Technical Bulletin

POST HARVEST TECHNOLOGY OF MUSHROOMS

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CONTENTS

FOREWORD

The man has been consuming mushrooms as food, medicine and even as intoxicant, since time immemorial by collecting them from the wild. Mushroom-hunting is still a game or a hobby with many. The appearance of mushrooms in the wild is, however, uncertain and seasonal depending upon many factors like habitat and climate etc. The need and greed to ensure the regular availability of mushrooms impelled the mankind to domesticate some of the most delicious mushrooms. It started with the domestication of paddy straw mushroom (*Volvariella volvaceae*) and black ear mushroom (*Auricularia polytrica*) in China, but undoubtedly it was the introduction and cultivation of the common white button mushroom (*Agaricus bisporus*) in the limestone caves in France in late eighteenth century which can be truly termed as biggest milestone in the history of mushroom production. Since then more than 20 types of edible and medicinal mushrooms have been domesticated and technologies have been improved to the commercial level.

Realizing the importance of mushrooms for ensuring nutritional and social security of the underprivileged small farmers and landless labourers, the Indian Council of Agricultural Research established the National Research Centre for Mushroom (NRCM) in 1983 to conduct research and transfer the technology on all aspects of mushrooms. There are very few countries like India, which can boast of a multidisciplinary national research establishment exclusively on mushrooms. During the past 25 years, the NRCM has delivered the results and met the objectives for which it was established; there has been many folds increase in the productivity and production of the common button mushroom. Besides, the mushroom growing has spread far and wide in various regions of the country. Introduction and cultivation of the tropical mushrooms like oyster, paddy straw and milky mushrooms have brought in much-needed diversification in the mushroom portfolio of the country. Like any other food crop research organization, NRCM too has crop improvement (breeding), crop production (agronomy), crop protection and crop nutrition & utilization (postharvest technology) programmes and accordingly the sections (divisions). Keeping in view very short shelf -life of mushrooms, postharvest research was given due emphasis right from the establishment of the NRCM. The centre has well-equipped postharvest laboratory with canning unit, cabinet drier, dehumidified air cabinet drier, freeze drier, fluidized bed drier, water activity

meter, modified atmosphere packaging machine and O_2 & CO_2 analyser etc. Besides the techniques for proper packaging and storage, many processing and value-addition technologies of mushrooms have been developed at the centre. A need was felt to bring out a comprehensive technical bulletin on these technologies to serve the needs of the researcher, grower, processor and consumer.

I must congratulate the authors, Dr. R.D.Rai and Er. T. Arumuganathan for bringing out the bulletin in a unique blend of scientific as well as popular format. I am happy to present the bulletin to the mushroom fraternity.

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PREFACE

Production and consumption of mushrooms have tremendously increased in India due mainly to increased awareness of the commercial and nutritional significance of this commodity. Needless to emphasize the relationship between the consumption of such fancied items and the purchasing power of the masses; consumption of mushrooms shall continue to rise with the current phenomenon of rise in the income level of the populace.

Mushrooms have very short shelflife – these cannot be stored or transported for more than 24 hours at the ambient conditions prevailing in most parts of year and the country. Browning, veil-opening, weight-loss and microbial spoilage are the most common postharvest changes in the mushrooms which often result into enormous economic losses. Proper, sound and appropriate postharvest practices of storage and processing are needed to sustain the budding mushroom farming and industry in the country. In India, more than 90% of the total mushroom production is still contributed by the common button mushroom (*Agaricus bisporus*). Understandably and justifiably, most of the postharvest aspects dealt in the present publication relate to this mushroom. However, many of these hold true for other mushrooms as well and the technologies can be easily extended, with slight modifications, to other mushrooms.

We have endeavoured to deal with most important postharvest aspects of mushrooms – physiological and biochemical changes, packaging and storage of fresh mushrooms, long-term storage, processing and value-addition. As the canning and pickling are the most important preservation technologies in the country, for the domestic as well as international trade, these aspects have been covered in detail, including the infrastructure, technical details and also the economics of these processes. Efforts have also been made to enlist the leading manufacturers and suppliers of the machinery and equipments.

While drafting the bulletin, we have kept in mind the needs of both, researchers as well as growers. The citations have been incorporated for the most important post harvest aspects and about 185 references are given at the end of the bulletin for the researchers and students concerned with the postharvest R & D on mushrooms. The growers and industrialists shall find

the style quite understandable; they have to just ignore the citations and references. We have tried to present this technical bulletin in a blend of technical & popular format.

Many of the technologies have been developed, refined, modified and improved at the NRCM, as would be evident from the photographs. We would, therefore, like to acknowledge the contributions of our predecessors and colleagues who, at any stage and in any form, have been associated with the development of the technologies – Dr. Sanjeev Saxena, Dr. V. Chandrasekar, Dr. O.P. Ahlawat, Ms. Kusum Ahlawat, Mr. Anil Hemkar, Dr. Shwet Kamal, Er. Rajesh Kumar, Mr. Vinay Kumar Khare, Mr. Lekh Raj Rana and Mr. Raj Kumar. We wish to thank Ms. Shailja Verma and Ms. Sunila Thakur for excellent support in the photography and word processing, respectively.

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1. INTRODUCTION

The production and consumption of mushrooms is increasing very fast throughout the world, mainly due to greater and greater awareness of their nutritive and medicinal attributes, besides, of course, unique flavour and texture; consumption of such fancied items is also a natural corollary to the general economic development of a country and, needless to say, the world economies are booming. World production of mushrooms is estimated about 12 million tonnes and the annual growth rate is still above 8 %; India too, though late starter, is fast catching up and the current production has crossed lakh tonne mark with annual growth rate of above 15 %; the venture is no more confined to the seasonal growing in the northern region, it has spread far and wide in the country. Besides the seasonal farmers, many big environmentally-controlled units have also come up as export-oriented units. The country is proud to have the biggest mushroom unit of the world producing 200 tonnes button mushroom per day and its export accounts for about 25 % of the US imports.

Currently, about twenty species of mushrooms are being commercially cultivated world over, but significant production is of the button mushroom (*Agaricus bisporus*) (Fig. 1), Shiitake *(Lentinula edodes*) (Fig. 2), Oyster mushroom (*Pleurotus* spp.) (Fig. 3), Black ear mushroom (*Auricularia polytricha*) and paddy straw mushroom (*Volvariella volvacea*) (Fig. 4). In India, button mushroom still contributes more than 85 % of the total mushroom production, though its

Fig. 1. Button mushroom (*Agaricus bisporus*)

Fig. 2. Shiitake mushroom (*Lentinula edodes*)

Fig. 3. Oyster mushroom (*Pleurotus florida*)

share is below 40 % in the global trade. Besides the button mushroom, oyster mushroom and paddy straw mushroom are the other types grown in limited but significant quantities mostly in the tropical pockets of the country. Milky mushroom (*Calocybe indica*) (Fig. 5), which may be the only commercial mushroom with fruiting

Fig. 5. Milky mushroom (*Calocybe indica*)

Fig. 4. Paddy straw mushroom (*Volvariella volvacea*)

temperature between 35-40^{0}C, is the new introduction from India to the world and its production is catching up fast in different parts of the country during the summer months and the mushroom has revolutionized the so-called *off-season* mushroom growing. Fresh mushroom market is largely catered by the seasonal growers who do not have cool- chain storage and transport facilities and sell the produce in highly localised markets; needless to mention that such seasonal players at times face the consequences of over-saturated market and understandably resort to distress sales at un-remunerative prices.

Mushrooms are a good source of very good quality protein especially rich in lysine and thus supplement well the cereal based Indian diet. FAO recognizes mushrooms as the right source of protein to fight protein

malnutrition in the cereal–dependent developing countries like India. These are very low-calorie food suited to all those interested in cutting down the calorie intake, like obese persons. Being low in fat, but desirable fat devoid of cholesterol, these make an ideal diet for the heart patients. Mushrooms are a low-calorie: high protein diet, with no starch and sugars, and are called the diabetics delight (Tables 1 and 2). These are also

Table 1. Nutritional properties (g/100g dw) of culinary mushrooms

Mushroom	Protein	Fat	Poly unsaturated fat	Total unsaturated fat	Saturated fat	Carbohydrate	Complex carbohydrate
A.bisporus Portobello	34.44	3.10	1.43	1.46	0.30	47.38	24.68
A.bisporus Crimni	33.48	2.39	0.41	0.44	0.26	46.17	24.27
Lentinus edodes Shiitake	32.93	3.73	1.30	1.36	0.22	47.60	31.80
Pleurotus ostreatus Pearl oyster	27.25	2.75	1.16	1.32	0.20	56.61	35.31
Pleurotus pulmonarius (*sajor caju*) Phoenix oyster	19.23	2.70	0.53	0.62	0.11	63.40	51.60

Source: Stamets (2005)

Table 2. Nutritional properties of culinary mushrooms

Mushroom	Sugar (g/100g)	Calories	Calcium (mg /100g)	Copper (mg /100g)	Iron (mg /100g)	Potassium (mg /100g)	Sodium (mg /100g)	Selenium (mg /100g)
A.bisporus Portobello	22.70	355	23	4.33	2.1	4500	52	0.415
A.bisporus Crimni	21.90	340	9	20.80	4.8	4800	3	0.066
Lentinus edodes Shiitake	15.80	356	23	1.23	5.5	2700	18	0.076
Pleurotus ostreatus Pearl oyster	22.30	360	20	1.69	9.1	2700	48	0.035
Pleurotus pulmonarius (*sajor caju*) Phoenix oyster	11.80	355	9	1.03	6.5	2600	16	0.09

Source: Stamets (2005)

rich in vitamins and minerals especially B- Complex and iron. Vitamin B-12 and Folic acid, which are normally not found in vegetarian items are present in mushrooms and along with availability of iron and protein, are reported to maintain hemoglobin level as single source of diet; anemia is rampant in India specially in pregnant women (Tables 3 and 4). With very high fibre and alkaline elements, mushrooms are suited to those suffering from hyperacidity and constipation; consumption of fibre has gained importance in general health

Table 3. Nutritional properties of culinary-medicinal mushrooms

Mushroom	Dietary Fiber (g/100g)	Thiamine B_1 (mg /100g)	Riboflavin B_2 (mg /100g)	Niacin B_3 (mg /100g)	Pantothenic acid B_5 (mg /100g)	Vitamin C (mg /100g)	Vitamin D (IU/100g)
A.bisporus Portobello	20.90	0.27	4.13	69.20	12.70	0	235
A.bisporus Crimni	19.90	0.23	3.49	38.50	21.70	0	26
Lentinus edodes Shiitake	28.80	0.25	2.30	20.40	11.60	0	110
Pleurotus ostreatus Pearl oyster	34.10	0.16	2.40	54.30	12.30	0	116
Pleurotus pulmonarius (*sajor caju*) Phoenix oyster	48.60	0.10	1.68	23.80	8.80	0	178

Source: Stamets (2005)

Table 4. Comparison of mushroom with common vegetables per 100 g of article

Name	Calories	Moisture	Fat	Carbohydrate(%)	Protein(dry weight basis)
Mushroom	16	91.1	0.3	4.4	26.9
Beet root	42	87.6	0.1	9.6	12.9
Brinjal	24	92.7	0.2	5.5	15.1
Cabbage	24	92.4	0.2	5.3	18.4
Cauliflower	25	91.7	0.2	4.9	28.8
Celery	18	93.7	0.2	3.7	20.6
Green beans	35	88.9	0.2	7.7	21.6
Green peas	98	74.3	0.4	17.7	26.1
Lima beans	128	66.5	0.8	23.5	22.2
Potato	83	73.8	0.1	19.1	7.6

Source: Rai (1995)

maintenance. Many mushrooms possess significant medicinal attributes like hypocholesterolemic, hypoglycemic and hypotensive properties. Mushrooms also exhibit strong anti-oxidant and hepatoprotective properties.

Post harvest losses are very high in most of the horticultural commodities and it may be one of the highest in mushrooms. Mushrooms even after harvesting continue to grow, respire, mature and senesce resulting in weight loss, veil-opening, browning, wilting and finally in spoilage. Almost all the mushrooms have very short shelf-life but the paddy straw mushroom has the shortest (few hours at the ambient) and Milky has very good shelf-life (3-5 days) if microbial spoilage is taken care of. Most damaging post harvest changes in mushrooms vary with species—it is blackening in the button mushroom, cap-opening in the paddy straw mushroom and mucilage in the oyster mushroom, which affect their marketability significantly. Weight loss is very serious problem in all the mushrooms as these contain very high moisture (85-90 %) and are not protected by the conventional cuticle. Due to very high moisture and rich nutritive value, microbial spoilage in mushrooms is also a problem. In case of the button mushroom all the four most deleterious changes namely, browning, veil-opening, weight loss and microbial spoilage ask for the utmost post-harvest care. Needless to say that these changes are also accompanied by changes in the nutritional and medicinal attributes of these mushrooms.

Utmost post harvest care of mushrooms is needed not only for the fresh market but also for the processing, as most of these changes are irreversible. Gluts and distress sales are not uncommon in mushroom marketing specially during the peak months when seasonal produce hits the market in a big way. Withholding of the fresh mushrooms at any point of the chain— grower, wholesaler or the retailer—, is neither feasible nor advisable as it may result in further deterioration in quality leading to the total loss. Information about proper post harvest care and processing of such a perishable commodity is therefore of vital importance to keep the wheels of this industry moving at the right speed; with the adoption of proper packaging, storage and processing technologies, problems in marketing, like seasonal gluts and distress sales, can also be ameliorated.

A sizeable production of the button mushroom and almost entire production of other mushrooms still comes from the small seasonal growers although many commercial units produce button mushroom throughout the year under the controlled conditions. The problem of gluts exacerbates during the so-called

peak season (December-February). India is predominantly a market for the fresh mushrooms, with very little quantity sold as canned mainly for the institutional consumers. Almost entire export is in the canned form accompanied with mushroom pickles as a bye-product of the canneries. But future is going to witness greater contribution from the processing sector, both as stored and really processed mushrooms. Improved post harvest practices for the storage and processing of mushrooms including value-addition, readymade or ready-to-make products will not only be demanded but will add to the returns to the growers as well as processors.

Two most common post harvest practices and aspects of mushrooms are: proper packaging and storage for the fresh mushrooms; and processing for long-term storage as well as value-addition. Market for the fresh commodities is likely to continue; reverse trend has already started in the countries where processed products were being consumed. Therefore most important of all, it is the proper packaging and storage of the fresh mushrooms which should receive the attention of all the players in the field—researchers, growers and traders. Besides canning, drying, steeping and pickling currently resorted to for the long-term storage and trade, it is the production and consumption of the readymade or ready-to-make value-added mushroom products which have, of late, been receiving the attention of the mushroom research and industry. Mushroom-based soup powder, noodles and biscuits are already on the shelves. Technologies for ready-to-make mushroom pizza, mushroom curry in retortable pouches, nuggets, ketchup, preserve in sugar syrup (murabba) have been developed. The bulletin aims at giving current status of the science, art and technology for the post harvest storage, processing and value-addition of mushrooms with special emphasis on the button mushroom keeping in view its present production and consumption in the country. Adoption of proper post harvest practices of the storage and processing may partially ameliorate the problems of marketing of mushrooms during the peak periods.

2. POST HARVEST PHYSIOLOGICAL AND BIOCHEMICAL CHANGES

Mushrooms, like other fruits and vegetables, respire, grow, mature and senesce after the harvest which affect quality and shelf-life significantly. Understanding of the postharvest physiological processes which affect the quality and shelf life and how these could be managed to ameliorate the situation is required.

2.1. Colour

Whiteness is the most important quality attribute in the button mushroom, besides, of course, shape and size. In a survey conducted in UK on the preference of the consumers about quality in the button mushroom, whiteness got the greatest score. Whiteness categories for mushrooms have been quantified by Gormley (1975) based on Hunter L* (Lightness values); (1) Higher than 93, excellent (100 is the theoretical maximum); (2) 90-93, very good; (3) 86-89, good; (4) 80-85, reasonable; (5) 69-79, poor; (6) below 69, very poor. Mushrooms with values below 80 were considered unacceptable at wholesale and below 69 at retail. Lower storage temperature retarded the changes. 'Smooth white' is term used by the spawn producers to denote the strains which will give smooth (not scaly) white fruit bodies. Hyphae of white strains are virtually colourless and translucent but they contain enzymes which under certain conditions react with the substrates in the cell content to form pigmented compounds, the reason for postharvest mushroom browning (Burton, 1986). Tyrosinase, commonly known as phenol oxidase (monophenol monooxygenase EC 1.14.18.1) is responsible for post harvest browning (Fig. 6). Mishandling during harvesting, enzymes and substrates, which are perhaps in separate cell compartments, get mixed up and the reaction is activated. Colourless phenols, after initial reaction form quinones, which transform and

Fig. 6. Enzymatic browning in button mushroom

polymerise into pink, purple to brown compounds. Like any enzymatic reaction, the rate of reaction will depend upon quantity and activity of enzyme protein, amount of substrate available and favourable conditions for the reaction (pH, temperature etc). But no doubt, brown mushrooms represent mishandled and aged mushrooms after the harvest (Nichols, 1985).

