

STORAGE AND PROCESSING OF EDIBLE MUSHROOMS

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Abstract. This paper presents a review of the Polish and foreign literature concerning the storage and processing of edible mushrooms. Mushrooms are difficult raw materials for the processing industry: fresh mushrooms cannot be stored for long periods; moreover, during processing they readily change colour and texture. In order to guarantee acceptable quality of canned and processed mushrooms, fresh pilei should be kept at low temperatures. Before processing they should undergo preliminary treatment using substances preventing changes in colour and texture; the storage conditions for finished products must be appropriate to the processing method applied. The most frequently used methods of processing are: drying, marinating, sterilization and freezing.

Key words: edible mushrooms, storage, preliminary treatment, processing

INTRODUCTION

Owing to their attractive taste, aroma and nutritional values, edible mushrooms are valuable components of the diet [Brodziak and Majchrzak 1984, Manzi et al. 1999, Mattila et al. 2001, Karmańska et al. 2002, Czapski 2003, Vetter 2003]. Fresh mushrooms are highly perishable and – in the case of forest mushrooms – are subject to seasonal availability, hence in periods when supply exceeds demand, processing is recommended. This chiefly concerns wild mushrooms but also applies to cultivated species [Burton and Noble 1993, Tseng and Mau 1999, Czapski 2000]. The consumption of mushrooms throughout the year, particularly of species harvested in natural habitats, is made possible through the use of appropriate processing methods. The food processing industry provides a wide range of canned and processed mushroom products, including frozen, sterilized, dried, pickled, marinated, and salted mushrooms; mushroom powder; paste; and concentrates and extracts [Bąkowski and Michalik 1982, Woźniak et al. 1996, Vivar-Quintana et al. 1999, Kondratowicz and Kowalko 2000, Czapski 2003]. Freezing and pickling are among the processing methods which least affect the taste and aroma compounds and the nutritive value of the raw material [Kreb and Lelley 1991, Joshi et al. 1996, Kondratowicz and Kowalko 2000].

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Poland is an important European producer and exporter of fresh cultivated mushrooms as well as of canned and processed products. In the total production of processed vegetables, mushrooms constitute 7.0% [Kubiak 2003]. Commercial production includes *Agaricus bisporus* (Lange) Sing. and *Pleurotus ostreatus* (Jacq.:Fr.) Kumm., the former species accounting for 90% of the total production of cultivated mushrooms in Poland [Kubiak 2001]. About 60% of mushroom production is exported to foreign markets, chiefly to EU countries. In 2002-2003 an increase in the export of frozen and salted *Agaricus bisporus* (Lange) Sing. and a decrease in that of processed mushrooms in air-tight containers were recorded [Smoleński 2004 a]. Apart from *Agaricus bisporus* (Lange) Sing., *Pleurotus ostreatus* (Jacq.:Fr.) Kumm. is fairly popular in foreign markets, as are *Cantharellus cibarius* (Fr.:Fr.) Fr. (chanterelle), *Boletus edulis* (Bull.:Fr.), *Xerocomus badius* (Fr.) Kühn.:Gilb. (boletus scaber) and *Tricholoma equestre* (L.:Fr.) Kumm. (green night cap) [Krajewski 1994]. Fresh *Pleurotus ostreatus* (Jacq.:Fr.) Kumm. is exported to Germany, USA and Canada, and frozen to Finland, Sweden and Denmark [Kubiak 1999].

THE AIM OF THE WORK

The aim of the work is to present the technological aspects of the storage and processing of edible mushrooms based on the Polish and foreign literature.

STORAGE OF MUSHROOMS

Pilei of edible mushrooms are characterized by the seasonal availability; briefness of abundant supply; remarkable variability of yield; and very poor keeping qualities [Tseng and Mau 1999, Czapski 2000, Szweykowska and Szweykowski 2003]. Their rapid deterioration is chiefly caused by the content of water; biological processes; the activity of enzymes; and the presence of micro flora; and is also affected by the degree of ripeness and any damage to the pilei [Burton and Noble 1993, Burton et al. 1995, Evered and Burton 1995, Jolived et al. 1995, Plaza et al. 1995, Czapski 2000]. The storage conditions are highly important for the quality of fresh mushrooms. The best results are obtained by storing pilei in a cool chamber. The most favourable storage temperature is 0-2°C, with relative air humidity of 90% [Beelman et al. 1973, Murr and Morris 1975, Umięcka 1986, Lopez-Briones et al. 1992, Minato et al. 1999]. At 0-1°C *Agaricus bisporus* (Lange) Sing. can be stored for 7-9 days [Gormley 1975, Umięcka 1986]; at 15°C for 2-3 days [Gormley 1981]; and at room temperature for 18 hours only [Woźniak and Gapiński 1996 b]. Storing mushrooms at low temperatures limits weight loss [Woźniak and Gapiński 1996 c] and maintains freshness, as well as firmness and white colour of the flesh [Umięcka 1986, Burton and Noble 1993, Czapski 2001]. According to numerous authors, the storage of *Agaricus bisporus* (Lange) Sing. at a temperature exceeding 2°C affects its quality, as seen in the darkening of pilei; elongation of stems; opening of caps; and hardening of the flesh [Murr and Morris 1975, Umięcka 1986, Lopez-Briones et al. 1992, Burton and Noble 1993, Czapski 2000, 2001]. Changes in the level of some chemical constituents also occur [Mau et al. 1991, Tseng

