to the detriment of the industry.

7.3 Survey results

Of the industry group surveyed, 65% of respondents were growers or field pickers who mostly packed their own product, 10% who repacked and distributed, and 25% who only distributed specialty mushrooms, for example market agents and wholesalers. Most growers specialize in one type of mushroom, usually oyster, or cultivate other types such as swiss brown as part of their *Agaricus bisporus* growing operation. Repackers usually purchase their product locally or

from overseas in bulk, and package it in retail size units under their own brand name. Large distributors deal with all mushroom varieties and usually have good facilities and some expertise in handling the product while smaller wholesalers may deal only in the specialty types.

It was found that 70% of packers and distributors imported fresh specialty mushrooms due to the fact that some varieties aren't cultivated in Australia and due to limited supply of locally-grown product. Price is also a factor as the cost of imported product is generally less than Australian grown mushrooms though the quality is usually poorer.

7.3.1 Varieties

An important aim of the survey was to determine the main mushroom varieties grown on which to base this project and future work. Figure 1 shows that oyster (46%), shiitake and swiss brown (23% respectively) are by far the most commonly cultivated specialty mushrooms. At present shimeji and enoki are only cultivated by a few growers but can be considered as important varieties in the medium term particularly in replacing imported product.

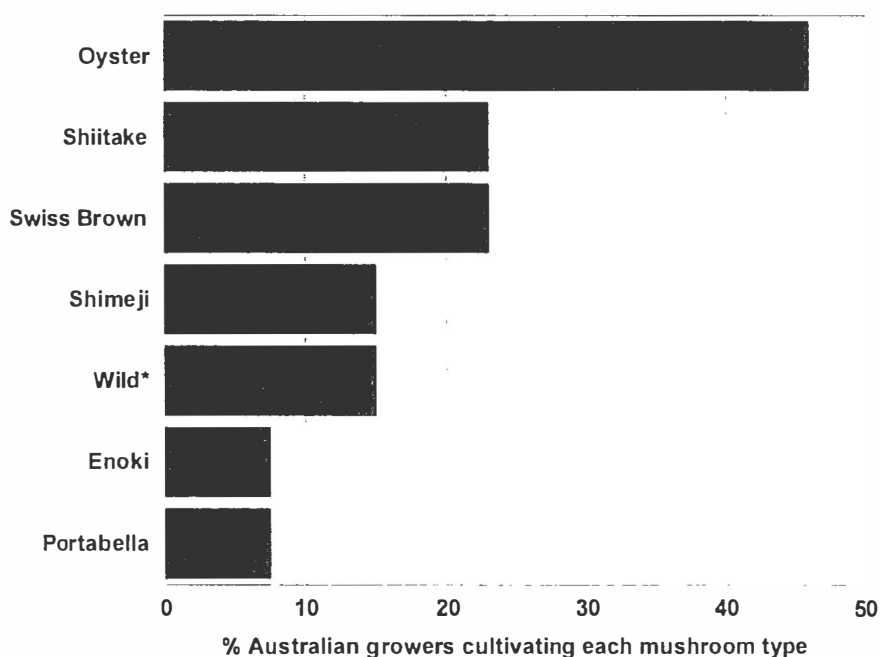


Figure 1. Percentage of Australian growers cultivating each variety of specialty mushroom. (*Wild mushrooms are field picked and include morels, blewitts and ceps).

7.3.2 Product cooling and storage

The specialty mushroom handling and marketing chain generally followed in Australia is illustrated in Figure 2. Due to the small size of most farms, mushrooms are manually harvested and ready to be cooled within a few hours. It was found that cooling facilities were often rudimentary with only one grower having forced-air cooling facilities and this was largely due to the fact that they also cultivated *A. bisporus* mushrooms. A company that picked wild mushrooms had no need for cooling facilities due to their rapid product turnover. In virtually all cases mushrooms were packed into plastic, cardboard or styrofoam trays and precooled in standard refrigerated stores of varying size and capacity.

It was difficult to determine how effective these cooling methods were in rapidly lowering mushroom temperatures as very few growers measured pulp temperature before grading. Successful precooling was estimated to take between 2-12 hours depending on the cooling method employed and coolroom setup. The industry survey found that 56% of growers, packers and distributors cooled and/or stored mushroom product between 0-3°C while 39% stored it at 4-8°C. In many cases these were estimates as temperatures in coolrooms were not usually monitored. During cooling and storage in open bulk containers mushrooms are susceptible to moisture loss unless a high humidity is maintained. This can have a significant impact on quality if they are stored for a day or more and cause a substantial loss in saleable yield (Tingsgaard *et al*, 1993). The survey found that 100% of growers and distributors didn't know what the relative humidity level in their coolrooms was but 59% made an estimate while 41% could not provide even an estimate of cool room humidity levels (Figure 3).

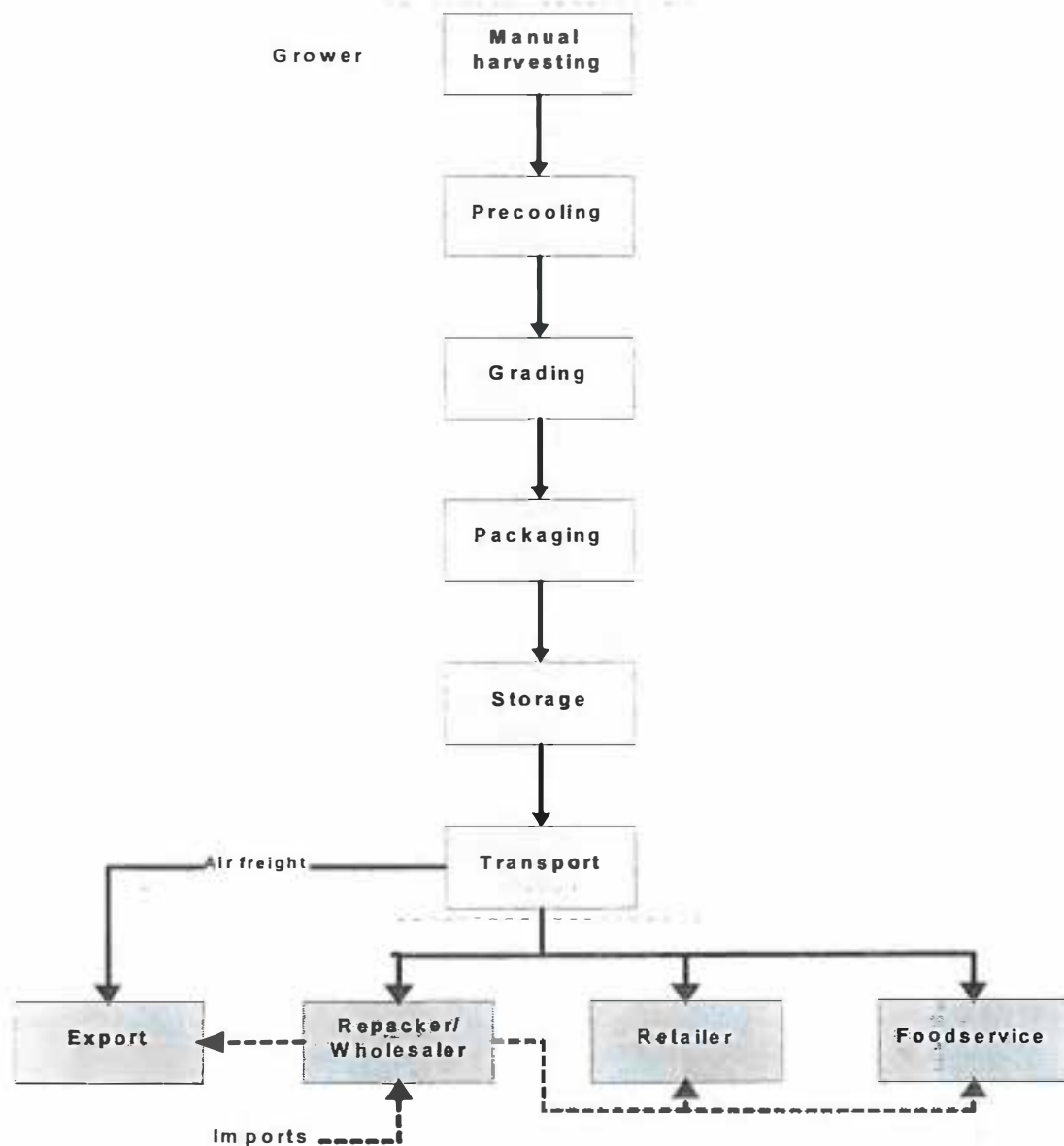


Figure 2. Generalized fresh specialty mushroom handling and marketing chain.

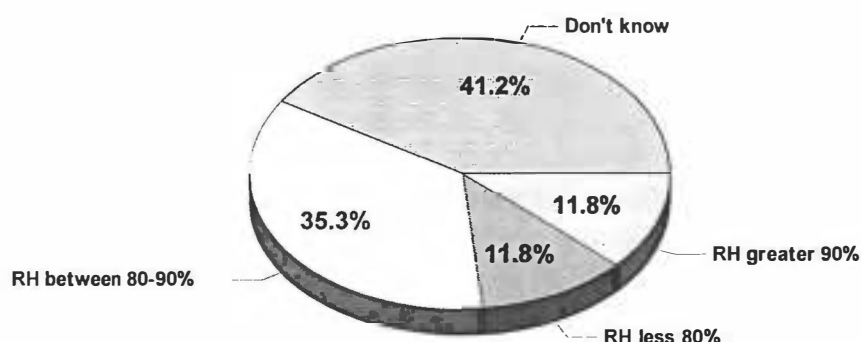


Figure 3. Estimates provided by growers and distributors of relative humidities in coolrooms used in the specialty mushroom industry.

7.3.3 Grading and packaging

After precooling mushrooms are sorted into different grades before packaging. Discussions with industry have demonstrated that currently individual growers have their own grading systems and standards. Usually the mushrooms are divided into 2 or 3 grades with the premium grade commanding the best prices. A limited specialty market exists in the foodservice sector for large, small or unusually shaped mushrooms and markets may exist for sliced products produced from lower grade mushrooms.

Table 5 lists the results obtained from a survey of growers and repackers when asked to name the grading standards they used in rejecting mushrooms from their premium grades. Across all industry sectors, mushroom size, maturity and physical damage were the key quality criteria used during sorting. Further discussions suggest that a medium sized mushroom is preferred by customers, so this is the size used in premium grades. Physical injury during harvest and distribution is a major factor leading to wastage and product down grading. Growers use their own maturity standards based on experience and market requirements as no uniform industry guidelines exist. As retailers handle all mushroom varieties in a similar manner any variation in maturity between different growers' products or even inside individual prepacks may lead to some premium grade mushrooms deteriorating more rapidly than others and thus to variable quality in a single display or inside a prepack.

Table 5. Main factors for rejection of fresh specialty mushrooms from premium grades.

Quality factors	Incorrect size	Incorrect shape	Physical damage	Incorrect maturity	Blemishes/ Disease	Postharvest rots	Other
Whole industry	59%	12%	59%	341%	12%	12%	6%
Growers	54%	15%	39%	54%	15%	-	8%

Specialty mushrooms grown for the local wholesale and fresh retail market are commonly prepacked into polystyrene trays and overwrapped with plastic film or supplied in bulk, using open waxed or unwaxed cartons (Figure 4). Unit sizes of packaging and the relative merits of

different packaging will be discussed further in the marketing and handling section of this report. Polystyrene trays and plastic films such as Vitafilm® are used for retail packs due to their low cost but they provide little product protection and their merits in maintaining mushroom quality have yet to be demonstrated. Bulk cartons are mainly used for swiss brown mushrooms in a similar fashion to *A. bisporus* and provide little protection against moisture loss. Recently, overwrapped plastic punnets have been used for shiitake and delicate mushrooms such as shimeji and may soon become as common as polystyrene trays as industry sees the benefits in terms of product protection and presentation. Other more expensive packaging systems such as plastic 'clam shell' punnets may also be used in the future.

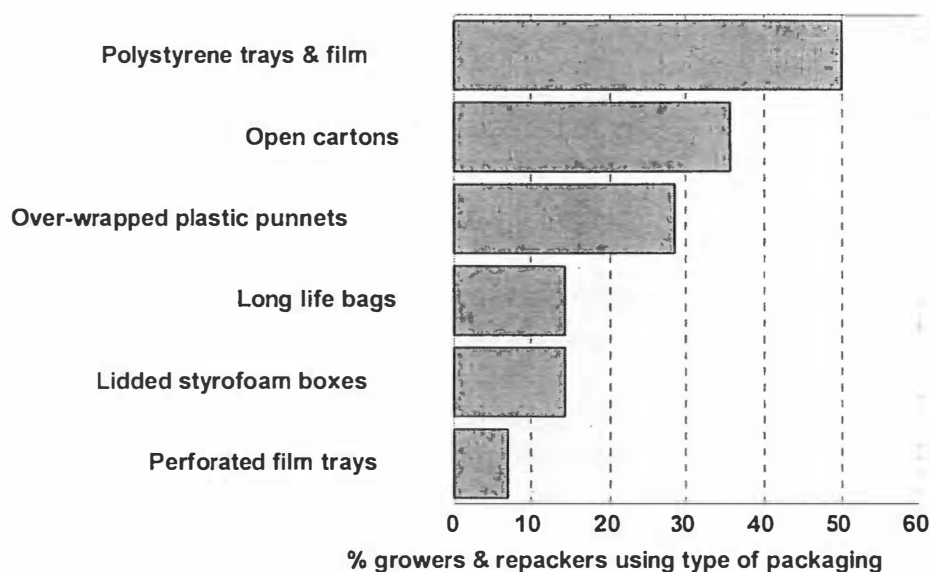


Figure 4. Most commonly used packaging systems for fresh specialty mushrooms in Australia.

A number of growers are using various proprietary 'long life' modified atmosphere packaging (MAP) bags in their bulk packages. Growers have suggested that at present this is mainly a marketing exercise as the benefits, if any, of this packaging in maintaining or extending mushroom shelf-life have not been determined. Packaging systems to extend mushroom shelf-life are likely to be required as retailers demand continuous supplies of high quality product. Currently, day-to-day supply is to a large extent determined by cropping cycles which by their very nature are uneven. MAP may be an appropriate method of storing product for an extended period to smooth out this uneven supply.

7.3.4 Distribution

At present growers and distributors store packaged mushrooms for a relatively short time before they are distributed to customers due to high demand and reliance on quick-turnover which reduces the risk of quality loss to the product. Refrigerated road or air transport (usually 3-8°C) is commonly used to distribute product between states while the majority of growers and repackers use unrefrigerated vans for local distribution, again relying on rapid handling.

Survey results suggest that specialty mushrooms are stored for up to 4 days on average by growers, repackers and distributors while retailers and consumers may store these same mushrooms for up to another 8 days based on feedback received by the wholesalers and market agents interviewed. In general, the industry view is that most mushroom types have a shelf life of

over 2 weeks if handled properly and stored correctly during marketing. A number of growers doubted whether this shelf-life was possible with current handling practices used by distributors and retailers. Under ideal conditions it is likely that many specialty mushrooms can keep for over 2 weeks and still have acceptable quality. At present relatively poor temperature management during distribution and marketing and inappropriate packaging are combining to reduce mushroom shelf-life and quality.

7.3.5 Quality issues

The final part of the survey aimed to gather information on mushroom quality and technology transfer issues. Growers and distributors were asked to list three main factors they thought were contributing to quality loss and wastage of mushrooms during postharvest handling and marketing. It was found that poor customer/retailer knowledge of the product was felt to be the major contributing factor to poor quality (22.5%) closely followed by physical injury, poor harvest quality and poor temperature management (Figure 6). Other factors accounted for 36.7% of responses which included postharvest rots and browning.

Growers and distributors were also asked to nominate the three types of information they thought industry (including retailers) required to improve mushroom quality. The results are presented in Figure 7. General postharvest handling information had the highest response (24.4%) while many felt that mushroom grade and quality descriptions were required to set industry standards and to guide retailers and consumers. Information regarding better packaging systems was also felt to be important, although surprisingly, industry felt that current packaging was only a minor contributor to mushroom quality loss (Figure 6).

Growers and distributors were also given the opportunity to discuss other issues concerning the postharvest handling and marketing of specialty mushrooms. Of major concern was the poor handling of their mushroom product by retailers, particularly chain stores and the lack of control they had after the mushrooms were distributed. The general consensus was that retailers felt they were forced to carry these product lines and so treated them as relatively unimportant compared to other produce. This was also demonstrated by the lack of consumer information available at the point of sale and contributed to the generally poor quality of specialty mushrooms.

A number of growers felt that there was high wastage of their specialty mushrooms (10-15% in some cases) at the retail level and that postharvest systems needed to be in place that could extend shelf-life up to 14 days. Good temperature management was acknowledged as being a critical factor in achieving this storage life. A few industry representatives suggested that only large scale production of specialty mushrooms by a few growers will lead to increased market growth and industry improvement. It was felt that industry 'critical mass' would allow growers to have greater control over their product during distribution and marketing and that it would allow implementation of improved quality systems.

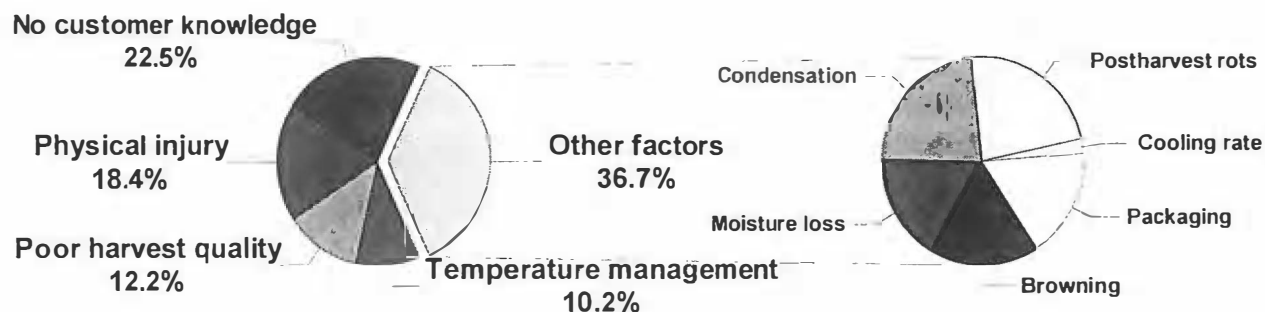


Figure 6. Major factors limiting the quality and shelf-life of specialty mushrooms (as a percentage of total responses obtained; each respondent named up to three factors).

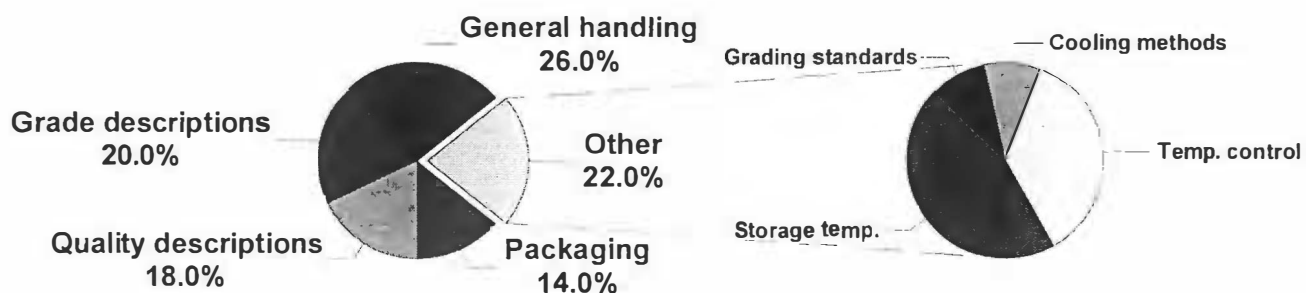


Figure 7. Industry and retail sector information requirements concerning the postharvest handling, storage and packaging of specialty mushrooms (as a percentage of total responses obtained; each respondent named up to three areas).

11

2017
2018

8. Overview of specialty mushroom cultivation

Recently the cultivation of economically-significant specialty mushrooms has been reviewed by Royse (1997). Specialty mushroom quality is influenced by many factors including substrate, cultural practices and strain. An overview of mushroom production techniques will provide the basic knowledge required to appreciate the many variables affecting specialty mushroom yields and quality. It will focus on mushroom varieties currently grown and marketed in Australia.

8.1 Cultivar selection and spawn production

The development, evaluation and maintenance of new mushroom genotypes has progressed at variable rates according to species with the major world-wide focus on the more common artificially cultivated mushrooms such as shiitake, oyster, enoki and bunashimeji (Wu, 1990). Extensive testing and selection of many genotypes is necessary to identify high-quality, productive strains (Royse, 1997). Through small-scale trials to commercial production, hybrids are evaluated for the required characteristics of high yield, appearance etc., until a few candidates are eventually released as new cultivars.

Mushrooms are grown from mycelium obtained from stored culture which is propagated on a base of steam-sterilized cereal grain such as rye or millet (Royse, 1997). The mixture of cereal grain and mycelium is known as spawn and is used to seed mushroom substrate. In Australia, specialty mushroom spawn suited to local substrates is difficult to obtain from commercial suppliers and so a number of growers produce their own. Spawn is produced and handled in aseptic 3-5 litre glass bottles or in 'breathing' polypropylene bags. A high quality spawn must have vigour, be biologically pure and must have a good past production record.