Susceptibility of white button mushroom to browning is a serious commercial problem. It would be important and beneficial to understand the enzyme and its mechanism of action. Tyrosinase is a copper containing enzyme found in *Agaricus bisporus* fruit bodies and catalyses hydroxylation of monophenols to diphenols which alongwith the native diphenols are then oxidised to quinones which polymerise to form brown insoluble pigment called melanin. Tyrosinase is normally found as 4 isozymes (Robb and Gutteridge, 1981) with different substrate affinities but similar amino acid composition. The enzyme is composed of two different types of subunits: a light chain of MW 13600 and a heavy chain of MW 43700. It has been thought that the predominant form of enzyme is a tetramer of two heavy and tow light chains. Some peptide inhibitors of Tyrosinase have been reported in *Agaricus bisporus* (Hammond and Wood, 1985).

Tyrosine and DOPA have traditionally been considered as *in vivo* substrate for the Tyrosinase. It has been suggested that L-glutaminyl-4-hydroxy benzene (GHB) is the natural substrate for mushroom tyrosinase (Stussi and Rast, 1981). GHB is present in larger amounts than DOPA in mushroom and in similar amounts to tyrosine.

Oxidation of phenol by polyphenol oxidase resulted in the browning complex (Yamaguchi *et al*., 1970; Nichols, 1985; Rai and Saxena, 1988; Bartley *et al*., 1991). Fang *et al*. (1971) were able to inhibit polyphenol oxidase activity in sliced mushroom by dipping in a solution of sodium metabisulphite (200 ppm SO_2) and 2 per cent NaCl and blanching in boiling water for 2 min followed by evaporative cooling. Increased browning of mushrooms stored at high temperature was observed and was correlated with increased activity of polyphenol oxidase (Murr and Morris, 1974; Goodenough, 1976; Goodenough and Ricketts, 1977).

The enzyme tyrosinase catalyses the reaction of phenols with oxygen from the air. Button mushroom is highly prone to enzymatic browning when the surface of the mushroom is exposed to air. Enzymes *viz*., tyrosinase and poly phenol oxidase released at the surface act on the polyphenols present in the mushroom

and oxidize them to orthoquinones (Murr and Morris, 1975b; Swaminathan, 1988; Jolivet *et al*., 1995). The essential components of the browning reaction *viz*., phenols and tyrosinase are kept in separate sub-cellular compartments of the hyphae. The phenols are probably confined to the vacuole and the tyrosinase to the cytoplasm as in higher plants (Mayer and Harel, 1979). During handling, storage and ageing of mushrooms, the membranes separating the compartments are ruptured and breakdown the contents mix, the enzyme becomes activated and the browning reaction begins (Burton, 1986; Burton *et al*., 1995; Jolivet *et al*., 1995). Tyrosinase is therefore commercially important in the storage of mushrooms because it catalyzes the first step in the formation of melanins (Long and Alben, 1968; Smith *et al*., 1993; Wichers *et al*., 1995). Tyrosinase can oxide both *ortho* (o)- and *para* (p)-diphenols and are usually inactive against monophenols (Wichers *et al*., 1995; Jolivet *et al*., 1995).

Non-enzymatic browning is due mainly to (i) Maillard reaction involving interaction between reducing sugars, amino acids and proteins (ii) reaction of oxidation products of ascorbic acid with proteins or amino acids (iii) reaction of oxidation products of polyunsaturated fatty acids with amino acids and proteins and (iv) caramelisation of sugars. Mushrooms do contain sugars, amino acids and proteins and hence non-enzymatic browning is inevitable when this high moisture content product is stored above 5°C (Swaminathan, 1988).

2.2. Post harvest metabolism

Harvesting results in severing the supply of substrates by the mycelium for growth and respiration despite the fact that mushrooms after harvest continue to grow (expand) with development of gills and formation of basidiospores. Expectedly, metabolic shift takes place resulting in compositional changes. The shorter shelf life of mushrooms is due to its very high respiration rate-of about 28.2-43.6 mg CO_2 per kg fresh weight per hour at 0°C (Hammond and Nichols, 1975; USDA, 1977) and 280 mg CO_2 per kg fresh weight per hour at 19°C (Nichols, 1985). The respiratory heat in mushrooms is reported to be 14 kcal / kg / 24 h at 20°C (Nichols and Hammond, 1975) and mannitol acts as the preferred post harvest respiratory substrate. There is deceleration in participation of HMP pathway with reduced G-6-PDH activity (Hammond, 1979). It may be mentioned that reverse was the case during crop appearance- the metabolic tilt was towards activated HMP shunt with enhanced G-6-PDH synthesizing NADPH favouring mannitol synthesis.

There is decrease in glycogen and trehalose contents during post harvest storage indicating their role as secondary respiratory substrates after mannitol. Storage of mushrooms at higher temperature (18 to 20°C) resulted in reduction in protein with accumulation of free amino acids due to activated protease enzyme activity (Murr and Morris, 1975b; Rai and Saxena, 1988) and decrease in free amino acids and cell wall glucan (Murr and Morris, 1975a; Hammond, 1979). Lower storage temperature retarded the changes. At higher temperature urea accumulation (Hammond, 1979) and breakdown of nucleic acids and other nitrogenous substances may occur. Chitin production is essential for growth of the stipe and for cap expansion, which occur after harvest. These developmental changes could be prevented by application of the chitin synthetase inhibitor polyoxin D (Wood and Hammond, 1977).

Button mushroom stored at 10 and 20^0C shows a sigmoid pattern of growth, but at 0^0C growth is retarded substantially. The post-harvest growth exhibited at 10 and 20^0C could be related to a decrease in free amino nitrogen while at 0^0C the level of free amino nitrogen significantly increases during storage. Protease activity in the tissue increases from 0, 10 and 20^0C. It appears that the postharvest maturation of mushrooms is promoted by the utilization of low molecular weight nitrogenous compounds formed through increased protein degradation. Mushrooms stored at 20^0C toughen and mature faster than at 0 and 10^0C (Pathak *et al*., 1998).

Eby *et al*. (1977) reported a change in electrophoretic protein patterns during storage at 12°C, and an increase in free amino acids. Reduction in temperature to 0°C prevented the increase in protease activity, but caused a greater accumulation of free amino acids (Murr and Morris, 1975a). Cytokinins have been reported to affect various growth processes in button mushroom (Hammond and Wood, 1985; Braaksma *et al*., 2001). Zeatin and Zeatin ribonucleotide were found in sporophores and stimulated cap opening at low levels (Dua and Jandaik, 1979; Kovacs, 1982 a). Kovacs (1982b) also reported that postharvest treatment of mushrooms with kinetin (100 mg / kg) inhibited cap opening during subsequent storage, while the low concentration (16 to 32 mg / kg) stimulated it. Hammond and Nichols (1975) found that mannitol was the major carbohydrate (13 per cent dry weight) and the main respiratory substrate during storage of button mushroom. They also reported that the rate of loss of mannitol was sufficient to account for about half of the carbon respired. Maximum ethylene production occurred subsequent to veil-break as the gill colour changed from pink to

brown followed by a decline as the fruit body sporulated and senesced (Wood *et al*., 1977).

Hammond (1979) reported a decrease in non-structural polysaccharides from 10 to 5 per cent after 4 days of storage and an increase of 50 per cent in chitin content of cell walls. The total sugars, soluble proteins and total phenol content of white button mushroom during storage declined while, there was an upsurge in the polyphenol oxidase enzyme activity (Rai and Saxena, 1989). De la Plaza *et al*. (1995) reported that the atmosphere in PE packages (10 per cent O_2 + 7 per cent CO_2) delayed firmness-loss but induced the metabolic changes (sugar and organic acids) and colour (yellowness) and reduced the mushroom quality at 18°C after 8 days of storage at 3°C. Kompany and Rene (1995) used three (100, 25 and 8 min) freezing rates (time required to reduce temperature of mushroom centre from initial 20°C to -20°C) and found that flavour retention was best at the highest freezing rate (8 min). During frozen storage, maximum loss in flavour was reported within first 5 days after which no significant loss was found. They found that there was no significant difference in flavour of frozen mushroom during storage at –20°C or –60°C.

Mushrooms with high dry matter content had an increased firmness, better shelf life and decreased shrinking during canning (Van Loon *et al*., 2000). Ates *et al*. (2001) used honey to inhibit the Polyphenol Oxidase (PPO) activity in mushroom and observed that the lowest Arrhenius activation energy (E_a) was 27.71 kJ/mol, whereas E_a in the control was 83.14 kJ/mol. This implies that the temperature coefficient of PPO inactivation was lower in the presence of honey. Quality indices of stored mushrooms were determined after exposure to ethyl alcohol and methyl jasmonate with ethyl alcohol vapours. Ethyl alcohol vapour markedly inhibited cap expansion, stipe elongation and maturity compared with the control. Methyl jasmonate with ethanol vapours was shown to have beneficial effect on whiteness, appearance and decreased activity of active form of catechol oxidase (Czapski, 2001).

3. STORAGE OF FRESH MUSHROOMS

Obviously, fresh mushrooms need to be properly stored to retard post harvest deterioration till these are consumed. Needless to reiterate that the refrigeration or cold-storage is the most essential part of the post harvest care of all the horticultural commodities including mushrooms. Pretreatments, if any, packing and precooling precede the refrigerated storage in most cases.

3.1. Cooling and refrigeration

Cold-preservation of mushrooms is the most important aspect of the storage and can be classified in two categories: refrigeration and freezing. Household and commercial refrigerators usually run at 4–7^{0}C. Cold or chill storage may use a slightly lower temperature (–1 to –4^{0}C), depending upon the freshness of the mushrooms to be refrigerated. Freezing is done at a temperature of below -18^{0}C. Chill storage will preserve perishables for days or weeks and frozen storage (deep freezing) will preserve for months or even years. Refrigeration has certain advantages over freezing as it takes less energy to cool mushrooms to just above its freezing point than to freeze it. The temperature of the button mushroom after picking, which varies between 15 and 18^{0}C, rises steadily during the storage due to respiration and atmospheric temperature and the heat causes deterioration in quality; in addition, the respiratory rate increases with the increase in the storage temperature leading to a vicious cycle. It has been estimated that mushrooms at 10^{0}C have 3.5 times higher respiratory activity than those at 0^{0}C, which necessitates immediate shifting of mushrooms to the refrigerated zone. Hence the heat should be removed immediately after the harvest and the temperature of mushrooms should be brought down to 4-5^{0}C as quickly as possible. Low temperature retards the growth of microorganisms, reduces the rate of postharvest metabolic activities of the mushroom tissues and minimizes the moisture loss. The choice of the cooling system depends upon the quantity to be handled; it may be a refrigerator for a small grower or consumer a cold room with all the facilities for a commercial grower. Forced-chilled air, ice-bank or vacuum-cooling systems are the other systems in vogue at commercial level. The view of button mushrooms during the refrigerated transport and storage is shown in Figure 7.

Fig. 7. Button mushroom packs and stacks during refrigerated transport and storage

The size and shape of the packs play important role in the selection of the cooling room system and design. Packs with more than 10 kg mushrooms or with 15 cm thick layers of mushroom cause problems. Vertical flow of air is more suitable for cooling. The mushrooms should not be stored in the same cooler alongwith fruits as the gases produced by fruits cause discolouration of mushrooms. As the simple forced-chill air-cooling system is time consuming, the vacuum cooling is becoming popular. To ensure high quality mushrooms in the market place with enhanced shelf-life, these must be cooled as quickly as possible after picking and kept cool throughout the cold chain (Rai and Arumuganathan, 2003).

Storage under low temperature is an excellent method for restricting deterioration of harvested mushrooms for a limited period of time. The maturation and textural changes in button mushrooms were slowed down at 0^0C ensuring the maintenance of excellent quality (Murr and Morris, 1975 a). Minamide *et al*. (1980) observed that the shelf-life of the button mushroom was about 14-20 days at 1^0C, about 10 days at 6^0C and 2 to 3 days at 20^0C. Also, polyphenol oxidase activity and respiration rate were enhanced at 20^0C storage. Baker *et al*. (1981) observed that in button mushrooms, forced air cooling resulted in a weight loss of about 2.5 per cent within 15-30 min. Minamide *et al*. (1985) reported that hydrocooling of button mushroom near their freezing point for 3 h within 6 h of harvest, packing in 100 per cent nitrogen gas (N_2) for 2 h and then transferring to room temperature (20^0C) preserved them for 15 days.

Chopra *et al*. (1985) recommended 100 gauge polythene bags with 0.5 per cent venting area for packing button mushroom in case of refrigerated storage. Nichols (1985) recommended optimum temperature and relative humidity for storage of button mushrooms as 0-2^0C and 85-90 per cent respectively. Saxena and Rai (1988) however, reported the adverse effects of over-ventilation of polythene packs; mushrooms were best preserved in non-perforated 100 gauge polypropylene bags kept at 5^0C. Varszegi (2003) conducted an experiment to determine the relationship between the bacterial growth on mushroom cap and the pre-

cooling methods (forced wet cooling and vacuum cooling) and found that vacuum cooling provided the longest period of time needed to reach the maximum value of microbial population and this method was found beneficial for the quality. Blanching for a short period is absolutely essential for producing good quality frozen mushrooms. Steam blanching for 3 min prior to freezing recorded retention of qualities of oyster mushroom also (Das and Pathanayak, 2003).

3.2. Vacuum-cooling

In vacuum-cooling, the water in cell walls and interhydral spaces of mushrooms gets evaporated under low pressure, and the evaporative cooling lowers the temperature from the ambient to 2^0C in 15 to 20 min. Vacuum-cooling is a uniform and faster process, where mushrooms are subjected to very low pressure and water evaporates giving off the latent heat of vaporization. The vacuum-cooled mushrooms have superior colour than conventional-cooled mushrooms. The major drawback of the system is the high capital cost and loss of fresh weight of the produce during the process of cooling. Filling and emptying the cooling chamber adds to the marketing cost. However, air spray-moist chillers can also cool the mushrooms rapidly. The temperature can be lowered by 16-18^0C in an hour without any moisture loss.

3.3. Ice-bank cooling

With a view to reduce the weight loss during the conventional vacuum-cooling, ice bank cooling of mushrooms is now in vogue where a stack of mushrooms is passed through forced draft of chilled but humidified air from the ice bank (Water body maintained at sub zero temperature).

3.4. Irradiation

Radiation preservation offers a method of “cold sterilization” where the mushrooms may be preserved without marked change in their natural characters. Low dosages of γ-radiation could be used to reduce the microbial contamination and extend the shelf-life of mushrooms. However, irradiation should be given immediately after harvest for optimum benefits. Various types of beneficial effects of radiation have been observed in preserving the button mushroom (Staden, 1967; Campbell *et al*., 1968; Wahid and Kovacs, 1980; Roy and Bahl, 1984 a; Lescane, 1994) and oyster mushroom (Roy *et al*., 2000). Irradiation has been found to delay the maturation *i.e*. development of cap, stalk, gill and spore and also reduce the loss of water, colour, flavour, texture and finally the quality losses. Cobalt 60 (Co_{60}) has been used as a common source of γ rays. A dose of 400 krad gave whiter buttons than the controls when the atmospheric temperature during growth and

subsequent handling was slightly lower than 20^0C (Roy and Bahl, 1984 b). A dose of 10 kGy (Kilo Gray) is reported to completely destroy microorganisms. Enhancement in shelf-life of *Agaricus bisporus* upto a period of 10 days was achieved by application of gamma rays close to 2 kGy and storage at 10^0C (Lescane, 1994). Irradiation reduces the incidence of fungal and bacterial infection and also retards the breakdown of mannitol and trehalose. However, the loss of flavour components has been noticed in irradiated mushrooms. But amino acids in fresh mushrooms were better preserved by γ irradiation and this showed that irradiation at low levels proved better than irradiation levels of 1 & 2 kGy (Roy and Bahl, 1984 a).

Benoit *et al*. (2000) investigated the effect of gamma irradiation on some biochemical parameters of the mushrooms: higher doses significantly reduced the rate of respiration compared to samples irradiated with 0.5 kGy and non-irradiated mushrooms. Ionizing treatments significantly increased phenylalanine ammonia-lyase (PAL) activity and total phenolic concentration.