and Mau 1999]. In investigating the mushroom *Volvariella volvacea* (Bull.) Sacc. Yen [1992] found that the storage of this species at 4°C and 25°C for five days brought about a rapid increase in the level of biogenic amino acids, substances indicating progressive deterioration of the pilei; and that increases in the content of these compounds occurred at higher temperatures (Table 1). The storage of fresh mushrooms also affects the level of sugars, free amino acids and 5'-nucleotides (Table 1). 12-day storage of *Agaricus bisporus* (Lange) Sing. at 12°C causes a 36% decrease in the level of total sugars; 42% decrease in mannitol; 89% decrease in fructose; and a 9% decrease in substances giving the pilei their taste (5'-nucleotides); while a 195% increase was found in the content of total free amino acids [Tseng and Mau 1999]. During the storage of *Agaricus bisporus* (Lange) Sing. Wurzenberger and Grosch [1983] and Mau et al. [1991] also observed a rapid decrease in the level of volatile constituents, particularly of 1-octen-3-ol. According to Minato et al. [1999], in *Lentinula edodes* (Berk.) Pegl. (shiitake) mushrooms stored for 7 days at 20°C the activity of glucanase and polyphenoloxidase was higher and the content of lentinane (a polysaccharide of health-promoting properties) was reduced compared with pilei stored at 1°C (Table 1).

Table 1. The effects of storage on level of selected constituents in mushrooms
Tabela 1. Wpływ przechowywania grzybów na poziom wybranych składników chemicznych

Mushroom species Gatunek grzyba	Chemical constituent Składnik chemiczny	Temperature and storage time Temperatura i czas składowania	Level Poziom
<i>Volvariella volvacea</i> (Bull.) Sacc.	tryptamine ^a , mg·kg ⁻¹ f.m. tryptamina ^a , mg·kg ⁻¹ ś.m.	0 days – 0 dni	3.4
		4°C 5 days – 5 dni	28.5
		25°C 5 days – 5 dni	141.7
	histamine ^a , mg·kg ⁻¹ f.m. histamina ^a , mg·kg ⁻¹ ś.m.	0 days – 0 dni	0.7
		4°C 5 days – 5 dni	8.3
		25°C 5 days – 5 dni	244.4
<i>Agaricus bisporus</i> (Lange.) Sing.	fructose ^b , g·kg ⁻¹ f.m. fruktoza ^b , g·kg ⁻¹ ś.m.	0 days – 0 dni	26.2
		12°C 12 days – 12 dni	2.8
	mannitol ^b , g·kg ⁻¹ f.m. mannitol ^b , g·kg ⁻¹ ś.m.	0 days – 0 dni	236.2
		12°C 12 days – 12 dni	136.7
	total sugars ^b , g·kg ⁻¹ f.m. cukry ogółem ^b , g·kg ⁻¹ ś.m.	0 days – 0 dni	319.4
		12°C 12 days – 12 dni	205.2
	total amino acids ^b , g·kg ⁻¹ f.m. aminokwasy ogółem ^b , g·kg ⁻¹ ś.m.	0 days – 0 dni	77.9
12°C 12 days – 12 dni		151.7	
total 5'-nucleotides ^b , g·kg ⁻¹ f.m. 5-nukleotydy ogółem ^b , g·kg ⁻¹ ś.m.	0 days – 0 dni	11.3	
	12°C 12 days – 12 dni	10.3	
<i>Lentinula edodes</i> (Berk.) Sing.	lentinan ^c , mg·g ⁻¹ d.m. lentinan ^c , mg·g ⁻¹ s.m.	0 days – 0 dni	12.8
		5°C 7 days – 7 dni	9.3
		20°C 7 days – 7 dni	3.7

f.m. – fresh matter, d.m. – dry matter.

^aYen 1992, ^bTseng and Mau 1999, ^cMinato et al. 1999.

ś.m. – świeża masa, s.m. – sucha masa.

^aYen 1992, ^bTseng i Mau 1999, ^cMinato i in. 1999.

The storage period of mushrooms can be lengthened using a controlled atmosphere [Lopez-Briones et al. 1992]. In the case of vegetables and mushrooms it is recommended to lower the concentration of oxygen and to increase the content of carbon dioxide compared with natural conditions [Roy et al. 1995, Czapski and Radziejewska 2001]. According to Simón et al. [2005], a modified atmosphere containing 2.5% CO₂ and 10-20% O₂ improves the appearance of *Agaricus bisporus* (Lange) Sing. and reduces the bacteria count. According to Roy et al. [1995], the storage of this mushroom species in a modified atmosphere containing 26% CO₂ decreases the weight loss by 3.0-4.5%.

Table 2. The effects of preliminary processing on whiteness of *Agaricus bisporus* (Lange) Sing.
Tabela 2. Wpływ obróbki wstępnej na białość *Agaricus bisporus* (Lange) Sing.