8.2 Commercial mushroom production

Specialty mushroom production in Australia is characterised by various levels of capital investment and thus by different types of production facilities. These can range from old railway tunnels to relatively sophisticated controlled environment growing rooms. The production efficiency achieved will also vary depending on the level of sophistication of the growing facilities, as this will determine the level of temperature and humidity control, hygiene standards and lighting. The majority of varieties are cultivated on artificial substrate also known as synthetic "logs".

8.2.1 Oyster mushrooms

Pleurotus species are wood-destroying, saprophytic fungi that have the ability to directly breakdown unfermented cellulose- and lignin-bearing materials (Zadrazil, 1978). They can be grown on substrates consisting of plant wastes such as wheat straw, rice husks, cottonseed hulls and wood products such as beech sawdust, or a combination of several of these. Substrate preparation involves milling the plant materials, adding lime and water and pasteurising the mixture to destroy the vegetative form of competing organisms. The cooled substrate is then spawned and a supplement such as soybean or corn gluten may be added to increase yield. The inoculated substrate is then filled into perforated polyethylene bags and incubated at a compost temperature of 25-30°C for 2-3 weeks. At completion of the spawn run the bags are removed from the substrate to induce formation of fruiting bodies.

The key environmental factors affecting fruit body development and yield are temperature, light, relative humidity and air exchange (Kurtzman & Zadravil, 1982). If these factors are not optimal then primordia and fruit bodies will not be induced. Depending on the species, fruiting temperatures can range from 16-30°C with 16-18°C being the optimum for *Pleurotus ostreatus*. Light is an initiating factor in the development of primordia and it has been shown that the duration and intensity of light affects yield and growth (Eger *et al*, 1974).

8.2.2 Shiitake

Shiitake is a wood-decaying basidiomycete that degrades cellulose and lignin to obtain the nutrients it requires for growth. Traditionally, it has been cultivated on freshly-cut hardwood logs. As suitable logs have become scarce or unavailable in some areas, commercial cultivation on sterilized cellulose-containing materials has increased worldwide. This is the method currently employed by growers in Australia. Przybylowicz & Donoghue (1990) provide detailed information on all aspects of shiitake production.

8.2.2.1 Cultivation on logs

Shiitake is cultivated on the wood of dead deciduous trees. The most suitable species come from the Fagaceae family and include oaks, chestnut and beech (Ito, 1978). Live trees are cut during the dormant season when their sugar content is high. Within two months the logs are inoculated with actively growing spawn. Logs are then stacked and managed to create favourable conditions during spawn run i.e. mycelial colonization of the wood. Depending on the strain and environmental conditions, full colonization can take from 6-9 months (Royse, 1997). Inoculated logs are then moved to a 'raising' yard which is usually cooler and at a higher humidity than the spawn run area. This provides an optimum environment for growth and development of mushrooms. Logs can be forced to fruit by soaking or irrigating them with water. Depending on their size and number of fruitings per year, logs can produce mushrooms periodically for 2-5 years (Przybylowicz & Donoghue, 1990).

8.2.2.2 Synthetic log production

Shiitake can be grown on substrates comprised of sawdust (*Eucalyptus* spp. is commonly used in Australia) supplemented with starch-based ingredients such as grain, bran, rye corn or other sources of carbohydrates and nitrogen (Chung, 1994; Royse, 1997). The substrate is then mixed with water and filled into heat-resistant plastic bags. The filled bags are stacked on racks and sterilised to kill organisms that will compete with the mushrooms. After a 3-4 week spawn run at 25°C the bags are cut off and the logs are exposed to an environment conducive to browning of the exterior log surface i.e. oxidation of surface mycelium. Once the mycelium has depleted the easily available carbohydrates in the substrate (usually over a 4 week period), fruiting is initiated with light, and cooler (16°C), humid conditions. Fruit development is stimulated by soaking the logs in water.

Fruiting requires specific environmental conditions including an air temperature of 13-20°C, 75-95% relative humidity, light, fresh air and sufficient water reserves in the log. Approximately 12 days after soaking, mushrooms are ready to harvest. Logs are soaked between flushes to replace water lost during mushroom tissue production and flushes occur at intervals of 20-30 days. The total cropping from sawdust logs lasts from 3-6 months.

The main advantages of using synthetic over natural logs is reduced time to produce the same quantity of shiitake, increased biological efficiency, reduced competition from other fungi for nutrients and controlled conditions during fruiting.

8.2.3 Enoki

Enoki is a wood-destroying fungi that grows naturally on the trunks or stumps of aspens, willows and elms. Cultivation on sawdust medium is now common as the mushrooms produced are of a much higher quality than those cultivated on logs. Sawdust consisting primarily of *Cryptomeria japonica* and *Chamaecyparis obtusa* mixed with rice bran and water is commonly used as a substrate for cultivation. Much of the lignin, cellulose and monosaccharides are provided in the sawdust. After mixing, polypropylene bottles are filled with the substrate and sterilised.

Substrate in the bottles is inoculated with sawdust spawn at 20°C and the bottles are then incubated at 18-20°C for 20-25 days. When the mycelia has spread over the whole bottle, the inoculated spawn is removed, and the surface of the media is made smooth for fruiting. The air temperature is then lowered to 10-12° and after 10-14 days primordia are formed.

To improve quality during fruiting, temperatures are lowered to 3-8°C until harvest and air movement is provided. As the mushrooms begin to elongate above the lip of the bottle a plastic film is rolled around the mouth to hold the fruit body upright. When the mushrooms are 13-14 cm long the rolled plastic is removed and the mushrooms are pulled as a bunch from the substrate (Royse, 1997). Usually only one flush of mushrooms is harvested before removal of the spent substrate from the bottles. Enoki fruiting and development is highly dependent on the relative humidity of the environment, fruiting air temperature and low carbon dioxide levels in the air.

8.2.4 *Agaricus* spp.

Swiss brown and portabella mushrooms are cultivated in a similar manner to the common white mushroom (*Agaricus bisporus*) although optimum spawn run and fruiting temperatures may vary according to the variety and species. Briefly, a number of production stages are required to grow these varieties. Phase 1 involves the preparation of the compost which is made up of horse and chicken manure, straw and gypsum. With the addition of water this mixture is heated in a pile over a number of days usually in the open. In phase 2 pasteurisation kills any parasitic organisms in the compost and conditioning allows beneficial organisms to develop while fermentation forms nutrients which the mushrooms can utilise. This process usually takes 7-10 days. Compost is then inoculated with grain spawn, placed in large trays and mycelium allowed to develop. Optimum substrate temperature for mycelial growth is about 25-27°C. After approximately two weeks a 3 cm layer of peat moss, known as casing, is spread over the colonized compost and trays are placed in growing rooms where the substrate is maintained at 25-27°C under high humidity and high CO₂ levels (Ingratta, 1980).

Once mycelium has grown through to the surface of the casing the pinning stage is initiated by cooling the beds down to about 20°C and introducing fresh air. This allows hyphae to bundle and form pins which are the generative phase of the mushroom. Room conditions are maintained at 13-18°C (air temperature), 85-90% RH and 0.08% CO₂ and after about 15-20 days the first flush of mushrooms is ready for harvest. The interval between flushes is approximately one week and

three flushes are usually picked. Environmental conditions during mushroom growth such as air temperature, CO₂ levels, ventilation and humidity will influence their quality at harvest.

9. Specialty mushroom handling and marketing

At present the major markets for specialty mushrooms are the wholesale, retail and foodservice sectors. Opportunities exist to further develop these areas and with increasing production, expansion into import substitution and export markets will be possible. Issues impacting on these opportunities will include presentation, packaging, product handling and distribution (Richards, 1996). Packaging and postharvest preservation is emerging to be a major strategic issue for the industry. As markets and consumers become more sophisticated and demanding of product quality, the demands for postharvest handling and packaging will need to be developed accordingly (Lee, 1995). Each market sector will have different packaging requirements and this will be further complicated by the packaging and distribution needs of individual mushroom species.

9.1 Domestic marketing

The domestic marketing chain for specialty mushrooms has been outlined in Figure 2. Specialty mushrooms are typically packaged in either retail size prepacks or in bulk. Prepacks usually consist of 100-150 grams of mushrooms packed on polystyrene trays covered with a plastic film such as Vitafilm[®] (Plate 13). These packs are usually packed in a master carton for shipping to individual customers. The pack size is largely determined by pricing factors. Growers also pack oyster, shiitake and swiss brown mushrooms in 2-2.5 kg lidded, polystyrene boxes (Plate 14) or in open corrugated cartons of varying designs and shapes. Bulk packs are mainly used by wholesalers who repack mushrooms, by the foodservice industry or by some retailers who merchandise loose mushrooms.

Specialty mushrooms are mainly distributed through wholesalers in the capital cities. This group includes market agents and specialty product suppliers who may repack mushrooms. Market agents usually specialise in selling *A. bisporus* while also supplying exotics that they source from all over Australia and overseas if necessary. Specialty product suppliers are likely to deal in cultivated and field picked specialty mushrooms as well as fresh herb lines and other low volume, high value products. The majority of growers use the wholesale market as their major distribution point.

Some growers and distributors have established direct links with major retail chains who require a consistent supply of high quality product. Wholesalers have indicated that one of the fastest growing market sectors for Asian vegetables are the large supermarket chains (Lee, 1995). Over recent years, retailers have increased their sales of package branded prepacks of specialty mushrooms. These are usually labelled with the name of the grower or distributor and in some cases, storage and usage information is also provided. At present 'use-by-dates' are not used on packaged mushrooms although they are likely to be a supermarket requirement in the near future. In general, supermarket display of specialty mushrooms is below standard with a variable product range that is poorly presented and is often handled incorrectly by placing prepacks on top of one another or displaying them at the incorrect temperature. Little information is provided to consumers on their handling requirements and usage.

At present industry relies heavily on rapid distribution to overcome shelf-life limitations of the product. This distribution system may be applicable for the foodservice sector such as restaurants, but as wholesale and retail markets grow, practical methods of maintaining specialty

mushroom quality over a longer period must be considered which will entail using improved postharvest handling practices and packaging.

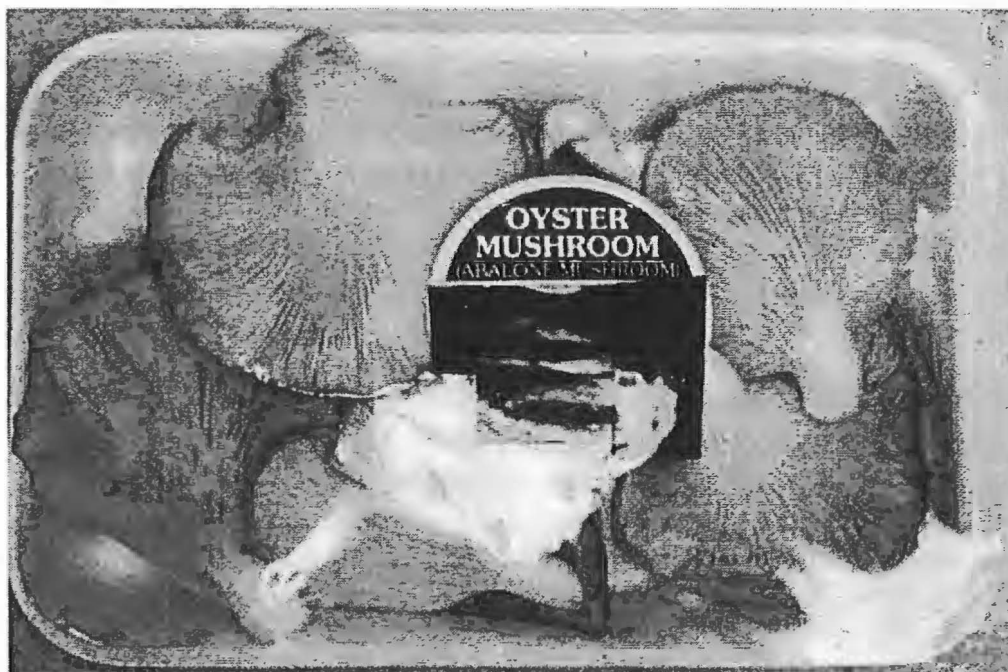


Plate 13. Oyster mushrooms prepacked on a polystyrene tray and overwrapped with PVC film.



Plate 14. Shiitake mushrooms packed in bulk inside a styrofoam container.

9.2 Export markets

At present only very low volumes of fresh specialty mushrooms are exported from Australia due to industry fragmentation, high production and air freight costs, limited scale of production and poor market intelligence. In general terms, export markets require a regular supply of top-quality produce, attractively presented and packaged so that quality is maintained throughout distribution and marketing. With increasing production and correct postharvest handling, opportunities exist to market Australian specialty mushrooms based on the 'clean' and healthy image of local produce.

In the short term, a greater potential exists to substitute locally produced exotics for imported fresh product in the domestic market. For example, to meet the high domestic demand for shiitake a substantial volume is imported but invariably the quality is much poorer than the local product as mushrooms may have been harvested 2-3 weeks before reaching the Australian market.

9.3 Marketing in the USA

Although larger in terms of production volumes the USA specialty mushroom industry is structured in a similar manner to the Australian industry. It is made up of many relatively small growers who lack the financial capability to implement major marketing programs (Richards, 1996). Co-ordination between grower groups and organisations such as the American Mushroom Council has overcome this marketing barrier so that the main specialty mushrooms command almost equal publicity with *A. bisporus* (Sorenson, 1992).

In recent years, the trend for specialty mushroom sales has been toward the retail market (Gunn, 1992). This trend has been driven partly by an increased interest in the product and by the convenience to the consumer of packaged mushrooms. Often specialty mushrooms are used to highlight the common cultivated mushroom (Royse, 1997).

9.3.1 Grading and packaging

There is no formal established grading system for specialty mushrooms in the United States at present. Two grades are generally used for varieties such as swiss brown, shiitake and oyster mushrooms that closely mirror the grading system used for *A. bisporus* mushrooms. No consensus has been developed on size grades. Any size standards adopted will reflect the requirements of final mushroom consumers.

The market for specialty mushrooms is divided into two major segments: food service and retail (Schroeder, 1989). Mushrooms are usually sold to the food service industry in 3, 5 or 10 lb. (1.4 - 4.6 kg) bulk standard cartons made of corrugated cardboard. Most retail product is sold in prepacked punnets or trays. The most common retail package contains 3.5 oz. (100 g) of product and consists of either a labelled clear plastic punnet or tray overwrapped with polyethylene or stretch polyvinyl chloride (PVC) film. The packs are packed 6 or 12 in a master carton for shipping to individual stores. USDA regulations require that there be two 3.2 mm holes in the film of each prepack to ensure that aerobic conditions are maintained inside the package to reduce the risk of botulism. Hermetically sealed polyethylene bags are commonly used for enoki and have also been successfully used with shiitake (Przybylowicz & Donoghue, 1990).

Packers overweigh the amount of mushrooms in a prepack by up to 5% to guarantee the consumer receives the labelled weight of mushrooms when it is purchased. Many also have use-by-dates on each prepack to protect themselves from abusive handling and excessive shelf-life in

retail stores (Schroeder, 1989). In the US growers and packers commonly use unrefrigerated air freight to quickly ship fresh specialty mushrooms.

9.3.2 Merchandising

Retailers have increased specialty mushroom sales in the last few years by focusing on presentation and product availability. The marketing effort has concentrated on ensuring a consistent supply of swiss brown, shiitake, oyster and enoki (Plate 15). A full product range is generally available in a consistent and coordinated display. Bulk and prepackaged whole and sliced mushrooms in various size categories are offered to consumers as are leaflets and cards providing detailed information on their handling and usage. These information resources are also used to educate retailers. Prepacked mushrooms are handled carefully to avoid bruising and ample display space is provided to prevent stacking of packages on top of each other.

9.3.3 Market comparisons

At present the US specialty mushroom industry is 5-10 years ahead of the Australian industry in terms of its size, organisation and marketing activities. Cooperation between industry members in the US combined with industry growth has made resources available for promotion and consumer education. A number of producers have also become large enough to directly influence the marketing and handling of mushrooms by retailers. Strong emphasis is placed on good postharvest handling and packaging although problems with temperature management still exist, particularly during distribution.

A continuing lack of cooperation between Australian producers is preventing further expansion, growth and diversification of the domestic specialty mushroom industry. Although the food service sector is being successfully supplied the larger retailers do not place great importance on marketing and handling issues concerning specialty mushrooms due to a lack of industry influence and consumer information.

9.4 Value-adding opportunities

Several opportunities exist to develop new mushroom products that give consumers more purchasing choice and that could in some cases compete with imported canned and dried specialty mushrooms. These products can include sized, sliced or flash-blanching mushrooms.

In the US a number of fresh specialty mushroom products are now available including loose mushrooms sized into several categories that can be used in various ways by consumers. For example large mushrooms can be stuffed and small buttons can be used in salads. Prepacks of sliced portabellas and *A. bisporus* mushrooms are also available. The industry has also developed flash-blanching mushrooms that are quickly cooked and cooled to retain texture and flavour. Other products include baby versions of portabella mushrooms known as 'portabellini' that are a smaller and more savory version of the more mature portabellas (Anon., 1995).

Domestically, some value-adding takes place with premium-branded and fungi mix prepacks. A few growers are also able to sell large or unusually shaped product to the food service sector. Large scale value-adding in Australia is unlikely to take place until production of oyster, shiitake and swiss browns begins to exceed market demand for the whole product which is unlikely to occur in the short-term. Very little potential exists for the substitution of imported canned and dried mushrooms with fresh product as the processed products are generally used by a different market sector than that using the fresh equivalent (Anon., 1994).

Sliced *A. bisporus* mushrooms are already available at the retail level and it is likely that the greatest opportunity for value-adding in the long term lies with semi-processed specialty mushrooms.

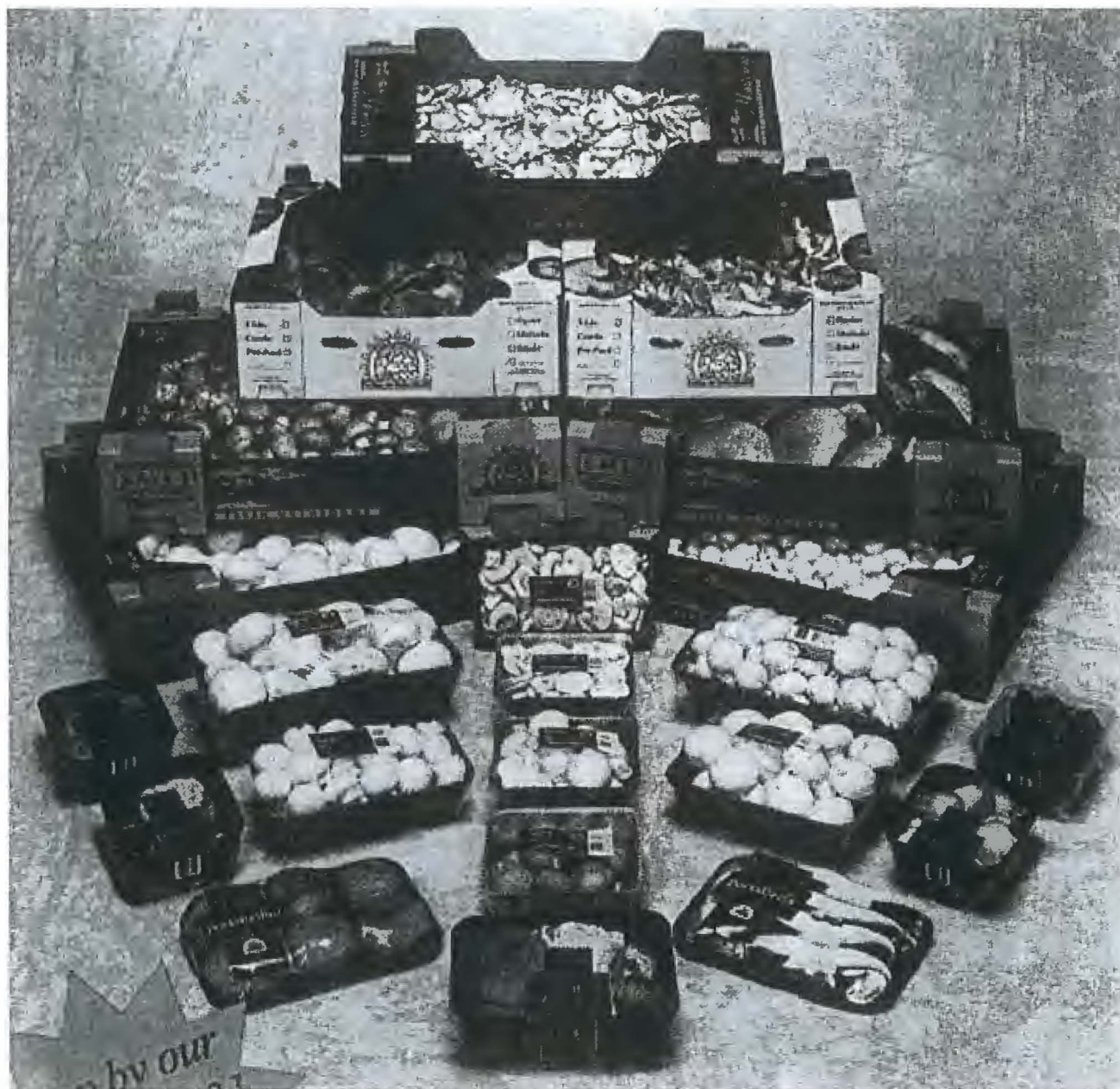


Plate 15. Range of specialty mushrooms consistently supplied to retailers in the US (Monterey Mushrooms®).