Koorapati *et al*. (2004) evaluated the effect of electron-beam irradiation on quality of white button mushroom and observed that irradiation levels above 0.5 kGy prevented microbes-induced browning. They recommended that irradiation at 1 kGy was the most effective in extending the shelf-life of mushroom slices. A study was conducted by Escriche *et al*. (2001) to determine the effect of ozone on post harvest quality of mushroom. Ozone treatment (100 mg / h) of mushrooms prior to packaging increased the external browning and reduced the internal browning rates. The ozone treatment exhibited no significant differences in terms of texture, maturity index and weight loss of mushrooms.

4. PACKAGING

Packaging plays very important role in handling, marketing and consumption of the produce and products, protects the quality during the storage and transport, keeping in retail and storage with the consumer. Packaging of mushrooms from the production site upto the consumer including packaging for export market is an important aspect of post harvest handling. Generally, the see-through packaging increases the consumer confidence in the product. If the packaging and storage is not done properly, mushrooms not only deteriorate in their saleable quality but also in nutritional quality due to enzymatic changes (Nichols and Hammond, 1975; Rai and Saxena, 1988 & 1989; Rai *et al*., 1988). The tray-packed button mushroom and milky mushroom are shown in Figures 8 and 9, respectively.

The oyster mushrooms are harvested, stem-cut and adhered straw, if any, is removed. The cleaned mushrooms are packed in polypropylene bags of about 100 gauge thickness with perforations having vent area of above 5 per cent. Though the perforation causes slight reduction in weight during the storage, it helps maintain the freshness and firmness of the produce. Storage of *dhingri* at very low temperatures especially in non-perforated polypacks results in condensation of water, sliminess of the surface and softening of the texture. Cooling with positive ventilation is desirable *i.e*. cold air

Fig. 8. Tray-packed button mushroom

Fig. 9. Tray-packed milky mushroom

should be directed through the packed produce. For transporting *dhingri*, the fruitbodies are stacked in trays or baskets. Few polypouches containing crushed ice are kept alongwith mushrooms if refrigerated transport is not available. The tray is then covered with thin polythene sheet with perforation (Fig. 10). The prepacked polythene packs with perforations may also be transported in this way.

Fig. 10. Tray-packed oyster mushroom

Paddy straw mushrooms are packed in polythene bags (Fig. 11) as well as tray packs (Fig. 12). As very low temperature storage causes frost injury and deterioration in quality, the best way of storage is at 10-15^{0}C in polythene bags with perforations. Mushrooms packed in bamboo baskets with an aeration channel at the center and dry ice wrapped in paper placed above mushrooms, is in practice for transportation in Taiwan. Packing in

Fig. 11. Packed paddy straw mushroom

Fig. 12. Tray-packed paddy straw mushroom

wooden cases for transport by rail or boat is practiced in China (Saxena and Rai, 1990).

Paddy straw mushrooms can be stored more effectively at the button stage than at any other stage. At temperatures below 10^0C, however, the mushrooms liquefy rapidly, irrespective of the packaging and stage of development (button or umbrella stage), due to chilling injury (Pathak *et al*., 1998). Figure 13 shows open retailing of paddy straw mushroom in Orissa state of the country where its cultivation has become very popular.

Button mushrooms are packed in many ways as per the retail, wholesale and transport requirements. Gormley and MacCanna (1967) conducted a study to identify the various quality attributes of fresh mushrooms preferred by the consumers (Table 5). Two most important quality factors that affect the sale of fresh button mushroom at the retail shop are the whiteness and stage of maturity *i.e*. the unopened button stage.

Table 5. Quality factors in fresh mushrooms

S. No.	Quality factor	Consumer emphasis*
1.	Whiteness	3
2.	Degree of maturity	3
3.	Free from viral disease	3
4.	Flavour	2
5.	Aroma	2
6.	Toughness	2
7.	Cleanliness	2
8.	Size and shape	2
9.	Nutritional value	1

* (3= very important, 2 = less important, 1 = not very important)
Source: Gormley and MacCanna (1967)

The most common method of packing in developing countries like India is small polyethylene or polypropylene packets containing mostly 200 or 400 g of mushrooms and generally these small packets are

Fig. 13. Open retail sale of paddy straw mushroom in Orissa

Fig. 14. Button mushrooms with vegetable vendors

stored for a few days by retailers or consumers (Fig.14). Quantities more than this have a tendency to loose their acceptability due to price factor. For transportation, these small packs are stacked in large containers (Sethi and Anand, 1976; 1984-85).

Keeping in view the family-demand and price, mushrooms are also packed in plastic punnets (trays) over-wrapped with PVC film. Packaging of the button mushrooms for retail market, by the seasonal farmers is admittedly, primitive: washed mushrooms packed in thin (<100 gauge) polypropylene bags, hand-sealed and unlabelled. Of late, some improvements with respect to labelling and machine-sealing have been introduced. Some firms have introduced unwashed mushrooms in plastic trays over-wrapped with PVC films; six trays of 200 g each in the printed card board boxes (Fig. 15).

Fig. 15. Unwashed mushroom packed in card board boxes

Mushrooms need to be packed for transporting them to the market. Needless to emphasize that while a good pack sells a product, a mediocre pack can adversely affect the sale of an otherwise excellent product. Saxena and Rai (1988) stored button mushrooms in polypropylene bags of less than 100 gauge thickness with perforations having vent area of about 5 per cent and they observed exacerbated veil-opening, browning and reduction in weight during the storage in the perforated bags kept at 15°C; mushrooms were best preserved in non-perforated bags kept at 5°C. They also suggested that button mushroom should be stored in polystyrene or pulp-board punnets for transporting to the long distances, instead of using polythene bags. Plastic punnets with size of 130 x 130 x 72 mm, cardboard chip of 4 lb capacity with size of 305 x 125 x 118 mm, plastic trays of 5 lb capacity with size of 400 x 300 x 100 mm, expanded polystyrene containers of 5 lb capacity with size of 330 x 280 x 145 mm and expanded polystyrene container of 10 lb capacity with size of 400 x 333 x 167 mm packs are used for bulk packaging in the developed countries.

Maaker and Merkens (1969) over-wrapped the mushrooms with moisture permeable film and found that the film retarded wilting without causing accumulation of free moisture on the film and undesirable condensation. The mushrooms became waterlogged and discoloured internally when condensation occurred inside the package during storage (Ryall and Lipton, 1979). Langerak (1972) reported that 600 g chip-board box lined inside with an absorbent paper and outside with water-proof paper was one of the best packing material for mushrooms. It was also observed that mushrooms discoloured faster in the PVC-boxes with the perforated cover than in closed boxes of chipboard and desiccation was much less in the closed cardboard box than in the PVC-box.

Dhar (1992) also found that fruit bodies of summer white button mushroom (*Agaricus bitorquis*) could be stored without significant loss of quality for 6 days at 15°C in non-perforated packs without any chemical treatment or washing in water. De la Plaza *et al*. (1995) found that use of oriented polypropylene (OPP) film can double the storage period compared to PE film, and maintains mushroom quality for at least 2 days at 18°C.

Other improved packaging systems especially in the developed countries are modified atmospheric packaging (MAP), controlled atmospheric packaging (CAP) and modified humidity packaging (MHP). Due considerations have to be given for other alternatives available like corrugated fibre board boxes, corrugated polypropylene bond boxes,

plastic trays, crates, woven sacks, thermoformed plastic trays and stretch film and shrink wrapping.

4.1. Modified atmosphere packaging (MAP)

Modified atmosphere is created in a sealed package of a fresh horticultural produce as a result of exchange of respiratory gases namely oxygen (O_2) intake and carbon dioxide (CO_2) evolution. When the rate of gas permeation through the packaging material equals respiratory gas exchange, consequently an equilibrium concentration of O_2 and CO_2 are established. The equilibrium depends on temperature, respiration rate of specific product, product weight, O_2 and CO_2 permeabilities of the packaging material, free volume in the package and film area (Zakio Bano *et al*., 1997). Properties of the packaging materials play most critical role in modifying the inside atmosphere around the product and consequently the product quality.

Modified atmosphere can be created by two methods: active and passive modifications. In passive modification, the product is just sealed in a polymeric package and due to the respiration of the fresh produce and permeation of gases in / out of the package, the atmosphere is modified. In passive modification, it takes a long time to reach the steady-state conditions within the package. In active modification, desired gas(es) is initially flushed into the package, so that the steady state atmosphere is reached quickly after packaging.

Modified atmosphere packaging (MAP) of mushrooms has been shown to delay senescence and maintain quality of mushrooms during post harvest storage by several workers (Henze, 1989; Burton, 1991; Burton and Maher, 1991; Briones *et al*., 1992; Saray *et al*., 1994; Roy *et al*., 1995 a; Tano *et al*., 1999). Mushrooms covered with PVC-film resinite had a shelf-life of 5-7 days at 15-21°C, as compared to those left uncovered which had a shelf-life of 2-4 days under similar conditions (Gormley and MacCanna, 1967).

The MAP technology for extending the shelf life of button mushroom using modified atmosphere package was tried at the Institute of Horticultural Research, Littlehampton (UK). The incorporation of a small area of a microporous film into the overwrapping film created modified atmospheres in mushroom punnets with moderately low but acceptable oxygen levels. The technique delayed mushroom development and reduced browning and incidence of visible symptoms of diseases on mushrooms at 18°C storage (Burton, 1988). Nichols and Hammond (1973) packed the mushrooms in six different types of films, stored them at two different

temperatures (2 and 18°C) and evaluated the effect of modified atmospheres on the quality. They found that at 2°C, equilibrium was established roughly after 24 h at 4 to 10 per cent CO_2 and 11 to 17 per cent O_2; the mean concentration was dependent on the type of film. At 18°C, equilibrium was established at 8 to 15 per cent CO_2 and 1 to 2 per cent O_2. They suggested that film should be chosen according to the storage temperature of the product. The poor keeping quality of mushroom was mainly attributed to enzyme and microbial activity. The high levels of polyphenol oxidases present in the mushroom reduced the keeping quality in the presence of oxygen and resulted in discoloration. In absence of oxygen, phenol oxidase activity was reduced and there was less brown discolouration of the cap. An atmosphere containing 5 per cent CO_2 with or without 1 per cent O_2 level prevented cap opening of mushroom up to five weeks at 0°C (Murr and Morris, 1974). Nichols and Hammond (1974) reported that 1-4 pin-holes (one mm diameter) in over-wrapping PVC film could control the degree of modification of the atmosphere. Bush and Cook (1976) reported that the optimum conditions for retaining the most acceptable colour and appearance of mushrooms were to store them in perforated plastic packs at 4-7°C and 40-50 per cent relative humidity. According to Nichols (1985) the overwrap films should be perforated to keep the oxygen levels above 4 per cent to prevent anaerobiosis.

The punnets over-wrapped with differentially permeable polyvinyl chloride (PVC) or poly acetate films, created modified atmosphere of about 10 per cent CO_2 and 2 per cent O_2 within the punnet during storage. When a combination of microporous and a relatively impermeable film was used for packing, significant reduction in loss of quality during storage of button mushroom was observed (Burton *et al*., 1987 a & b; Burton *et al*., 1989). Burton and Twyning (1989) compared the modified atmosphere storage of button mushroom at the ambient (18°C) and lower storage temperature (10°C and 2°C) and reported that the combination of low temperature storage with modified atmosphere delayed the post harvest development of mushroom.

Halachmy and Mannheim (1991) reported that there was no chilling injury to mushrooms at temperatures as low as 1.5°C. The respiration rates were found to decrease with temperature and reduction in temperature resulted in the best appearance of mushrooms. The critical O_2 and CO_2 concentration for best quality were found to be 1.5-2 per cent and 12 per cent, respectively. Briones *et al*. (1993) determined the optimal atmosphere for storage of mushrooms and found that CO_2

concentration of 2-5 per cent gave the best colour. They suggested that 2.5-5 per cent CO_2 and 5-10 per cent O_2 were the optimum storage conditions for mushrooms. On the other hand, Anantheswaran *et al*. (1994) recommended 4-6 per cent as an optimum concentration of O_2 for modified atmosphere storage of mushrooms.

Kuyper *et al*. (1993) investigated the effect of modified atmospheric packaging in combination with the addition of calcium hypochlorite on the colour and microbial quality of mushroom, using different combinations of perforated and non-perforated polymeric materials (PVC and LDPE) during storage of button mushroom and found that there was no improvement in colour due to calcium hypochlorite. It significantly reduced the microbial counts in the PVC treatment with two perforations.

Roy *et al*. (1996) found that increased in package relative humidity (IPRH) of 87-90 per cent maintained the best colour in fresh button mushrooms during the modified atmosphere storage. Chi JeongHyun *et al*. (1996 & 1998) studied the effect of packaging materials (Polyvinylidene chloride coated, oriented nylon, anti-fogging wrap or vacuum packing film) in modified atmosphere storage on the keeping quality of mushrooms and found that the antifogging film maintained the quality of mushrooms for 24 days. Gonzalez Fandos *et al*. (2000) observed that the non-perforated packages had the highest contents of CO_2 (6-7 per cent), the lowest contents of O_2 (0.013-0.17 per cent) and the most desirable quality parameters (texture, development stage and absence of moulds).

Singh *et al*. (2001) observed that freezing of mushrooms in liquid nitrogen before storage at subzero temperature and low temperature storage under modified atmosphere with air replaced by nitrogen gas were effective in maintaining the shelf life of button mushroom for 12 days. Shi QiLong *et al*. (2004) optimized the modified atmosphere storage conditions for button mushroom and found that the optimum range of mushroom diameter was 30-40 mm for MA storage; browning degree could be effectively reduced by avoiding mechanical injury during postharvest. They found that optimum composition of package mode was the package materials with PE (0.05 mm, anti-fog), 80 per cent package content and drilling two small holes at single side of package sack.

Wang Xiang You *et al*. (2004) conducted studies to determine the effect of chemical fresh-keeping substance on the keeping quality of modified atmosphere stored button mushroom and reported that the best browning inhibitor and concentration

for stored button mushroom are 0.1 per cent sodium sulfite, 0.06-0.10 per cent ascorbic acid and 0.8-2.6 mmol/ litre cysteine. They also observed the best constitute and proportion for fresh-keeping substance are 0.15 per cent sodium sulfite, 0.05 per cent ascorbic acid, 12 mmol/litre cysteine and 8 min soaking time.

4.2. Controlled atmosphere packaging (CAP)

As compared to the conventional MAP (passive modification of atmosphere within the packs due to produce and film property), very few investigations have been carried out on the controlled atmosphere package (CAP) *i.e.* deliberate and active modification of atmosphere by flushing of gases from outside source. Ramanathan *et al*. (1992) studied the quality of oyster mushrooms stored in different thickness of polyethylene bags under controlled atmosphere storage and found that 300 gauge and 150 gauge polyethylene bags maintained the keeping quality of mushroom up to 20 days at 15 per cent CO_2 and 1 per cent O_2 gas composition. Zheng Yong Hua *et al*. (1994) conducted studies on controlled atmosphere storage of fresh button mushrooms and found that 8 per cent O_2 + 10 per cent CO_2 was the best atmosphere for maintaining the quality of fresh mushrooms.

4.3. Modified humidity packaging (MHP)

Most polymeric films used in the conventional packing have lower water vapour transmission rates relative to transpiration rates of the fresh produce, which often leads to nearly saturated conditions within the packages. The high in-package relative humidity (IPRH) may cause condensation of water vapour within the package and allow microbial growth; it also reduces the visibility of the produce for inspection. This may either increase or decrease the spoilage depending on the product's transpiration coefficients and water potentials (Cook and Papendick, 1978).

To obtain the desired IPRH, there are two possible approaches: perforation of the package, which precludes the possibility of achieving the modified atmosphere conditions within the package, and use of in-package water absorbing compounds, like calcium chloride, can maintain the required IPRH (Eaves, 1960). Roy *et al*. (1996) found that MAP in combination with MHP further improved the shelf-life of fresh mushrooms. An IRPH of 87-90 per cent was desirable for best colour in mushrooms during storage.

The shelf-life of the mushrooms could be further extended by

supplementing some chemicals in addition to modifying the atmosphere inside the package during storage. Use of sorbitol pouches maintained the best colour in mushroom when it was packed and stored along with fresh mushroom wrapped with PVC films (Roy *et al*., 1995 b). Anantheswaran and Ravi Sunkara (1996) used commercially available food grade moisture absorbers such as montmorillonite clay and silica gel and extended the shelf-life of mushrooms in modified atmosphere packs.

