Frozen Mushrooms Quality as Affected by Strain, Flush, Treatment Before Freezing, and Time of Storage

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ABSTRACT: Four strains of mushrooms (*Agaricus bisporus*)—U3, hybrids of U3 (3/1, M-300), and in-between strain No. 200—were treated before freezing: washed in water, washed in water containing sodium metabisulfite (3g·L^{-1}), and washed in water containing sodium metabisulfite (5g·L^{-1}) then immersed in boiling water for 20 s. Appearance and whiteness of frozen mushrooms were most affected by the washing in water containing sodium metabisulfite. The residue of sulfur dioxide changed from 52 mg·kg^{-1} after 1 d to 27 mg·kg^{-1} after 90 d of storage. The whitest mushrooms (fresh and frozen) were for No. 200 strain. Short-time immersion in boiling water markedly increased toughness of stored frozen mushrooms.

Key Words: mushroom, strain, treatment, freezing, storage, quality

Introduction

A NUMBER OF POST-HARVEST CHANGES OCCUR IN MUSHROOMS (*Agaricus bisporus*) including surface discoloration, cap expansion, stipe elongation, and microbial decay. Shelf life of fresh mushrooms is usually limited to 1 to 3 d at room temperature (Burton and Twyning 1989) and 5 to 7 d at 0 to 2 °C (Lutz and Hardenburg 1968; Gormley 1975a, 1975b). Various post-harvest treatments intended to slow the post-harvest changes include: overwrapped and control atmosphere storage (Gormley and McCanna 1967; Nichols and Hammond 1973; Czapski and Bakowski 1986; Lopez-Briones and others 1992), modified atmosphere packages (Beit-Halachmy and Mannheim 1992; Kuyper and others 1993; Roy and others 1995), irradiation (Smierzchalska and Wojniakiewicz 1986), and addition of calcium chloride to irrigation water (Beelman and others 1992). But the most important parameters for extending shelf life of fresh mushrooms were low temperature and proper internal relative humidity (Beit-Halachmy and Mannheim 1992). Since mushrooms in the fresh state have a short shelf life, it is necessary to preserve considerable amount of raw material. One of the post-harvest treatment of mushrooms is freezing. While numerous factors are involved in quality loss in frozen mushrooms, the most detrimental is the enzymatic browning reaction (Fuster and others1982). It has been reported (Steinbuch 1979, 1986; Lee and Lee 1988) that blanching was harmful to the characteristic structure of mushrooms. The blanching process itself reduced the initial mushroom whiteness (Gormley 1972), and blanched frozen mushrooms showed a remarkable toughness after thawing and cooking. However, the omission of the blanching process resulted in a maintenance of the original structure characteristics but did not alter the enzyme activity in the mushroom tissue. Excellent results in stabilization of the color of frozen mushrooms by inhibiting undesired discoloration were obtained after washing fresh mushrooms in sodium metabisulfite solutions (Czapski and Bakowski 1995). The application of sulfite was mostly directed on a required bleaching effect on such a level whereby the residue of SO_2 should be minimal. The initial SO_2 residue of mushrooms washed in 1000 ppm solution of sodium sulfite was 48.1 ppm, and after storage during 11.8 h and 15.6 h at 15 °C and 5 °C, respectively, fell below the detectable level of 10 ppm (Beelman and others 1988). According to Taylor and others (1988), the sulfite-sensitive people with asthma did not necessarily react after ingestion of sulfited foods. The likelihood of a reaction was dependent on the nature of food, the level of residual sulfite, the individual man sensitivity, and perhaps on the form of residual sulfite, and the mechanism of the sulfite-induced reaction. According to E.U. Directives, the highest allowed amount of sulfite compounds (calculated as SO_2) depends on the foodstuff, but there are only a few limits for fresh and prepared vegetables as, for example, peeled potatoes (50 mg·kg^{-1}) or frozen potatoes (100 mg·kg^{-1}) (Laurila and others 1998). In the United States, sulfite compounds are generally recognized as safe when used in accordance with good manufacturing practice except that they are not allowed to be used on fruits and vegetables intended to be served raw to consumers or sold raw to consumers or to be presented to consumers as fresh (FDA 1996). Our previous paper showed that whiteness and SO_2 residue of frozen mushrooms depended on concentration, sorption, and dynamics of sorption of sodium metabisulfite solution by fresh mushrooms during washing (Czapski 1994). The objective of this study was to evaluate how different washing methods used on fresh mushrooms of different strains and flushes influenced the quality of frozen ones after storage.