No. Lp.	Kind of preliminary processing Rodzaj obróbki wstępnej	Whiteness (L-Hunter value) Białość (wskaźnik L-Huntera)	
		point of reference punkt odniesienia	stored mushrooms after preliminary processing grzyby składowane po obróbce wstępnej
1	Treatment ethyl alcohol vapours (ET-OH) and storage for 5 days in 13°C ^a Traktowanie parami alkoholu etylowego (ET-OH) oraz składowanie przez 5 dni w 13°C ^a	mushrooms stored without preliminary processing grzyby składowane bez obróbki wstępnej 71	73
2	Treatment methyl jasmonate and ethyl alcohol vapours (JA-Me) and storage for 5 days in 13°C ^a Traktowanie parami estru metylowego kwasu jasmoneowego (JA-Me) i alkoholu etylowego (ET-OH) oraz składowanie przez 5 dni w 13°C ^a	mushrooms stored without preliminary processing grzyby składowane bez obróbki wstępnej 71	75
3	Washing in H ₂ O ₂ (5%) aqueous solution and sodium erythorbate (4.5%), cysteine hydrochloride (0.2%) and Na ₂ EDTA (0.1%) aqueous solution and storage for 3 days in 13°C ^b Mycie w roztworze wodnym H ₂ O ₂ (5%) i roztworze wodnym izoaskorbinianu sodu (4,5%), chlorowodorku cysteiny (0,2%) i Na ₂ EDTA (0,1%) oraz składowanie przez 2 dni w 1°C, a następnie przez 3 dni w 13°C ^b	mushrooms stored without preliminary processing grzyby składowane bez obróbki wstępnej 87	90
4	Washing in sodium metabisulfite (1000 mg·l ⁻¹), and blanching in water ^c Mycie w roztworze wodnym pirosiarczynu sodu (1000 mg·l ⁻¹) oraz blanszowanie w wodzie ^c	fresh mushrooms grzyby świeże 83-87	73-74
5	Washing in sodium metabisulfite (1000 mg·l ⁻¹), and subsequent vacuum soaking with water and blanching in water ^c Mycie w roztworze wodnym pirosiarczynu sodu (1000 mg·l ⁻¹), następnie nasączenie próżniowe wodą oraz blanszowanie w wodzie ^c	fresh mushrooms grzyby świeże 83-87	68-73

^aCzapski 2001, ^bCzapski 2002, ^cCzapski 1994 b.

Maintaining good quality in fresh *Agaricus bisporus* (Lange) Sing. during storage may be achieved by applying vapours of jasmonic acid and ethanol methyl ester to the pilei immediately after harvest [Czapski 2001]. This procedure allows the storing of this species at 13°C for five days, positively affecting their white colour (Table 2) and general appearance. Moreover, the application of vapours of ethyl alcohol alone inhibits the elongation of the stem, increases the cap diameter and enhances the ripening process of the pileus. The shelf life of fresh mushrooms can also be extended by ionizing irradiation [Ostrzycka et al. 1993, Mau and Hwang 1997, Beaulieu et al. 1999]. Irradiation is carried out using so-called accelerators [Śmierzchalska et al. 1989]. For *Agaricus bisporus* (Lange) Sing. the most frequently applied irradiation doses vary from 0.5 to 2.5 kGy [Śmierzchalska et al. 1989, Ostrzycka et al. 1993]. According to Śmierzchalska et al. [1989], an irradiation dose of 2.0 kGy extends the shelf life of fresh mushrooms to 8 days at 10-16°C and to 6 days at 18-19°C. However, according to Ostrzycka et al. [1993] and Mau and Hwang [1997], irradiation unfortunately affects the level of octo-carbon aromatic compounds present in the mushroom; the level of these compounds decreases with increases in the irradiation dose and the storage period. This phenomenon affects among others, 1-octen-3-ol, the main aromatic compound of mushrooms, as well as 3-octanone; 3-octanol; 1-octanol; and 2-octen-1-ol [Mau and Hwang 1997].

The quality of stored mushrooms also depends on how they are packed. Among the most popular methods is vacuum packing [Czapski and Radziejewska 2001]. Packing in a modified atmosphere (the MAP method) is also fairly popular: it is based on “injecting” an atmosphere of a specific gaseous composition at the moment of packing [Adamicki 2000]. The type of packaging also significantly affects the quality of mushrooms. The packaging currently used – so-called Vitafilm, i.e. polyvinyl chloride film – is not only expected to prevent drying and darkening of pilei, but also “control” the gaseous composition of the atmosphere and the relative air humidity [Czapski 2000, Zuchowicz et al. 2004 a, b].

Owing to the short shelf life of fresh mushrooms – from just a few days to a dozen days or so – they should be processed directly after harvest in order to maintain their supply to consumers throughout the year [Kondratowicz and Kowałko 2000].

PROCESSING OF MUSHROOMS

The selection of the method for processing mushrooms depends, among other things, on the ultimate use of the products as well as on the storage period envisaged. The long-term preservation of mushrooms can be achieved by freezing, drying and sterilization. Apart from using these methods, food processing plants also produce salted mushrooms as a semi-finished product; pickled and marinated mushrooms; powders; pastes; and concentrates and extracts [Bąkowski and Michalik 1982, Krieb and Lelley 1991, Joshi et al. 1996, Vivar-Quintana et al. 1999, Kondratowicz and Kowałko 2000, Czapski 2003, Vetter 2003]. From the point of view of diet, freezing, pickling and appertizing can be recommended, since with these processing methods the nutritive value and flavour of the products are higher than that of marinated or salted mushrooms [Horubała and Wiśniewska 1978, Kondratowicz and Kowałko 2000]. Kubiak [2001] reports that in Poland, with its wide range of canned, processed and semi-finished products, sterilized and salted mushrooms dominate the market, followed by marinated and

frozen products. Processed mushrooms from Poland have a high export profile [Kubiak 2003]. According to Smoleński [2004 b], the export of frozen *Agaricus bisporus* (Lange) Sing. doubled in the years 1998-2002; that of processed mushrooms increased by 47%; and that of mushrooms in brine by 5%.