Cho Sungsan *et al*. (1998) studied the effect of various supplementary packaging materials (activated carbon, chitosan, potassium permanganate) on the quality of mushrooms stored in antifogging film at the ambient temperature and found that chitosan prolonged the shelf-life to 10 days, 4 days longer than the control treatment. Popa *et al*. (1998) studied the use of a humidity absorber (Silica gel) in the packages during the modified atmosphere storage and found washing in chlorinated water and incorporation of dehumidifiers decreased the microbial contamination and extended the shelf life of *Agaricus bisporus*.

4.4. Washing

In American and European countries, where peat is used as the casing soil and sprays are in the nature of 'washing down', the mushrooms are not washed before packaging. However, in India and some other countries, button mushrooms, which are often soiled due to the use of FYM-based casing soil, need to be washed before sale or processing. Consumers have developed a preference for the washed mushrooms, though enlightened people still go for the unwashed. Though washed mushrooms deteriorate faster than unwashed but washing becomes necessary to remove soil particles if non-peat casing soil is used. Mushrooms are trimmed with stainless steel knives immediately after harvesting (Fig. 16) and washed to remove the adhering casing soil and other foreign materials and then they are packed in suitable containers. Increased water content in the mushroom, however, results in shogging and spoilage by bacteria. Generally plain water is used for washing of the mushrooms, which makes the mushrooms free from the adhering casing soil only, but does not impart any whiteness to the mushroom. To improve and maintain whiteness many pretreatments have been tried: dipping of mushrooms in dilute solutions of hydrogen peroxide (1:3) for half an hour and then steeping in 0.25 per cent citric acid solution containing 550 ppm sulphur dioxide showed significant positive effect (Pruthi *et al*., 1984). Small growers wash the mushrooms in solution of other reducing agents also

Fig. 16. Harvesting and trimming (stem-cutting) of button mushroom

to retard the browning caused by polyphenol oxidase.

Beelman (1987) reported that Oxine, a stabilized form of chlorine dioxide, was effective in controlling bacterial growth and colour deterioration of the button mushroom when used at a level of 50 ppm or higher with a two minute or longer wash period. Use of sodium hypochlorite (100 ppm) and calcium chloride (0.55 %) with oxine (100 ppm) was found to result in increased antibacterial effectiveness. Use of calcium chloride and oxine also resulted in lower cap-opening and firmer mushrooms during the storage.

Maini *et al*. (1983, 1987) reported that washing of mushrooms prior to packing is very important for enhancing the shelf-life and extending its marketing period. Washing of fresh mushroom in water containing sodium sulfite solutions resulted in lower bacterial counts and improved initial appearance (Fig. 17), but more rapid bacterial growth and browning occurred during subsequent storage compared to unwashed controls (Guthrie and Beelman, 1989). Mushrooms washed in hard water (150 ppm calcium carbonate) reduced bacterial growth and there was less colour deterioration during storage while washing mushrooms in a solution consisting of Oxine (50 ppm), sodium erythroborate (0.1 per cent) and calcium chloride (0.5 per cent) resulted in significantly lower

Fig. 17. Washed button mushrooms

bacterial populations and less colour deterioration during subsequent storage.

Glandorf (1962) reported that washing mushrooms in 0.1 per cent solution of *potacki* (a mixture of salts of organic acids including citric acid) for 15 min improved their keeping quality and maintained the fresh appearance. Gormley (1972) could prevent discolouration of button mushroom by soaking in various concentrations of citric acid (0-1 per cent), but observed an adverse effect on flavour. Pre storage dips in citric acid (0.05 to 0.1 per cent) used to prevent oxidative browning due to o-diphenol oxidase, led to the development of typical flavours (Liebster *et al*., 1975).

Washing of mushroom in chlorinated water and incorporation of dehumidifiers like silica gel in the packs decreased the microbial contamination and extended the shelf-life of button mushroom (Popa *et al*., 1998). The washing treatment consisting of 1000 ppm chlorine in combination with 10000 ppm hydrogen peroxide had potential as an alternative to the use of sulphite in the washing of mushrooms (McConnell and Beelman, 1994). Hershko and Nussinovitch (1998) coated the button mushrooms with different gum-based coatings, including alginate and alginate-ergosterol, with and without emulsifier. They found that coated mushrooms had better appearance, colour and an added advantage in weight retention in comparison to the uncoated ones. The alginate-ergosterol- Tween coating combination was most suitable for maintaining the size, shape and quality of the coated mushroom. Sapers *et al*. (1999) found that washing of button mushrooms damaged the surface structure, which promoted microbial growth. Washing with 5 per cent hydrogen peroxide (H_2O_2) extended shelf-life from 4-6 days to one week but it induced browning. Washing with 5 per cent H_2O_2 followed by application of sodium erythorbate controlled the development of browning (Sapers *et al*., 2001). Czapski (2002) reported the best results by dipping mushrooms in hydrogen peroxide solution (1st stage) and then in solution consisting of sodium erythorbate, cysteine hydrochloride and EDTA. Saxena and Rai (1988) observed that washing of mushrooms in 0.05 per cent potassium metabisulphite improved the initial whiteness which lasted longer during the storage. EDTA (disodium) has also been found to give good results in washing of mushrooms (Ahlawat *et al*., 2000 a). The calcium chloride added to the irrigation water improved the quality and shelf life of button mushroom (Barden *et al*., 1990; Solomon *et al*., 1991; Miklus and Beelman, 1994; Simons *et al*., 1995 a; Miklus and Beelman, 1996; Ahlawat

et al., 2000 b) and also the yield and colour of the canned mushrooms (Simons *et al*., 1995 b). Sharma and Bahukhandi (2003) obtained the best results in terms of maintenance of fruiting body quality by washing with KMS, tartaric acid and ascorbic acid at 12 ± 2^0C.

4.5. Transportation

The positive effects of pre-cooling and packing will be partially neutralized if the product thereafter is stored and transported in a hot environment. Mushrooms, therefore need complete cool-chain for storage and transport. To keep the precooled mushrooms cool during the transport to the short distances under the ambient conditions, the polypacks of mushrooms are stacked in small wooden cases or boxes with sufficient crushed ice in polypacks (overwrapped in paper) by the small growers. For transport of the large quantities to the long distances, refrigerated trucks, though costlier, are indispensable.

5. LONG-TERM STORAGE

All techniques which store mushrooms, processed or unprocessed, longer than normal storage period for the fresh are together called long-term storage. Due to the improved strains, production technology and innovative techniques mushroom production in our country has increased over the years. Need for long-term storage may not arise during the off-season, but, to minimise the fall in prices in the peak season and also to avail the high price during the off-season, the grower and processors preserve them by different methods to extend the shelf-life and add value to the product. This long-term stored mushroom can be exported as well as made available during the off-season. Commonly followed long-term storage techniques for mushrooms are canning, drying, steeping and pickling.

5.1. Steeping preservation

Cost of the canned and freeze-dried mushrooms is very high and not many can afford such products. Steeping preservation of mushrooms (Bano and Singh, 1972; Adsule *et al*., 1981; Pruthi *et al*., 1984; Sethi *et al*., 1989 & 1991; Sandhu and Aggarwal, 2001) is convenient as well as economical for extension of the shelf-life of mushrooms and also for transport this highly perishable commodity to the distant places. The method is simple, economical and mushrooms can be preserved for periods ranging from 3-6 months by steeping them in concentrated solutions of salts and or acids. Steeping preservation of mushrooms helps to extend shelf life as well as retain whiteness. Cleaned mushrooms are washed in plain water or chemical-added water and filled in large plastic containers. Five minutes blanching in brine solution is some times done before filling them in containers. Brine solution is then added into the cans or containers. The steeped button and oyster mushrooms are shown in Figure 18.

Various researchers have tried different chemical cocktails for steeping preservation. Solution consisting of 2 % sodium chloride, 2 % citric acid, 2 % sodium bicarbonate and 0.15 % KMS (Kapoor, 1989) and of 2 % salt, 2 % sugar, 0.3 % citric acid, 0.1 % KMS and 1 % ascorbic acid (Singh *et al*., 1995) were used for steeping preservation of the blanched button mushrooms for 8-10 days at 21-28^{0}C. Dipping of mushroom in dilute solutions of hydrogen peroxide for half an hour and then steeping in 0.25 per cent citric acid solution containing

Fig. 18. Steep preserved button and oyster mushroom

550 ppm sulphur dioxide had significant effect on the whiteness of mushroom (Pruthi *et al*., 1984). Singh (1997) demonstrated that cream white colour of button mushroom can be retained and their shelf life extended up to 375 days under the ambient conditions by steeping preservation. He washed mushrooms for one min in water, blanched them for 3 min in boiling 2 per cent NaCl and steeped in a solution of 5 per cent NaCl + 1 per cent sugar + 0.3 per cent citric acid + 0.5 per cent ascorbic acid + 1000 ppm KMS. Huawang and Cheng (1978) conducted studies on mushrooms treated with salt and organic acids and reported that salt concentration higher than 10 per cent intensified the browning reaction of the mushroom but when the cover-brine was equilibrated at pH 4 with organic acids, no further browning was observed. Treatments of mushrooms with higher concentrations of organic acids, however, reduced the hardness of mushrooms.

This type of preservation can be done by two methods.

5.1.1. Unexhausted steeping preservation

Fresh mushrooms were washed and blanched in 0.05 per cent of KMS for 5 min. After draining off, mushrooms were washed with cold water for 4-5 times and then filled in the bottles or cans. Hot brine of 18 to

20 % NaCl and 0.1 % citric acid was filled in the bottles. After proper lidding, the bottles were kept for storage at room temperature. This method of steeping preservation is known as unexhausted steeping preservation and was good for storing mushrooms upto 3 months (NRCM, Annual Report-2000-01).

5.1.2. Exhausted steeping preservation

Upto filling of the brine solution in the bottles, the procedure is same as described above. After filling the brine + acid solution, the bottles are kept in hot water bath until the temperature of brine reaches 80 to 85^{0}C in the center. After maintaining the brine temperature at 85^{0}C for 10 min, the bottles are sealed and kept for storage (NRCM, Annual Report-2000-01). Only water-blanched mushrooms impart yellow colour to lesser degree and whiteness is maintained excellently in the treated mushrooms (Pruthi *et al*., 1984).

To consume the steep preserved mushroom, it has to be thoroughly washed (debrined) with water and then it can be used as per requirement. The technique has also been to accumulate the quantities sufficient for a batch of canning as well as for transporting steeped mushrooms to long distances by shipping, for canning.

5.2. Drying

Drying is perhaps the oldest technique known to the mankind for preservation of food commodities for long duration. It is the process of removal of moisture from the product to such a low level that microbial and biochemical activities are checked due to reduced water activity which makes the products suitable for safe storage and protection against the attack by microorganisms during the storage. Mushrooms contain about 90 per cent moisture at the time of harvesting and are dried to a moisture level down below 10-12 %. At a drying temperature of 55-60^{0}C, the insects and microbes on the mushrooms will be killed in a few hours, which gives us the dehydrated final product of lower moisture content with longer shelf-life. The temperature, moisture of the mushroom and humidity of the air affect the colour of the dried product (Yapar *et al*., 1990). Dehydrated mushrooms are used as an important ingredient in several food formulations including instant soups, pasta, snack seasonings, casseroles, and meat and rice dishes (Tuley, 1996; Gothandapani *et al*., 1997).

Most of the mushrooms, except the button mushroom, have been traditionally dried for long-term storage *e.g*. oyster, shiitake, paddy straw, *Auricularia* etc. In case of button mushroom it is the blackening

and irreversible change of texture, which often discourage the use of this otherwise simple technique of preservation.

5.2.1. Sun-drying

Sun-drying is the cheapest and oldest method among various drying methods. It is a very simple operation, where no fuel or mechanical energy is required. However, it is completely dependent on weather and it is not possible round-the-clock and round-the-year. Even though the quality of the product is affected by the environmental factors, due to free availability of heat source, it is considered to be the lowest-cost method of drying. Mushrooms are spread over the trays or sheets and kept in open under the sun; favourable atmospheric conditions are above 25^{0}C temperature, with less than 50 per cent relative humidity and high wind velocity. Sun dried product contains more than 10-12 % moisture and should therefore be oven dried at 55-60^{0}C for 4-6 h to further reduce the moisture to 7-8 % to avoid any spoilage during storage. The dried product regains to a large extent its flavour and texture after rehydration. The technique has however, been not used for the button mushroom. Other mushrooms are generally sun-dried by resource-poor growers (Rai *et al*., 2003). Saxena and Rai (1990) reported that *dhingri* could be sundried during the days with high temperature (above 25^{0}C), low humidity (less than 50 percent RH) and high wind velocity. The fruit body of the *dhingri* can be beaded in a thin wire or thread and hanged in the air in direct sunlight for efficient dehydration and freeness from dust. The weight of the end product of this method had 10-12 percent of its original weight. They also recommended that the sundried product should be oven dried at 55-60^{0}C for 4-6 h before packing in air-tight packs.

Rama and John (2000) reported that when the temperature during sun-drying ranged from 21.6^{0}C to 35.7^{0}C, time taken was 14 h for the pretreated oyster mushroom and 12 h for the untreated oyster mushroom, to reach 5-6 per cent moisture level. They also reported that the dehydration ratio, shrinkage ratio and rehydration ratio of the sun dried product (Fig. 19) was 10.64, 0.19 and 2.21 respectively. The colour of the final product varied from brown to creamy white.

Fig. 19. Sun-dried oyster mushroom

Nehru *et al*. (1995) designed and developed a solar mushroom drier with a capacity of 2.5 kg fresh oyster mushroom / day. The oyster mushrooms treated with 0.5 per cent KMS for 15 min and 0.5 per cent sodium benzoate for 15 min had the same amount of nutrients (protein, sugars and amino acids) as fresh mushrooms. The highest rehydration ratio (5.25) and best organoleptic quality was obtained for the sample treated with 0.5 per cent KMS.

Sugana *et al*. (1995) conducted trials with a natural convection solar cabinet drier for drying oyster mushroom and it took a drying time of 7 h when the ambient temperature varied between 29 and 32^{0}C. Arumuganathan *et al*. (2004) conducted the experiments on sun-drying of oyster mushroom and found that the treatment with 0.05 % KMS + 0.1 % citric acid yielded good quality dried oyster mushroom.

5.2.2. Cabinet air drying

Cabinet air drier which is also known as tray-drier (Fig. 20) consists of series of trays placed in the plenum chamber and hot air at constant air flow rate is allowed to pass through this plenum chambers.

However, the conventional oven-drying method results in dark brown coloured product with a tough texture in case of the button mushroom; other

Fig. 20. Cabinet drier

mushrooms give reasonably acceptable product. Due to little air movement inside the conventional oven, the evaporated water condenses on fruit bodies increasing the mucilage and deteriorating the quality. Large quantity of condensed water may also damage the equipment. Hence, a cabinet drier with circulated air supply was found to be superior (Mudahar and Bains, 1982). This process utilizes mechanical means for ventilating natural/hot air through mushrooms to accomplish the removal of moisture. Its features are

1. The rate of drying can be controlled by adjusting the temperature of hot air ventilating through the mushroom. The process, therefore, makes possible the reduction of temperature and moisture stress developed during the drying process.

2. Mushrooms can be dried irrespective of weather conditions,

day or night, as the process does not depend on any natural sources like sunlight.

3. The process is automatic and requires unskilled labour except a trained person to operate the dryer.

4. There are practically no losses to insects, birds and rodents in the process.

5. It, however, requires fuel and electrical or mechanical power to drive the air blower, elevators *etc*. therefore the cost of drying per kg of mushroom is higher compared to sun drying.

6. It requires less space for operation.

The drying temperature of 55^{0}C in the plenum chamber has been found to give the end product with the desired qualities of texture, colour and rehydration. Home made cabinet drier is essentially a galvanised box of size 90 x 60 x 90 cm with perforated iron sheet at the bottom. The sides and the top of the box are fixed in a wooden frame and the whole thing is supported on an angle iron stand of about 38 cm height. There are two slits (5 cm x 3.7 cm) along the top end of the two long sides and about 10 cm below the top. These slits are provided with metallic shutters for opening and closing. About seven trays (87 cm x 60 cm) can be stacked on supports in staggering positions. The perforated iron plate at the bottom of the cabinet can be heated by means of a charcoal oven or oil stove.