10. Literature review

A critical review of scientific and industry literature concerning postharvest handling of specialty mushrooms will provide valuable information for industry as well as establishing the current knowledge base in this area. It will cover the major specialty mushroom varieties identified in the industry survey and some of the new species with market potential (depending on the literature available).

10.1 Preharvest factors affecting postharvest shelf life

A number of preharvest factors are likely to substantially influence postharvest shelf life of specialty mushrooms. These may include effects due to genotype differences between strains of a particular species or morphological and metabolic variability across or between species. Production methods and harvest maturity can also play a role in determining mushroom quality and postharvest behaviour. Studies on *Agaricus* spp. have demonstrated that these factors can be important but to date little information is available which specifically relates to specialty mushrooms.

10.1.1 Botany and morphology

The group of edible fungi presently field picked and cultivated around the world contain many different mushroom varieties. In many cases these fungi have a similar morphology, and physiological characteristics to the common white mushroom, *Agaricus bisporus*. Each variety may also include a number of species suitable for cultivation that have varying quality attributes after harvest. Documented evidence of differences between species is scarce. Zadrazil (1978) found that *Pleurotus eryngii* has a good consistency (cap and stem), aroma and culinary qualities that would probably make it preferable to other *Pleurotus* species.

A number of quality factors are known to be influenced by mushroom strain. Differences in cap size and colour, dry matter content, nutritive value and in shelf-life have been observed between *Agaricus* strains (Schisler, 1983; Walton, 1987). A difference in texture (shear strength) between grey and Florida strains of oyster mushrooms stored at 2°C over ten days has been observed by Gormley and O'Riordain (1976). Currently, little is known about the effects of strain on the postharvest quality attributes of specialty mushrooms. Studies have mainly focused on comparing yields obtained using different mushroom strains and have been carried out for shiitake (Chung, 1994; Sabota, 1996). Shiitake quality is based on mushroom size, shape and thickness of the cap and stem, flavour intensity, flesh density and moisture content. Subjective evidence suggests that many of these quality traits are strain dependent. Warm weather strains have been found to produce thinner-fleshed log-grown shiitake while thick-fleshed fruit bodies are obtained using cold weather strains (Przybylowicz & Donoghue, 1990). Strains also differ in the number of aborted and misshapen mushrooms they produce. Although relative humidity during fruiting can modify mushroom moisture content, Royse and Bahler (1986) found that different shiitake strains grown under identical conditions produced mushrooms with different moisture contents. This difference affects storage life as mushrooms with a high moisture content generally have a shorter shelf life than those with a lower moisture content (Carey & O'Connor, 1991).

All fungi, with the exception of yeasts, grow as microscopic filaments called hyphae which extend and branch to form mycelium. This is the vegetative phase of fungal growth and in many

fungi is capable of unlimited growth given an unrestricted supply of nutrients (Elliott, 1985). The sexual phase of the fungi is represented by many types of spore-bearing structures of which edible mushrooms are just some. Most economically important fungi are Basidiomycetes that produce spores from club-shaped cells called basidia.

Mushrooms are an order of this group called Agaricales. Shiitake, oyster, swiss brown and the common white mushroom are members of this order. Typically these have gills, a cap (pileus) and a stem (stipe). Gills are thin, leaf-like flaps of tissue arranged on the underside of the cap on which spores are formed (Przybylowicz & Donoghue, 1990). The fruiting body of most Agaricales is made up of a mass of delicate, thread-like structures aggregated together and so is highly susceptible to bruising and discolouration. Mushrooms are also susceptible to rapid moisture loss as they have a high moisture content and lack the protective waxy cuticle commonly found on other horticultural produce.

Wood ear and white fungus belong to another order of Basidiomycetes known as Jelly Fungi and are characterised by spore production inside pores on the underside of woody or leathery gelatinous fruiting bodies. Morphological differences between mushrooms may account for differences in perishability. Chen & Hou (1978) determined that as with shiitake, the packing of white jelly fungus was far less of a problem than the packing of the white common mushroom as premature opening and discolouration was unlikely during storage. Poor handling practices were found to be less conspicuous in the white fungus than in other mushrooms with a delicate texture. It is very likely that the 'woody' nature of some mushrooms and leathery texture of jelly fungi are beneficial in preventing rapid quality loss during storage but as yet no information is available to confirm this hypothesis.

10.1.2 Cultural factors

Cultural practices including substrate selection and preparation, water relations and growing environment will have a significant affect on quality and postharvest shelf life. Growing practices determine quality of mushrooms at harvest, which is the point of optimum quality of the crop. Thereafter, quality loss can only be minimised and harvest qualities cannot be improved. Carey & O'Connor (1991), Noble & Burton (1993) and Beelman (1988) have reviewed studies on husbandry factors known to influence postharvest shelf life of *Agaricus bisporus*. In general, insufficient nutrition and water supply will lead to small, soft and misshapen fruit bodies while a high carbon dioxide level during cropping causes stipe elongation and leads to mushrooms with small caps and open veils. Moisture content of the compost was also found to influence mushroom quality after harvest. It has been demonstrated that mushrooms from drier composts have higher moisture contents which is undesirable as mushrooms with a high dry matter content have a firmer texture, greater nutritional value and are less prone to microbial decay (Schisler, 1983; Beelman, 1988). Dry composts also cause quality defects such as water-soaked stems and 'weepers', mushrooms which exude water. Variations in mushroom quality from one flush to another have been well documented. First flush mushrooms have greater protease activity and higher protein levels which may account for their generally shorter shelf life and poorer texture. Beelman (1988) found that lower cropping temperatures (11-13°C) resulted in yield reduction but significantly increased firmness and calcium levels compared to mushrooms grown at normal temperatures (17-19°C). These findings may also be applicable to swiss brown cultivation as both mushroom types are grown using similar substrates, and under similar environmental conditions.

The relationship between substrate composition and mycelial growth, and yield is well understood for cultivated edible fungi such as shiitake, oyster and straw mushrooms. Its effects on mushroom size, texture and shape, and postharvest shelf life are less clear and it is likely that these will be minor in comparison to the environmental affects on fruit body development. It is known that mushrooms grown on natural logs can have different quality attributes than those cultivated on artificial substrates.

Tomomura (1978) found that enoki grown on sawdust logs were more white, stiff and durable than natural log mushrooms and so better met market requirements. Shiitake produced on logs are more dense, have a stronger flavour and generally have a longer storage life than those grown on sawdust (Przybylowicz & Donoghue, 1990). Zadrazil (1978) found that preharvest factors affecting development of oyster mushroom fruit bodies are complex and that composition of substrate in connection with fruit body development is only slightly amenable to control and not well understood. In general, quality and quantity of shiitake and other mushrooms produced on a given medium, is in part, a function of the quantity and type of nutrients to which the fungi have access (Royse, 1985). For example, Arita (1978) determined that maltose was a better carbon source than glucose for fruiting of nameko mushrooms as it produced heavier fruiting bodies at harvest. The affects of different flushes and substrate moisture levels on specialty mushroom quality have yet to be fully quantified but it is common in shiitake production for the first flush of mushrooms to have a high percentage of aborted or misshapen fruit bodies (Przybylowicz & Donoghue, 1990).

Environmental conditions during cultivation are by far the most important factors influencing growth and quality of edible fungi. These can include air temperature, relative humidity, carbon dioxide (CO₂) level, ventilation and light. In many cases these factors affect the quality and shelf life of *A. bisporus*, shiitake, oyster and other mushroom types in a similar manner.

10.1.2.1 Growing temperature

Normal fruiting body development takes place at an optimum air temperature range that depends on species and strain. Outside these temperatures mushroom development may stop, slow down or abnormal fruit bodies can be formed with undesirable quality characteristics. Cropping temperature affects the speed of maturation and flesh density of shiitake with lower temperatures (below 15°C) resulting in denser and more intensely flavoured mushrooms that take longer to mature (Przybylowicz & Donoghue, 1990). Tomomura (1978) observed that at 10-12°C enoki fruit bodies grow rapidly but are slender, long and of poor quality while at 3-8°C they are stiffer and drier. Nameko mushrooms grown at 15°C or above tended to have a small pileus and slender stipe. Cropping temperature below 8°C produced mushrooms with larger fruiting bodies and that opened later during storage (Arita, 1978). It has also been noted that the quality of straw mushrooms diminished when cultivated above their optimum temperature range of 28-32° (Chang, 1978).

10.1.2.2 Relative humidity

Relative humidity of the growing environment affects fruit body growth and final moisture content. Low humidity causes mushrooms to transpire large quantities of water leading to scaliness and severe cracking of the mushroom surface (Flegg & Wood, 1985). 'Off-white' and brown strains are even more susceptible. These symptoms are commonly found when the transpiration rates of *A. bisporus* mushrooms are greater than 6 mg/cm²/hour while growth of enoki is severely restricted when the transpiration rate is higher than 1.4 mg/cm²/hour (Plunkett,

1956). High humidities (i.e. greater than 95%) tend to produce mushrooms that have a soft texture and that are more susceptible to bruising (Schisler, 1983). Przybylowicz & Donoghue (1990) found that the relationship between relative humidity and mushroom quality for shiitake is the same for log and sawdust cultivation.

Low humidity during cultivation (e.g. less than 80%) results in a drier mushroom generally having a higher quality but it can also cause drying out of the substrate and depletion of water reserves required for proper growth. Relative humidities greater than 85% tend to deform *Pleurotus* spp. resulting in shrivelled fruiting bodies of poor appearance (Zadrazil & Kurtzman, 1982).

10.1.2.3 Carbon dioxide levels

Carbon dioxide levels during mushroom development can have a significant affect on the shape and size of the fruiting bodies. Generally, high levels cause stem (stipe) elongation and a smaller cap (pileus) to be formed. High concentrations, up to 5% by volume, during *Agaricus* cultivation cause excessive elongation of the stipe, stretched veils and poor pileus development leading to a mushroom with a 'drum stick'-like appearance (Flegg & Wood, 1985). In another study, Walton (1987) found that increasing CO₂ levels from 1% to 1.7% during the development stage produced firmer mushrooms and reduced the incidence of open veil.

During shiitake production CO₂ levels must remain below 1.2% as higher levels can cause small-capped mushrooms with elongated stems (Royse, 1985). Composition of air in the growing room and *Pleurotus* fruit body development are directly related with lower CO₂ levels reducing the number of fruiting bodies per unit area but increasing mushroom quality. The effects of high CO₂ on the development of *Pleurotus* can be seen in Figure 7. The fungus (1) shows normal fruit body development. Air deficiency, high CO₂ concentration (1-2%) and less light results in a longer and thicker stipe and reduced size of the pileus (2 & 3) (Zadrazil, 1978). While there should be no problem in avoiding these extremes, it is necessary to avoid even a small amount of stipe elongation in the production of high quality mushrooms (Kurtzman & Zadrazil, 1982). The development of enoki (*Flammulina velutipes*) is highly dependent on CO₂ level. Plunkett (1956) showed that under continuous exposure to CO₂ in the air during cultivation, enoki pileus diameter decreased with increasing concentration of CO₂ (0.06 to 4.9% CO₂). Stipe elongation was less sensitive to CO₂ concentration than pileus expansion. It was also found that at very high CO₂ concentrations the rate at which mushroom growth and expansion occurred decreased markedly.

10.1.2.4 Light and mushroom development

Most cultivated mushrooms, other than *A. bisporus* and swiss browns, require light for the initiation of fruiting and for their normal development. There have been no carefully executed experiments on either the qualitative or quantitative light needs of most mushroom species (Kurtzman & Chang-Ho, 1982). The only qualitative information for a cultivated species that appears useful is the data of Aschan-Aberg (1960). He found that blue (short wavelength) light in the range of 435 to 470 nm was most effective for the development of enoki fruit bodies. Only a very small amount of light of the proper wavelength is required, but relatively large amounts of white light may be necessary. For practical purposes, the amount of light from a fluorescent lamp which is difficult to read by at the surface of the substrate is adequate for proper mushroom development.

Light appears to be an essential factor in the fruiting and development of wood ear fungus (*Auricularia* spp.) as under complete darkness the pileus fails to expand and the fungus develops a whitish colouration instead of the typical brownish-red colour (Quimio, 1982). Without light, only rudiments of enoki fruiting bodies are formed. Under these conditions, the stipe develops but not the pileus (Aschan-Aberg, 1960). Under dark or limited illumination the development of shiitake pilei and gills diminishes and fruiting bodies develop abnormally (Tokimoto & Komatsu, 1978). Similar morphological abnormalities occur during nameko development under dark conditions (Arita, 1978). Shiitake requires light during growth for the cap to develop colour (Royse, 1985). As shown in figure 7 light deficiency combined with high CO₂ leads to the development of *Pleurotus* mushrooms with longer and thicker stems and smaller caps (2 & 3). According to the observations of Zadrazil (1978) the gaseous environment is more important than light during the fruit development phase of this species.

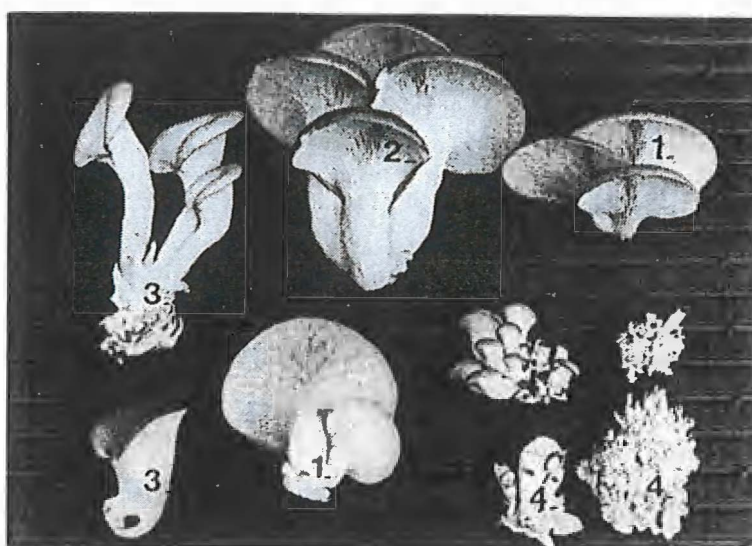


Figure 7. Influence of climatic conditions on the development of *Pleurotus ostreatus* (Zadrazil, 1978).

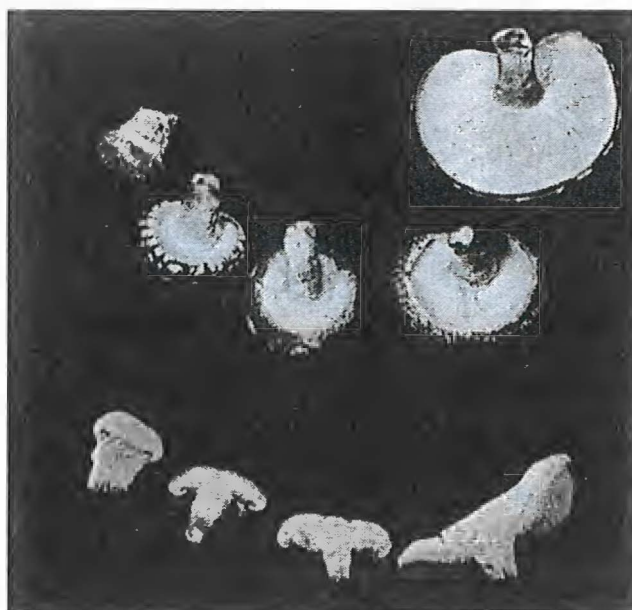


Figure 8. Stages in mushroom development of shiitake (Przybylowicz & Donoghue, 1990).

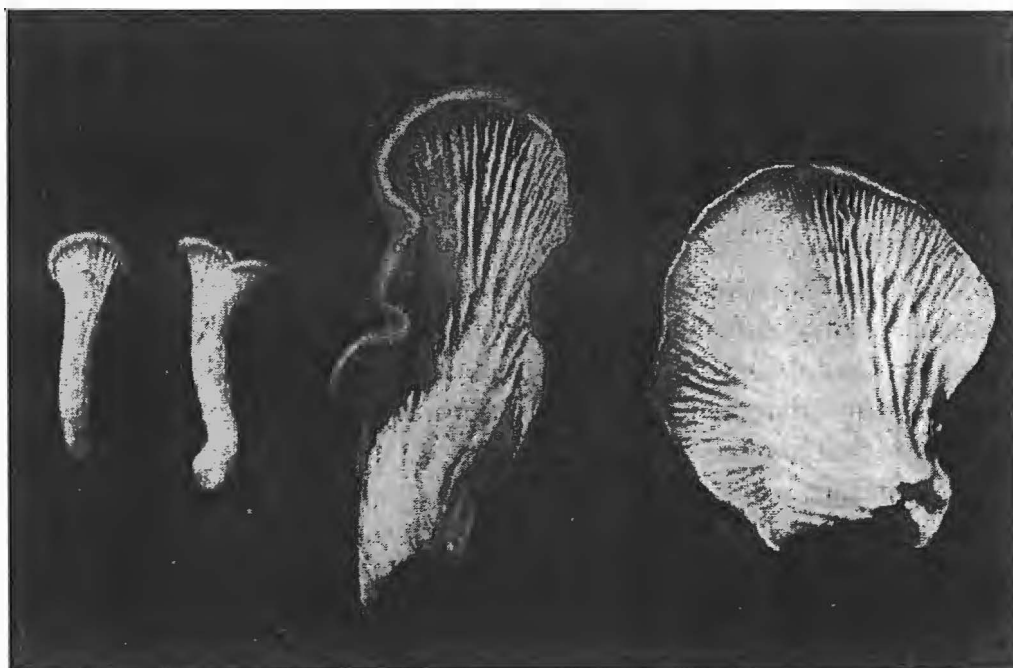


Figure 9. Various maturity stages of oyster mushroom. The second mushroom from right is at optimum maturity for marketing (Kurtzman & Zadrazil, 1982).

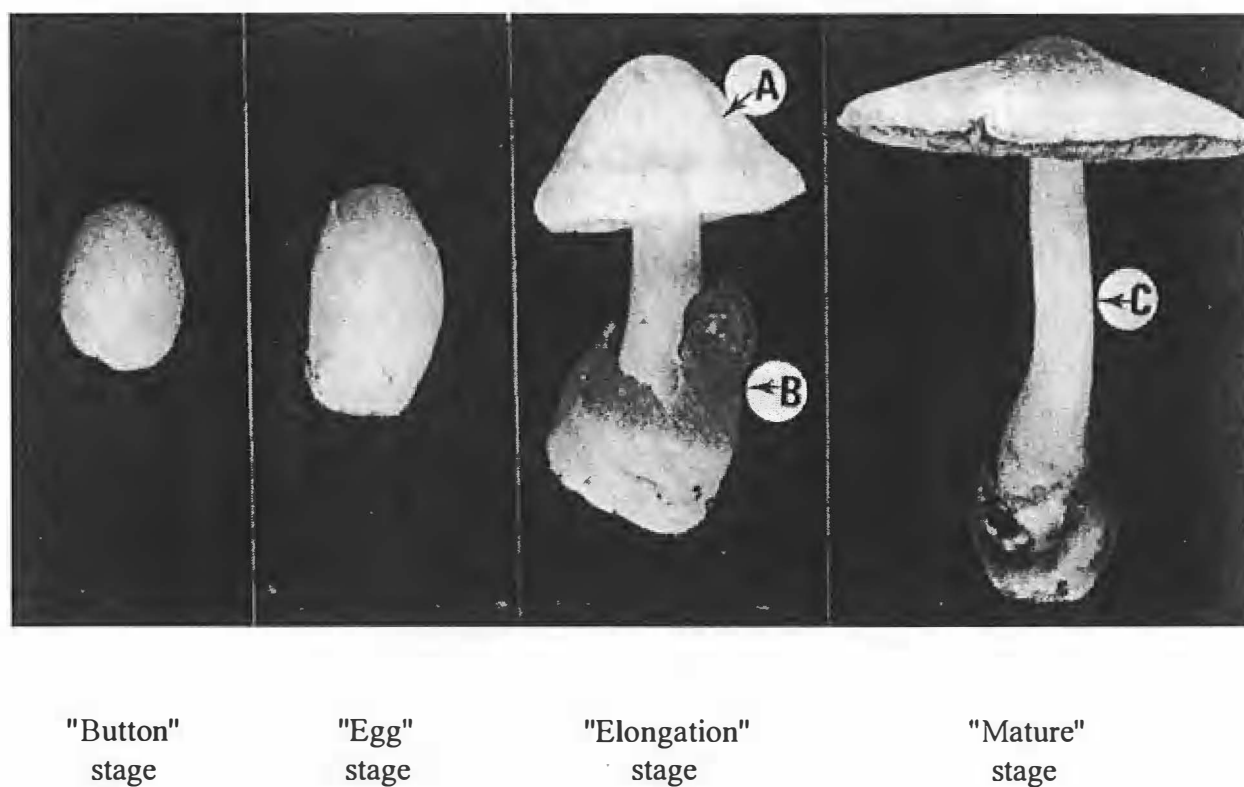


Figure 10. Different stages of development of the straw mushroom (*V. volvacea*) (Cho *et al*, 1982).