PRELIMINARY PROCESSING

The proper quality of mushroom products can be obtained by eliminating or inhibiting adverse changes in the colour and texture of pilei [Czapski and Szudyga 2000]. Particular attention is also paid to the minimization of weight loss during preliminary processing and canning procedures [Okereke and Beelman 1990, Czapski 1994 b, Devece et al. 1999]. Preliminary processing most frequently includes washing [Czapski and Bąkowski 1995, Źródłowski 1995, Sapers et al. 1999, 2001]; blanching [Murr and Morris 1975, Czapski 1994 a, b, 1995, Vivar-Quintana et al. 1999, Coşkuner and Özdemir 1997, 2000]; and soaking or vacuum moistening in solutions of compounds preventing the darkening of pilei [Czapski 1994 b, Kukura et al. 1998, Vivar-Quintana et al. 1999, Jaworska et al. 2003]. Among these compounds are: table salt; citric acid; L-ascorbic acid [Beelman et al. 1973, Coşkuner and Özdemir 1997, 2000, Jaworska et al. 2003]; hydrogen peroxide; versenic acid [EDTA]; sodium erythorbate; cysteine hydrochloride [Coşkuner and Özdemir 2000, Czapski 2002]; methyl jasmonate vapors and ethyl alcohol vapors [Czapski 2001]; calcium chloride [Kukura et al. 1998] and metabisulfites [Czapski 1994 a, Czapski and Bąkowski 1995, Vivar-Quintana et al. 1999, Jaworska et al. 2003]. In modern production practice metabisulfites are very frequently used [Steinbuch 1986, Lee and Lee 1988, Czapski 1992]. They inhibit the activity of mushroom enzymes such as polyphenoloxidase; lactase; peroxidase [Ratcliffe et al. 1994]; and lipoxygenase [Kuribayashi et al. 2002], which are responsible for changes in colour [Dawley 1993, Espín and Wichers 1999 a, b].

Washing is one of the first measures applied in the preliminary processing of mushrooms. Although it is desirable from the point of view of hygiene, the washing of pilei in water alone considerably decreases the quality of stored *Agaricus bisporus* products. The delicate cell membranes which separate the enzyme – o-phenol oxidase – from the substrata are damaged, causing darkening and bronzing of the pilei [Ponting 1960, Burton and Noble 1993]. Hence, in order to maintain the proper quality of products, mushrooms are washed in solutions of such compounds as sodium metabisulfite, which has a beneficial effect on the whiteness of pilei by inhibiting undesirable changes in colour (Table 2). The washing of *Agaricus bisporus* (Lange) Sing. in a solution of hydrogen peroxide and then in a solution containing sodium erythorbate, cysteine hydrochloride and sodium salt of versenic acid (Na_2EDTA) also has a beneficial effect on the colour of pilei. According to Czapski [2002], this procedure decreases the activity of polyphenoloxidase and – due to leaching – the level of free phenols. Sapers et al. [1999], however, reached different conclusions concerning the washing of mushrooms in a solution of hydrogen peroxide followed by spraying with a solution of sodium erythorbate, cysteine hydrochloride and sodium salt of versenic acid. These authors found a higher content of free phenols in washed *Agaricus bisporus* pilei compared with unwashed ones. Mushrooms subjected to preliminary processing with H_2O_2 and sodium erythorbate (Table 3) are characterized by a lower content of soluble phenols than these

Table 3. Content of soluble phenols in *Agaricus bisporus* (Lange) Sing. in dependence on preliminary processing, mg·g⁻¹ dry matter
 Tabela 3. Zawartość rozpuszczalnych polifenoli w *Agaricus bisporus* (Lange) Sing. w zależności od obróbki wstępnej, mg·g⁻¹ suchej masy

Kind of technological procedure Rodzaj zabiegu technologicznego	Soluble phenols Polifenole rozpuszczalne	
	unwashed mushrooms grzyby niemyte	washed mushrooms grzyby myte
Washing in H ₂ O ₂ (5%) aqueous solution and sodium erythorbate (4%) solution, spray application ^a Mycie w roztworze wodnym H ₂ O ₂ (5%), a następnie natrysk roztworem izoaskorbinianu sodu (4%) ^a	2.9-3.1	3.8-4.7
Washing in water containing 2-5 ppm chloride ^a Mycie w wodzie zawierającej 2-5 ppm chloru ^a	2.9-3.1	2.5-3.0
Washing in sodium hypochlorite (0.01%) aqueous solution ^b Mycie w roztworze wodnym podchlorynu sodu (0,01%) ^b	5.4	4.9

^aSapers et al. 1999, ^bChoi and Sapers 1994.

^aSapers i in. 1999, ^bChoi i Sapers 1994.

washed in an aquatic solution of sodium hypochlorite (NaOCl). According to Choi and Sapers [1994], sodium hypochlorite used during mushroom storage for controlling microbiological changes in the pilei [Park et al. 1991] causes darkening owing to the oxygenation of L-3,4-dihydroxyphenylalanine (L-DOPA) to brown quinones. As was mentioned above, *Agaricus bisporus* (Lange) Sing. can be washed in an aquatic solution of sodium metabisulfite, which is strongly recommended for frozen [Czapski and Bąkowski 1995] and sterilized products [Czapski 1992]. Sulphur compounds reduce the tendency for finished products to darken. According to Czapski and Bąkowski [1995], the optimum concentration of sodium metabisulfite in solutions used for washing before freezing should be 4000 mg/dm³. In determining this concentration the intensity of washing should be taken into consideration: the higher the intensity, the greater the sorption of sodium metabisulfite [Czapski 1994 a]. As mentioned above, metabisulfites prevent undesirable changes of colour; however, the residue of sulphur dioxide is harmful, especially for people with asthma [Linn and Gong 1999].