Bano *et al*. (1992) reported that the mechanically-dried oyster mushrooms packed in air-tight containers have more than one year of shelf-life. Rama and John (2000) studied the mechanical drying of oyster mushroom. They maintained the temperature at 60^{0}C for the first 4 h and later at 50^{0}C for the rest of the 11 h of drying to reach a moisture content of 5-6 per cent except the samples without any pretreatment which took only 8 h. The dehydration ratio, shrinkage ratio and rehydration ratio of the mechanically dried product were 9.89, 0.2 and 2.61 respectively. The colour of the dried product varied from brown to creamy white. Dehydrated oyster mushrooms should be packed in foil-laminated pouches for better storage stability (Kumar *et al*., 1980). Figure 21 shows the picture of the cabinet dried oyster mushroom.

Conditions of dehydration of tropical paddy straw mushrooms have been standardized by Pruthi *et al*. (1978). For the inactivation of peroxidase and catalase prior to dehydration of mushrooms, optimum time of water blanching was found to be 3-4 min and that of steam blanching as 4-5 min. Dehydration process in a

Fig. 21. Cabinet air-dried oyster mushroom

cross-flow drier at 60°C took about 8 h, while dehydration in a phased manner at 70-65-60°C took about 7 h. Authors recommended a three-phase dehydration process, which is as follows: initial drying temperature of 70°C for 2 h followed by 65°C for 2 h and 55-60°C for the rest of the time.

Thickness of mushroom is an important factor affecting the drying characteristics; other factors are temperature and ratio of the air-film to mushroom resistance towards water diffusion. Pruthi *et al*. (1984) reported that longitudinally sliced and blanched button mushrooms when dried at 60^0C for 5 h, had a drying ratio of 10.8:1 and rehydration ratio of 2.78 as against cross slit mushrooms with drying time of 8 h, drying ratio of 10.9:1 and rehydration ratio of 2.80. According to Arora *et al*. (2003), blanching of both button and oyster mushroom in boiling water for one min and treating in solution containing 0.1 % citric acid and 0.25 % KMS for 15 min at room temperature resulted in lowest browning index and the activation energy values of button and oyster mushroom were determined to be 19.79 and 23.59 kJ/mol in the cabinet drying method. Pandey *et al*. (2002) conducted dehydration studies on milky mushroom and observed that rehydration of oven-dried product was better than room temperature or sun-dried samples.

Drying in mechanical dehydrator was reported to be fastest by Katiyar (1985) because of high air temperature and forced air circulation. Mean dehydration time was 8.4 h where as 16.8 sun hours were needed in sun-drying. However, Ashwani Kumar (1992) dehydrated *Agaricus bisporus* for 9 h at 60 ± 2^0C to a constant weight. Lidhoo and Agrawal (2006) dried white button mushroom in a hot air oven and observed that minimum browning

index was recorded at 65^{0}C and rehydration ratio obtained at this temperature was 2.9.

5.2.3. Dehumidified air-cabinet drying

Dehumidified air-cabinet drying is accomplished by dehumidifying air cabinet drier (Fig. 22). The principle in which this drier works is shown in Figure 23. Ambient air is passed through an air heater and gets heated up. Hot air passes into the drying cabinet and removes moisture from the mushroom. Air gravitates to or / is sucked onto the condenser (chiller) where it deposits its moisture. The other type of dehumidified air drying is to expose the moisture-laden air to pass through the desiccated medium *eg*. Silica gel. The desiccator (silica gel) absorbs moisture from the air, as a result, relative humidity of air is reduced and at the same time there is an increase in its temperature. When such dehumidified air comes in contact with fresh mushrooms, transfer of moisture from mushroom to drying air takes place faster (Sahay and Singh, 1994). Figure 24 shows the picture of excellent oyster mushrooms dried by dehumidifying-air cabinet drying method. The process allows faster drying at relatively lower temperature as compared to the

Fig. 22. Dehumidifying air cabinet-drier

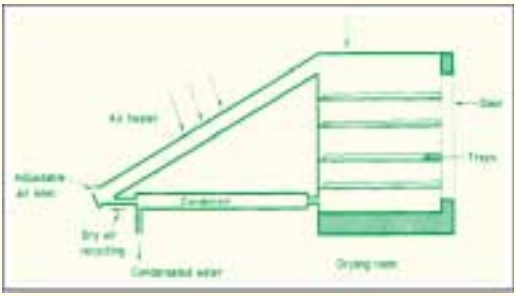


Fig. 23. Working principle of dehumidifying air cabinet-drier

Fig. 24. Dehumidifying cabinet air-dried oyster mushroom

conventional cabinet-air drying *e.g.* it is possible to dry button mushroom slices and oyster mushroom (whole) at 45^0C or even lower in dehumidifying air cabinet drier to give superior product (NRCM, Annual Report-2004-05).

5.2.4. Osmo-air drying

Osmotic dehydration is a novel technique suitable for high-moisture and perishable commodities *viz*., fruits and vegetables. It is a two-stage process: first step consists of keeping the material in a concentrated salt solution called osmotic syrup; in the second stage, a stable dehydrated product will be produced after doing proper air drying of the product taken out of the osmotic syrup. Main principle involved in the osmotic dehydration is removing moisture at lower temperatures avoiding thermal treatments to get a product with colour, flavour and textural qualities nearest to the natural one (Amuthan *et al*., 1999). Yang and Le Maguer (1992) conducted studies on osmotic dehydration of the button mushroom in a continuously circulated contacting reactor and recommended 15 per cent NaCl as the optimum. Pretreatments of the mushrooms in high concentrations of sucrose, followed by high salt concentration was most effective method to remove water and loading salt to further lower the water activity in the mushroom. Kar and Gupta (2001) reported that osmosis using 15 per cent brine solution could remove about 35 per cent of initial moisture in one hour. Amuthan *et al*. (1999) conducted studies on osmo-air drying of milky mushroom (*Calocybe indica*) and found that the moisture removal was higher by osmosis at 25 per cent concentration of salt in 6 h duration. The osmosed samples took about 170 min to dry and the rehydration of the mushroom osmosed with 25 per cent salt concentration was obtained in a shorter period of 50 min. The colour of the osmo-air dried sample was very good as compared to the cabinet-drying.

Fig. 25. Osmo-air dried button mushroom

5.2.5. Freeze-drying

Removal of water from a substance by sublimation from the frozen state to the vapour state is known as freeze-drying. Freeze-drying takes place in three stages: water present in the product is removed by formation of ice crystals; the ice crystals are then

removed from the outer surface of the material by sublimation; after removal of all the ice, the little quantity of water left is then removed by evaporation in the freeze dryer (Fig. 26). In a freeze-drying system, original shape and size can be retained and the shrinkage, which is a problem with other drying methods, is almost negligible.

Fig. 26. Laboratory freeze drier

Mushrooms are freeze dried at -20^{0}C and the moisture is removed by sublimation at a very low vacuum (0.012 mbar) for 12-16 h. The freeze-dried mushrooms (Fig. 27 & Fig. 28) have superior flavour and appearance but are brittle (Kapoor, 1989). The appearance of freeze dried mushrooms is very similar to fresh mushrooms but as the product is brittle, it is packed in sturdy packings and cushion-packs flushed with nitrogen for better keeping quality (Saxena and Rai, 1990). The product can be stored upto 6 months without any change in its quality and appearance. However, this is a very costly and energy-intensive process and the venture depends upon the demand and price for such products.

Fig. 27. Freeze dried button mushroom

Fig. 28. Freeze dried oyster mushroom

Freeze-drying has been tried by the following method also. The sliced mushrooms are immersed in a solution of 0.05 per cent KMS and 2 per cent salt for about 30 min. The

pretreated mushrooms are then blanched in boiling water for two min followed by cooling. The product is frozen at -22^{0}C for one min. The frozen mushrooms are dried to moisture content of 3 per cent in a freeze drier and packed under vacuum (Kannaiyan and Ramsamy, 1980).

5.2.6. Fluidized-bed drying

Fluidized-bed drying is the process of removing moisture by exposing commodities into a high velocity of hot air. The velocity of the hot air should be such that it should not throw out but keep the material in the fluidized condition. Fluidized-bed drying, besides providing high quality product, reduces drying time also. A laboratory model fluidized bed drier is shown in Figure 29, the cap is yet to be placed on top of it.

Fig. 29. Fluidized bed drier

Singh *et al*. (2001) studied the drying characteristics of the fluidized-bed drying of the button mushroom and found that quality of the dehydrated mushrooms was significantly influenced by the pretreatments as well as temperature; the samples treated with 1 per cent KMS, 0.2 per cent citric acid and 3 per cent salt solution and dried at 50^{0}C gave satisfactory results. Suguna *et al*. (1995) designed a batch type fluidized-bed drier of 6 kg / batch capacity and obtained a satisfactory shelf-life of 5 months. The optimum temperature was found to be 50^{0}C with an air flow rate of 35 m^3/ min. Figure 30 shows the picture of the oyster mushrooms dried using fluidized bed drier.

Fig. 30. Fluidized bed dried oyster mushroom

Deshpande and Tamhane (1981) dried paddy straw mushroom using fluidized bed drier and found that drying at 80^{0}C took 90 min to obtain acceptable paddy straw mushroom.

Further, they observed that dried paddy straw mushrooms stored at higher temperature (37^0C) and higher relative humidity developed off-flavour while samples stored at 25^0C temperature and relative humidity of less than 60 per cent remained acceptable upto 2 months.

5.2.7. Microwave drying

Increasing demand for foods that offer greater convenience in preparation and are time-saving have forced the food processors and consumers to go for microwave-drying. It offers the products with good organoleptic and nutritional values (Sahni *et al*., 1997). Microwaves are generated by magnetron, a device that converts electric energy at low frequencies into an electromagnetic field with centers of positive and negative charge that change direction billions of times per second. Penetration and heating of foods by microwave energy sources are instantaneous. In contrast, conventional heating methods transfer thermal energy from the product surfaces towards the center 10 to 20 times more slowly. In a microwave oven, the product is exposed to an alternating electromagnetic field in frequency range of 800 to 3000 MHz. This region of electromagnetic spectrum falls between the frequencies associated with radio-waves and infrared radiation. Two frequencies are employed for generation of microwaves to prevent interference with radio communication or radar equipment; these are 896 MHz and 2450 MHz. The microwave energy is injected with a resonant cavity in which the target material is placed or passes through. Uniformity is achieved by rotating the product or by stirring the incoming microwaves by moving a deflector into the beam. Microwave radiation, by nature of its position in the electromagnetic spectrum is non-ionizing and therefore not capable of producing the long-term effects on the body associated with other types of radiation (Sahni *et al*., 1997). However, use of microwave heating for a complete drying process is likely to be uneconomical (Bengtsson and Ohlsson, 1986), but it may be advantageous to specify microwave heating for use during fallen period of drying operation where the heat and mass transfer mechanisms during conventional drying are rate limiting (Funebo and Ohlsson, 1998; Torringa *et al*., 2001). The mushrooms when dried with combined hot air-microwave lead to further shortening of the process time and good quality final product are achieved. Moreover, retention of the characteristic aroma compound (1-octen-3-ol) and its oxidation product (1-octen-3-one) are positively affected by microwave drying (Singh *et al*., 1995).

The first commercial application of microwave energy in food processing was drying of potato chips (Decareau, 1984). Rama and John (2000) dried the oyster mushrooms using a microwave oven of T-23 Touch Electronic model. The power output was 700 Watts with microwave frequency of 2450Hz. Three stage drying was given to the mushroom during microwave drying, where the initial power level as 100 per cent for 20 min, followed by 60 per cent for another 20 min and 50 min for the rest of the period of drying. It was found that the pretreated fresh oyster mushrooms took 90 min drying time to reach 5-6 per cent moisture content and the mushrooms without any pretreatment took only 75 min to accomplish 5-6 per cent moisture content. Spices and condiments may be added prior to, during or after microwave drying of the mushrooms for making ready-made snacks like mushroom chips from slices of button, paddy straw or whole oyster mushroom (Unpublished NRCM work).

5.3. Pickling

Preservation of fruits and vegetables by pickling is age-old method, second perhaps only to sun-drying and are very popular in India. Several recipes of pickle preparation in oil or vinegar are in practice in different parts of the country (Girdharilal *et al*., 1967). Pickling is a method of long-term storage to preserve mushrooms in an economically viable way. These pickles are good appetizers as well as they add palatability to the meal. It is also a process by which one can store to relish them during the off-season when the price of mushrooms is very high.

Mushrooms for pickling are either blanched or fried in oil till brown depending upon taste; various condiments as per local preferences and practices are also ground or fried in oil separately and added to the mushroom. The contents are mixed thoroughly and cooked slightly for few minutes. It is allowed to cool and then filled in the jars (lugs) of desired size. Vinegar may be added for taste and longer storage and the contents in the bottle or the container should be topped up with oil (Saxena and Rai, 1990).

According to a formulation developed and standardized at the NRCM, Solan, mushrooms are washed, sliced and blanched for 5 min in 0.05 per cent KMS solution. The blanched mushrooms are washed in cold water for 2-3 times and the excess water is drained off. Then the mushrooms are subjected to salt curing process, in which 10 per cent sodium chloride is added and kept over night. The excess water oozed-out of mushroom is removed on the next day and spices & preservatives are mixed

to the desired taste and quality of mushroom pickle. The various spices namely turmeric powder, black mustard seed powder (*rai*), red chilly powder, cumin seed powder, fenugreek seed powder, aniseed powder (*suwa/ shopa*), black pepper, carom seed (*ajwain*), nigella seed (*kalonji*), fennel seed powder (*saunf*) and mustard oil are added to prepare tasty pickle (Fig. 31). Acetic acid and sodium benzoate within the permitted limits are used as preservatives.

Fig. 31. Button mushroom pickle

The process flow chart for the preparation of mushroom pickle is shown in Figure 32. This pickle can be stored upto one year in the lug bottles (Saxena and Rai, 1990). The various ingredients required for preparing mushroom pickle using 1 kg blanched mushroom are listed in Table 6.

Good quality pickle can also be prepared from oyster mushroom (Arumuganathan *et al*., 2003). In a patented pickling process, cleaned mushrooms are blanched in hot water

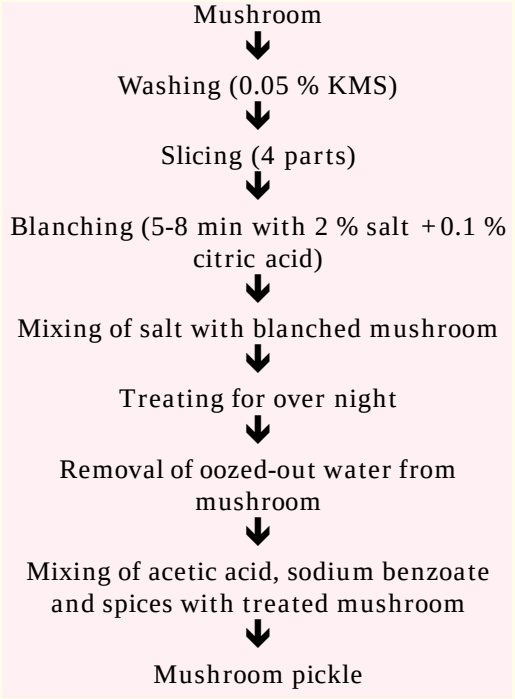


Fig. 32. Flow chart for mushroom pickle preparation

Table 6. Ingredients for mushroom pickle

S.No	Ingredients	g/kg
1	Black mustard seed powder (*rai*)	35
2	Turmeric powder	20
3	Red chilly powder	10
4	Cumin seed powder	1.5
5	Fennel seed powder (*saunf*)	1.5
6	Carom seed (*ajwain*)	10
7	Nigella seed (*kalonji*)	10
8	Oil	200 ml
9	Salt	90

(80^{0}C for 5 min), rapidly cooled and added to 60 per cent brine to obtain mushroom to brine ratio of 7:3 by

volume. The mixture is maintained at 15-20^{0}C for 15 days for fermentation and further kept at 0-4^{0}C to obtain a pH of 3.9. Sugar is added to the preparation at the rate of 3.3 per cent by weight to the brine and final salt concentration reached to 6.6 per cent by weight (Singh *et al*., 1995). Singh and Bano (1977) studied the suitability of *Pleurotus* spp. for pickle preservation. They reported that the product could be stored for a minimum period of 6 months at the ambient temperature (22-34^{0}C) without any off flavour. Khader and Pandya (1981) prepared a pickle from paddy straw mushroom having good keeping quality.

5.4. Canning

Canning is technique by which the mushrooms can be stored for longer periods up to a year and most of the international trade in mushrooms is done in this form. The canning process can be divided into various unit operations namely cleaning, blanching, filling, sterilization, cooling, labeling and packaging. In order to produce good quality canned mushrooms, these should be processed as soon as possible after the harvest. In case a delay is inevitable, mushrooms should be stored at 4 to 5^{0}C till processed. The mushrooms with a stem length of one cm are preferred and are canned whole, sliced and stems-and-pieces as per demand (Beelman and Edwards, 1989). Longitudinal (mushroom shape) slicing is common (Mudhahar and Bains, 1982; Pruthi *et al*., 1984).