Results and Discussion

Whiteness and sulfur dioxide content of frozen mushrooms

Since blanching is undesirable because of weight loss and toughness increase during storage of blanched frozen mushrooms (Lee and Lee 1988), the problem of keeping frozen mushrooms white is difficult. The whiteness of mushrooms (measured as L-value) 1 d after freezing as affected by treatment and strain is presented and compared with the fresh mushrooms whiteness on Table 1. Washing, freezing, and 1-d storage markedly contributed to the loss of L-value. The most pronounced effect occurred for washed mushrooms in sodium metabisulfite solution; frozen mushrooms remained whiter as compared with those from other treatments, after all time of storage (Table1, Fig. 1). Loss of frozen mushrooms whiteness after 1 d, as compared with fresh ones, varied an average from 6% to about 17% (treatments 2 and 3 on Table 1, respectively). Mushrooms of No. 200 strain fresh and fro-

zen were significantly whiter than those of other strains. No significant change in whiteness of frozen mushrooms during 90 d of storage was detected when short-time dipping in boiling water was applied (Fig.1). However, their whiteness was significantly reduced as compared with mushrooms washed only in water containing sodium metabisulfite. One can observe significant loss in whiteness with storage time for mushrooms washed in water. According to Gormley (1975b), wholesalers would probably be reluctant to buy fresh mushrooms with an L-value less than 80, and mushrooms with L-values less than 69 would not be acceptable to the normal consumer. Mushrooms immersed in boiling water before freezing (Fig.1) were quite acceptable for the consumer for all time storage even though they lost about 7 L-units as compared with mushrooms washed in water containing sodium metabisulfite. After 14 d of storage, mushrooms washed in water would not be acceptable for the normal consumer. Only mushrooms washed in water with sodium metabisulfite would be acceptable to the wholesalers even after 30 d of storage (Fig.1). Washing in water caused an increase in storage browning of frozen mushrooms. Physical damage to the mushrooms during washing contributed to the rupture of the membranes separating the compartments of polyphenol oxidase (PPO) enzyme and phenolic substrates. The subsequent mixing of enzyme and substrates forms brown compounds and reduced whiteness (Burton 1986). Sulfur dioxide and its derivatives are the most powerful and extremely versatile PPO inhibitors, which inhibit enzymatic as well as nonenzymatic browning of vegetables, fruits, and mushrooms during their storage, freezing, and processing (Roberts and McWeeny 1972; Laurila and others 1998). Since sulfites are essential additives with important effects on the whiteness stability of frozen mushrooms, determination of the minimum amount of SO_2 required to maintain optimum of frozen mushrooms quality seems to be necessary. Lines on Fig. 1 were drawn from values that were obtained by averaging sulfur dioxide content of all investigated strains and flushes. The length of mushroom storage affected SO_2 content for washing in sodium metabisulfite solution (Fig.1). Those stored longest (90 d) had lowest SO_2 content. Rate of decrease of SO_2 content for 14 and 30 d of storage did not change. After 1 d of storage, sulfur dioxide residue remained on the level of 52 mg·kg^{-1} then after 14 d decreased to 42 mg·kg^{-1} and remained on this level up to 30 d of storage. Time of storage had no effect on SO_2 content in mushrooms immersed in boiling water before freezing (Fig.1). Immersion of mushrooms in boiling water after washing in sodium metabisulfite solution had a dual effect: a significant loss of whiteness and a decrease of SO_2 content as compared with mushrooms washed in sodium metabisulfite solution (Fig.1).