Two treatments recommended by many authors, and frequently used before blanching, are vacuum moistening and soaking [Beelman et al. 1973, Czapski 1994 b, Vivar-Quintana et al. 1999, Jaworska et al. 2003]. Vacuum moistening helps preserve the natural colour of blanched pilei and reduces the weight loss associated with blanching [McArdle et al. 1974, Czapski 1994 b]. According to Czapski [1994 b], these losses can be reduced by as much as half compared with mushrooms not having undergone vacuum moistening in pre-processing. Beelman et al. [1973] showed the positive effects of placing mushrooms in the vacuum for 5 minutes (0.26 KPa) and then dipping them in water for 10 minutes. Apart from vacuum moistening, mushrooms are also soaked. Jaworska et al. [2003] showed that by soaking fresh mushrooms in a solution of citric acid and L-ascorbic acid before blanching, the loss of weight in the raw material due to blanching can be reduced by 10%; however, after this treatment the level of water solu-

ble compounds was reduced. For a 9% increase in the yield of appertized *Agaricus bisporus*, Beelman et al. [1973] recommend soaking in water for 20 minutes before blanching, storing at 2°C for 18-24 h and then soaking again for 2 h.

Blanching is another treatment applied in the preliminary processing of mushrooms. They are usually blanched in water or in aquatic solutions of antioxidative substances at 95-98°C. The length of this treatment can vary from 20 s [Czapski 1995] to 15 minutes [Czapski 1994 a, b, Coşkuner and Özdemir 1997, 2000, Vivar-Quintana et al. 1999]. The large time differential depends on numerous factors, but above all on the purpose of the treatment. The investigation conducted by Woźniak and Gapiński [1996 b] suggests that in the case of sterilized *Agaricus bisporus* (Lange) Sing. the most favourable parameter of blanching in water is: the temperature of 90°C for a period of 4 minutes. However, Lee and Lee [1988] postulate that the blanching of *Agaricus bisporus* (Lange) Sing. before freezing should not exceed 1-2 minutes, since prolonging blanching to 5 minutes results in a distinct hardening of the pilei. According to Czapski [1995], 20-second blanching in water can be applied to preserve good colour and minimize the hardening of frozen pilei of *Agaricus bisporus* (Lange) Sing., which follows full blanching (5-8 minutes); however, in this case blanching must be preceded by washing the raw material in a solution of sodium metabisulfite. Blanching should be lengthened to 15 minutes in order to minimize the darkening of pilei caused by the activity of enzymes; it is only then that the total inactivation of peroxidase can be achieved [Coşkuner and Özdemir 2000]. According to numerous authors [Fuster et al. 1982, Gormley and Walsh 1982, Vivar-Quintana et al. 1999], the blanching of *Agaricus bisporus* (Lange) Sing. before freezing is indispensable since it prevents the darkening of pilei during storage and defrosting. According to Steinbuch [1986] and Czapski [1995], however, this measure has a detrimental effect on the texture of frozen mushrooms, making them hard and rubbery, particularly after a longer period of storage. The composition of solutions used in blanching mushrooms affects the quality and chemical composition of pilei. According to Vivar-Quintana et al. [1999], blanching with the addition of citric acid before sterilization reduces the weight loss in *Agaricus bisporus* (Lange) Sing. caused by processing. However, Okereke and Beelman [1990] showed that, compared with blanching in water and using brine made from table salt, blanching in a solution of citric acid and the use of brine made from table salt and sodium-calcium salt of versenic acid (CaNa₂EDTA) have a positive effect on the colour and texture of sterilized mushrooms and also increase the microbiological stability of products. The results of the investigation into the blanching of mushrooms conducted by Rodrigo et al. [1999] suggest that the replacement of citric acid by glucono-δ-lactone also enables canned mushrooms to maintain good colour, texture and yield but, unlike citric acid, glucono-δ-lactone does not leave a strange or acidic taste and smell in the pilei. According to Sobkowska and Woźniak [1974], the blanching of *Tricholoma equestre* (L.:Fr.) Kumm. affects the level of some traits of the chemical composition of pilei. After blanching conducted in the medium of citric acid and table salt, the above authors found a 20% decrease in dry matter content; a 5% decrease in total sugars; and a 12% decrease in proteins. Coşkuner and Özdemir [2000] report that blanching mushrooms in solutions of citric acid at different concentrations does not significantly affect the level of iron, copper, manganese or zinc in pilei, unlike blanching in EDTA solution, which decreases the content of iron and copper.

In recent years attempts have been made to replace traditional blanching with a modified method which combines blanching in a microwave oven with blanching in hot water. In comparison with the traditional method, the modified procedure improves the final quality of the product and considerably reduces the degradation of texture and the loss of weight [Ponne et al. 1994]. Moreover, combined blanching causes rapid inactivation of polyphenoloxidase, thus preventing the bronzing of the tissue [Devece et al. 1999].

METHODS OF PROCESSING MUSHROOMS

Drying

The oldest and simplest method of processing mushrooms is drying. According to Horubała and Wiśniewska [1978], the species most suitable for drying are: *Boletus edulis* (Bull.:Fr.); *Gyromitra esculenta* (Pers.:Fr.) Fr. and *Morchella esculenta* (L.:Fr.) Pers.:St-Am. (morel). Because of rapid darkening of the pilei during traditional drying, a temperature of 40°C is used at the start [Bąkowski and Michalik 1982, Achremowicz et al. 1984, Woźna et al. 1996], followed by 50-60°C towards the end [Kaczmarek and Sobiech 1973, Achremowicz et al. 1984]. Correctly dried mushrooms are characterized by pleasant flavour and crispness, their water content not exceeding 12% [Achremowicz et al. 1984]. As Bąkowski and Michalik [1982] report, during blast drying numerous changes occur in both the appearance and the chemical composition of pilei, with a considerable reduction in the level of vitamin C. Owing to the concentration of chemical constituents, dried pilei show a high content of potassium and an average content of magnesium and iron. Table 4 shows that the level of carbohydrates, lipids, and ash as well as of nitrogen compounds in mushrooms depends of the species. The highest content of the above constituents is found in *Stropharia rugosoannulata* Farlow ex. Murr. and *Lentinula edodes* (Berk.) Pegl. (shii-take). A comparison of the different chemical constituents shows that the highest level of most of them can be found in *Stropharia rugosoannulata* Farlow ex. Murr. and *Pleurotus ostreatus* (Jacq.:Fr.) Kumm.