5.4.1. Cleaning

The mushrooms are sorted to remove diseased, damaged, bruised and browned ones. Fresh mushrooms white in colour, without dark marks in either cap or stem are preferred for canning. The veil should be in tight closed condition and not stretched otherwise the mushroom will open in the blanching and will be rejected in can-filling process. Grading based on cap diameter is also followed (Azad *et al*., 1987). Then the whole mushrooms are washed 3-4 times in cold running water to remove adhering substances. Use of iron free water with 0.1 per cent citric acid prevents discolouration. Hydration with jets before blanching is now a common practice in the industry; it washes as well as hydrates the mushrooms to reduce weight-loss in canning.

5.4.2. Blanching

Blanching is normally done to inhibit polyphenol oxidase enzyme activity and to inactivate microorganisms. It also removes the gases from the mushroom tissue and reduces bacterial counts. The mushrooms are blanched in stainless steel kettles filled with a boiling solution of 0.1 per cent citric acid and 1 per cent common salt. The blanching

time ranges from 5-6 min at 95-100^{0}C (Tanga, 1974; Saxena and Rai, 1990). Some plants blanch the mushrooms in slightly acidified water to improve the colour of the canned product. The foam developed during blanching should be removed constantly. The loss of weight during blanching is about 20-25 per cent of the fresh weight of the product. If blanching time is reduced to restrict weight loss, the loss of weight at sterilization will be accordingly higher. Six minute blanching is common to give proper drained weight of the final product especially in A-2½ cans. Over-blanching can cause poor quality of colour and texture with loss of free amino acids and sugars (Lal Kaushal and Sharma, 1995). Different blanching times should be used for the various sizes to prevent over-blanching and shrinkage. A short spray of cold water should follow the blanching process to cool the mushrooms to 36^{0}C or lower.

5.4.3. Filling

The mushrooms after blanching are manually filled in tin cans; it takes care of the rejection of mushrooms broken and opened during blanching (rejection is almost 10 % of the original weight). The size of the can depends on the amount of produce to be filled in them as per the requirements of the customer. In our country generally A-2½ and A-1 tall can sizes containing approximately 440 and 220 g drained weight respectively are preferred (Saxena and Rai, 1990). However, for export A-10 (3 kg with drained weight of 1.96 kg) is preferred. The cans are thoroughly washed to remove any adhering dust or foreign matter. All the cans are sterilized before use. Mushrooms can be filled in the cans either manually or mechanically in case of automatic can filling machines.

Brine solution (2 % salt with 0.1 % citric acid or 100 ppm ascorbic acid) is added to the mushroom-filled cans after bringing its temperature to 90^{0}C. After filling, the cans are exhausted by passing them in exhaust box for 10-15 min (length of exhaust box coupled with speed of conveyor takes care), so that the temperature in the centre of the cans reaches upto 85^{0}C. Then the cans are sealed hermetically with double seamer and kept in upside down position. Azad *et al*. (1987) recommended a brine solution with 2 % common salt, 1 % sugar and 0.05 % citric acid for filling the cans for better results. Adsule *et al*. (1983) suggested a novel double purpose preservation of tomato juice in place of brine solution for canning of mushrooms; unlike brine solutions there is no need to add citric acid to tomato juice for lowering the pH of the filling medium. Further, the nutrients of the mushrooms could be retained in the tomato juice for human consumption. Arumuganathan *et al*. (2004 a) obtained improved quality of the

canned button mushroom when the mushrooms were pre-treated with EDTA.

5.4.4. Lidding or Clinching

The cans after being filled are covered loosely with the lid and passed through exhaust box. In large-scale process, this has certain disadvantages such as spilling of the contents, toppling of the lids *etc*. Lidding has now been modernized by the clinching process in which the lid is partially seamed to the can by a single first roller action of a double seamer. The lid remains sufficiently loose to permit the escape of dissolved as well as free air from the contents and also the vapour formed during the exhaust process.

5.4.5. Exhausting

Before sealing, it is necessary to remove all air from the contents. The process by which this is achieved is known as exhausting. By removing air, risk of corrosion of the tin plate, pinholing during storage and discolouration of the products are reduced; because oxidation is prevented. To be effective, the temperature of the brine in the can should be at least 80^0C. Removal of air also helps in better retention of vitamins, especially of vitamin C. The exhausting process will also assist in avoiding overfilling or underfilling of can, which normally happens due to the tendency of expanding or shriveling during heating. The other advantages of the exhaust process are: prevention of bulging of the can when stored at high altitudes or in hot climates, reduction of chemical reaction between the container and contents; and prevention of excessive pressure as well as strain during sterilization. Cans are exhausted in the exhaust box where filled cans are passed through a hot steam at about 100^0C on a moving chain conveyor through a covered double jacketed steam box. The time of exhaust varies from 10 to 15 min. At the end of the exhaust box, the temperature at the centre of the can should be about 80^0C.

5.4.6. Sterilization

Sterilization is the process of heating the cans to prevent the spoilage by microorganisms during storage. Saxena and Rai (1990) mentioned two procedures for common sterilizing of the cans:

a) A continuous process called ‘steriflame’ in which cans are treated by passing them over gas burners. This process lasts for 3-8 min.

b) A batch process, in which the cans are placed in an autoclave and sterilized for 25-30 min, under 15 lb/sq inch (1.06 kg/sq cm) (time and pressure varies with can and mushroom size).

The sterilization temperature should not be above 118^{0}C to avoid discolouration and burnt taste.

5.4.7. Cooling

The cans are cooled immediately after sterilization process to stop over-cooking and to prevent stack-burning. Cooling can be done by placing the cans in a cold-water tank. It also gives an abrupt shock to the microorganisms to get rid of their adverse activities.

5.4.8. Labeling and Packing

The outer surface of the can should be completely dry as even small traces of moisture are likely to cause rusting. The clean and dry cans are labeled manually or mechanically and packed in strong wooden crates or corrugated cardboard cartons. The cans are stored in a cool and dry place before dispatch. In a hot country like India, where the ambient temperatures are high during several months in a year, basement stores are useful, especially during the summer months. Figure 33 shows the different types of cans and canned button mushroom (whole and sliced).

Fig. 33. Canned button mushroom (Can sizes- 8 Ounce, A-1 tall, A-2½, A-10, wholes and slices)

Very high loss in weight of the mushrooms is the most serious problem in the canning. This is also known as 'shrinkage', which is caused by the removal of water as well as solids from the mushrooms during processing operations. The losses vary from 35-40 per cent and seriously affect the profitability of the cannery. To ameliorate this problem, various methods have been tried to varied degrees of success. Water binding additives *viz*., sodium polyphosphate, sodium alginate, Agar-agar, methyl cellulose, carboxy methyl cellulose, pectin and pectin-calcium chloride have been used by various workers in increasing the drained weight (reducing the shrinkage) of canned products (Singh *et al*., 1982). The shrinkage losses can also be decreased by the vacuum treatment of the fresh mushroom, cutting the blanching time and also prehydration treatments. The level of the vacuum achieved and the quality of the mushroom will affect the shrinkage losses of 5 to 10 per cent (Steinbuch, 1978). Kapoor (1989) documented a

standardized canning process and recommended steam blanching for low loss in weight. Figure 34 shows the canned paddy straw mushrooms in the markets of Orissa.

Fig. 34. Canned paddy straw mushroom

Weight loss or shrinkage of mushrooms during canning is a major problem in the mushroom cannery. In order to maintain the desired weight in the final product, the common industry practice is to reduce major portion of shrinkage during the blanching operation and thus minimize the shrinkage during thermal processing of the canned mushrooms. Konanayakam *et al*. (1987) developed a method to determine the shrinkage of mushrooms during processing based on liquid displacement method. The method consists of immersing the sample in a glass container with an over flow spout. Water treated with a surfactant was used as the displacement liquid in the glass container.

6. VALUE-ADDED PRODUCTS

Indian mushroom industry is still predominantly production and trade of the fresh produce; processing too is restricted to the preservation rather than the real value-addition. Almost entire domestic trade is in the fresh form while all the export in the preserved form (canned or steeped). Current era is characterized by greater awareness about quality and, above all, with the demand for the readymade or ready-to-make food products. As mushrooms contain high moisture and are delicate in texture, these can not be stored for more than 24 hours at the ambient conditions of the tropics —weight loss, veil opening, browning, liquefaction and microbial spoilage often make the product totally unsaleable. Effective processing techniques will not only diminish the postharvest losses but also result in greater remuneration to the growers as well as processors. Value can be added to the mushrooms at the various levels and to varied extent, right from grading to the readymade snacks or the main-course item. Improved and attractive packaging is another important but totally neglected area in mushrooms- it is still unprinted plain polypouches whereas attractive and labeled over-wrapped trays are in vogue in the developed countries. Real value-added product in the Indian market is the mushroom soup powder. Technologies for production of some other products like mushroom based biscuits, nuggets, preserve, noodles, papad, candies and readymade mushroom curry in retort pouches have been developed but are yet to be popularized. Attractive packaging of the value-added products is yet another area which may be called the secondary value-addition. While small growers may add value by grading and packaging, industry may go for the processed products for better returns as well as improvement in the demand which shall have cascading positive effect on the production.

6.1. Mushroom soup powder

Soups are commonly used as appetizers but also as main course by the diet-conscious. Experiments were conducted to prepare good quality ready-to-make mushroom soup powder (Fig. 35 and Fig. 36) using quality mushroom powder produced from the button mushroom and oyster mushroom dried in the dehumidifying air cabinet-drier.

Fig. 35. Button mushroom soup powder

Fig. 36. Oyster mushroom soup powder

Dried button mushroom slices or whole oyster mushrooms were finely ground in a pulveriser to pass through 0.5 mm sieve. Mushroom soup powder is prepared by mixing this powder with milk power, corn flour and other ingredients (Table 7). The detailed process flow chart (Fig. 37) for the preparation of mushroom soup powder is given below.

Table 7. Ingredients for mushroom soup powder

Ingredients	Parts(%)
Mushroom powder	16
Corn flour	5
Milk powder	50
Refined oil	4
Salt	10
Cumin powder	2
Black pepper	2
Sugar	10
Ajinomoto	2

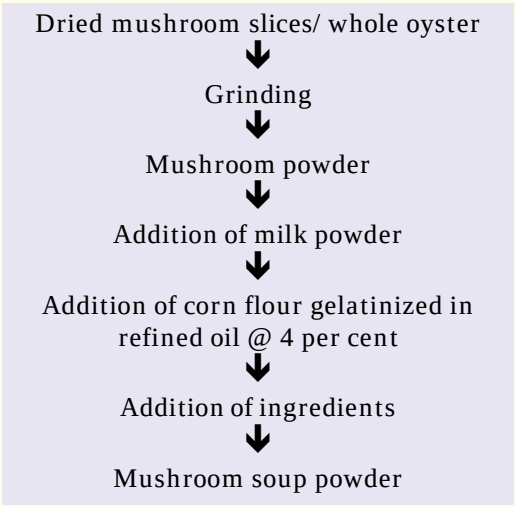


Fig. 37. Flow chart for preparation of mushroom soup powder

This has to be mixed with equal quantity of water for the preparation of good quality mushroom soup with characteristic aroma and taste.

Singh (1996) developed a ready-to-reconstitute mushroom soup powder utilizing the vacuum concentrated whey, a byproduct of dairy industry.

6.2. Mushroom biscuit

Very delicious and crunchy mushroom biscuits (Fig. 38) were prepared at NRCM, Solan using mushroom powder (both button and oyster) and ingredients *viz*., maida, sugar, oil, baking powder, ammonium bicarbonate, salt, vanilla, milk powder and glucose. Fat in the form of oil is used in biscuits to remove hardness and to improve the softness of the biscuits – that is to lower the forces necessary to break and crush the biscuits. The main sweetening agent is sugar and it also leads to enhanced colour in the baked biscuit because of the Maillard reaction and polymerization. Sugars also affect the heat denaturation of flour proteins. Ammonium carbonate is an aerating agent and it has the advantage that it leaves no residue and evolves a greater volume of gas per unit weight than any of the other aerating agents but, in the absence of phosphate and sodium ions, it leaves a new taste in the biscuits.

The various ingredients required for the preparation of mushroom biscuits are listed in Table 8.

Table 8. Ingredients for mushroom biscuits

Ingredients	Parts(g)
Maida	100
Sugar	30
Fat	45
Baking powder	0.6
Ammonium bicarbonate	0.3
Salt	0.6
Vanilla essence	0.02
Milk powder	1.5
Glucose/Fructose	1.5
Water	12 to 22 %

The flow chart for mushroom biscuit preparation is presented below as Figure 39. Sharma *et al*. (1991) also successfully prepared biscuits from mushrooms.

All the ingredients have to be mixed in a mixer for 3 to 5 min. The

Fig. 38. Mushroom biscuits

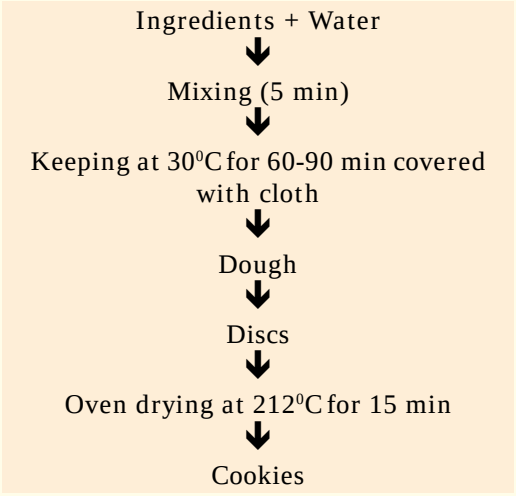


Fig. 39. Flow chart for mushroom biscuits

dough is kept at 30⁰C in oven for 90 min and then spread to a thickness of 2 to 4 mm over a cleaned platform and cut into circular or rectangular shapes (required shape) and baked for 10-12 min at 210⁰C in laboratory baking oven.

6.3. Mushroom nuggets

'Nuggets' are generally prepared out of 'pulse' powder namely, Black gram powder, Soybean powder, Urad dhal powder *etc*., and used in the preparation of vegetable curry in North India. The nuggets add taste as well as nutrients to the meal, since it is prepared from pulse powder. For preparation of mushroom nuggets, mushroom powder (dried and coarsely ground mushrooms) is mixed with the 'Urad' dhal powder and a paste is prepared by adding required quantity of water. Ingredients and spices are added to the prepared paste and round balls of 2-4 cm dia are made out of the paste. The prepared balls are spread over a steel tray and are dried by sun-drying method and thus the mushroom nuggets (Fig. 40) are prepared.

Fig. 40. Mushroom nuggets

The ingredients used in the preparation of nuggets at NRCM, Solan are listed in Table 9.

Table 9. Ingredients for mushroom nuggets

Ingredients	Parts(%)
Mushroom powder	10
Urad dhal powder	80
Salt	2
Red chilly powder	1
Sodium bicarbonate	0.01
Water	7

These nuggets can be relished in two ways: straightaway this can be deep-fried and used as snacks or can be used in vegetable curry preparation along with suitable vegetables or

alone. Figure 41 shows flow chart for the preparation of nuggets.

Fig. 41. Flow chart for mushroom nuggets

6.4. Mushroom ketch-up

Ketch-up is a common and popular product relished for its typical taste and texture as accompaniment with snacks. It is made by concentrating the juice / pulp of the fruits / vegetables without seeds and pieces of skin, as the skin and seed spoil the appearance of the ketch-up. It does not flow freely and is highly viscous in nature. They also contain more of sugar and less of acid.

Fig. 42. Mushroom ketch-up

Freshly harvested button mushrooms are washed, sliced and cooked in 50 per cent of water for 20 min. Mushroom paste is prepared using a mixer grinder. Arrarote (0.2 per cent), acetic acid (1.5 per cent) and other ingredients (as given below) are mixed in the paste and cooked to bring its TSS to 35^{0}Brix. Then the ketch-up is filled in the sterilized bottles or jars. The various ingredients required for the preparation of mushroom ketch-up are listed in Table 10.

Table 10. Ingredients for mushroom ketch-up

Ingredients	Parts(%)
Salt	10
Sugar	25
Acetic acid	1.5
Sodium benzoate	0.065
Onion	10
Garlic	0.5
Ginger	3
Cumin	1
Black pepper	0.1
Red chilly powder	1
Ajinomoto	0.2
Arrarote	0.2

Fresh button mushrooms
↓
Washing
↓
Slicing
↓
Cooking in 50 per cent of water for 20 min
↓
Making of paste
↓
Addition of ingredients
↓
Cooking (35^0Brix)
↓
Filling in sterilized cans
↓
Mushroom ketch-up

Fig. 43. Flow chart for mushroom ketch-up

Joshi *et al*. (1991) developed sweet chutney from button mushroom and the storage life of the product was more than a year.