10.1.3 Harvest maturity

The stage of development at which edible fungi are harvested is essentially determined by market requirements. In some cases this maturity stage may not coincide with the optimum developmental stage for extended mushroom storage. Very few studies have quantified the relationship between mushroom maturity at harvest and shelf life of specialty mushrooms. Qualitative evidence suggests that respiration rates and susceptibility to damage during handling change with increasing maturity (Hammond & Nichols, 1975). Maturity may be defined either in a true biological sense or in a market sense. Biologically speaking, maturity of edible fungi is the time when spores are released. For marketing purposes, biological maturity is over-maturity (Kurtzman & Chang-Ho, 1982). Once a mushroom has reached this maturity stage, it serves its biological function in a very short time and then becomes a waste product of the fungus that produced it and thus would be expected to have a very short shelf-life.

Kohlí (1984) recommended that *Agaricus* spp. such as swiss brown mushrooms be picked at 'the closed button stage when they have gained maximum weight without deterioration in quality'. The flavour and aroma of mushrooms are important quality characteristics and it has been determined that properly mature, tight veiled, medium-sized mushrooms have a more desirable aroma than either small buttons or large flats. Commonly shiitake are harvested after the veil that covers the gills has ruptured, but before the cap has fully expanded. This corresponds to the cap being 50-70% open. The highest quality mushrooms have an in-rolled edge on the caps (Figure 8, Przybylowicz & Donoghue, 1990). Any mushrooms picked after this stage, with the cap fully expanded, will have a very short shelf life, poor texture and will be down graded in quality (Schroeder, 1989).

Oyster mushrooms should not be allowed to reach biological maturity before harvesting as at this developmental stage they become fragile, and it is difficult to handle and ship them without damaging them. Also they will tend to have a shorter shelf life than less mature mushrooms (Kurtzman & Zadrazil, 1982). Biological maturity is reached at the time the edge of the cap extends out straight and is no longer curled under (Figure 9). It appears that a market mature, high quality mushroom will have a curled edge, well-formed gills, be as compact as possible and have a very short stem. Cho *et al* (1982) determined that straw mushrooms harvested at the button stage could be stored longer than those at other stages, while there was no obvious shelf life difference among those at the egg, elongation and mature (open cap) stages (Figure 10).

10.2 Postharvest physiology of specialty mushrooms

Compared to most other horticultural products, edible fungi have a short shelf life after harvest. Mushroom metabolism adapts to sustain gill growth and spore production once the nutrient and water supplies have been cut off (Noble & Burton, 1993). These changes are reflected in changes in respiration rate and thus in levels of metabolic substrates (such as carbohydrates) in the tissue (Nichols, 1985). The readily observable changes due to these physiological processes are discolouration, water loss and changes in texture, aroma and flavour (Cho *et al*, 1982). Physiological processes involved in the postharvest deterioration of *A. bisporus* mushrooms has been comprehensively studied and reviewed (Beelman, 1988; Noble & Burton, 1993). The lack of literature concerning the postharvest physiology of other edible fungi means that there is a poor understanding of these processes and their affect on shelf life and quality.

10.2.1 Metabolism and development

The changes in respiration, ethylene and soluble carbohydrates (which make up 30-50% of mushroom dry weight) during postharvest storage of *Agaricus bisporus* have been investigated by Hammond and Nichols (1975). During 4 days storage at 18°C, mannitol levels in intact sporophores (fruiting bodies) have been shown to fall from 24.5 to 4% and glycogen levels from 11.8 to 4.5%. Minamide *et al* (1980c) found that mannitol levels fell by 45% and arabitol levels by 79% in shiitake mushrooms stored for 4 days at 20°C. The disappearance of significant quantities of mannitol from the sporophore during storage indicates that this is one of the main respiratory substrates and approximately half of the respired CO₂ can be accounted for by the oxidation of mannitol. The study of axenic (pure) cultures of *A. bisporus* showed that maximum ethylene production occurred subsequent to veil break as the gill colour changed from pink to brown. Ethylene production then declined as the fruiting body sporulated and senesced. Soluble carbohydrates decreased by over 50% in oyster mushrooms (*Pleurotus flabellatus*) stored at ambient temperature for 24 hours (Rajarathnam *et al*, 1983), indicating their probable utilization as respiratory substrates during storage. Hammond and Nichols (1975) found that the pattern of postharvest respiration depended on the maturity of the mushroom at harvest. A respiratory peak was observed, and this peak appeared to correspond with the phase of rapid gill development which occurred after the harvest of immature fruiting bodies. In general, harvested mushrooms have a short storage life and a correspondingly high respiration rate at ambient temperature relative to other horticultural products (Lutz & Hardenberg, 1968). It is conceivable that tropical fungi such as the straw mushroom (*Volvariella volvacea*) may have an even higher respiration rate than most cultivated fungi (Cho *et al*, 1982).

Proteins are the main source of nitrogen for redistribution after harvest. The level of soluble proteins in sporophore tissue decreases during postharvest storage (Burton, 1988). Protease activity increased throughout the 24 hour storage time of oyster mushrooms (*P. flabellatus*) corresponding to a rise in free amino acid levels (Rajarathnam *et al*, 1983). Minamide *et al*, (1980a) found that free amino acid content increased in shiitake, nameko and oyster mushrooms during storage for 7 days at 20°C. Such a liberation of low molecular weight nitrogenous compounds is thought to support the postharvest development of cultivated fungi (Murr & Morris, 1975a). Postharvest expansion of the pileus by growth of gills and elongation of the stipe are supported by increased nitrogen-containing chitin and protein levels in the cell walls (Hammond, 1979).

Studies by Beelman *et al*, (1987) found that mushroom textural properties change after harvest. At harvest mushrooms are firm (resist deformation) and tender (easy to shear or chew), but they subsequently soften and toughen during postharvest deterioration. Minamide and Ogata (1978) observed changes in the sugars and amino acids of log-cultivated shiitake during different harvest seasons and their effect on the quality of mushrooms after harvest. Taste tests demonstrated that texture of shiitake was better in spring and autumn, and sugar and free amino acid content was found to be higher in summer. There appears to be no studies of the changes in lipid or fatty acid composition of mushrooms during storage. Lipids are likely to play an important role in storage since most lipids are contained in the cell membrane which would also undergo changes as the mushroom deteriorates. It has been suggested that the straw mushroom (*Volvariella volvacea*) which contains a substantial amount of unsaturated fatty acids is incapable of adjusting its fatty acid composition adequately during low temperature storage. This may explain its susceptibility to chilling injury, liquefaction and subsequent autolysis (Cho *et al*, 1982). Hammond and Nichols (1975a) have demonstrated that gill dry weight increases

during storage while the dry weight of the pileus and stipe diminish. Ajlouni *et al* (1992) found that the rate of cap opening depends on stipe length indicating that the stipe acts as a major nutrient source for developing gill tissue.

The ageing of mushrooms during storage is characterized by the loss of flavour and aroma (Cho *et al*, 1982). The flavour of mushrooms is due to many non-volatile components such as amino acids, carbohydrates and nucleotides but their distinctive flavour and aroma is due to volatile compounds. The most important of these components in *A. bisporus* and most other cultivated fungi is a C₈ compound, 1-octen-3-ol, that possesses an intense flavour typical of mushrooms (Manning, 1985). During postharvest storage of mushrooms, the contents of both 1-octen-3-ol and the enzymes responsible for its synthesis were found to decline (Mau *et al*, 1993). It has been established that the main difference in the volatiles of *A. bisporus* present after cooking was an increase in the content of 1-octen-3-one, a compound with a very strong flavour. This compound is believed to be formed by the oxidation of 1-octen-3-ol (Manning, 1985). Various methods of drying mushrooms have been found to result in major losses of these volatile compounds (Sulkowska & Kaminski, 1977).

10.2.2 Enzymatic browning

The browning reaction of mushrooms is a normal feature of postharvest ageing, but the rate at which it occurs can be increased by mechanical damage or bacterial infection. The major enzyme responsible for browning is tyrosinase, a copper-containing oxidase, which catalyses the oxidation of colourless phenols (Noble & Burton, 1993). During normal mushroom development this enzyme and its phenolic substrate are kept apart by membrane boundary layers within the cells. As a result of bruising or ageing, enzymes and substrate intermix and react with oxygen to form brown pigments (quinones) (Nichols, 1985). The activity of the enzyme and the amount of substrate present determine the intensity of browning. Tyrosinase activity and phenol concentration have been shown to be higher in the skin of the pileus than in the underlying pileus flesh (Burton *et al*, 1993).

Rajarathnam *et al* (1983) determined that during storage of white oyster mushrooms (*P. flabellatus*), O-diphenoloxidase activity increased with a parallel decrease in total phenolic content. The discolouration produced by enzymatic browning was more visible on the ventral gill bearing side than on the dorsal surface and this supports the fact that phenol oxidases are concentrated in the gills.

10.2.3 Role of carbon dioxide and oxygen

The senescence-retarding effects of increased carbon dioxide levels and decreased oxygen levels on *A. bisporus* mushrooms has been well documented (Burton, 1991). These affects lead to delayed cap browning, and the retarding of postharvest development and microbial spoilage. Murr and Morris (1975b) showed that CO₂ *in vivo* reduced the diphenol oxidase activity of *A. bisporus*. Briones *et al* (1992) found that increased CO₂ levels had a greater influence on retarding cap discolouration than reduced O₂ levels and that CO₂ was a major factor influencing texture and cap opening of *A. bisporus*. Modified atmospheres can inhibit respiration and mannitol loss but the fruiting body can adapt by increasing its rate of respiration (measured in air) particularly in response to increased CO₂ concentrations. Murr and Morris (1975b) showed that a reduction of O₂ level to 2% or an increase of CO₂ to 5% had no effect on the induction of postharvest protease activity.

Minamide *et al* (1980c) showed that elevated CO₂ strongly inhibited polyphenol oxidase activity and the increase in free amino acid content during storage of shiitake mushrooms at 20°C while only levels of O₂ below 2% had the same effect. An atmosphere comprising 2% CO₂ and 2% O₂ was found to minimise changes in nucleotide and protein levels in shiitake stored at 2°C for 120 days (Kim *et al*, 1989). The same study also determined that high amounts of ethanol and acetaldehyde were produced from mushrooms stored in different CA conditions after 20 days storage at 2°C while changes in the levels for mushrooms stored in air were negligible. After 40 days, ethanol and acetaldehyde production in CA-stored shiitake had dropped to negligible levels while production in air-stored mushrooms began to increase significantly. Ethanol and acetaldehyde are major off-flavour compounds produced during CA storage of mushrooms but the accumulated ethanolic odour of CA-stored mushrooms can be eliminated by aeration for a few hours with fresh air after storage as demonstrated by Minamide *et al* (1980c).

10.3 Postharvest handling of specialty mushrooms

Specialty mushroom quality during marketing can only be maintained using proper postharvest handling practices. Factors such as physical handling, grading, package design and postharvest environment will influence mushroom shelf life and so need to be considered and understood.

10.3.1 Harvesting and handling

Edible fungi are highly susceptible to bruising and physical injury. Mishandling mushrooms during marketing can lead to increased respiration rates and enzyme induced deterioration such as discolouration which substantially reduces shelf life. Oyster, enoki and to a lesser extent shiitake mushrooms and wood ear fungus are easily injured when squeezed, shaken or dropped. The effects of mild bruising on the shelf life of *A. bisporus* were clearly demonstrated by Burton and Noble (1993). Controlled shaking of mushrooms in an oscillating polystyrene carton for 10 seconds caused an increase in discolouration which reduced their shelf life by 36 hours.

Careful harvesting will minimise physical injury. *Agaricus* and swiss brown mushrooms are picked by gripping the cap and twisting and bending to break off the stem at the base. This is easily done with closed mushrooms; open ones are more fragile and more care is needed to ensure that the stem breaks at the bottom, not at the top (Edwards, 1978). Shiitake are picked by twisting or cutting them off at the substrate surface. Generally, the lower portion of the stem is grasped firmly and the mushroom is twisted and pulled off (Schroeder, 1989). Only the stem should be touched during picking as bruises on the cap or gills will discolour rapidly. Twisting does not work well with wet mushrooms, since bruising of the stem is unavoidable. Cutting shiitake from the substrate minimizes physical damage to both the mushroom and the substrate (Przybylowicz & Donoghue, 1990).

10.3.2 Grading systems

At present there is no accepted terminology for grades, let alone grade standards in Australia for the main cultivated mushrooms such as shiitake, swiss brown and oyster due to high consumer demand and specialty mushroom industry fragmentation. In the long term mushroom size and maturity standards are required to educate retailers and consumers. Once these are defined quality issues can then be addressed (Lanz, 1994). Standards for *A. bisporus* mushrooms have been set by the United Nations, Economic Commission for Europe (UN/ECE) which concern the marketing and commercial quality control of cultivated mushrooms. These standards have set specifications concerning cap diameter, maturity (ie. cap opening) and stalk length. Mushrooms

are placed in two categories, either open or closed and each one of these includes small, medium and large sizes.

The Japanese grading system for fresh shiitake is currently the most detailed and is shown in Table 6 (Anon., 1979). An informal grading method has developed in the United States that closely mirrors the grading system used for white button mushrooms and is more descriptive than the Japanese system (Table 7, Schroeder, 1989). No information is currently available on grading standards for oyster mushrooms in Australia and second grade oysters that consist of either very large or very small, mis-shapen or diseased mushrooms are not packed.

Table 6. Japanese fresh shiitake grading system.

Grade	Cap opening	Cap shape	Cap diameter	Other characteristics
"A" (premium)	Veil partially intact or <70% open	Round and regular	Large (6-8 cm) Medium (4-6 cm) Small (<4 cm)	Thick, dry flesh
"B" (standard)	>70% open	May be irregular	Large (6-8 cm) Medium (4-6 cm) Small (<4 cm)	Usually has thinner, wetter flesh than "A"

Table 7. Informal US fresh shiitake grade standards.

Grade*	Cap opening	Cap characteristics	Size	Colour	Cap diameter to stem length
#1 (premium)	50-70% open	Round, no irregularities	Medium approx. 4 to 8 cm	Light to chocolate brown cap and creamy white gills	1.6 to 1
#2	Fails any requirements for cap expansion, size, shape, colour or stem length				

*Both grades exclude mushrooms with disease, spots, insect injury, decay and damage by any cause.

Wilcke *et al* (1989) have designed a shiitake mushroom grading and packing line that large growers or co-operatives could use to weigh, clean, sort, grade and pack incoming mushrooms. The packing line is designed to reduce physical damage during grading and packing and increase the efficiency of the process. It was determined that seven workers could pack three hundred 100 gram prepacks per hour.

Success in marketing of straw mushrooms depends on good quality mushrooms that must meet important grades or criteria. Unopened fruit bodies (buttons) are preferred over fully-opened flats. Acceptable size of premium grade mushrooms must fall between 2.5-3.5 cm in diameter and colour can vary from dark grey to white. A round mushroom is desired but oblong is acceptable (Chang, 1978).

10.3.3 Precooling systems and quality

The purpose of precooling is to slow the temperature-dependent metabolic changes associated with growth and development of mushrooms as quickly as possible. The most common techniques for precooling mushrooms are vacuum cooling, forced air cooling and room cooling. Vacuum cooling relies on the evaporative heat loss resulting from reduced pressure in a vacuum chamber. Very rapid cooling (under 20 minutes from ambient to 2°C) ensures maximum shelf life retention. However, the high capital cost of equipment, the additional requirement for a cold store to keep produce cool and the high mushroom volumes required make this system impractical for many producers. Mushroom weight losses of 2% per 10°C fall in temperature are also incurred (Noble & Burton, 1993). Forced air or pressure cooling relies on humid, cold air passing through and around mushrooms stacked in cartons. The containers must be properly ventilated to allow the passage of air. The main advantages of this cooling process is that the high moisture content of the air reduces product weight loss to 1.3% per 10°C drop in temperature and that it reduces the cooling time by up to ten times compared to room cooling. That is, from 7.8 hours to 0.7 hours (Wade, 1982). Forced air ventilation systems have been developed that are able to achieve cooling performances similar to those of vacuum coolers. The commonest cooling method used by Australian specialty mushroom growers is room cooling. Mushrooms are placed in cartons or trays and depending on the quantity, either stacked or placed on racks. Cold air then flows around and over the containers and heat must travel from the middle to the outside of the stack by conduction which is a slow process. Single containers placed on racks optimises air-to-package contact. Room cooling was demonstrated to be a slow cooling method as mushrooms placed in single cartons inside a cool room at 0°C took up to 8 hours to cool from 20°C to 2.5°C (Wade, 1982). Although inexpensive, room cooling will often be too slow for optimum maintenance of shelf life.

Marketing experience suggests that the rate at which mushrooms are cooled after harvest will have a significant impact on storage life and quality as the respiration of shiitake is 3-4 times higher at 10°C than 0°C (Schroeder, 1989). Documented evidence of this quality difference for cultivated fungi is minimal. Minamide *et al* (1980b) has demonstrated that delayed or incomplete precooling of shiitake mushrooms after harvest has a detrimental affect on shelf life. The effect of pressure cooling compared to room cooling on quality of *A. bisporus* was determined by Noble and Bartlett (1986). The whiteness of mushrooms stored at 5°C in a cool room for 20 hours was not significantly different to that of mushrooms pressure cooled and then stored in a similar manner. Other quality parameters were not measured and quality differences may have been detected if a longer storage time was used. A similar experiment where vacuum cooled and room cooled mushrooms were stored at 18°C for 5 days showed that vacuum cooled mushrooms were significantly better with regard to colour and reduced enzymatic browning, than those conventionally cooled (Burton *et al*, 1987a).

10.3.4 Package design

Modern mushroom packaging, whether in the form of punnets or larger bulk cartons, must protect the product from bruising. The majority of mushroom prepacks presently used in Australia provide very little protection against pressure or compression damage and so quality is compromised at retail outlets. Some plastic punnets have also been found to cause pressure damage to mushrooms due to the use of ribbing to strengthen the punnet. Schaper *et al* (1988) suggested that if the unit weights of packed mushrooms exceed a certain value then it is very likely that mushrooms in the bottom layers will develop pressure spots that reduce their quality. Other aspects of packaging which influence postharvest shelf-life are the effect on cooling performance, minimisation of weight loss and the use of modified atmosphere packaging (which will be discussed in a separate section).

Since rapid cooling of mushrooms after harvest is extremely important in extending their shelf-life, bulk containers must have sufficient openings to allow efficient precooling. Due to the small-scale of production and rudimentary cooling facilities used locally, rack-cooling of specialty mushrooms in cartons or plastic trays has become the most common precooling technique. These open containers allow cold, humid air to pass over and around mushrooms and cool them relatively quickly. The only information available on the effects of package type on cooling efficiency and shelf life concerns *A. bisporus* but this information is still useful as most other mushrooms are handled in a similar manner.

Noble (1989) assessed the suitability of different marketing containers for the rapid cooling of mushrooms using forced-air cooling. The containers tested included 1.8 kg cardboard cartons, 2.3 kg plastic trays, 2.3 kg and 4.6 kg polystyrene boxes, and 230 g plastic punnets. Each type of container had ventilation holes of various sizes and number. It was determined that the cardboard cartons had the longest half-cooling time while the plastic trays the shortest. Weight loss during cooling was greatest in the plastic trays and least in the cardboard cartons. In general, the container with the shortest cooling time had the highest weight loss. No significant difference was found between containers in terms of mushroom discolouration during storage but there was an increase in the amount of cap opening in mushrooms cooled in cardboard cartons compared with other containers after 48 hours storage. Total weight loss during precooling and storage was greatest from mushrooms in cardboard cartons and plastic trays and least from expanded polystyrene containers.

The effect of different types of container on mushroom cooling rates and quality during vacuum cooling were documented by Noble (1985). It was demonstrated that there was no significant difference in cooling time between three types of container, 1.4 kg cardboard and plastic trays, and 230 g plastic punnet. Differences in mushroom weight loss between product cooled in each of these containers were found to be negligible. Gormley (1975) found that film over-wrap had a beneficial effect in maintaining the appearance of vacuum cooled mushrooms by possibly reducing the enzyme activity which causes browning. However, if vacuum cooling is to be effective the over-wrap must be perforated.

10.3.5 Temperature management

Good temperature management during storage, distribution and marketing is critical in maintaining mushroom quality after they have been pre-cooled to their optimum temperature. Very few studies documenting actual mushroom temperatures during distribution or describing better handling systems are available. Partis and Noble (1989) describe the use of insulated

containers for the cool distribution of small unit loads of mushrooms (*A. bisporus*) to a number of outlets. This study is particularly relevant as this distribution scenario is very common in Australia. In practice the management of insulated containers proved straightforward. Temperature control and humidity levels were better compared to the standard cool chain distribution system using open pallets. The produce in insulated containers also arrived at retail outlets in better condition. This system was recommended for use when high ambient temperatures are encountered between harvest and distribution and when the standard cool chain is not continued into the retail outlet.

Temperature monitoring of mushrooms during routine postharvest handling and transport highlighted the difficulties encountered in maintaining a complete cool chain (Gormley, 1991). Data obtained illustrated that many growers did not precool their mushrooms properly and that product temperatures generally ranged from 8°C to 10°C during packing and transport. The pinpointing of weak links in the cool chain allowed growers to take corrective action and to evolve the best possible distribution system.