Table 1—Whiteness (L-value) of frozen mushrooms 1 d after freezing (means of I to III flushes for a strain)

Treatment	Strain			
	U3	3/1	M-300	No. 200
Fresh	86.8 b	85.4 b	87.2 b	91.6 a
1.Washing in water for 2 min	67.8 h	74.0 f	76.9 e	80.2 d
2. Washing in sodium metabisulfite solution (3 g·L^{-1}) for 2 min	79.9 d	82.4 c	83.5 c	85.8 b
3. Washing in sodium metabisulfite solution (5 g·L^{-1}) for 2 min then immersion in boiling water for 20 s and cooling	70.9 g	69.9 g	75.5 ef	75.0 ef

Note: Data followed by the different letters differ significantly at P = 0.95 using Newman-Keuls test.

Effect of strain and flush

The results of whiteness and sulfur dioxide content presented in Table 2 were obtained by averaging L-values and SO_2 content of all 3 flushes for a strain, using data only for mushrooms washed in water containing sodium metabisulfite. Most data of whiteness are on the wholesale acceptability level (L = 80) and can be considered commercially significant. Frozen mushrooms of strains M-300 and No. 200 were distinctly whiter than U3 and 3/1 throughout the storage. The whiteness of the worst U3 strain decreased significantly during the storage. Ninety-d storage markedly decreased sulfur dioxide content an average 39% of mushrooms of all strains. No significant differences between strains in SO_2 content was observed during 1 to 30 d of storage; the level of SO_2 residue ranged 35 to 45 mg·kg^{-1}. The results of mushrooms whiteness as influenced by strain and flush (Fig. 2) were obtained by averaging L-values of all periods of storage only for mushrooms washed in sodium metabisulfite solution. The whiteness of frozen mushrooms was affected by flush. In general, frozen mushrooms from flushes 2nd and 3rd were less whiter than those from the 1st one. The whiteness of frozen mushrooms of U3 strain was the worst as compared with other tested strains.

Texture

The results presented in Table 3 show that the texture of fresh mushrooms of U3 and 3/1 strains is quite similar independently of flush. This differed significantly from M-300 and No. 200 strains. The highest value of shear press was observed for the **first?** flush of M-300 and No. 200 strains and the lowest 1 for the **second?** flush

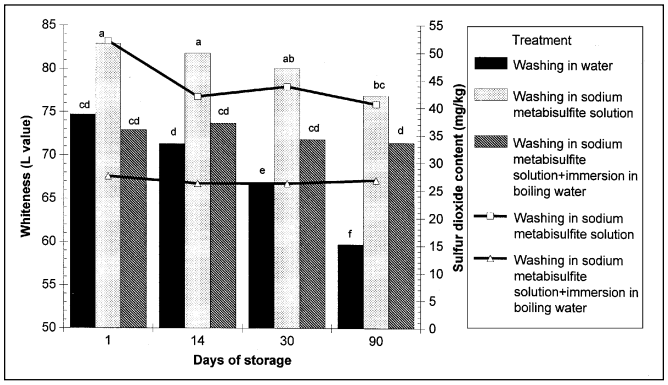

Fig. 1—Whiteness of frozen mushrooms (bars) and sulfur dioxide content (lines) as influenced by the time of storage at –20 °C and treatment (means of all strains and flushes). Bars labeled by different letters differ significantly at P = 0.95 using Newman-Keuls test. For sulfur dioxide content (lines), $LSD_{0.95}$ = 12.0 mg·kg^{-1}.

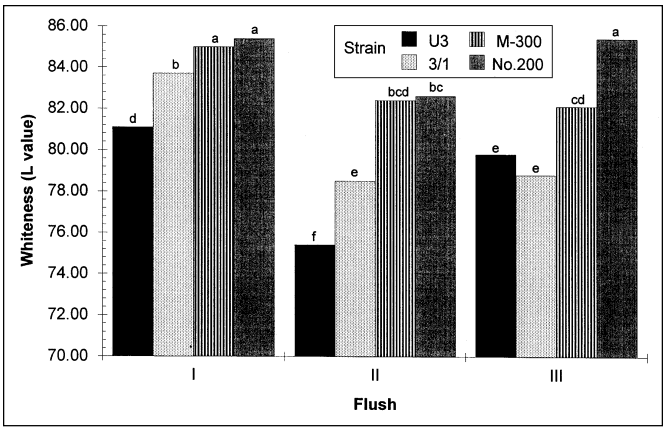

Fig. 2—Whiteness of frozen mushrooms as influenced by strain and flush (means of all periods of storage at –20 °C). Treatment: washing in sodium metabisulfite solution (3 g·L^{-1}) for 2 min. Bars labeled by different letters differ significantly at P = 0.95 using Newman-Keuls test.