6.5. Mushroom candy

A fruit or vegetable impregnated and coated with sugar, subsequently taken out and dried is called a candied fruit or vegetable. The process for making candy is practically the same as that employed in the case of mushroom preserve described elsewhere, with the difference that the produce is impregnated with a higher concentration of sugar. The total sugar content of the impregnated produce is kept at about 75 per cent to prevent fermentation.

Fresh mushrooms after harvesting are washed and halved longitudinally into two pieces. Halves are blanched for 5 min in 0.05 per cent of KMS solution. After draining for half an hour these are treated with sugar. Sugar treatment is given at the rate of 1.5 kg sugar per kg of blanched mushroom. Initially sugar has to be divided into three equal parts. On the first day, blanched mushrooms are covered with one part of sugar and kept for 24 h. Next day, the same mushrooms are covered with second part of sugar and are kept over night and on the third day mushrooms are removed from the sugar syrup. The sugar syrup is boiled with 3rd part of sugar and 0.1 per cent of citric acid to bring its concentration up to 70°Brix. Mushrooms are mixed with this syrup and again the contents are boiled for 5 min to bring its concentration upto 72°Brix. After cooling, the mushrooms are removed from the syrup and drained for half an hour. The drained mushrooms are placed on the sorting

Fig. 44. Button mushroom candy

Button mushroom
↓
Washing
↓
Halving
↓
Blanching in 0.05 per cent KMS for 5 min.
↓
Sugar treatment @ 1.5 kg per kg of blanched mushroom for 3 days
↓
1st day – covering blanched mushrooms with 1st part of sugar for overnight
↓
2nd day-covering with 2nd part of sugar
↓
3rd day- removal of mushrooms from the syrup
↓
Addition of remaining sugar + 0.1 % of citric acid to the syrup
↓
Boiling up to 70^{0}Brix.
↓
Cooling
↓
Addition of mushroom pieces
↓
Boiling for 5 min to bring syrup concentration to 72^{0}Brix.
↓
Cooling and removing of mushroom pieces from syrup
↓
Sorting
↓
Drying at 60^{0}C for 10 h
↓
Packing and storage at cool and dry place

Fig. 45. Flow diagram for mushroom candy

tables to separate, to reject defective and unwanted pieces. Finally mushroom pieces are subjected to drying in a cabinet dryer at 60°C for about 10 h. As soon as these become crispy, all mushrooms are taken out, packed in polypropylene bags and sealed. The mushroom candy (Fig. 44) can be stored up to 8 months with excellent acceptability and good chewable taste.

The flow diagram for preparation of button mushroom candy is given as Figure 45.

6.6. Mushroom preserve (*Murraba*)

Murabba (preserve) is made from matured fruit or vegetable, by cooking it whole or in the form of pieces in heavy sugar syrup, till it becomes tender and transparent. In *murabba* preparation, around 45 kg of fruit or vegetable is used for every 55 kg of sugar and cooking is continued till a

Fig. 46. Mushroom *murabba*

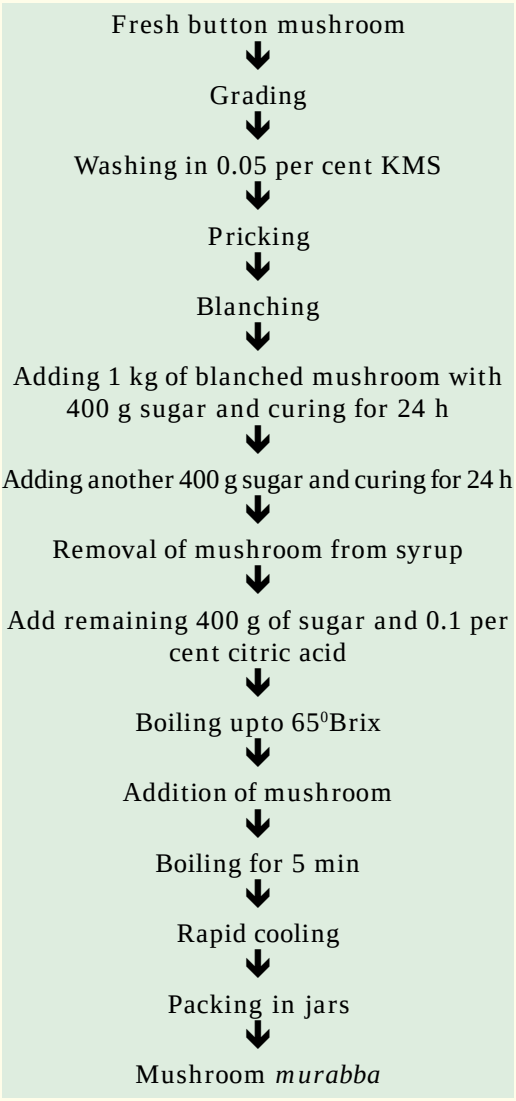


Fig. 47. Flow chart for mushroom *murabba* (preserve)

concentration of at least 68 per cent of soluble solid is reached.

Fresh button mushrooms are graded, washed, pricked and blanched in 0.05 per cent KMS solution for 10 min. It is treated with 40 per cent of its weight of sugar daily for 3 days. Then, mushrooms are taken out from the syrup and 0.1 per cent citric acid and remaining 40 per cent of sugar is mixed in the syrup. After bringing its concentration to 65^{0}Brix, mushrooms are added in the syrup and good quality *murabba* (Fig. 46) is prepared.

The process flow chart for preparation of mushroom *murabba* is given in Fig. 47.

6.7. Mushroom chips

The freshly harvested button mushrooms are washed, sliced (2 mm) and blanched in 2 per cent brine

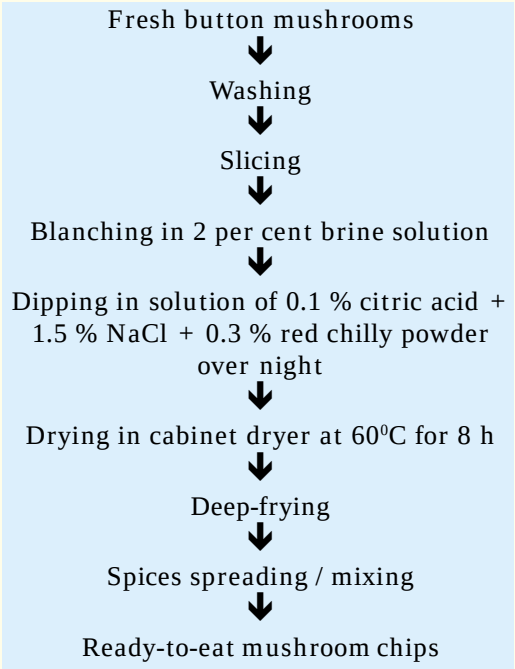


Fig. 48. Flow chart for mushroom chips

solution. The mushrooms are dipped overnight in a solution of 0.1 % of citric acid + 1.5 % of NaCl + 0.3 % of red chilly powder. After draining off the solution, the mushrooms are subjected to drying in cabinet dryer at 60^0C for 8 h. Then it is fried in the refined oil and good quality chips are prepared. The flow chart for preparation of mushroom chips is given in Figure 48. Garam masala and other spices can be spread over the chips to enhance the taste. After spices mixing, the chips are packed in polypropylene packets and sealed after proper labeling.

6.8. Ready-to-serve mushroom curry

In view of the growing market for the readymade / ready-to-eat food items and keeping in mind the popularity of the Indian 'Curry' world over, a technology was developed at NRCM, Solan for production of "Mushroom curry in flexible-retortable pouches" by Chandrasekar *et al*. (2001). Flexible retort pouch is an ideal alternate to metal containers for packing and storage of heat processed foods. Flexible retort pouches, besides being cheaper, have many other advantages

Table 11. Physical properties of the flexible retort pouch (laminate)

Thickness		105 µ
Polypropylene- outer layer		80 µ
Aluminium- middle layer		12.5 µ
Polyester–outer Layer		12.5 µ
Tensile strength	MD	451.5 kg/cm^2
	CD	425.4 kg/cm^2
Elongation at Break	MD	20 %
	CD	20 %
Heat seal strength	MD	70.25 N / 25 mm width
	CD	60.75 N / 25 mm width
Bursting strength		2l psi
Bond strength of inner layer (Polyester)		184 g / 10 mm width
Bond strength of outer layer (Polypropylene)		110 g / 10 mm width
Pouch size		20 x 16 cm^2
Weight		10 g
Seal size		10 mm
Lip size		4 mm

MD-along machine direction **CD-along cross direction**

– easy bulk-packing and transport, sale and very convenient to the end-user. The retort pouch of 105 m thick with polypropylene outer layer (80 m), aluminium middle layer (12.5 m) and polyester inner layer (12.5 m) available in the market was used for packing mushroom curry. The physical properties of the flexible retort pouch (laminate) are given in Table 11.

The ingredients used to prepare the curry are presented in the Table 12. In a frying pan, oil was added and heated. Sliced onions and green chillies were added to the oil and fried till golden brown. Garlic and ginger were ground into a paste, added and lightly fried till oil reappeared. Curry powder, salt and red chilly powder were added and lightly fried. About one litre of water was added to the spices mixture and boiled till thick consistency was obtained. Hundred grams of cut mushrooms were filled in the retort pouch and 50 g of curry was added into the pouch. Then it was heat processed for FO value of 10 (final 13.2) at 121^{0}C for 43 min and cooled rapidly.

Table 12. Ingredients for mushroom curry

Ingredients	Quantity
Onion	510 g
Garlic	250 g
Ginger	200 g
Red Chilly powder	150 g
Curry powder	100 g
Green chilly	250 g
Oil	400 ml
Salt	160 g
Water	1000 ml

The ready-to-serve mushroom curry (Fig. 49) prepared was delicious with good taste, attractive colour and a storage life of one year. Mushroom curry was also successfully prepared from dried oyster mushroom and button mushroom after its rehydration (Arumuganathan *et al*., 2004 b & c).

Fig. 49. Ready-to-serve mushroom curry in retort pouch pack (NRCM-Process)

6.9. Packaging materials for mushroom products

Arumuganathan and Rai (2004) conducted studies to identify the suitable packaging materials for the mushroom products. The different packaging materials used were, polythene, polypropylene, lug bottles, laminated pouches, PVC wrapped

Table 13. Suitability of packaging materials for mushroom products

Name of the packaging material	Mushroom Product	StoragePeriod
Polythene bag	Dried Mushroom	2 Months
	Mushroom Powder	2 Months
Polypropylene	Mushroom Candy	6 Months
	Mushroom Soup Powder	6 Months
	Mushroom Powder	6 Months
	Dried Mushroom	3 Months
	Mushroom Chips	3 Months
Lug bottles	Mushroom Pickles	1 Year
PET jar	Mushroom biscuits	3 months
	Mushroom Candy	6 months
Butter Paper	Mushroom Candy	3 months
	Mushroom biscuits	2 months
PVC wrapped trays	Mushroom Nuggets	1 month
Laminated pouches	Mushroom curry	1 year
Tin Cans	Canned Mushroom	1 year

trays, plastic jars and tin cans. The suitability and adoptability of these packaging materials were studied in terms of keeping quality during the storage period and are given in the Table 13. It is inferred that different products required different type of packaging materials.

7. CANNING UNIT

Among various preservation methods, canning is the most extensively used method for storage and trade of mushrooms. The process of sealing foodstuffs hermetically in containers and sterilizing them by heat for long term storage is called canning or appertization. Canning is the most popular method of preserving the mushrooms for more than one year. Many Asian countries like India, China, Taiwan, Korea *etc*., export their produce to the American and European Countries in the form of canned mushrooms. Infrastructure for a canning unit is described here. It may be mentioned that this canning unit can be used for canning any produce and the capacity of most of the machine is one ton mushroom per shift of 8 hours (3 tons per day). However, bigger, automated, imported and FDA approved canning units are established in 100 % EOU big mushroom commercial units in India (Fig. 50).

Fig. 50. Imported automatic canning unit

7.1. Lid-Embossing machine

This machine (Fig. 51) is used to emboss the lids with the required reference letter or figures like date of manufacture, date of expiry, rate, batch number, brand name and quantity. This machine is operated by a foot treadle which, when depressed, embosses the lid by virtue of marker dies, without piercing it.

Fig. 51. Lid embossing machine

7.2. Can reformer

This is simple machine (Fig. 52), which makes the flattened can bodies to round, prior to flanging. The flattened can is mounted on to the rubber roller and on depressing the pedal, it presses the can against the rotating steel roller there by giving it a round shape. The capacity of the can reformer varies from 600 to 800 cans per hour.

Fig. 52. Can reformer

7.3. Can flanger

This simple hand operated machine, shown in Figure 53, is used for simultaneous flanging of both sides of the round can obtained from can-reformer. A toggle motion balanced hand-lever enables the machine to be operated with minimum exertion.

Fig. 53. Can flanger

7.4. Flange rectifier

This is a simple hand operated machine (Fig. 54) used for rectification of misshaped flanges of cans. The misshaped flanged can is placed on the die and by simple application of the handle the flange is rectified.

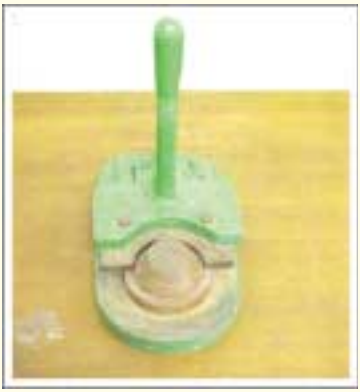


Fig. 54. Flange rectifier

7.5. Steam jacketed kettle

This machine (Fig. 55) is mounted on a heavy duty mild steel stand with tilting arrangement. The pan has a double jacket for maximum steam utilization and efficiency. Both the pan and jacket are made up of high quality stainless steel. This is mainly used for batch heating and blanching of mushrooms in brine solution. The capacity of the steam jacketed kettle

Fig. 55. Steam jacketed kettle

is 100 Gallons. It is also available in the smaller capacity of 25 and 50 Gallons.

7.6. Exhaust box

This machine (Fig. 56) consists of a chain conveyor moving at low rpm to keep the cans filled with mushrooms to contact with steam for 1 to 2 min to get it sterilized. It can pass two A-2½ size cans at a time and the over all length of the exhaust box varies from 14, 16 and 18 feet.

Fig. 56. Exhaust box

7.7. Double-seamer

This is a semi-automatic machine (Fig. 57), most suitable for seaming processed cans as well as flanged cans with the embossed lids on both sides. The capacity of the double seaming machine is approximately 600 cans per hour and heavy-duty double seamers also available at the capacity of about 2000 cans per hour.

Fig. 57. Double-seamer

7.8. Canning retort

This equipment (Fig. 58) is used for sterilization of cans under pressure, after filling and seaming. It is equipped with pressure gauge and safety valve. The capacity of the canning retort is 280 to 300 cans of A-2½ size and it is also available in the smaller capacities like 21, 75-80, 90-100 cans of A-2½ size

7.9. Layout of canning unit

A general layout of a canning unit of about 200 TPA is given here.

Fig. 58. Canning retort

However, minor modifications can be done according to availability of land and capital. Canning unit or any processing unit should not be less 100 m^2 area as per FPO. Before establishing a commercial canning unit, it is necessary to consider certain important factors such as investment, factory site, factory building, water supply, labour *etc*., in addition to FPO license from the Ministry of Food Processing. A typical layout of a canning unit is given in the Figure 59.

7.9.1. Investment

The capital outlay for canning unit includes investment on land, factory building and machinery. The running or operational expenses include the cost of raw material, labour, processing, storage, transport and distribution. The entrepreneur should plan the type and size of production according to the existing demand in the national and global market, which would be most advantageous.

7.9.2. Canning unit site

While selecting the site for the factory, the following points should be considered.

a. Desired quantities of the type of mushrooms should be readily available at reasonable price in the locality, because mushrooms are highly perishable and deteriorate in long distance transport.