10.3.6 Postharvest pathogens

Growth of microorganisms in mushrooms may cause bacterial soft rot, production of off-odours and in some extreme cases production of toxic compounds such as mycotoxins. Microbial growth can occur at low temperatures if the product is contaminated by moulds or psychrophilic bacteria. At high temperatures thermophilic bacteria dominate (Cho *et al*, 1982). Bacterial growth is a major factor in postharvest deterioration of fresh mushrooms. High initial bacterial populations, high storage temperatures and free water on mushroom surfaces have been determined as the major causes of microbial spoilage in cultivated fungi (Beelman *et al*, 1989). Cho *et al* (1982) showed that storage of straw mushrooms at 30°C and 37°C not only increased the respiration rate but also the rate of microbial spoilage. Studies have shown that preharvest watering of *A. bisporus* with chlorinated water reduces bacterial populations at harvest but the effectiveness of this treatment is somewhat nullified by the increased moisture in the mushrooms which can lead to rapid bacterial growth during storage particularly in over-wrapped product (Beelman *et al*, 1989). Overly wet mushrooms or condensation inside packages induced by temperature changes results in microbial spoilage. Other factors that influence susceptibility to disease include chilling injury and physical damage. Briones *et al*, (1992) found that low O₂ concentrations during storage reduced the growth of microorganisms in *A. bisporus*, including *Pseudomonas* spp.

The bacteria causing botulism (*Clostridium botulinum*), which is fatal to humans, only grows rapidly and produces toxin in low oxygen conditions. It is not a problem during storage unless mushrooms are packed in air-tight containers and stored at warm temperatures (Kautter, 1978). Sugiyama & Yang (1975) determined that inoculated *A. bisporus* prepackaged in PVC film and stored for 6 days did not become botulinogenic when held at 4°C but that botulinum toxin was found after 3-4 days storage at 20°C. The high mushroom respiration rate used up O₂ more rapidly than it could enter through the semi-permeable film, so that the equilibrium O₂ concentration fell below 2%.

Knowledge of the affects of postharvest fungi on mushroom deterioration is limited and further research is required. Over-mature or excessively wet log-grown shiitake mushrooms can be infected by fungi during storage (Przybylowicz & Donoghue, 1990). No research to date has been specifically aimed at determining the best methods of preventing disease and decay in

specialty mushrooms. At present wastage due to microbial spoilage is not a major problem for locally grown mushrooms but poor temperature management and the lack of understanding of its cause are areas that need to be addressed. Microbial spoilage seems to be a greater problem with imported product as it has usually been stored for long periods and is bruised or damaged by the time it is marketed in Australia.

10.4 Environmental factors influencing postharvest shelf life of specialty mushrooms

Relatively more is known about the environmental factors influencing the shelf life of cultivated fungi than other postharvest handling factors that impact on quality.

10.4.1 Temperature

Temperature influences the physiology of cultivated fungi by its effect on metabolic and enzyme activity, moisture loss and growth of microorganisms (Nichols, 1985; Cho *et al*, 1982).

10.4.1.1 Metabolism and respiration rate

The rates of chemical change in living tissue are determined by the rates of enzyme activity. Broadly, they are doubled or halved for every 10°C rise or fall in temperature respectively so that at 0°C metabolic activity is slowed down, but not stopped (Wills *et al*, 1989).

The affects of temperature on the postharvest physiology and shelf life of *Agaricus bisporus* has been well documented (Beelman, 1988; Nichols, 1985; Murr & Morris, 1975a; Hammond & Nichols, 1975). Due to their relatively short shelf life, cultivated fungi would be expected to have high respiration rates and this is confirmed by the few studies made. Bohling and Hansen (1989) determined the respiration activity of fresh oyster mushrooms (*P. ostreatus*) after 7 days storage at 1, 3.5, 8 and 15°C (Figure 11), and evaluated their quality characteristics after a further 2-3 days under marketing conditions at 12-15°C. Respiration rate correlated with visible quality deterioration quite well. It was only marginally higher at 3.5°C than 1°C, but increased exponentially with further temperature elevation and hence may be regarded as a reliable criterion for the ageing rate of oyster mushrooms.

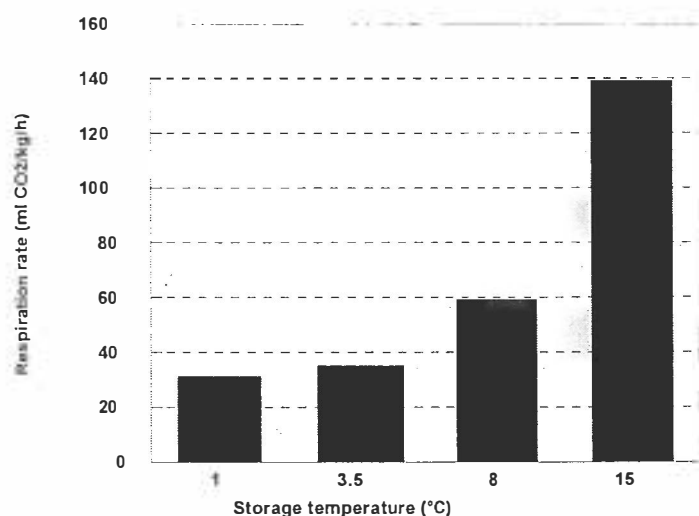


Figure 11. Postharvest respiratory activity of oyster mushroom (*Plerotus ostreatus*) after 7 days storage at indicated temperatures (Bohling & Hansen, 1989).

The relationship between respiration rate and deterioration, as indicated by discolouration and undesirable mushroom growth for log-grown shiitake, enoki, nameko and oyster mushrooms stored for up to 20 days at 1, 6 and 20°C has been documented by Minamide *et al* (1980a). Table 7 gives an indication of the differences in peak respiration rates at various storage temperatures. High respiration rates, as compared to other horticultural products, were observed for all fungi studied and ranged from between 90 and 230 ml/kg/h at 20°C. Increased polyphenol oxidase activity, cap opening and stipe elongation were particularly well correlated with increased amounts of CO₂ respired by shiitake mushrooms (Figure 12). Although published respiration data during mushroom storage is limited a few studies have demonstrated that cultivated fungi have relatively high respiration rates and that this is closely related to their high perishability during storage.

Table 7. Peak respiration rates of enoki, nameko and oyster mushrooms store at indicated temperatures for up to 20 days (Minamide *et al*, 1980a).

Mushroom	Storage time at measurement (days)	Respiration rate (ml CO ₂ /kg/h)		
		1°C	6°C	20°C
Enoki	5	47	104	234
Nameko	3	35	83	170
Oyster	5	16	46	134

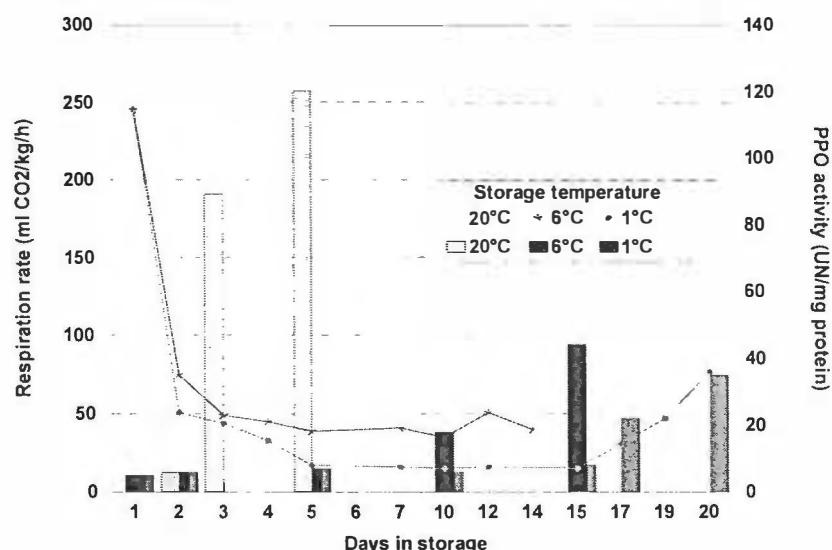


Figure 12. Changes in respiration rate and polyphenol oxidase activity of shiitake mushrooms during storage at indicated temperatures (Minamide *et al*, 1980a). Vertical bars represent PPO activity and lines represent respiration rate.

10.4.1.2 Storage temperature

Proper temperature management during postharvest handling is the most important factor in maintaining cultivated mushroom quality. The recommended optimum storage temperature for most fresh mushrooms varies according to the source of the data but it is generally agreed that it is in the range of 0-2°C (Nichols, 1985; Schroeder, 1989; Cho *et al*, 1982; Tomkins, 1966; Sveine *et al*, 1967). The majority of research concerning storage temperature and shelf life of

specialty mushrooms has been conducted under predictable environmental conditions. The unpredictability of conditions during marketing is recognised but has been overlooked so that storage lives determined in these studies may be unrealistic and can be misinterpreted (Nichols, 1985). In general, mushrooms stored outside their optimum temperature range will deteriorate at a faster rate due to increased metabolic activity, growth of microorganisms, increased postharvest growth and moisture loss, and faster discolouration. Most of the literature on the effects of storage temperature on quality and shelf life concerns *A. bisporus* with some information available on oyster and shiitake mushrooms.

Murr and Morris (1975a) demonstrated that *A. bisporus* stored at 10°C and 20°C showed a sigmoid pattern of growth, while at 0°C growth was retarded. The postharvest growth exhibited at 10°C and 20°C could be related to a decrease in free α -amino nitrogen whereas at 0°C there was a significant increase in the level of free α -amino nitrogen during storage. Mushrooms stored at 20°C toughened and matured faster than those stored at 10°C and 0°C. Changes in enzyme activity as a function of both temperature and storage period has been studied and it was determined that colour changes at 2°C and 10°C were slight after ten days but at 25°C colour was unacceptable after only four days and deteriorated badly after six days. When the enzymatic oxidation of O-diphenol was lowered by storage at 0°C, *A. bisporus* did not deteriorate over a period of thirty days (Goodenough, 1976).

Bohling and Hansen (1989) evaluated the quality preservation of oyster mushrooms (*P. ostreatus*) stored at 1, 3.5, 8 and 15°C for one week followed by a two day marketing period at 15°C. Evaluation was based on visual characteristics such as colour, shape, surface appearance, mycelial growth and mushroom firmness. Methods used to measure these changes were not described. Storage of mushrooms in air at 1°C and 3.5°C allowed good quality preservation for one week. Quality of mushrooms stored at 3.5°C was not significantly different to that of those stored at 1°C. After storage for one week at 8°C mushroom quality was still acceptable although there was noticeable discolouration and loss in firmness compared to mushrooms stored at lower temperatures. Oyster mushrooms stored at 15°C were spoilt after seven days due to severe darkening of the cap and gills, decreased turgor, and soggy caps. A phenomenon particularly conspicuous in oyster mushrooms was the growth of hyphae beyond the surface of the stem, cap and gills, causing the impression of mould infestation.

Gormley and O'Riordain (1976) observed the quality changes of grey and Florida strains of oyster mushrooms stored in uncovered fibreboard trays at 2°C and 17°C. The limiting factor on shelf life was the appearance of the mushrooms which was adversely affected by the growth of superficial mycelium on the mushroom cap. This generally developed in 1-2 days in mushrooms stored at 17°C and after 6-8 days in mushrooms held at 2°C. Mushroom weight loss in a given time was less at the lower temperature while no significant differences were detected in flavour or colour between mushrooms stored at the two temperatures.

Minamide *et al* (1980a) comprehensively studied the effect of storage temperature on the shelf life and quality of button (*A. bisporus*), oyster (*P. ostreatus*), shiitake (*Lentinus edodes*), nameko (*Pholita nameko*) and enoki (*F. velutipes*) mushrooms. In general the shelf life of these mushrooms under experimental conditions was about 14-20 days at 1°C, about 10 days at 6°C and 2-3 days at 20°C. It was found that deterioration of mushrooms was mainly caused by opening and browning of the pilei, as well as elongation and browning of the stipes. Browning of the gills, stipe and pilei and increased polyphenol oxidase activity was particularly evident for *A.*

bisporus and shiitake stored at 20°C. The effect of storage temperature on the visual quality of the mushrooms is summarised in Table 8. A freshness score below 2 indicated that mushrooms had badly deteriorated and were virtually unsaleable. Figure 13 demonstrates the effect of temperature and storage time on the rate of pileus (cap) opening for enoki while figure 14 shows the loss of whiteness or rate of discolouration (represented by Hunter L values) of shiitake stored at different temperatures. Shiitake storage life is similar to *A. bisporus* and is 2-3 weeks at 0-2°C and 85-95% humidity when stored in open containers (Przybylowicz & Donoghue, 1990).

Table 8. Effect of temperature on visual quality and freshness of mushrooms after storage for 3 and 8 days (Minamide *et al*, 1980a).

Mushroom	Freshness score ¹ after storage at indicated temperature ²					
	3 days storage			8 days storage		
	1°C	6°C	20°C	1°C	6°C	20°C
Button	7.8	6.8	1.2	4.8	2.6	-
Shiitake	7.9	7.7	1.4	7.0	5.2	-
Nameko	7.8	7.4	1.6	4.1	2.2	-
Oyster	7.9	6.5	2.8	3.7	2.6	-
Enoki	7.9	7.3	3.6	4.8	-	-

¹ Freshness score: 8=fresh, 6=slightly deteriorated, 4=deteriorated, 2=markedly deteriorated but saleable, 0=unsaleable.

² Mushrooms stored at 6°C and 20°C all had freshness scores of 2 or less after 10-13 days storage.

A US merchandising guide (Anon., 1996) recommends the following storage temperatures for specialty mushrooms; shiitake and enoki at 1-3°C; oyster mushrooms at 3°C; and swiss browns and portabella mushrooms at 1°C. These specific optimum temperatures were most likely obtained through industry experience as no reference source was given.

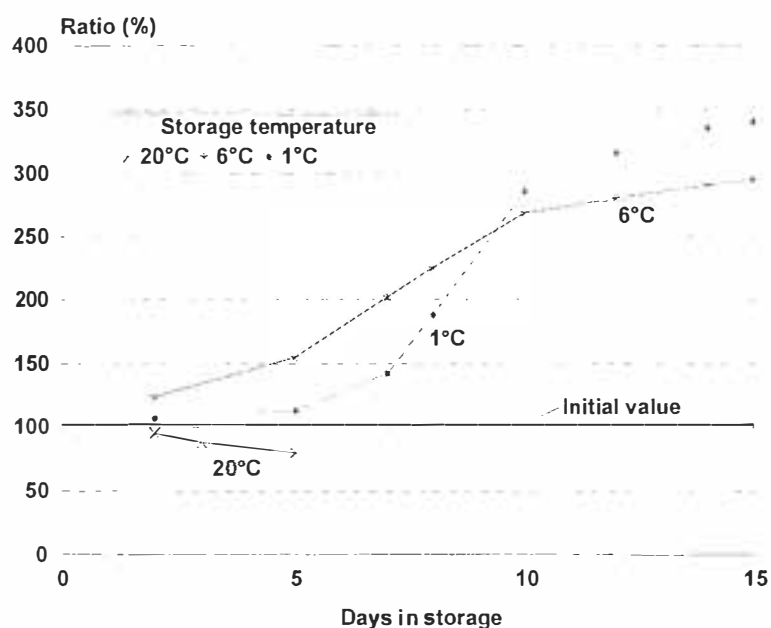


Figure 13. The changes in pileus (cap) opening of enoki during storage at indicated temperatures. Ratio is expressed as a percentage of the initial value = 100%. (Minamide *et al*, 1980a).

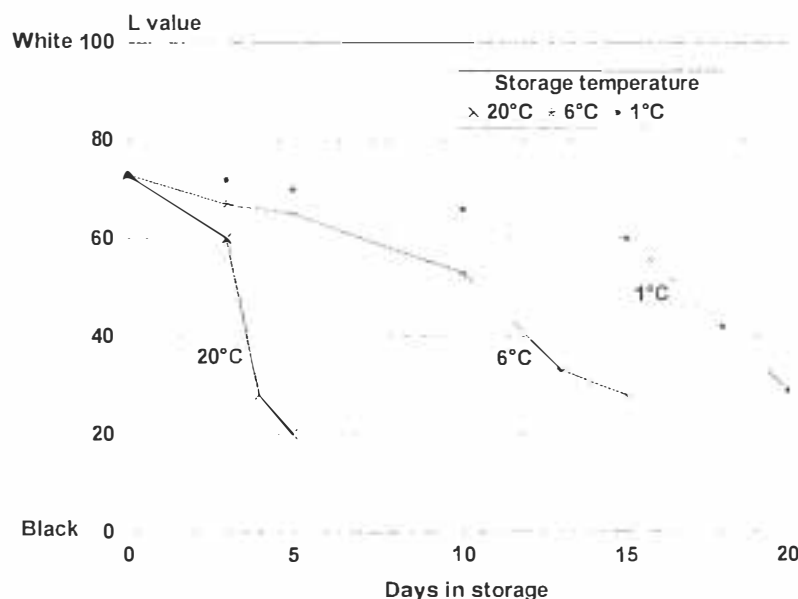


Figure 14. Loss of whiteness (Hunter L values) for shiitake during storage at indicated temperatures. 100 = white and 0 = black. (Minamide *et al*, 1980a).

There is very little information on the storage of straw mushrooms at low temperatures and the optimal storage temperature is yet to be determined but would be expected to be higher than most other cultivated fungi. Cho *et al* (1982) studied the storage life of straw mushrooms at various temperatures ranging from 0 to 30°C. It was determined that mushrooms liquefy rapidly when stored below 6°C and at 30°C.

At 10°C they could be stored for 2-3 days, although nearly half of their moisture content had been lost. While the pattern of results was similar at 15°C, there was a marked improvement in quality when mushrooms were stored in perforated bags. Mushrooms stored at 20°C could be stored for a longer period than at 4-6°C but for a shorter time than at 10-15°C. The percentage of veil opening of straw mushrooms was found to be related to storage temperature. At 25°C veil opening increased greatly and mushrooms in the egg state rapidly developed and elongated into their mature stages. Veil opening in straw mushrooms may be prevented or delayed by precooling at 15°C for four hours. San Antonio and Fordyce (1972) found that straw mushrooms tended to liquefy at 4°C and their shelf life was about 3 days when stored at 10-15°C.

10.4.1.3 Freezing and chilling injury

Although low temperatures are an effective means of retarding quality loss during storage, at temperatures below 0°C freezing injury can occur leading to rapid deterioration of mushrooms on rewarming. At about -0.9 to -1.2°C water in mushroom tissue freezes (Whiteman, 1957) and changes from the liquid to the solid phase which creates ice crystals which disrupt the cell structure. On returning to temperatures above freezing, enzyme/substrate interactions resume which results in rapid tissue blackening, a characteristic of thawed mushrooms after freezing (Nichols, 1985; Wills *et al*, 1989).

Cho *et al* (1982) found that straw mushrooms could be kept at below 0°C for at least two weeks without obvious sign of deterioration as shown by organoleptic tests. No moisture loss occurred and the veil remained closed. However, on thawing the mushrooms liquified and degenerated

rapidly. The aroma typical of fresh mushrooms was also lost. The phenomenon of straw mushrooms rapidly deteriorating when stored below 6°C is typical of chilling injury; symptoms may not be evident during exposure to low temperatures and only become noticeable after transfer to room temperature.

10.4.2 Moisture loss and humidity

Mushrooms have a high water content (usually 85% to 95%) and this essential water is rapidly lost by evaporation and respiration. Water loss is loss of saleable weight and thus is a direct loss in earnings (Wills *et al*, 1989). The main effect of water loss is quality deterioration due to wilting and shrivelling causing mushrooms to become tough and eventually inedible. The rate at which water loss occurs depends on the structure and condition of the mushroom, the relative humidity and temperature of the environment and air movement. Data illustrating the effect of these factors on moisture loss of specialty mushrooms is limited and much of the information available is based on studies of *A. bisporus*. Noble and Burton (1993) determined that based on the literature available, a relative humidity of 85-95% at 0-2°C was optimal for most mushroom varieties. The amount of water lost before mushrooms become unsaleable is yet to be established but is likely to be around 10-15% of fresh weight for many cultivated fungi.

10.4.2.1 Structure and condition

Cultivated fungi appear to have little or no physical structure to prevent loss of water comparable, for example, with that presented by the waxy cuticle of fruits and higher plants (Nichols, 1985; Wills *et al*, 1989). San Antonio and Flegg (1964) have shown that the rate of moisture evaporation from growing mushrooms is comparable to that from a free water surface and the same consideration probably applies to the harvested mushroom. Most mushrooms have a high surface area-to-volume ratio and so are more prone to moisture loss than many other horticultural products. Bruising damages the surface organisation of tissues in mushrooms which allows greater flow of gaseous material through damaged areas and leads to increased evaporation rates (Wills *et al*, 1989). Przybylowicz and Donoghue (1990) determined that to some extent the degree of wilting in shiitake during storage depended on mushroom density which is influenced by strain and also by conditions during fruiting.

10.4.2.2 Humidity and temperature effects

Water status of mushrooms is largely influenced by storage temperature (Peggie, 1985). Relative humidity (RH) is defined as the ratio of the water vapour pressure in the air to the saturation vapour pressure possible at the same temperature, expressed as a percentage. Saturated air, therefore, has a relative humidity of 100% (Wills *et al*, 1989). Relative humidity is not necessarily a useful guide to the rate at which water is lost from tissue unless temperature is taken into account. For example, at 80% RH measured at 15°C and 2°C, water will evaporate 2.5 times faster at 15°C than at 2°C

The combination of high temperature and low relative humidity can cause rapid water loss. Closed cup *A. bisporus* mushrooms lost 28% of their original fresh weight in 24 hours when stored at 20° and 40% RH in open containers (Nichols, 1985). In a similar experiment, Nichols and Hammond (1973) found that mushrooms lost 50% of their fresh weight when stored for 5 days at 18°C and 40-50% RH, which was significantly worse than a weight loss of only 8% at 2°C and 85-95% RH. Rajarathnam *et al* (1983) observed that oyster mushrooms (*P. flabellatus*) stored at 25°C and 50-70% RH for 24 hours lost 32% of their moisture. Studies with straw mushrooms (*V. volvacea*) indicated that the loss of moisture in mushrooms after storage for 4

days at 10°C could be as high as 40-50%. Noble and Burton (1993) established that low temperature and high humidity storage of mushrooms will minimise moisture loss to 1-2% per day when they are stored in open containers.