Table 2—Whiteness of frozen mushrooms and sulfur dioxide content as influenced by strain (means of I to III flushes) and time of storage for treatment: washing in sodium metabisulfite solution (3 g·L^{-1}) for 2 min

Strain	Whiteness (L-value)				Sulfur dioxide content (mg·kg^{-1})	
	1 d	14 d	30 d	90 d	1 d	90 d
U3	79.9 bc	79.6 cd	76.8 e	71.2 f	37.3	26.6
3/1	82.4 b	80.0 cd	78.5 de	78.5 de	41.8	21.8
M-300	83.5 ab	83.0 ab	83.1 ab	79.1 ec	41.8	23.6
No. 200	85.8 a	84.7 ab	83.0 ab	78.2 de	34.9	24.4
					$LSD_{0.95}$ = 9.0 mg·kg^{-1}	

Note: Data followed by the different letters differ significantly at P = 0.95 using Newman-Keuls test.

Table 3—Texture (shear press) of fresh mushrooms as influenced by strain and flush (N·g^{-1})

Strain	Flush No.		
	I	II	III
U-3	18.5 bc	16.8 cd	17.9 bc
3/1	18.9 bc	17.9 bc	19.9 b
M-300	22.8 a	15.1 d	17.1 cd
No. 200	22.0 a	19.6 b	19.4 b

Note: Data followed by the different letters differ significantly at P = 0.95 using Newman-Keuls test.

Table 4—The effect of treatment before freezing and storage time at -20 °C on texture (shear press, N·g^{-1}) of frozen mushrooms after thawing (means of all strains and flushes)

Treatment	D of storage			
	1	14	30	90
Washing in water for 2 min	14.1 ef	15.6 bc	15.4 bcd	16.2 bd
Washing in sodium metabisulfite solution (3 g·L^{-1}) for 2 min	13.5 f	14.8 cf	15.3 bc	15.2 bc
Washing in sodium metabisulfite solution (5 g·L^{-1}) for 2 min then immersion in boiling water for 20 s and cooling	15.9 bd	16.6 ad	17.5 a	17.6 a

Note: Data followed by the different letters differ significantly at P = 0.95 using Newman-Keuls test.

of M-300. According to Gormley (1969), texture differences in mushrooms may be caused by variation in dry-matter content. Those mushrooms containing higher dry-matter content usually had a higher shear-press reading. However, in our studies, percentage of dry-matter content of fresh mushrooms from the **I-st** flush of M-300 and No. 200 strains was not significantly higher as compared with U3 and 3/1 **ones** (data not presented here.) Since statistically equal dry matters of mushrooms gave significantly different shear-press readings (Table 3), this may suggest that the nature of cellular material was different (Gormley 1969). More than 1-d storage of frozen mushrooms washed before freezing caused significant increase of shear-press readings as compared with 1 d of storage (Table 4). Immersion of mushrooms in boiling water caused a very distinct increase in toughness as the storage time of frozen mushrooms increased more than 14 d (Table 4). Lee and Lee (1988) demonstrated that blanching time before freezing had a significant effect on texture of frozen mushrooms. Frozen whole mushrooms, blanched for 5 min, had markedly tougher texture than those blanched for 1 or 2 min. As storage time of frozen mushrooms increased from 3 to 6 mo, shear press increased very significantly. The result of sensory evaluation for texture was in a good agreement with shear-press value. Fuster and others (1982) tested 13 different chemical treatments and found the best treatment for whole, quartered, and sliced mushrooms. This included scalding in boiling water and immersion in potassium metabisulfite or sodium thiosulfite solution. Dipping mushrooms in 0.1% or 0.5% sodium metabisulfite solution for 5 min after blanching resulted in best color and other quality characteristics after freezing (Fang and others1976). As can be seen in Table 4, even 20-s immersion of mushrooms in boiling water before freezing was harmful to their texture.