Apart from traditional blast drying, vacuum drying with microwave heating can also be used. As Kaczmarek and Sobiech [1973] show, compared with blast drying, this method yields dried mushrooms of better general appearance, colour and consistency, with a higher capacity for water absorption, almost of 100%. Besides the above methods, good results are also obtained using freeze-drying [Le Loch-Bonazzi and Wolff 1991]. According to Fang et al. [1971], this method used in drying *Agaricus bisporus* (Lange) Sing. restrict polyphenoloxidase activity, producing dried mushrooms of light colour. Freeze-drying also allows pilei to retain their natural shape and size. The freeze-drying of *Agaricus bisporus* (Lange) Sing. has a significant effect on the content of 8-carbon aromatic compounds, chiefly 1-octen-3-ol; 3-octanol; and 3-octanone, whose level is drastically reduced (by 72, 76 and 78%) after this treatment compared with that found in fresh pilei [Le Loch-Bonazzi and Wolff 1991].

Table 4. Content of selected chemical constituents in dried edible mushrooms, in 100 g dry matter
Tabela 4. Poziom wybranych składników chemicznych w suszonych grzybach jadalnych, w 100 g suchej masy

Chemical constituent Składnik chemiczny	Mushroom species – Gatunek grzyba			
	<i>Pleurotus ostreatus</i> (Jacq.:Fr) Kumm. bocznik ostrygowaty	<i>Agaricus bisporus</i> (Lange) Sing. pieczarka dwuzarodnikowa	<i>Lentinula edodes</i> (Berk.) Pegl. shiitake	<i>Stropharia rugosoannulata</i> (Farlow ex. Murr.) pierścieniak
Moisture, g Wilgoć, g	3.9 ^a -10.8 ^b	3.9 ^a	6.6 ^c -11.2 ^c	13.0 ^d
Total carbohydrates, g Węglowodany ogółem, g	19.2 ^c	*	30.4 ^c -38.2 ^c	33.7 ^d
Fat, g Tuszcz, g	4.2 ^a -6.9 ^c	2.7 ^a	1.3 ^c -8.7 ^c	2.6 ^d
Total nitrogen, g Azot ogółem, g	3.3 ^b -4.0 ^a	6.5 ^a	4.0 ^c -4.5 ^c	5.7 ^d
Protein nitrogen, g Azot białkowy, g	2.0 ^b -2.2 ^a	3.8 ^a	2.2 ^c -2.6 ^c	4.1 ^d
Ash, g Popiół, g	6.6 ^a -7.4 ^b	10.4 ^a	4.2 ^c -6.5 ^c	11.4 ^d
Ca, mg	47.7 ^a -56.5 ^b	30.9 ^a	2.8 ^c -79.7 ^c	98.3 ^d
P, mg	496 ^b	*	281 ^c -497 ^c	1 205 ^d
Mg, mg	83.6 ^a	84.9 ^a	43.7 ^c -77.7 ^c	*
Fe, mg	2.0 ^a -33.5 ^b	4.1 ^a	6.6 ^c -25.3 ^c	32.5 ^d
Cu, mg	2.2 ^b -55.8 ^a	8.4 ^a	3.3 ^c -5.8 ^c	8.6 ^d

*Lack of data.

^aKarmańska et al. 2002, ^bLasota and Sylwestrzak 1982, ^cLasota and Sylwestrzak 1989, ^dBrodzińska and Lasota 1981, ^eWoźniak et al. 1998.

*Brak danych.

^aKarmańska i in. 2002, ^bLasota i Sylwestrzak 1982, ^cLasota i Sylwestrzak 1989, ^dBrodzińska i Lasota 1981, ^eWoźniak i in. 1998.

Processing in air-tight containers

Apart from drying, a popular method of mushroom processing is the use of air-tight containers. This type of product includes marinades and mushrooms canned in brine [Achremowicz et al. 1984, Woźniak et al. 1996, Coşkuner and Özdemir 1997, Vivar-Quintana et al. 1999, Jaworska et al. 2003].

Acetic acid (3-5%) is used in marinade production, usually containing salt and sugar [Achremowicz et al. 1984]. The raw material can be fresh, salted or, more rarely, pickled mushrooms. Apart from the popularly used *Agaricus bisporus* (Lange) Sing., other species, such as *Pleurotus ostreatus* (Jacq.:Fr.) Kumm. [Achremowicz et al. 1984] and *Lentinula edodes* (Berk.) Pegl. (shiitake) [Woźniak et al. 1996] can also be used as the raw material.