Fluctuations in temperature around a highly water-saturated mushroom can result in condensation of vapour to form free water droplets. The usual condition in which condensation is observed is after transfer of cold produce to a warm, moist atmosphere. This may not cause problems if mushrooms are packed in open containers as water droplets soon evaporate into the atmosphere. On the other hand, film over-wraps or other impermeable or semi-impermeable materials prevent water escaping. The presence of free water can lead to microbial spoilage (Nichols, 1985). As the temperature falls, water vapour within the packed mushrooms condenses on the plastic film to be replaced by further water loss from the mushroom when the temperature rises. If this pumping action is repeated sufficiently, wilting often follows (Cho *et al*, 1982). Condensation can be prevented to an extent by making sure film packages are vented (Peggie, 1985).

10.4.2.3 Control of moisture loss

An effective method to reduce water loss from mushrooms is to increase the relative humidity of the air. This reduces the vapour pressure difference between the produce and the air and hence the amount of water required to be evaporated from the produce before the air is saturated with water vapour. In storage this can be achieved by spraying water as a fine mist, by introducing steam, increasing the heat exchange surface of the cooling system or by increasing the temperature of the refrigeration coils (Wills *et al*, 1989). Excessive air flow over mushrooms in storage can increase water loss substantially. Air movement is required to remove heat from mushrooms but its effect on moisture loss must be considered. Weight loss will be relatively less from mushrooms packed deeply in an open carton than from mushrooms packed to a depth of only a few layers owing to the protection given by one mushroom to another.

During room cooling product should not be placed in the direct path of fans and during forced-air cooling water loss will be relatively high for a short time as mushrooms are precooled using high air volumes. As soon as mushrooms are cooled the air flow is cut back and water loss reduced (Blacker, 1989). If this situation is compared to room cooling, the mushrooms will lose more water in total during a slow cooling process.

Overwrapping of mushrooms is principally used to retard moisture loss and thereby conserve fresh weight and maintain mushroom quality. In practice this is achieved by enclosing the mushrooms in a container with a plastic film that is either perforated or semi-permeable to water vapour. Cho *et al* (1982) found that straw mushrooms packed in perforated polyethylene (PE) bags for 4 days at 10°C only lost 10% of their moisture compared to unpacked mushrooms under the same conditions which lost 40-50%. Lee *et al* (1991) observed that unpacked shiitake stored at 2°C for 60 days lost 33% of their fresh weight while shiitake stored in polyethylene bags of thicknesses ranging from 40 µm to 100 µm lost between 6 and 13% of their fresh weight after 60 days storage. The lowest weight loss occurred from mushrooms stored in 60 µm thick PE bags. Shanthy *et al* (1979) determined that samples of oyster mushroom (*Pleurotus sajor-caju*) stored at 8-10°C lost 55% of their initial moisture content after 24 hours of storage while samples packed in vented polyethylene bags had minimal weight loss after storage for 4 days at the same temperature.

Kim *et al* (1989) also found that shiitake mushroom weight loss could be reduced by storage in controlled atmospheres. It was observed that the weight loss of mushrooms stored at 2°C in air increased relatively quickly and was 15% after 20 days storage and 33% after 60 days. On the other hand, weight loss of mushrooms stored in 2% CO₂ : 2% O₂ was only 4% after 60 days storage at 2°C.

10.4.3 Storage atmosphere

The beneficial effects of controlled-atmosphere (CA) storage of mushrooms in delaying senescence, reducing discolouration and retarding undesirable growth and microbial spoilage has been well documented (Burton, 1991; Murr and Morris, 1975b; Sveine *et al*, 1967; Briones *et al*, 1992). Studies have mainly focused on *Agaricus bisporus* and to a lesser extent on shiitake and oyster mushrooms. Generally, a modification of storage atmosphere by lowering the oxygen (O₂) and/or increasing the carbon dioxide (CO₂) levels combined with strict temperature control retards mushroom respiration and deterioration.

Briones *et al* (1992) comprehensively studied the effect of CA storage on the shelf life of the common mushroom (*Agaricus bisporus*) and this was assessed using six parameters correlated with its commercial qualities. The results obtained in this study provide a sound starting point for a review of CA storage of cultivated fungi. Low CO₂ concentrations up to 2.5% reduced brown discolouration compared to the control in air. Higher CO₂ concentrations enhanced both external and internal browning while low O₂ reduced growth of microorganisms, including pseudomonads. Respiration rate, when the mushrooms were placed in air after CA storage, was proportional to CO₂ concentration suggesting that carbon dioxide exhibits a phytotoxic effect on mushrooms. Mushrooms stored in a 5% CO₂ atmosphere for 7 days at 10°C did not break their veil but their texture was very soft and spongy. Texture losses decreased when CO₂ concentrations increased.

These results suggest that to optimize storage conditions for many *Agaricus* spp. the storage atmosphere should contain from 2.5 to 5% CO₂ and from 5 to 10% O₂. Oxygen content is less important than CO₂ content, so the major aim when using modified atmosphere packaging (MAP) should be to maintain CO₂ concentration below 5% at a temperature below 10°C.

Juhasz and Dobray (1977) reported that the storage life of oyster mushrooms could be extended and weight loss reduced if mushrooms were placed in high CO₂ concentrations (up to 25%) in a storage chamber using dry ice or CO₂ and kept at either 1-5°C or 10-12°C. The shelf-life of oyster mushrooms (*P. ostreatus*) was extended to 4 weeks at 0°C under a 15% CO₂:2% O₂ atmosphere and up to 6 weeks in 10% CO₂:2% O₂ (Kim, 1996). Storage life was limited by yellowing, off-flavour development and mycelial growth under both conditions. Weight loss during the 4-6 week storage period was less than 1% under both atmospheric conditions, whereas untreated oyster mushrooms lost 8.4% of their moisture in one week.

Henze (1989) studied the effect of various storage atmospheres on taste and mycelial growth of oyster mushrooms stored at 1°C and 94% RH for 7 to 21 days (Table 9). The rating scale for both quality factors ranged from 10 (optimum) to 1 (unacceptable) where a rating of 5 represented the limits of saleability. It was found that mushrooms had a shelf life of about 7 days when stored in air whereas storage under 15% CO₂ and low O₂ conditions increased shelf life to approximately 14 days. Mushrooms stored at 30% CO₂:1% O₂ had the highest quality after 14 days storage and were still saleable after 21 days storage. At 15% CO₂ and 0% O₂ mushrooms remained in good condition during the first week but during the second week of storage an off-

flavour developed which was probably due to anaerobic respiration and fermentation. Using very high initial CO₂ concentrations (50%) followed by air storage resulted in mushrooms maintaining their quality quite well for over two weeks. The data suggests that high CO₂ concentrations could be used to extend oyster mushroom storage life, for example, in shipping containers for transport of large quantities of product.

Bohling and Hansen (1989) determined that controlled atmospheres improved the quality of oyster mushrooms only marginally compared with those stored in air at 1°C and 3.5°C. However, clear differences in quality were observed at higher temperatures with a storage atmosphere of 10% CO₂ and 2% O₂ giving the best results. Under these conditions mushrooms stored at 8°C for 7 days were comparable in quality to those stored at 3.5°C in air. The same effect was observed when CO₂ levels were elevated up to 20% or 30% without lowering the oxygen content. As would be expected changes in respiration rate corresponded with changes in quality under the various storage conditions. The inhibiting effect of controlled atmospheres on metabolic activity was low at 1°C and 3.5°C, while at the higher temperatures respiration rate was lowered by 50% compared to air.

Table 9. Effect of storage atmosphere on maximum storage time, taste and mycelial growth of oyster mushrooms (*P. ostreatus*) Henze (1989).

Atmosphere		Storage period (days)	Rating values	
%CO ₂	%O ₂		Taste ²	Mycelium
Air		7	4	5
		14	5	3
		21	4	2
30	1	7	8	10
		14	5	6
		21	6	6
15	1	7	6	6
		14	5	4
		21	5	3
15	0	7	9	9
		14	7	4
		21	5	1
50 ¹	10	7	8	6
		14	8	7
		21	6	5

¹High initial concentration with subsequent storage in air after one week

²All organoleptic ratings were made with uncooked material

Few studies have been conducted to determine the influence of controlled atmosphere storage on the quality of shiitake mushrooms. A comprehensive investigation has been conducted by Minamide *et al* (1980c) who measured both the visual and physiological changes in shiitake

during storage in various atmospheres at 20°C. Four experiments were carried out using a range of atmospheres: 0-80% CO₂ and 5% O₂; 5-100% CO₂ and 0% O₂; 0% CO₂ and 0-20% O₂; 20-40% CO₂ and 0-5% O₂. Regardless of CO₂ concentration, shiitake storage life was increased compared to mushrooms stored in air. An O₂ level below 2% also markedly suppressed browning of the gill and increased mushroom shelf life but under anaerobic conditions (0% O₂) fermentation occurred and off-flavours developed. It was determined that the optimum atmosphere to maintain quality of shiitake at 20°C was 40% CO₂ and 1-2% O₂. Using this treatment shiitake shelf life was extended to 8 days compared with only 2 days for mushrooms stored in air (Figure 15).

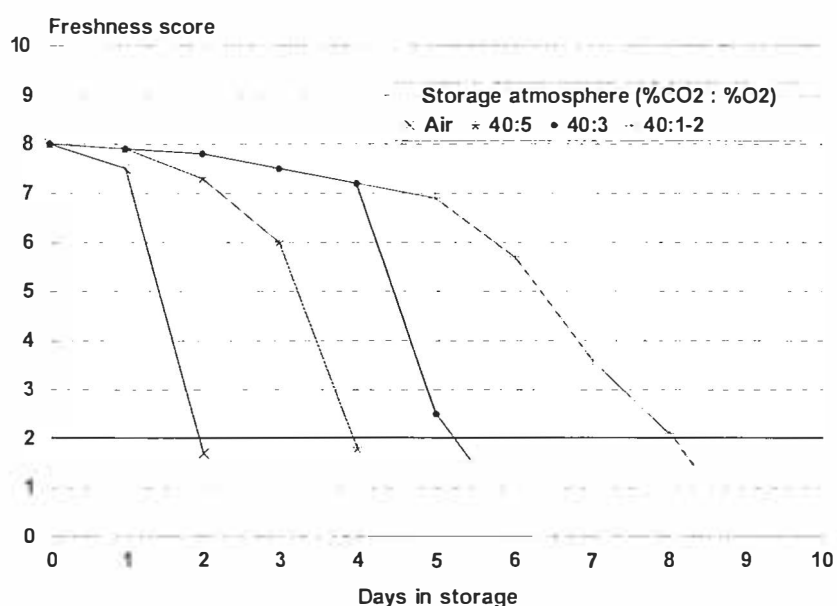


Figure 15. Effect of CO₂ and O₂ levels on the freshness of shiitake stored at 20°C. Score of 2 is the limit of saleability. (Minamide *et al*, 1980c).

10.5 Modified atmosphere packaging of specialty mushrooms

As well as good temperature management, modified atmosphere packaging (MAP) can be used to extend the storage life of mushrooms. When produce is sealed inside a semi-permeable plastic film an atmosphere around the produce is created containing higher carbon dioxide levels and reduced oxygen levels that are not as precisely controlled as in CA storage (Kader *et al*, 1989). The atmosphere is modified by the respiratory activity of the produce and the permeability characteristics of the film. If the package is well designed, gas levels should equilibrate within the range shown to benefit the produce in CA storage. The O₂ level aimed for is usually higher than the recommended CA-storage level due to the passive nature by which the atmosphere is achieved and a higher O₂ level reduces the risk of anaerobic respiration during short-term temperature fluctuations (Wilkinson & Tomkins, 1995).

10.5.1 Mushroom MAP requirements

Until recently, the films used for MA packaging of fresh produce were not permeable enough to balance the high respiration rate of mushrooms leading to a rapid exhaustion of oxygen within the packs, thus promoting spoilage (Lopez-Briones *et al*, 1993; Hobson & Burton, 1989). For this reason, mushroom prepacks are routinely punctured or vented to allow oxygen to enter. The most widely used films in mushroom packaging are stretch PVC and polyethylene. A larger

range of films including a number that are microporous in nature, such as orientated polypropylene, are now available. These have been shown to successfully delay senescence of *Agaricus* spp. in an experimental system as measured by internal and external browning, undesirable growth, firmness and microbial growth (Lopez-Briones *et al*, 1993; Hobson & Burton, 1989; Roy *et al*, 1996; Burton *et al*, 1987b; Nichols & Hammond, 1973; De la Plaza *et al*, 1995). For MAP of mushrooms to be practical and commercially viable, the following factors must be addressed: (1) Optimal and effective gas concentrations for delaying mushroom senescence. (2) Interaction of MAP and cooling. (3) Presence of free water in packs. (4) The possibility of anaerobiosis due to temperature fluctuations. (5) The cost-effectiveness of MAP in enhancing storage life (Burton, 1991).

10.5.2 MAP systems for specialty mushrooms

The effects of MAP on quality and shelf-life of *Agaricus bisporus* have been extensively studied whereas relatively little is known about the effects of different packaging systems and films on specialty mushroom quality. This lack of information is compounded by the fact that studies concerning MAP of oyster and shiitake mushrooms have only been based on the use of polyethylene films and not on more advanced and appropriate microperforated or microporous films. Other problems with the data available is that in most cases atmospheres inside packages have not been measured, MA packaging has not been properly designed using optimum CA conditions and in many cases trials have been conducted at temperatures incompatible with domestic handling methods i.e. greater than 20°C. Little MAP information is available for enoki and virtually none for wood ear, swiss brown and other commercial varieties.

Currently, specialty mushroom retail packs are commonly sealed or overwrapped with plastic films. Stretch PVC films with differing gas permeabilities are usually used (Przybylowicz & Donoghue, 1990; Schaper *et al*, 1988). It has been demonstrated that MAP of oyster and shiitake mushrooms reduces quality loss during storage compared to storage in air (Table 10). The benefits of MAP storage on quality compared to air storage include reduced weight loss, increased firmness, maintenance of colour and freshness, and retention of flavour.

Gormley and O'Riordain (1976) determined the shelf life of two strains of oyster mushroom (grey and Florida) at 2°C and 17°C when packaged in uncovered fibreboard trays, prepacked using stretch PVC film (Vitaform[®]) and sealed inside 38 µm thick polyethylene bags. The mushrooms were tested for weight loss, texture and colour of the cap, and were subjectively assessed for appearance and flavour. Covered and packaged mushrooms were still in marketable condition after 8-10 days storage at 2°C and after 3 days at 17°C due to reduced weight loss and retarding of the growth of superficial mycelium. Condensation on the inside of bags was a problem in samples packed in polyethylene.

Polyethylene bags of various thicknesses and perforated area were assessed by Shanthy *et al* (1979) for their suitability in maintaining *P. sajorikaju* shelf life at 8-10°C and 28-30°C. Changes in weight, colour, texture, smell, appearance and ascorbic acid content were recorded periodically. Mushrooms packed in 50 µm thick bags with 1.0% perforated area and stored at 28-30°C retained their original colour and firm texture for up to 20 hours while samples packed using other treatments had lost flavour and colour after this storage period. Discolouration ranged from yellow to yellowish brown; mushrooms became soft and limp; and in some cases shrivelling occurred. Unpacked control samples and those packed in sealed bags deteriorated within 5 hours. Polyethylene bags of 25 µm thickness and 0.5% perforated area were found to

maintain mushroom freshness, their firm texture, colour and smell for up to 4 days at 8-10°C. Excessive dehydration, loss of firmness and slight discolouration were noticed in unpacked controls after 24 hours of storage while mushrooms sealed in bags at this temperature developed a fermented smell after 20 to 24 hours but colour and texture remained unaffected.

A detailed study of the storage life of *P. flabellatus* in sealed and perforated polyethylene bags of 25 and 50 µm thickness was conducted by Rajarathnam *et al* (1983). To determine the optimum MA package at 3-7°C and 25°C bags containing various mushroom weights (50-250 g inside a 16 by 25 cm bag) and perforated areas (1 to 5 pin holes) were tested. Each pin hole was approximately 1 mm in diameter. Degree of whiteness, texture, CO₂ concentration inside the pack, appearance and taste of cooked mushrooms was assessed.

It was found that increased levels of CO₂ (up to 7%) inside packages resulted in mushrooms with no appreciable loss in whiteness, firmness or flavour after storage for 5 days. Significant increases in CO₂ concentration were observed when using either sealed bags, packaging having only 1 or 2 pinholes or as a result of increasing mushroom weight. Oyster mushrooms packed in 25 µm thick polyethylene bags with two pinholes in lots of 200 grams maintained their quality for up to 24 hours at ambient temperature with CO₂ levels equilibrating at 4.5%. Mushrooms packed in polyethylene bags with two pinholes at 3-7°C became very soggy after 24 hours storage which lead to the testing of sealed 25 µm polyethylene bags. A shelf life of 6 days was achieved using this packaging with CO₂ levels reaching 6% inside the bag. At both storage temperatures increasing the perforated area in the bags lead to increased sogginess in the mushrooms, increased discolouration and loss of texture. It was suggested that this was caused by mushroom respiration rates remaining high due to only relatively small increases in CO₂ levels resulting in higher condensation levels inside the bags.

Minamide *et al* (1980b) determined that shiitake shelf life could be improved by packing mushrooms in a 30 µm polyethylene film bag. It was found that by using this type of packaging mushroom quality was still acceptable after 18 days at 1°C, 14 days at 6°C, 7 days at 15°C and 4 days at 20°C. These results were achieved by precooling shiitake down to 1°C and maintaining a constant storage temperature thereafter. The maximum shelf life of unpacked shiitake was found to be 7 days at 1°C. In another trial, shiitake were packed inside polyethylene bags perforated with either 4, 8 or 12 holes and stored at the same four temperatures. It was observed that mushroom quality deteriorated more rapidly as hole number increased and that in all cases shiitake shelf life was shorter compared to mushrooms stored in sealed bags at the same temperature. The improvements in storage life of shiitake using polyethylene bags has been confirmed by Lee *et al* (1991). Using bags with thicknesses ranging from between 40-100 µm shiitake were stored for up to 60 days at 2°C with minimal deterioration observed. After 20 days storage atmospheres inside the bags reached equilibrium at 2.5-4.5% CO₂ and 4-7% O₂. The lowest weight loss was recorded in mushrooms stored in 60 µm thick bags while high levels of ethanol and acetaldehyde were produced in the 100 µm thick bags during storage possibly caused by O₂ levels falling below 4%.

Hermetically sealed polyethylene bags are commonly used overseas for enoki mushroom storage and have been successfully used for shiitake (Minamide & Ogata, 1978). It has been found that shiitake mushrooms in hermetically sealed bags have a shelf life of 22 days at 1°C and 17 days at 6°C. A summary of the published literature relating to MAP storage of specialty mushrooms is presented in Table 10.

Table 10. Summary of the effect of modified atmosphere packaging on quality and shelf life of specialty mushrooms.

Author	Mushroom	Species	Atmosphere (%CO ₂ : %O ₂)	Temperature (°C)	Storage period	Comments [†]
Gong <i>et al</i> (1993)	Shiitake	<i>Lentinus edodes</i>	10 : 1	20°C	6 days	-Browning in PE bags reduced compared to air storage. -Inhibition caused by by endogenous ethanol accumulation in shiitake under conditions of high CO ₂ and low O ₂ .
Gormley & O'Riordain (1976)	Oyster	<i>P. ostreatus</i> (grey and Florida strains)	Unknown	2°C 17°C	Up to 10 days	-Samples stored in air, PVC (Vitafilem) prepacks and PE bags (38 µm) and weight loss, texture, colour and flavour assessed. -Superficial mycelial growth and water loss was slowed in packaged mushrooms especially at 2°C. Condensation a problem in samples packed in PE bags. Packaged mushrooms were still acceptable after 8-10 days storage at 2°C and 3 days storage at 17°C.
Lee <i>et al</i> (1991)	Shiitake	<i>Lentinus edodes</i>	2.5-4.5 : 4-7 (equilibrium values)	2°C	Up to 60 days	-2 kg samples stored in 40, 60, 80 and 100 µm thick PE bags (30 by 60 cm size). -Large amounts of ethanol and acetaldehyde produced in thickest bag during storage. Lowest weight loss occurred in 60 µm thick PE bag.
Minamide <i>et al</i> (1980b)	Shiitake	<i>Lentinus edodes</i>	Unknown	1°C 6°C 15°C 20°C	Up to 18 days	-100 g samples stored in 30 µm thick PE bags (20 by 26 cm size). PE bags also perforated with 4, 8 or 12 holes in separate trial. -Shiitake shelf life was 18 days at 1°C, 14 days at 6°C, 7 days at 15°C and 3 days at 20°C in PE bags. Using perforated bags maximum shelf life achieved with 4 holes/bag (15 days at 1°C, 13 days at 6°C and 4 days at 20°C).
Rajaratnam <i>et al</i> (1983)	Oyster	<i>P. flabellatus</i>	1-7% CO ₂ O ₂ unknown	3-7°C 25°C	Up to 6 days	-50 to 250 g sample packed in 25-50 µm thick PE bags (16 by 25 cm size) either perforated with 1-5 pin holes or intact. Assessment included texture, colour and freshness. -200 g samples packed in 25µm thick PE bags with one pin hole on either side stored up to a period of 24 hours at ambient and up to 6 days at 3-7°C in intact PE bags.
Shanthy <i>et al</i> (1979)	Oyster	<i>P. sajorkaju</i>	Unknown	8-10°C 28-30°C	Up to 4 days	-50 g samples stored PE bags (15 by 20 cm) of 25, 38 and 50 µm thickness and 0.5, 1.0, 1.5 and 2.0% vent areas. Changes in weight, colour, texture, smell and appearance were assessed. -PE bags of 25 µm thickness and 0.5% vent area recommended at for shelf life of 4 days at 8-10°C while 50 µm bags with 1.0% vent area recommended for storage of up to 20 hours at 28-30°C.