Conclusions

APPEARANCE AND COLOR OF UNBLANCHED FROZEN MUSHROOMS were most affected by washing them in sodium metabisulfite solution before freezing. Storage time of frozen mushrooms resulted in lower discoloration of mushrooms washed in water containing sodium metabisulfite or immersed in boiling water for 20 s than did mushrooms washed in water only. Strain markedly influenced the whiteness of frozen mushrooms; the whitest mushrooms (fresh and frozen) were for No. 200 strain. Their texture (shear-press reading) was higher as compared with other tested strains. Immersion in boiling water of mushrooms previously washed in water containing sodium metabisulfite had a dual effect: a marked loss of whiteness and a significant decrease of SO_2 content. Beside this, they showed marked toughness during storage. So heat treatment of mushrooms was not a successful alternative for sulfites to use before freezing. However, their use (concentration and time of washing) can be at as low SO_2 residue level as possible.

Materials and Methods

MUSHROOMS GREW ON CHICKEN MANURE-BASED COMPOST in The Mushrooms Experimental Facility at the Research Institute of Vegetable Crops in Skierniewice, Poland. Four strains were tested: U3, hybrids of U3 (3/1, M-300), and in-between strain No. 200. The growing conditions were applied according to general recommendations for U3 and in-between strains. Mushrooms of each strain were harvested on the peak d of each individual flush (I to III) examined. About 30 kg of mushrooms free of blotch were transported within 1 h to the laboratory and were selected on the basis of size (30 to 40 mm in dia). Diseased, damaged, and open-veiled mushrooms were discarded. Stems were hand-trimmed to stipe length of about 5 mm. Mushrooms were washed in a kettle supplied with a perforated tube on the bottom, allowing to stir washed mushrooms by air. Every portion of mushrooms was washed using steady pressure of air - 1 Atm.

Treatment and freezing

The following treatments of mushrooms before freezing were used: washing in water for 2 min; washing in water containing sodium metabisulfite (solution, 3g·L^{-1}) for 2 min; washing in water containing sodium metabisulfite (solution, 5g·L^{-1}) for 2 min, then immersion in boiling water for 20 s, and cooling in cold water (15 °C) for 2 min.

Mushrooms from all treatments were drained, weighed, and then air-blast frozen at −25 °C for 2 h. Then they were stored at −25 °C for a night and were packed (about 700-g samples) into polyethylene bags and stored at −20°C. Mushrooms were analyzed (2 bags per treatment) after 1, 14, 30, and 90 d of storage. The frozen mushrooms were thawed by low circulating air at 25 °C as reported by Nilsson and Ekstrand (1995) for thawing of

frozen rainbow trout. Thawing time was defined as the time to increase fruit body center temperature from storage temperature to 1 °C. At 1 °C thawing was defined as completed.

Measurements of quality characteristics

Surface whiteness (L-Hunter value) of fresh and frozen mushrooms was measured with HunterLab ColorQuest 45 °/0 ° Spectrocolorimeter (Hunter Association Laboratory, Inc. Reston, Va., U.S.A.) The instrument was calibrated with the standard black-and-white plates. Ten mushrooms were randomly chosen, and L-values were measured to describe their whiteness. The reversibly bound and free sulfites were determined by using a modified method of Monier-Williams (DeVries and others 1986). The distillation time of 20 min was established for frozen mushrooms experimentally. Four samples (about 100g) of randomly selected frozen mushrooms from 2 tested bags were quartered, and 4 50-g-each weightings of randomly selected quarters were analyzed for SO_2 content. The shear press was used for measuring mushroom texture by Instron model 1140 Food Testing System and Kramer Shear Cell, CS-1. About 300 g of randomly selected mushrooms were thawed and then sliced vertically with an egg slicer. The slices were mixed thoroughly before taking triplicate 35-g samples for shear-press readings (Gormley 1969).

Statistical analysis

Data on whiteness, sulfur dioxide content, and texture of mushrooms were subjected to analysis of variance (AW-2 computer program, version 1, Research Institute of Vegetable Crops, Skierniewice, Poland). To determine significant differences between means for whiteness an texture, the Newman-Keuls test ($P = 0.95$) was used (Sachs 1972). For data of sulfur dioxide content, means were evaluated using least significant differences (LSD) value.

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