Sterilized mushrooms are more versatile in use: they are processed in brine containing sodium chloride and, sometimes, a small addition of citric acid, L-ascorbic acid, and sodium or potassium metabisulfite [Sobkowska and Woźniak 1974, Coşkuner and Özdemir 1997, Vivar-Quintana et al. 1999, Jaworska et al. 2003]. Such products remain suitable for consumption for as long as 24 months and storage costs are relatively low [Horubała and Wiśniewska 1978]. For this kind of production the raw materials chiefly include *Agaricus bisporus* (Lange) Sing., *Cantharellus cibarius* (Fr.:Fr.) Fr. (chanterelle), *Boletus edulis* (Bull.:Fr.), *Lactarius deliciosus* (L.:Fr.) Gray (saffron milk cap) [Coşkuner and Özdemir 1997, Vivar-Quintana et al. 1999, Gębczyński et al. 2003, Jaworska et al. 2003]; *Pleurotus ostreatus* (Jacq.:Fr.) Kumm. [Zuchowicz et al. 2004 b] and *Lentinula edodes* (Berk.) Pegl. (shii-take) [Woźniak et al. 1996]. Desalted mushrooms can be also used for canning in air-tight containers [Czapski 2003]. According to Woźniak et al. [1996] and Vivar-Quintana et al. [1999], the optimum conditions for mushroom sterilization are a temperature of 118-121°C for 20 minutes. The pre-processing of pilei before sterilization plays an important role in maintaining good quality of canned products. The measures most frequently applied in preliminary processing are soaking and blanching in solutions preventing the darkening of the products [Beelman et al. 1973, Okereke and Beelman 1990, Rodrigo et al. 1999]. As Jaworska et al. [2003] report, the addition of brine in the production of sterilized mushrooms brings about, among other effects, a 26-28% decrease in dry matter; a 12-29% decrease in total sugars; a 29-36% decrease in total acids; and a 24-29% decrease in total nitrogen in comparison with the raw material after blanching or after soaking followed by blanching. According to Czapski [2003], the only criterion in determining the origin of *Agaricus bisporus* (Lange) Sing. used for canned products, i.e., whether fresh or desalted pilei have been used, is the content of potassium. However, Vetter [2003] postulates that this method of edible mushroom processing does not significantly affect the content of protein or fats in the pilei, but decreases the level of dry matter and ash, and also of some mineral constituents such as potassium, phosphorus, magnesium, at the same time increasing the content of sodium, calcium and iron. The nutritive value of canned products is given in Table 5. It should be noted that, as in the case of frozen products, it depends above all on the raw material used in the production.

Freezing

Freezing is the best processing method for preserving the natural taste and aroma of mushrooms [Łobaszewski and Paczyńska 1995]. In general, it is accepted that the nutritive value of frozen products exceeds that of sterilized food. However, on the basis of the results into investigations into the nutritive value of mushroom products (Table 5), it is difficult to draw definitive conclusions on this point. There are very few data available in the literature concerning the comparison of chemical composition of the above-mentioned products obtained from the same raw material.

Only fresh pilei of very high quality, ideally straight from the harvest, are used for freezing. The species suitable for freezing are: *Boletus edulis* (Bull.:Fr.), *Lactarius deliciosus* (L.:Fr.) Gray (saffron milk cap), *Cantharellus cibarius* (Fr.:Fr.) Fr. (chanterelle), *Agaricus bisporus* (Lange) Sing., *Tricholoma equestre* (L.:Fr.) Kumm. (green night cap) [Sobkowska and Woźniak 1974, Czapski 1989, Rapior et al. 1996, Czapski and Szudyga 2000, Kondratowicz and Kowałko 2000]; *Pleurotus ostreatus* (Jacq.:Fr.) Kumm.

Table 5. Content of selected chemical constituents of canned and frozen *Agaricus bisporus* (Lange) Sing., g·100 g⁻¹Tabela 5. Zawartość wybranych składników chemicznych sterylizowanych i mrożonych *Agaricus bisporus* (Lange) Sing., g·100 g⁻¹

Chemical constituent Składnik chemiczny		canned mushrooms konserwy sterylizowane			frozen mushrooms mrożonki	
		from blanched in sodium metabisulfite mushrooms z grzybów blanszowanych w roztworze piro-siarczynu sodu	from fresh mushrooms z grzybów świeżych	from desalted mushrooms z grzybów odsolonych	from blanched in sodium metabisulfite mushrooms z grzybów blanszowanych w roztworze piro-siarczynu sodu	from fresh mushrooms z grzybów świeżych
Dry matter Sucha masa	ś.m. f.m.	6.09 ^a	6.37 ^b -8.60 ^c	8.40 ^c	8.37 ^a	5.20 ^b
Protein, N × 4.38	ś.m. f.m.	1.27 ^a	1.53 ^b -2.73 ^c	3.22 ^c	1.66 ^a	1.30 ^b
Białko, N × 4,38	s.m. d.m.	*	40.60 ^d	*	*	*
Fat Tłuszcz	ś.m. f.m. s.m. d.m.	*	0.11 ^c -0.33 ^b	0.11 ^c	*	0.22 ^b
Ash Popiół	ś.m. f.m. s.m. d.m.	1.02 ^a	0.77 ^b -1.29 ^c	0.91 ^c	0.55 ^a	0.62 ^b
Total carbohydrates Węglowodany ogółem	ś.m. f.m.	*	4.50 ^b	*	*	3.73 ^b

f.m. – fresh matter, d.m. – dry matter.

*Lack of data.

^aJaworska et al. 2003, ^bManzi et al. 1999, ^cCzapski 2003, ^dVetter 2003.

ś.m. – świeża masa, s.m. – sucha masa.

*Brak danych.

^aJaworska i in. 2003, ^bManzi i in. 1999, ^cCzapski 2003, ^dVetter 2003.

[Zuchowicz et al. 2004 a]; and *Lentinula edodes* (Berk.) Pegl. (shii-take) [Woźniak et al. 1996]; in the food industry the basic species used for freezing is still *Agaricus bisporus* (Lange) Sing. [Kubiak 2001, Smoleński 2004 b].