†PE-Polyethylene

11. Processed specialty mushrooms

Although analysis of the affects of mushroom processing on quality and storage life is beyond the scope of this report a brief assessment of some value-added mushroom products will establish the potential of these products in an expanding domestic market in comparison to fresh mushrooms. Several processing methods are used to preserve edible fungi or market new mushroom products. These include blanching, canning, air drying, freeze drying, vacuum sealing and minimal processing.

11.1 Drying

Due to their relatively short shelf life, a large proportion of edible fungi grown world wide are air dried. This method is commonly used for shiitake and straw mushrooms, and also for wood ear and white jelly fungus. Drying preserves the edible fungi by removing enough water to inactivate enzymes and microorganisms and mushrooms are usually dried to a moisture content of 6% to 13%. Shiitake are usually air dried to a moisture content of 13% and reconstitute well after drying. Their colour is retained although they may be slightly tougher than fresh mushrooms. Drying gives the mushrooms a more intense flavour and aroma as cell rupture and rehydration leads to the production of lenthionine, a sulphur-containing compound that gives shiitake its distinct aroma (Maga, 1981). Dried oyster mushrooms were found to be brittle, requiring protective packaging, and on reconstitution became chewy and inedible (Gormley & O'Riordain, 1976).

White jelly fungus is usually dried to a moisture content of 6-8%, packed in plastic bags and kept in air tight cartons during storage while wood ear fungus is dried down to about 9-15% moisture. Straw mushrooms can be kept for up to a year when dried down to 10% moisture. Although dried mushrooms have a relatively long shelf life microbial spoilage and mould growth can occur due to insufficient dehydration or to absorption of sufficient moisture from the environment (due to incorrect packaging). Furthermore, since drying is mostly by hot air, water holding capacity on rehydration is often lost or reduced because of denaturation of proteins or cross linking of cellulose or starch (Cho *et al*, 1982). With the exception of shiitake, hot-air dried mushrooms are generally unacceptable to consumers as their flavour and texture on rehydration are inferior to that of the fresh product. Aoyaki and Sugahar (1986) determined that dehydration results in loss of texture in mushrooms and that nutrients in mushrooms are lost during rehydration.

Freeze drying is the process where dehydration is obtained by sublimation of water from its solid state into a gas. Cho *et al* (1982) freeze dried freshly harvested straw mushrooms under a vacuum after freezing them at -30°C. The moisture loss was about 90% of the total fresh weight. On rehydration mushrooms were far superior to the air dried product, based on sensory tests. On reconstitution they were almost indistinguishable in appearance from fresh product. Gormley and O'Riordain (1976) found that oyster mushrooms were not suitable for blanching and then freeze drying. Blanching caused a loss of flavour in mushrooms while unblanched, freeze dried mushrooms developed a serious off-flavour after 3 months storage at -30°C. Shiitake mushrooms can be freeze dried to 4-6% moisture with little change in shape and colour, and the aroma is similar to that of air dried shiitake. The quality of rehydrated shiitake is high; appearance and texture are similar to the fresh product. A unique feature of freeze dried shiitake is instant reconstitution, which is desirable in instant prepared foods (Tanaka *et al*, 1976). Freeze drying is

an expensive preservation method due to the energy costs involved in cooling and maintaining a vacuum during processing.

Tanaka *et al* (1976) compared the quality of shiitake processed by the following methods; (1) fresh; (2) air dried; (3) freeze dried; and (4) frozen at -20°C. Results of sensory tests demonstrated that methods (1) and (4) produced mushrooms superior in appearance, method (3) in colour, and (2) and (3) in aroma.

11.2 Minimal processing

Little information is available on the quality and shelf life characteristics of sliced edible fungi even though *Agaricus* spp., portabella and some other mushroom varieties are commonly sold as minimally processed product, particularly in the USA where shelf life of sliced products is estimated to be 4-6 days at 0-2°C (Anon., 1996). Sliced mushrooms have higher respiration rates than whole product and thus have a very short shelf life which is limited by browning and texture loss, and by excessive condensation inside prepacks leading to slimy product (Ballantyne, 1987). Incorrect packaging and poor temperature management can also cause anaerobic conditions inside prepacks leading to fermentation and development of off-odours.

Further research is required to successfully handle and market various sliced mushroom products. Proper MA packaging systems and in-package moisture absorption methods are required while treatment of mushrooms with anti-oxidants such as citric or ascorbic acid to increase shelf life need further study. These systems need to be used in conjunction with strict temperature management implemented by distributors and retailers.

12. Handling protocols

A preliminary postharvest handling protocol can be established for specialty mushrooms based on the literature reviewed. This protocol, by the nature of the information available, consists of general principles applicable for use by most growers, distributors and retailers. Presentation of grower-specific handling and packaging guidelines is beyond the scope of this project and is also not possible at present due to the lack appropriate information. Implementation of these guidelines by industry should ensure that, at least in the short term, the marketing of specialty mushrooms with a higher quality and longer shelf life than those presently available.

1. Harvesting

1.1 Harvest maturity

- Degree of cap opening is the best method of determining mushroom maturity.
- Mushrooms should always be picked before biological maturity (before caps are fully open).
- Open mushrooms are more susceptible to damage during handling and deteriorate more rapidly than less mature mushrooms.
- If the market requires open or very mature mushrooms that are fragile and have a shorter shelf life, then these factors should be taken into account during handling and selection of packaging.
- Specialty mushroom characteristics at optimum harvest maturity are:

Swiss brown	- medium-sized, closed buttons with a tight veil
Oyster mushrooms	- compact fruit body with curled edges, well-formed gills and short stem
Shiitake	- Cap opening of 50-70% with veil partially intact or broken

1.2 Picking

- Careful picking will minimise physical injury such as bruising.
- Damp mushrooms are more prone to bruising at harvest.
- After harvesting, mushrooms should be gently placed inside picking containers.
- Swiss browns should be picked by gently gripping the cap and twisting and bending to break off the stem at the base.
- Open mushrooms are more fragile and care is required to prevent the stem from breaking at the top.

Harvesting cont.

- Shiitake and oyster mushrooms are picked by gripping the lower portion of the stem and twisting and pulling them from the log.
- Only the stem should be touched during picking as bruises on the cap and gills will discolour rapidly.
- Cutting mushrooms from the log minimises physical damage.

2. Precooling

- Mushrooms should be cooled down to their optimum temperature as soon as possible after harvest.
- A more rapid precooling rate will extend mushroom shelf life.
- Average precooling times required to lower mushroom temperature from 20°C to 2°C using different cooling systems are:
Vacuum cooling - 20 minutes
Forced air cooling - 40 to 60 minutes
Room cooling - 6 to 8 hours
- High humidity (>85%) should be maintained inside cool rooms.
- Precooling rate inside cool rooms will depend on mushroom quantity, refrigeration capacity, efficient air movement and container placement.
- For large mushroom quantities room cooling is usually too slow for optimum maintenance of shelf life.
- Vented containers in a single layer placed on racks will optimise cold air-to-package contact.
- Containers should not be placed in the direct path of fans as freezing or rapid moisture loss may occur.
- Pulp temperatures should be checked before grading using a portable thermometer to ensure proper cooling has taken place.
- Avoid excessive precooling as this can lead to moisture loss and physiological stress which significantly reduces shelf life.

3. Sorting and grading

- Sorting should remove mushrooms with any of the following characteristics:
 - disease
 - spots
 - insect injury
 - decay
 - physical damage
- Preliminary grading standards for 'premium' or 'A grade' specialty mushrooms based on overseas standards are summarised in the following table.
- Market requirements will determine how strictly such standards are followed.

Variety	Cap opening	Cap characteristics	Size	Colour	Other
Shiitake	50-70% open	round, no irregularities	medium, approx. 4-8 cm cap	light to chocolate brown cap and creamy white gills	1.6 : 1 cap diameter to stem length
Oyster	curled edges	no misshapen mushrooms	compact, short stem	varies with species	well developed gills
Swiss brown	veil closed or partially open	round, no irregularities	medium button	light brown	no casing on mushroom surface
Enoki	closed	round, flat	2-3 cm cap, 2-9 cm stem length	white gills, yellowish to brown stem and cap	stiff stem
Straw	buttons (closed cap)	round or oblong	2.5-3.5 cm cap	white to dark grey	
Wood ear		smooth surface		dark brown to black	free of organic material on surface
Shimeji	open	flat		light grey	packed in clumps

4. Packaging

- Mushroom prepacks and bulk cartons used must provide protection against physical damage, water loss and discolouration.
- Mushrooms should be packed in plastic punnets without ribbing that surround the product and protect it.
- Prepacked mushrooms should not protrude above the lip of the punnet.
- If bulk carton weight exceeds a certain value mushrooms in the bottom layers may develop pressure bruising.
- Use of perforated or high permeability film (such as Vitafilm[®]) is recommended to prevent oxygen depletion inside prepacks due to poor temperature management.
- Perforated film will to some extent minimise condensation inside prepacks caused by temperature changes.
- Protective packaging should be used for a fragile mushroom such as enoki.

5. Storage

- After precooling and packing mushrooms should be maintained near their optimum temperature to maximise shelf life and maintain quality.
- In general, mushroom shelf life decreases by 50% when they are stored at 8°C rather than 4°C.
- Optimum storage temperature for specialty mushrooms are listed in the following table.
- Optimum relative humidity for unpackaged mushrooms is 85-95% and it should be monitored in cool rooms.

Variety	Temperature ¹
Shiitake	1-3°C
Swiss brown	1°C
Oyster	3°C
Enoki	1-3°C
Straw	10-15°C

¹'Mushrooms', The Packer (1996)

6. Distribution

- Prepacked mushrooms should be positioned carefully inside master cartons to prevent pressure bruising during transport.
- Whenever possible, mushrooms should be distributed using refrigerated transport (maximum temperature of 4°C).
- Distribution over short distances can be made with insulated trucks provided that the mushrooms have been precooled to the correct temperature before collection.
- Over long distances temperature data loggers should be used to ensure mushroom pulp temperature is being maintained.
- It is important that temperatures during distribution are kept constant as fluctuations will cause condensation to form inside prepacks that can lead to microbial spoilage.

7. Marketing

- At retail level, mushrooms should be dry at receipt and have a fresh, well-shaped appearance, firm texture and be free of bruises and spots.
- Prepacked mushrooms should be handled carefully to avoid bruising.
- Ample display space should be provided to prevent stacking of prepacks on top of one another.
- Bulk cartons should be emptied carefully and loose product should not be piled too deep as lower mushroom layers will become bruised and damaged.
- If possible display mushrooms in their original carton to avoid over handling.
- During marketing mushroom temperature should be maintained at 4°C or less to maximise shelf life.

13. Conclusions

A specialty mushroom industry survey and literature review have identified oyster, shiitake, swiss brown, wood ear and enoki mushrooms as the main mushroom varieties currently available in Australia. A number of Asian mushrooms such as shimeji are becoming available domestically and with increasing production will be potential export products. Grading and quality standards vary widely between growers of these varieties. The survey also identified a number of factors contributing to poor mushroom quality that is leading to wastage and limiting market expansion. Poor retailer and customer knowledge of the product is of major concern to growers and distributors. Incorrect handling leading to physical injury and poor temperature management during distribution and marketing are other major factors combining to reduce mushroom shelf life and quality. Current packaging systems have been relatively unsuccessful in extending shelf life due to these poor handling practices and lack of information on packaging requirements for individual mushroom varieties. At present industry relies heavily on rapid distribution to overcome handling and packaging limitations and although this distribution system may be applicable for the foodservice sector it is unsatisfactory if a greater extension in storage life is required. Specialty mushroom growers supplying more mature mushroom markets such as in the United States have placed strong emphasis on good postharvest handling and packaging. Cooperation between industry members has meant that resources are available for promotion and consumer education and has resulted in growers being able to directly influence the marketing and handling of mushrooms by retailers. The trend in these markets has been towards a consistent supply of prepacked mushrooms to large retailers that provide ample display space and who handle mushrooms carefully.

A critical and comprehensive review of industry and scientific literature has identified a lack of information in many areas concerning postharvest handling and packaging of specialty mushrooms. Little information is available concerning the effects of preharvest factors such as substrate and growing conditions on postharvest shelf life. Studies have found that storage temperature is critical to mushroom quality and the beneficial effects of modified atmosphere storage in retarding deterioration have been demonstrated. Fundamental storage requirements such as optimum temperature, relative humidity and storage atmosphere are either unknown or the information is not readily available. The majority of information available is from packaging research carried out on shiitake and oyster mushrooms grown on natural logs using out dated polyethylene films. The use of new and appropriate microperforated or microporous packaging for specialty mushrooms has not been studied. In general, packaging systems described in the literature are inappropriate and not practical for the Australian industry.

General horticultural handling principles and information obtained from the literature review have been used to develop a preliminary handling protocol for specialty mushrooms. This has been prepared in a format suitable for growers, packers and retailers and provides practical handling information for the major specialty mushroom species. In the short term this protocol will make growers and retailers more aware of proper postharvest handling practices and enable some industry sectors to improve specialty mushroom handling through better temperature management and physical handling. It has been determined that specific information for the local industry concerning correct handling and packaging methods, and quality and grading standards is not available and further research and extension activities in collaboration with growers, distributors and retailers are required to add value, reduce quality loss and increase shelf life of specialty mushrooms.

20

21

14. Recommendations

It has been determined that the following research and extension activities need to be implemented to maximise mushroom quality during distribution and marketing:

1. Research should be geared towards major commercial varieties such as oyster and shiitake, and towards other Asian mushrooms with high export potential such as shimeji and maitake.
2. Identification of mushroom strains and growing conditions that optimise mushroom quality and increase storage life.
3. Determination of optimum postharvest handling and storage protocols for such factors as harvest maturity, handling, precooling, storage temperature and humidity, and optimum CO₂ and O₂ levels, for commercially important varieties.
4. Development of grading and quality standards based on industry requirements and market expectations leading to production of information sheets and posters for industry and retailer use.
5. Development of new packaging systems utilising MAP technology to maximise storage life and quality of specialty mushrooms.
6. Testing the effectiveness of improved protocols and packaging under commercial handling, distribution and marketing conditions.
7. Facilitate closer collaboration between growers, researchers and retailers to ensure adoption and use of new protocols and packaging throughout the handling chain.
8. Development of quality assurance procedures including hazard analysis in conjunction with larger growers supplying the major domestic retailers and export markets.

15. Implications for the specialty mushroom industry

The specialty mushroom industry and retailers have the opportunity, in the short term, to adopt the handling protocol outlined in this project that will lead to reduced wastage and better quality. Marketing and packaging trends found in more mature overseas markets can also be implemented in Australia by industry. Finally, research requirements, particularly concerning mushroom packaging, that will assist in industry growth have been identified and need to be implemented.

It is difficult to determine what proportion of growers and distributors will improve their handling methods based on project findings. Due to industry fragmentation it is unlikely that a uniform approach will be taken in improving mushroom quality throughout the distribution chain. With increasing production and better marketing, it has been estimated that an integrated industry approach using improved packaging and correct handling methods to reduce wastage and improve quality could lead to an estimated \$25 million increase in domestic market value of specialty mushrooms over the next decade, not including potential income from import replacement and exports.

A few major growers have expressed interest in applying quality systems and MAP technologies to their handling methods. The opportunity exists for future collaboration between industry, retailers and researchers to develop better packaging for specific companies to meet their domestic and export requirements.

16. Communications strategy

Industry fragmentation means that direct communication with individuals is the most effective means of gathering and providing information concerning handling and packaging of mushrooms. In conducting the industry survey opportunities arose to exchange information with growers and distributors and this may lead to a process of self-assessment where they begin to consider their own handling methods and their effect on mushroom quality.

Significant outcomes will be communicated to industry by:

- Preparation of a practical handling protocol that is included in the final report, that in the short term can be used by growers, distributors and retailers to improve handling and storage of specialty mushrooms.
- Individual industry members will be sent a project summary and handling protocols to assist in adoption of outcomes.
- Presentation of a poster summarising project results at the 1997 Australasian Postharvest Horticulture Conference at the University of Western Sydney Hawkesbury, NSW. A written paper will be published in the conference proceedings.

The potential also exists to inform the specialty mushroom industry through articles in relevant industry publications.

17. Glossary

Agaricales the order of basidiomycetes containing typical mushrooms with gills

Amino acid basic building block of protein

Anaerobic living in absence of free oxygen

Axenic pure mycelial culture

Basidia club-shaped cells where sexual recombination and reduction division occurs, resulting in basidiospores

Basidiomycetes class of fungi whose sexual spores are produced by basidia

Biological efficiency a method of expressing mushroom yields where the fresh weight of the mushrooms is divided by the dry weight of the substrate

Carbohydrates compounds such as starch, sugars and cellulose that play an essential part in metabolism of organisms

Cropping temperature air temperature during growth of mushroom fruit body

Flush a synchronized fruiting of mushrooms

Fruiting body a specialized structure where sexual spore-bearing cells are produced i.e. mushrooms

Gill vertical, plate-like tissue covered with basidia on the underside of a mushroom cap

Half-cooling time time taken for produce temperature to drop to half the difference between initial pulp temperature and cool room temperature

Hyphae strands of filamentous fungal cells

Mycelium collective term for mass of hyphae that constitutes the vegetative part of a fungus

Organoleptic sensory evaluation including taste, aroma, texture etc.

Pasteurisation partial sterilisation of substrate to destroy undesirable organisms

Pileus cap of 'mushroom' shaped fungal fruit body bearing gills

Pinning the process of primordia formation, the beginning of mushroom development

Primordia the earliest stages of fruiting body development

Protein complex, organic compound which contain nitrogen, composed of amino acids

Relative humidity the amount of water vapour in the air expressed as a percentage of the maximum water-holding capacity of air at that temperature

Respiration the metabolic processes by which an organism takes in and uses oxygen and gives off products of oxidation including carbon dioxide, water and heat

Spawn the mycelium of fungi growing on a substrate and prepared for the propagation of mushrooms

Species a fundamental category of taxonomic classification, ranking below genus, consisting of organisms capable of interbreeding

Spore a general term for the small reproductive bodies found in fungi

Sporophore general term for a structure producing and bearing spores such as mushroom fruiting bodies

Stipe stalk of mushroom fruiting bodies

Strain genetically uniform mycelium possessing distinctive characteristics

Substrate materials on which fungi can grow and obtain their nutrition such as compost or logs

18. Literature cited

- Anon. (1996). Mushrooms. *Produce Availability & Merchandising Guide, The Packer*, Vol. cIII, No.53, pp.246-254.
- Anon. (1995). Portabella mushrooms: Baby version unveiled. *The Packer* (May 15), p.11b.
- Anon. (1994). The domestic market potential for specialty mushrooms. *RIRDC Research Paper Series No. 94/3*, Agtrans research, 25pp.
- Anon. (1979). Shiitake cultivation, techniques and management. 4th ed., *Japan Mushroom Centre*, Ienohikari Association.
- Ajlouni S.O., R.B. Beelman, D.B. Thompson & J.L. Mau (1992). Stipe trimming at harvest increases shelf-life of fresh mushrooms (*Agaricus bisporus*). *J. Food Sci.*, 57:1361-1363.
- Aoyaki Y. & T. Sugahar (1986). Studies on the rehydration of shiitake mushroom. *J. Food Sci. Techn.*, 33:244.
- Arita I. (1978). '*Pholiota nameko*', in *The biology and cultivation of edible fungi* (ed. Chang, Hayes), pp.475-494. Academic Press, London.
- Aschan-Aberg K. (1960). The production of fruit bodies in *Collybia velutipes*. III. Influence of the quality of light. *Physiol. Plant.*, 13:276-279.
- Ballantyne A. (1987). Modified atmosphere packaging of selected prepared vegetables. *Technical Memorandum No. 464*, Campden Food Preservation Research Assoc., 23-26.
- Beelman R. B. (1988). Factors influencing post harvest quality and shelf life of fresh mushrooms. *Mushroom Journal*, 182:455-463.
- Beelman R. B., B. Guthrie & D.J. Royse (1989). 'Influence of bacterial populations on postharvest deterioration of fresh mushrooms', in *Mushroom Science XII (Part II)*, pp.655-665.
- Beelman R. B., A. Okereke & B. Guthrie (1987). 'Evaluation of textural changes related to postharvest quality and shelf-life of fresh mushrooms', in *Developments in Crop Science 10, Cultivating Edible Fungi* (eds. Wuest, Royce, Beelman), pp.251-258. Elsevier Publ. Co., Amsterdam).
- Blacker K.J. (1989). 'Temperature management', in *Fresh Produce Manual* (ed. Story & Simmons), pp.25-44. Australian United Fresh Assoc.
- Bohling H. & H. Hansen (1989). Studies on the metabolic activity of oyster mushrooms (*Pleurotus ostreatus* Jacq.). *Acta Horticulture*, 258:573-577.