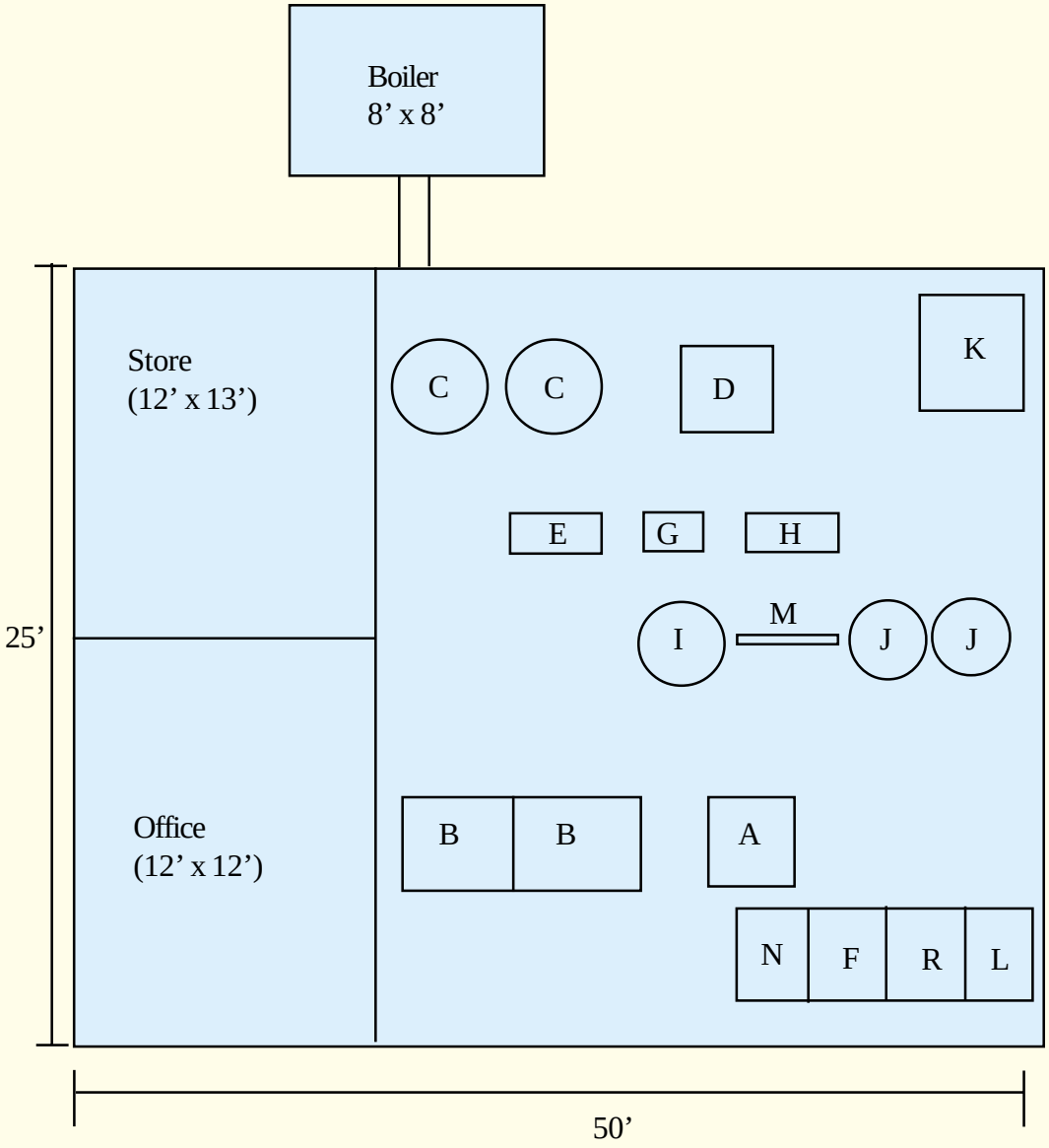
b. Proper transport facilities should exist for the movement of raw materials and finished products.

c. The factory environment should be clean and free from pollution and garbage *etc*. If the factory is to be located in an industrial area, the site should be at a considerable distance from other industrial factories spreading smoke and disagreeable odours, which may adversely affect the quality of the canned product. There should also be facilities for disposal of the cannery wastes.

d. There should be scope for future orderly expansion of the factory.

7.9.3. Cannery buildings

The building may be single-storeyed or multi-storeyed. Where the plant is a comparatively small one and



A- Grading table
B- Washing tanks
C- Steam jacketted kettles
D- Cooling & Steving (grading)
E- Can filling table
F- Can flanger
G- Brine tank
H- Exhaust box
I- Double seamer
J- Retorts
K- Cooling tank
L- Lid embossing machine
M- Chain pulley
N- Can Rectifier
R- Can Reformer

Fig. 59. Lay-out of a canning unit

works for short periods during the year, a single storeyed building of light construction will do. In case of the larger plants, that have to run almost throughout the year, multi-storeyed construction is desirable as it would facilitate and cheapen the movement of raw as well as finished products. For 200 TPA unit, single story building with processing area of not less than 100 m^2 with separate room for boiler, store room for empty can and filled cans will be sufficient.

Flooring should be firm and of good cement to withstand the constant use of water and the movement of heavy-wheeled machines. A slope of about 5.5 cm per metre is necessary for proper drainage. All doors, windows and ventilators should be provided with fine wire mesh to prevent entry of flies and other insects. The roof of the building should be high and well ventilated to provided outlet for vapours and steam. The windows should have large glass panes, and part of the roof should be of ground glass to permit gentle light inside. There should be provision for efficient artificial lighting as the cannery will have to work at night quite often.

A sufficient number of dressing and toilet rooms should be provided separately for men and women workers in the factory premises. The workers should be taught the importance of personal hygiene.

7.9.4. Water supply and drainage

Large quantities of water are required for cleaning mushrooms, making brine, washing floors and machinery *etc*. so there should be abundant supply of potable water. The water system should work at sufficiently high pressure so that supplies can be made at different points in the cannery without a break. The water should not be alkaline or very hard, and should be free from organic matter. Presence of iron and sulphur compounds renders it unsuitable for making brines. Saltish water should be avoided, as it would affect the taste of the products. If supplies of the desired quality are not available, it would be necessary to install a water-softening plant. Further, the boiler feed water requires ion-exchange treatment to bring it to the desired pH and make it free from scale-forming ions.

7.9.5. Labour and hygiene

All the workers in the factory, whether employed on regular basis or recruited during rush periods, should wear clean cloths and aprons to ensure hygienic conditions. They should be examined medically at regular intervals as a precaution against infectious diseases. An efficient system of chemical and microbiological control at various stages of the manufacturing process (HACCP) should be maintained to avoid the risk

of contamination and food positioning. There should be a food technologist to supervise the work and to ensure desired standard of production. A clean factory operated with strict observance of the fundamental principles of sanitation is mandatory for the production of canned mushrooms of high quality.

7.9.6. Machinery and equipments

Great attention is required in the selection of machinery and other equipments. Different types of units are in use, but the entrepreneur has to determine his own requirements. Efforts should be made to buy the whole unit from one supplier. The whole equipment should be arranged in a proper order so that minimum time and effort are needed for handling the products at all stages of manufacture. In short, the raw product should move practically in a straight line till it emerges as the finished product, ready for labeling and packing. During the off-season the entire machinery should be overhauled, greased and painted. A package of machinery required for 200 TPA mushroom canning is given below:

S.No.	Name of the machine	Unit	Cost (Rs)
1.	Can reforming unit of 600/800 cans per h capacity with flanging dies with rings and rubber mandral with shaft & Cone	1	60,000
2.	Double seaming machine of 600 cans/h capacity with seaming chucks & seaming rollers	1	55,000
3.	Lid embossing machine with 2 row 6 digits die	1	20,000
4.	Flange rectifier	1	10,000
5.	Steam jacketed double wall kettle (100 gallons)	2	2,00,000
6.	Exhaust box (16 ft / 18 ft)	1	80,000
7.	Canning retort with two crates (300 cans A 2½)	2	90,000
8.	Stainless steel working table (3' x 8')	2	30,000
10.	Hand refractometer	1	1,500
11.	Seam checking gauge	1	500
12.	Can tester	1	3,000
13.	Vacuum tester	1	1,000
14.	Aluminum trays for handling of cans	4	4,000
15.	Boiler with necessary fittings and accessories	1	1,00,000
	Total		6,55,000
	Unforeseen expenditure @ 5 %		32,750
	Total cost of canning unit excluding cost of land and building		6,87,750

8. ECONOMICS OF CANNING

LAND

S.No.	Particulars	Rs. in Lakhs
1.	Land 500 sq. meter	5.00
		Total Rs. 5.00

BUILDINGS

S.No.	Particulars	Area	Unit cost	Total (Lakhs)
1.	Boundary wall	90 M	1500/RMT	1.35
2.	Canning room (50' x 25')	1250 ft^2	750/ft^2	9.38
3.	Boiler room (8' x8')	64 ft^2	750/ft^2	0.48
4.	Road (inner)	-	-	1.00
				12.21

RAW MATERIALS

S.No.	Raw materials	Quantity	Rate	Amount
1.	Cans (A1 size)	5,00,000	Rs. 5/can	25,00,000
2.	Cans (A2½ size)	2,50,000	Rs. 10/can	25,00,000
3.	Mushroom (1.65 tons/ton of final product) (30 tons for 200 tons final product)	330 tons	Rs. 40/ton	1,32,00,000
4.	Chemicals, lables and miscellaneous items	-	-	3,00,000
				1,85,00,000

COST OF THE PROJECT

S.No.	Particulars	Rs. in Lakhs
1.	Land	5.00
2.	Buildings	12.21
3.	Plant and Machinery	7.00
4.	Contingencies	2.00
5.	Pre-operative expenses	2.00
6.	Margin money for the working capital	2.00
	Total	30.21

PROFITABILITY PROJECTIONS

S.No.	Cost	Rs. in Lakhs
1.	Raw materials	185.00
2.	Salaries and wages	3.00
3.	Power and fuel	2.00
4.	Overheads	2.00
5.	Depreciation (10% on building and 15% on machinery)	2.27
6.	Interest on term loan (15% of 25.00 lakhs)	3.75
7.	Interest on the working capital (18% of 6.00 lakhs)	1.80
	Total cost	**199.10 lakhs**
	Sales of 5,00,000 cans of A1 size at Rs. 25.00	125.00 lakhs
	Sales of 2,50,000 cans of A2½ size at Rs. 50.00	125.00 lakhs
	Total sales	**250.00 lakhs**
	Profit	**50.90 lakhs**

9. ECONOMICS OF PICKLING

9.1. Preparation of pickle

Pickling of mushroom is already a house-hold to commercial venture. Mushroom growers do prepare mushroom pickle of the market-surplus and also from the open and defective mushrooms. Small entrepreneurs buy mushrooms from the growers and make mushroom pickle. However, major production of mushroom pickle comes from the Canneries doing mushroom canning. In fact, canning rejects, which is about 10 % of the raw material, are converted into mushroom pickle thus saving an avoidable loss in the canning of mushrooms; cost of such pickle is also low.

Freshly harvested mushrooms are sorted based on their size and the graded mushrooms are washed thoroughly in clean water to remove the adhering casing soil and foreign matter on the surface (Fig. 60) and the excess water is drained off. The cleaned mushrooms are halved by using a sharp, clean stainless steel knife (Fig. 61) and the halved mushrooms are subjected to blanching immediately by dipping them in a boiling solution of 0.05 per cent KMS + 0.1 per cent of citric acid and 2 % brine for 10 min. Blanching is done to inhibit enzymatic activity and to inactivate microorganisms. The blanched mushrooms are subjected to salt curing process in which 10 per cent sodium chloride is added and kept overnight. The excess water oozed out of mushrooms is removed on the next day and appropriate preservatives are mixed to get organoleptically acceptable mushroom pickle.

Fig. 60. Washing of button mushroom

Fig. 61. Slicing of button mushrooms for pickle preparation

9.2. Preservatives and spices

The following preservatives and spices are used to prepare tasty button mushroom pickle.

1) Acetic acid (@ 1-1.25 %)
2) Sodium benzoate (@ 650 ppm)
3) Salt (@ 9-10 %)
4) *Rai* (Black mustard) powder (@ 3 %)
5) Turmeric powder (@ 2 %)
6) Redchilli powder (@ 1.5 %)
7) Cumin powder (@ 1 %)
8) Black pepper powder (@ 1 %)
9) Aniseed powder (@ 1 %)
10) Fenugreek seed powder (@ 1 %)
11) *Kalonji* (@ 1 %)
12) *Ajwain* (@ 1 %)
13) Mustard oil (@ 20 %)

Acetic acid and sodium benzoate are mixed with the salt treated mushroom pieces. All the spices except *ajwain* and *kalonji* are mixed in ground form and added to that. Finally *ajwain* and *kalonji* as a whole are fried for 2-3 min in mustard oil and mixed with the mushroom slices. At the end, mustard oil is poured and mixed into pickle. The prepared mushroom pickle can be stored upto one year.

The cost of preparation for the button mushroom pickle is worked out as outlined in the Table 14.

Table 14. Cost of preparation for the button mushroom pickle

S. N0.	Ingredient	Quantity	Rate/kg	Cost (Rs*)
1.	Button Mushroom	175 g	40.00	7.00
2.	Salt	15.75 g	7.00	0.110
3.	Acetic acid	1.7 ml	40.00	0.068
4.	Sodium benzoate	0.1225 g	50.00	0.006
5.	*Rai* powder	5.25 g	60.00	0.315
6.	Turmeric powder	3.50 g	100.00	0.350
7.	Red chilli powder	2.625 g	120.00	0.315
8.	Cumin powder	1.7 g	150.00	0.255
9.	Fenugreek powder	1.7 g	60.00	0.102
10.	Aniseed powder	1.7 g	100.00	0.170
11.	*Kalonji*	1.7 g	60.00	0.102
12.	*Ajwain*	1.7 g	100.00	0.170
13.	Oil	26.5 ml	50.00	1.325
	Fuel			1.00
	Labour charges			3.00
	NET MUSHROOM PICKLE	**238.95 g**		**14.288**

Cost of preparation for 1kg button mushroom pickle = Rs.60.00
* Cost at Solan Market

10. SOURCES OF MACHINERY / EQUIPMENTS

Boilers and blowers

1. Lal Sons & Company,
   1663/1, Mukerjee Marg,
   New Delhi - 110 006.

2. Indcon Boilers,
   D-9/6, Okhla Industrial Area,
   Phase-I, New Delhi - 110 020.
   Ph: 011-26815336
   Fax: 011-26815337
   www.indconboilers.com

3. Indvent Engineers Pvt. Ltd.,
   C-12, Amar Colony Market,
   Lajpat Nagar, New Delhi - 110 024.

4. Laxmi Boilers (North),
   602, Deepali, 92, Nehru Place,
   New Delhi - 110 019.

5. Thermax Ltd.,
   9, Community Centre, Basant Lok,
   New Delhi - 110 057.
   Ph: 011-46087200
   Fax: 011-26145311
   www.thermaxindia.com

6. Urjex Industries,
   S-26, Industrial Estate,
   Partapur, Meerut - 250 102.
   Telefax: 0121-2440597
   http://urjexboilers.net

7. Lalsons & Company,
   A-45, Mayapuri Industrial Area,
   Phase-I, New Delhi - 110 064.
   Ph: 011-25138121
   Fax: 011-25147483

Cabinet drier

1. Widsons Scientific Works,
   10, Sadar Thana Road, Sadar Bazar
   Delhi - 110 006.
   Ph: 011-23537765

Canning machinery and cans

1. Mather and Platt (India) Ltd.,
   805-806, Ansal Bhawan,
   16, Kasturba Gandhi Marg,
   New Delhi - 110 001.
   Ph: 011-3712840

2. M/s B. Sen Barry & Company,
   65/11, New Rohtak Road,
   Karol Bagh, New Delhi - 110 005.
   Ph: 011-25723553

3. M/s Bajaj Machines,
   21, Kantinagar, PO Krishna Nagar,
   Delhi - 110 051.

4. Divecha Glass Industries,
   249, Bal Rajeshwar Road,
   185, Marg Mulund (W),
   Mumbai - 400 080.

5. K.S.T. Foods and Services Pvt. Ltd.,
   C-07/87, Vishnu Prasad Mahant Road,
   Vile Park, Mumbai - 400 057.

6. M/s Techno Equipments,
   31, Parekh Street,
   Mumbai - 400 004.

7. Rollatainers Ltd.,
   13/6, Mathura Road,
   Faridabad - 121 003.
   Ph: 0129-2271709
   Fax: 0129-2275392
   www.rolapak.com

8. The Tin Plate Co. of India Ltd.,
   4, Bankshall Street,
   Kolkata - 700 001.
   Ph: 033-22435401
   Fax: 033-22204170
   www.tatatinplate.com

9. Poysha Industrial Co. Ltd.,
   Tiecicon House,
   Dr. E.Moses Road,
   Mumbai – 400 011.
   Ph: 022-4964378
   Fax: 022-4964379

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