Before freezing, mushrooms are washed in solutions containing metabisulfites, this preliminary treatment being applied to prevent adverse changes in the colour and texture of pilei [Fang et al. 1976, Fuster et al. 1982, Czapski and Bąkowski 1995, Czapski and Szudyga 2000]. Czapski and Szudyga [2000] show that, unlike blanching in water, blanching with the addition of metabisulfites favourably affects the colour of *Agaricus bisporus* (Lange) Sing. during 3-month storage. According to these authors, washing in a solution of sodium metabisulfite followed by dipping in hot water for 20 s before freezing, compared with washing in water or in a solution of sodium metabisulfite,

enables mushroom products with a better texture to be obtained, even after 3 months of refrigerated storage. According to Murr and Morris [1975], blanching also positively affects the colour of pilei during storage and defrosting. However, according to Steinbuch [1978, 1979], this treatment negatively affects the structure of frozen products, particularly during long-term storage. In experiments with freezing *Tricholoma equestre* (L.:Fr.) Kumm. (green night cap), Sobkowska and Woźniak [1974] found that blanching pilei in a 1% solution of citric acid and 2% solution of table salt before freezing resulted in a product of poorer consistency, taste and aroma compared with unblanched material. Jaworska et al. [2003] claim that blanching in water is sufficient in the production of frozen mushroom stuffing stored for 4 weeks. In order to minimize weight loss in mushrooms and increase their yield, it is recommended to precede blanching with soaking or vacuum moistening with water [Beelman et al. 1973, Czapski 1994 b].

The method of freezing also plays an important role in the production of frozen mushrooms. The blast method of freezing at temperatures from -25°C to -30°C is most frequently used [Sobkowska and Woźniak 1974, Czapski and Szudyga 2000]. When storing mushrooms at -30°C , no changes were found in the level of basic volatile compounds, such as: 1-octen-3-ol; 3-octanol; 1-octen-3-on; 3-octanone; and trans-octen-2-octen-1-ol [Pysallo 1978]. Good results were obtained by freezing mushroom using the cryogenic method which – in comparison with the fluidization or blast method – enables a higher quality product of good consistency and a strong mushroom taste and aroma to be obtained. Cryogenic freezing (in liquid nitrogen) carried out at temperatures from -80°C to -100°C for 5-6 minutes enables the storage period to be extended to as much as a year [Kondratowicz and Kowalko 2000]. The storage life of frozen mushrooms can also be extended using irradiation [Czapski 1989]. Irrespective of the freezing method, edible mushrooms must be stored at low temperatures. According to Fuster et al. [1982], good results are obtained storing frozen mushrooms at -20°C . In most cases polyethylene bags are used for packing this type of product [Horubała and Wiśniewska 1978].

Other processing methods

Among other methods of processing, the older procedures of salting [Yang and Maguer 1992] and pickling [Horubała and Wiśniewska 1978, Kreb and Lelley 1991, Joshi et al. 1996] should be mentioned. However, since full preservation using table salt can only be obtained at a concentration of 15-25%, this method has an adverse effect on both the nutritive value and the quality of the raw material [Yang and Maguer 1992]. In salted mushrooms the content of water soluble constituents is lower and the sodium/potassium ratio is less favourable [Horubała and Wiśniewska 1978]. In spite of their low nutritive value, salted mushrooms are desalted and used as semi-finished products in the production of marinades. Owing to their good keeping qualities and fairly low transport cost, salted mushrooms are always in demand in European markets, particularly in the Netherlands [Smoleński 2004 a].

Pickling mushrooms is a valuable processing method: it involves lactic bacteria, which have a beneficial effect on the human organism and impart a pleasant aroma and taste to pickled food. Among other mushrooms, *Pleurotus ostreatus* (Jacq.:Fr.) Kumm. is a species suitable for pickling. As Kreb and Lelley [1991] report, good results are obtained by pickling *Pleurotus ostreatus* (Jacq.:Fr.) Kumm. for 10 days at 21°C with freshly shredded cabbage. The obtained product has a pleasant, mild taste similar to that of pickled cabbage. Products of this type can be stored for six months, the pasteuriza-

tion of mushrooms before storage being unnecessary. Fermented mushrooms can be also used as a semi-finished product in the preparation of marinades [Horubała and Wiśniewska 1978] and sauces of good quality [Joshi et al. 1996].

CONCLUSION

The above review of the literature shows that edible mushrooms are difficult raw materials for the processing industry. Owing to the presence of various enzymes, the technological issue is to adapt the preliminary treatment to the kind of the raw material and to the processing method. The basic aim of preliminary processing is to prevent adverse changes in colour and to minimize the weight loss in mushrooms and changes in their nutritive value and sensory quality. Of the numerous methods of mushroom processing the most popular are drying, preserving in air tight containers, salting and freezing. The last method is one of the most rapidly developing trends in food processing.

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PRZECHOWYWANIE I PRZETWARZANIE GRZYBÓW JADALNYCH

Streszczenie. W pracy przedstawiono przegląd piśmiennictwa krajowego i zagranicznego dotyczącego przechowywania i przetwarzania grzybów jadalnych. Grzyby są dość trudnym surowcem dla przetwórstwa, w stanie świeżym nie nadają się do dłuższego składowania, natomiast podczas przerobu i konserwowania łatwo zmieniają barwę i teksturę. Aby zapewnić odpowiednią jakość konserw i przetworów grzybowych, świeże owocniki należy przechowywać w niskiej temperaturze. Ponadto przed konserwowaniem należy je poddać odpowiedniej obróbce wstępnej z udziałem substancji przeciwdziałających zmianom barwy i tekstury, a także zapewnić właściwe, dla określonej metody konserwowania, warunki składowania wyrobów gotowych. Najczęściej stosowanymi metodami konserwowania są suszenie, marynowanie, sterylizacja oraz mrożenie.

Słowa kluczowe: grzyby jadalne, przechowywanie, obróbka wstępna, konserwowanie

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