Briones G.L., P. Varoquaux, Y. Chambroy, J. Bouquant, G. Bureau & B. Pascat (1992). Storage of common mushroom under controlled atmospheres. *Intern. J. Food Sci. and Techn.*, 27:493-505.

Brown M. (1996). 'Towards 2010 - The specialty mushroom industry in Australia', in *Proceedings of the 23rd National Mushroom Conference*, AMGA, 43-56.

Burton K.S. (1988). The effects of storage and development of *Agaricus bisporus* proteases. *J. Horticultural Sci.*, 63:103-108.

Burton K.S. (1991). Modified atmosphere packaging of mushrooms - Review and recent developments. *Mushroom Science*, 13:683-688.

Burton K.S., C.E. Frost & P.T. Atkey (1987a). Effect of vacuum cooling on mushroom browning. *Intern. J. Food Sci. Techn.*, 22:599-606.

Burton K.S., C.E. Frost & R. Nichols (1987b). A combination plastic permeable film system for controlling post-harvest mushroom quality. *Biotechnology Letters*, 9(8):529-534.

Burton K.S., M.E. Love & J.F. Smith (1993). Biochemical changes associated with mushroom quality in *Agaricus* spp. *Enzyme and Microbial Technology*, 15:736-741.

Carey A.T. & T.P. O'Connor (1991). 'Influence of husbandry factors on the quality of fresh mushrooms (*Agaricus bisporus*)', in *Mushroom Science XIII, Volume 2. Proceedings of the 13th International Congress on the Science and Cultivation of Edible Fungi* (ed. Maher), pp.673-682. A.A. Balkema, Rotterdam.

Chang S.T. (1978). '*Volvariella volvacea*', in *The biology and cultivation of edible fungi* (eds. Chang, Hayes), pp.573-603. Academic Press, London.

Cho K.Y., K.H. Yung & S.T. Chang (1982). 'Preservation of cultivated mushrooms', in *Tropical mushrooms: Biological nature and cultivation methods* (eds. Chang, Quimio), pp.63-86. Chinese University Press, Hong Kong.

Chen P.C. & H.H. Hou (1978). '*Tremella fuciformis*', in *The biology and cultivation of edible fungi* (ed. Chang, Hayes), pp.629-643. Academic Press, London.

Chung B. (1994). The development of specialty mushrooms - Shiitake - as a new crop industry. *HRDC Final Report No. MU308*, 26pp.

De la Plaza J.L., R. Alique, J.P. Zamorano, M.L. Calvo & M.J. Navarro (1995). Effect of the high permeability to O₂ on the quality changes and shelf-life of fresh mushrooms stored under modified atmosphere packaging. *Mushroom Science*, 14:709-716, Vol. II.

Edwards R.L. (1978). 'Cultivation in western countries: growing in houses', in *The biology and cultivation of edible fungi* (ed. Chang, Hayes), pp.300-335. Academic Press, London.

Eger G., H.D. Gottwald & U. von. Nezer (1974). The action of light and other factors on sporophore initiation in *Pleurotus ostreatus*. *Mushroom Sci.* IX, 575-583.

Elliott T.J. (1985). 'The general biology of the mushroom', in *The biology and technology of the cultivated mushroom* (eds. Flegg, Spencer & Wood), pp.9-21. John Wiley & Sons, London.

Flegg P.B. & D.A. Wood (1985). 'Growth and fruiting', in *The biology and technology of the cultivated mushroom* (eds. Flegg, Spencer & Wood), pp.141-177. John Wiley & Sons, London.

Gong Y., K. Abe & K. Chachin (1993). Relation between endogenous ethyl alcohol and browning in shiitake (*Lentinus edodes* Sing.) mushroom during storage in polyethylene film bags. *J. Japan Soc. Food Sci. and Techn.*, 40(10):708-712.

Gong Y., Y. Ueda, K. Abe & K. Chachin (1994). Study of phenol oxidases on browning of shiitake (*Lentinus edodes* Sing.) mushroom. *J. Japan Soc. Food Sci. and Techn.*, 41(9):606-610.

Goodenough P.W. (1976). How chilled storage affect the physiology of mushrooms. *Mushroom Journal*, 43:208-210.

Gormley T.R. (1975). Vacuum cooling and mushroom whiteness. *Musroom Journal*, 27:84-86.

Gormley T.R. (1991) 'Monitoring mushroom temperature in the chill chain', in *Mushroom Science XIII, Volume 2. Proceedings of the 13th International Congress on the Science and Cultivation of Edible Fungi* (ed. Maher), pp.653-658. A.A. Balkema, Rotterdam.

Gormley T.R. & F. O'Riordain (1976). Quality evaluation of fresh and processed oyster mushrooms (*Pleurotus Ostreatus*). *Lebensm.-Wiss. u. -Technol.*, 9:75-78.

Gunn J. (1992). From specialty to mainstream. *Mushroom News*, 40(5):18-22.

Hammond J.B.W. (1979). Changes in the composition of harvested mushrooms (*Agaricus bisporus*). *Phytochemistry*, 18:415-418.

Hammond J.B.W. & R. Nichols (1975) Changes in respiration and soluble carbohydrates during post-harvest storage of mushrooms (*Agaricus bisporus*). *J. Sci. Food and Agric.*, 26:835-842.

Henze J. (1989). Storage and transport of pleurotus mushrooms in atmospheres with high CO₂ concentrations. *Acta Horticulturae*, 258: 579-584.

Hobson G. & K.S. Burton (1989). The application of plastic film technology to the preservation of fresh horticultural produce. *Professional Horticulture*, 3:20-23.

Ingratta F.J., T.J. Blom & W.W. Brown (1980). Commercial mushroom growing. *Ministry of Agriculture and Food, Ontario*, Public. No. 350, 32pp.

Ito T. (1978) 'Cultivation of *Lentinus edodes*', in *The biology and cultivation of edible fungi* (eds. Chang, Hayes), pp.461-473. Academic Press, London.

Juhasz M. & E. Dobray (1977). Experiments on mushroom storage in CO₂ atmospheres. *Kertgazdasag*, 9(6):69-77.

Kader A.A, D. Zagory & E.C. Kerbel (1989). Modified atmosphere packaging of fruit and vegetables. *Critical Reviews in Food Science and Nutrition*, 28:1-30.

Kautter D.A., T. Lilly & R. Lynt (1978). Evaluation of the botulism hazard in fresh mushrooms wrapped in commercial polyvinylchloride film. *J. Food Protection*, 41:120-121.

Kim D.M., H.H. Baek, H.H. Yoon & K.H. Kim (1989). Effect of CO₂ concentration in CA conditions on the quality of shiitake mushrooms (*Lentinus edodes*) during storage. *Korean J. Food Sci. and Techn.*, 21(4):461-467.

Kim G.H. (1996). A study on the postharvest quality maintenance of *Pleurotus ostreatus* under controlled atmosphere storage (in press). *Proc. 1996 International Postharvest Science Conference*.

Kohlii M.S. (1984). Judging when to pick a mushroom: an aid to pickers. *Mushroom Journal*, 138:207-209.

Kramer A. & B.A. Twigg (1970). *Quality control in the food industry*. 3rd Ed. Vol.3. AVI/Van Nostrand, New York.

Kurtzman R.H. & Y. Chang-Ho (1982). 'Physiological considerations for cultivation of *Volvariella* mushrooms', in *Tropical mushrooms: Biological nature and cultivation methods* (eds. Chang, Quimio), pp.139-165. Chinese University Press, Hong Kong.

Kurtzman R.H. & F. Zadrazil (1982). 'Physiological and taxonomic considerations for cultivation of *Pleurotus* mushrooms', in *Tropical mushrooms: Biological nature and cultivation methods* (eds. Chang, Quimio), pp.299-347. Chinese University Press, Hong Kong.

Lanz S. (1994). Development of national uniform grading standards. *Lanz Agricultural Consulting*, May 1994, 15pp.

Lee B. (1995). Audit of the Australian Asian vegetable industry. *RIRDC Research Paper Series No. 95/13*, 98pp.

Lee S.E., D.M. Kim & K.H. Kim (1991). Changes in quality of shiitake mushroom (*Lentinus edodes*) during modified atmosphere (MA) storage. *J. Korean Soc. Food and Nutrition*, 20(2):133-138.

Lopez-Briones G., P. Varoquaux, G. Bureau & B. Pascat (1993). Modified atmosphere packaging of common mushroom. *Inter. J. Food Science and Techn.*, 28:57-68.

Lutz J. M. & R.E. Hardenburg (1968). The commercial storage of fruits, vegetables, and florist and nursery stocks. *Agriculture Handbook No.66*, USDA, Washington.

Maga J.A. (1981). Mushroom flavour, *J. Agric. Food Chem.*, 29:1-4.

Manning K. (1985). 'Food value and chemical composition', in *The biology and technology of the cultivated mushroom* (eds. Flegg, Spencer & Wood), pp.211-230. John Wiley & Sons, London.

Mau J.L., R.B. Beelman & G.R. Zeigler (1993). Factors affecting 1-octen-3-ol in mushrooms at harvest and during postharvest storage. *J. Food Sci.*, 58:331-334.

Minamide T., T. & K. Ogata (1978). Studies on physiological and biochemical properties and keeping quality of shiitake (*Lentinus edodes*). *International Congress of Food Science and Technology*, p.136.

Minamide T., T. Habu & K. Ogata (1980a). Effect of storage temperature on keeping freshness of mushrooms after harvest. *J. Jap. Soc. Food Sci. and Techn.*, 27(6):281-287.

Minamide T., M. Tsuruta & K. Ogata (1980b). Studies on keeping freshness of shiitake (*Letinus edodes* Berk Sing.) after harvest. *J. Jap. Soc. Food Sci. and Techn.*, 27(10):498-504.

Minamide T., T. Nishikawa & K. Ogata (1980c). Influences of CO₂ and O₂ on the keeping freshness of shiitake (*Lentinus edodes* Berk Sing.) after harvest. *J. Jap. Soc. Food Sci. and Techn.*, 27(10):505-510.

Murr D.P. & L.L. Morris (1975a). Effect of storage temperature on postharvest changes in mushroom. *J. Amer. Soc. Hort. Sci.*, 100:16-19.

Murr D.P. & L.L. Morris (1975b). Effect of storage atmosphere on postharvest growth of mushrooms. *J. Amer. Soc. Hort. Sci.*, 100:298-301.

Nichols R. (1985). 'Post-harvest physiology and storage', in *The biology and technology of the cultivated mushroom* (eds. Flegg, Spencer & Wood), pp.195-210. John Wiley & Sons, London.

Nichols R. & J.B.W. Hammond (1973). Storage of mushrooms in prepacks: the effect of changes in carbon dioxide and oxygen on quality. *J. Sci. Food and Agric.*, 24:1371-1381.

Noble R. (1985). A review of vacuum cooling of mushrooms. *Mushroom Journal*, 149:168-170.

Noble R. (1989). Comparison of market containers for ice bank cooling of mushrooms. *Mushroom Journal*, 202:323-325.

Noble R. and D.I. Bartlett (1986). Ice bank cooling of pallet - Loads of mushrooms. *Mushroom Journal*, 162:205-208.

Noble R. & K.S. Burton (1993). Postharvest storage and handling of mushrooms: Physiology and Technology. *Postharvest News and Information*, 4(5):125-129.

Partis J.P. & R. Noble (1989). Use of insulated containers for the cool distribution of mushrooms. *Acta Horticulturae*, 244:163-170.

Peggie I.D. (1985). Packing and presentation for the market. *National Mushroom Conference*, Oct., 4pp.

Plunkett B.E. (1956). The influence of factors of the aeration complex and light upon fruit-body form in pure cultivars of an agaric and a polypore. *Annals of Botany*, NS, 20:563-585.

Przybyłowicz P. & J. Donoghue (1990). *Shiitake growers handbook*. Kendall/Hunt Publishing Co., Dubuque, Iowa.

Quimio T.H. (1982). 'Physiological considerations of *Auricularia* spp.', in *Tropical mushrooms: Biological nature and cultivation methods* (eds. Chang, Quimio), pp.397-407. Chinese University Press, Hong Kong.

Rajarathnam S., Z. Bano & M.V. Patwardhan (1983). Postharvest physiology and storage of white oyster mushroom *Pleurotus flabellatus*. *J. Food Techn.*, 18(2):153-162.

Richards R. (1996). Development of the Australian specialty mushroom industry. *HRDC Final Report MU402*, Meyers Strategy Group Pty. Ltd., 35p.

Roy S., R.C. Anantheswaran & R.B. Beelman (1996). Modified atmosphere and modified humidity packaging of fresh mushrooms. *J. Food Sci.*, 61(2):391-397.

Royse D.J. (1985). Effect of spawn run time and substrate nutrition on the yield and size of the shiitake mushroom. *Mycologia*, 77:756-762.

Royse D.J. (1997). 'Specialty mushrooms and their cultivation' in *Horticultural Reviews* (ed. Janick). John Wiley & Sons, Inc., New York.

Royse D.J. & C.C. Bahler (1986). Effects of genotype, spawn run time, and substrate formulation on biological efficiency of shiitake. *Appl. and Environ. Micro.*, 52(6):1425-1427.

Sabota C. (1996). Strain of shiitake mushroom [*Lentinula edodes* (Berk.) Pegler] and wood species affect the yield of shiitake mushrooms. *HortTechnology*, 6(4):388-393.

San Antonio J.P. & P.B. Flegg (1964). Transpiration from the sporophore of *Agaricus bisporus* 'White'. *Amer. J. Botany*, 51:1129-1132.

San Antonio J.P. & C. Fordyce (1972). Cultivation of the paddy straw mushroom, *Volvariella volvacea* (Bull. ex Fr.) Sing. *HortScience*, 7:461-464.

Schaper P.M., L.J. de Vlieger & L.J.L.D. van Griensven (1988). 'Sales', in *The Cultivation of Mushrooms* (ed. van Griensven), pp.423-445. Darlington Mushroom Laboratories, Sussex.

Schisler L.C. (1983). Quality/Size. *Mushroom Journal*, 123:81-89.

Schroeder G. (1989). 'Harvesting, postharvest handling and packaging of shiitake', in *Shiitake mushrooms: Proceedings of a National Symposium and Trade show*, pp.83-86,. Uni. of Minnesota, Educational development system, St. Paul, MN.

Shanthy A.P., A.S. Thirumaran & S. Neelakantan (1979). Prepackaging studies on *Pleurotus sajor-caju*. *Proc. First Indian Convention of Food Scientists and Technologists*, 65:67-68.

Sorenson R. (1992). Marketing of specialty mushrooms in California. *Mushroom News*, 40(10):14-15.

Sugiyama H. & K.H. Yang (1975). Growth potential of *Clostridium botulinum* in fresh mushrooms packaged in semipermeable plastic film. *Applied Microbiology*, 30(6):964-969.

Sulkowska J. & E. Kaminski (1977). Effects of different drying methods on quality and content of aromatic volatiles in dried mushrooms *Agaricus bisporus*. *Acta Alimentaria Polonaise*, 3:409-425.

Sveine E., A. Klougart & C. Riber Rasmussen (1967). Ways of prolonging the shelf-life of fresh mushrooms. *Mushroom Sci.*, 6(2):463-474.

Tanaka F., S. Saito & T. Esashi (1976). On the difference in quality and composition of shiitake according to different processing methods. *Mushroom Science*, 9(1):521-529.

Tingsgaard U., C. Frisina & B. Tomkins (1993). Controlled atmosphere storage of mushrooms. *Interim Report to Campbell's Mushrooms and the HRDC*, 9pp.

Tokimoto K. & M. Komatsu (1978). 'Biological nature of *Lentinus edodes*', in *The biology and cultivation of edible fungi* (eds. Chang, Hayes), pp.445-459. Academic Press, London.

Tomkins R.C. (1966). Refrigerated stores for the storage of mushrooms. *MGA Bulletin*, 201:477-478.

Tonomura H. (1978). '*Flammulina velutipes*', in *The biology and cultivation of edible fungi* (eds. Chang, Hayes), pp.410-422. Academic Press, London.

Vinning G. (1995). Market compendium of Asian vegetables. *RIRDC Research Paper Series No.95/12*, Asian vegetables series, pp.197-225.

Wade N.L. (1982). Temperature management of mushrooms. CSIRO Food Research Laboratory, Australia.

Walton M. (1987). Management of hybrid strains for quality. *Proc. Fifth National Mushroom Conf.*, Dublin, Ireland, p.4-11.

Whiteman T.M. (1957). Freezing points of fruits, vegetables and florist stocks. *USDA Marketing Research Report*, No. 196.

Wilcke W.F., C.G. Haugh, K.C. Diehl & C.W. Coale (1989). Design of a shiitake-mushroom packing line. *App. Eng. in Agric.*, 5(3):405-411.

Wilkinson I. & B. Tomkins (1995). The potential use of modified atmosphere packaging for fresh cauliflower export. *ANL Limited, Confidential report*, 20pp.

Wills R.B.H., W.B. McGlasson, D. Graham, T.H. Lee & E.G. Hall (1989). *Postharvest: An introduction to the physiology and handling of fruit and vegetables*. NSW University Press.

Wu L.C. (1990). Mushroom genetics and breeding. *Plant Breeding Review*, 8:189-215.

Zadrazil F. (1978). 'Cultivation of *Pleurotus*', in *The biology and cultivation of edible fungi* (eds. Chang, Hayes), pp.521-557. Academic Press, London.

Zadrazil F. & R.H. Kurtzman (1982). 'The biology of *Pleurotus* cultivation in the tropics', in *Tropical mushrooms: Biological nature and cultivation methods* (eds. Chang, Quimio), pp.277-297. Chinese University Press, Hong Kong.

19. Appendices

19.1 Specialty mushroom industry survey

Q.1 How would you describe your operation ?

Growing or field picking only

Growing or field picking and packing

Just packing and distributing

Just distributing

Q.2 Do you import any fresh mushrooms and if so why ?

Q.3 What are the top 5 highest volume mushroom types you grow, pack or distribute ?

What are the 2 main reasons for rejecting a mushroom (for each main type) from your top grade ? *(If Applicable)*

	Type	Wrong size	Wrong shape	Physical damage	Poor colour	Incorrect maturity	Disease	Other
1.								
2.								
3.								
4.								
5.								

Q.4 How do you cool your mushrooms ?

Forced-air cooling

Room cooling

Do not

Other.....

Q.5 Do you package your mushrooms before cooling them ? (If Applicable)

Yes (Go to Q.6)

No

Q.6 If you store your mushrooms in an open container before packaging then what is the relative humidity in your cool room ? (If Applicable)

Greater than 90%

80-90%

Less than 80%

Don't know

Q.7 At what temperature do you store your mushrooms ?

Specific temperature.....

0-3°C

4-8°C

9-15°C

Room temperature

Don't know

Q.8 What type of packaging do you use for your mushrooms ?

Open cartons

Polyethylene bulk bags

Perforated.....Yes

No

Other long life bags/film

Over-wrapped plastic punnets

Polystyrene trays/film

Plastic punnets ('clam shell')

Perforated.....Yes

No

Bags in styrofoam containers

Other packaging.

Q.9 What is the maximum time you store your mushrooms ?



Q.10 How do you transport your mushrooms ?

Road transport

Refrigerated

Unrefrigerated

Air-freight

Other.....

Q.11 If you are a retailer or sell directly to the final customer, how long can you store your mushrooms without loss in quality ?

.....days

Q.12 What are the 3 main factors that limit the quality and shelf-life of your mushrooms ?

None

OR

Difficulty in maintaining correct temperature

Moisture loss/Wilting

Browning

Postharvest disease/rots

Physical injury

Current packaging

Customer/retailer knowledge of product

Condensation in package

Poor harvest quality i.e incorrect shape

Other.....

Q.13 In what areas, if any, do you think the industry needs more information on postharvest storage, handling and packaging of specialty mushrooms (Choose up to 3 areas) ?

None

OR

General postharvest handling

Uniform grading standards

Correct storage temperatures

Better packaging for longer shelf-life

Better temperature control during storage and transport

Better cooling methods

Descriptions & pictures of high quality mushrooms

Descriptions & pictures of different mushroom grades

Other.....

14. Have you any comments about current postharvest handling practices in the specialty mushroom industry ?

19.2 Specialty mushroom suppliers

Arnott & Cox Pty Ltd, Melbourne Market, VIC

Campbells Mushrooms, Mernda, VIC

Doug Schirrippa, Adelaide, SA

E. Huon Valley Mushrooms, Glen Huon, TAS

E. Matt Browns Greens, Chippendale, NSW

Exclusive Mushrooms, Glen Waverley, VIC

First Sun Mushroom Co., Tyagarah, NSW

Forest Farm Mushrooms, Helensburgh, NSW

Fresh and Wild, Elsternwick, VIC

Gourmet Mushrooms, Wandin, VIC

Herb and Spice Garden, Ormond, VIC

John Ruggieri, Inverleigh, VIC

Just Mushrooms Exotic & Wild, Sth. Melb., VIC

Lee Mushroom Farm, Yarra Glen, VIC

Mr. Mushroom, Perth, WA

Muffett Mushrooms, Tamworth, NSW

President Mushrooms, Lilydale, VIC

Scarletts, Burrawang, NSW