



The combined effect of exposure time to sodium chlorite (NaClO₂) solution and packaging on postharvest quality of white button mushroom (*Agaricus bisporus*) stored at 4 °C

Fatih TARLAK¹, Murat OZDEMIR^{2*} , Mehmet MELIKOGLU²

Abstract

Agaricus bisporus was washed with 1 g/L sodium chlorite (NaClO₂) (SC) solution for 30, 60 and 120 s, packed with a non-perforated polyvinyl chloride (PVC) film and stored at 4 °C for 12 days. Washing the mushrooms with the SC solution and packaging with the PVC film slowed down the change in colour and firmness of the mushrooms, but treating the mushrooms with the SC solution longer than 60 s adversely affected the mushroom texture. After 12 days of storage, the weight loss of the mushrooms packed with the PVC film was less than 10% compared to the control. Headspace O₂ concentration decreased while CO₂ concentration increased throughout 12 days of storage and reached about 15% and 4%, respectively. *Pseudomonas* spp. counts for unwashed and unpacked mushrooms reached 10.30 log₁₀ CFU/g after 12 days of storage while the mushrooms washed with the SC solution and packaged with the PVC film had *Pseudomonas* spp. counts as low as 6.62 log₁₀ CFU/g. Treating the mushrooms with the SC solution for 60 s and packaging with the PVC film were found to be the most appropriate treatment to minimize the change on the postharvest quality of white button mushroom.

Keywords: mushroom spoilage; sodium chlorite; packaging; *Pseudomonas* spp.; shelf-life.

Practical Application: NaClO₂ solution can be used by the mushroom processors to prolong the shelf-life of fresh mushroom.

1 Introduction

Mushrooms have been consumed due to their nutritional and medicinal properties for centuries and are also one of the best sources of vitamins, especially vitamin B (Wani et al., 2010). More than hundreds of edible mushroom species exist in nature, but a few of those are cultivated commercially on industrial scale. Among those species, the button mushroom (*Agaricus bisporus*) is the most common edible mushroom all over the world (Doymaz, 2014a; Moradian et al., 2018). Button mushrooms have no cuticle to protect them from physical damage, microbial attack and water loss. They have very high respiration rate and high water content, making them prone to microbial spoilage and enzymatic browning (Brennan et al., 2000; Zalewska et al., 2018). *Pseudomonas* spp. have been isolated as the most abundant microorganism responsible for the spoilage of mushrooms (Simón & González-Fandos, 2010; Venturini et al., 2011). The shelf-life of mushrooms is very limited, and they lose their commercial value within a few days (Doymaz, 2014b; Gantner et al., 2017). This is a big problem for the distribution and marketing of the fresh mushrooms. Therefore, prolonging the shelf-life of mushrooms without any adverse effect on their quality would be important for the mushroom processors as well as the consumers. The most preferred way to extend the shelf-life is washing the mushrooms with solutions having antibrowning and/or antimicrobial properties to control respiration rate, and enzymatic and microbiological activity. Washing the mushrooms with antibrowning and antimicrobial agents including hydrogen

peroxide (Brennan et al., 2000), sodium hypochlorite (Simón & González-Fandos, 2010), citric acid (Simón & González-Fandos, 2010), malic acid (Singla et al., 2012), acetic acid (Sedaghat & Zahedi, 2012) and ascorbic acid (Sedaghat & Zahedi, 2012) reduced the microbial activity to some extent, but the shelf-life of the mushrooms is still limited.

Sodium chlorite (NaClO₂) (SC) is an effective antibrowning and antimicrobial agent. The use of SC solution (0.5-1.2 g/L) has been approved by the US Food and Drug Administration (FDA) for sanitizing food products, including processed fruits and vegetables (U. S. Food and Drug Administration, 2019). Lu et al. (2007) used the SC solution ranging from 0.1 to 1 g/L to inhibit enzymatic browning in apple slices and found that the SC solution of 1 g/L was the most effective treatment in reducing the browning in sliced apples. Allende et al. (2009) used the SC solution in concentration of 1 g/L to reduce total aerobic mesophilic bacteria and *Escherichia coli* O157:H7 on the fresh-cut cilantro, and they observed about 3 log₁₀ CFU/g reductions in microbial counts. Wei et al. (2017) used the SC solution in concentration of 1 g/L to reduce aerobic bacteria, *E. coli* O157:H7, moulds, yeasts and *Salmonella* Typhimurium on fresh strawberry, cherry tomato and red bayberry. They reported that the SC solution resulted in considerable reductions in microbial populations. These studies revealed that the SC solution can be used to inhibit browning and limit the microbial growth in foods.

Received 03 Sept., 2019

Accepted 04 Nov., 2019

¹Department of Nutrition and Dietetics, Istanbul Gedik University, Kartal, Istanbul, Turkey

²Department of Chemical Engineering, Gebze Technical University, Gebze, Kocaeli, Turkey

*Corresponding author: ozdemirm@gtu.edu.tr

The effect of the SC solution on the postharvest quality of white button mushroom and *Pseudomonas* spp. counts during storage were not known and not investigated. Therefore, the main objective of this work was to extend the shelf-life of white button mushrooms by investigating the effect of washing time with the SC solution followed by packaging with a non-perforated polyvinyl chloride (PVC) film on the quality parameters including colour, firmness, weight loss, pH and gas composition, and *Pseudomonas* spp. counts in the white button mushrooms during storage.

2 Materials and methods

White button mushrooms (*Agaricus bisporus*) were obtained from MUPA Agriculture and Industry Inc. (Izmit, Kocaeli, Turkey). Mushrooms were picked at the closed cap stage (cap diameter 3.5-4.5 cm). They were immediately shipped to the laboratory at 4 °C which is the industrial practice for storage and delivery of the mushrooms. Damaged, bruised and shrivelled mushrooms were discarded. After the stipes were trimmed at 1 cm, the whole mushrooms were washed with 1 g/L SC (Merck KGaA, Darmstadt, Germany) solution for 30, 60 and 120 s. No abnormal odour formation was detected after the washing treatments. Approximately ten mushrooms were placed in polystyrene trays (~125 g/tray) with the dimension of 22.5 × 13.5 × 3 cm. Some of the trays were overwrapped with a PVC film with a thickness of 9 µm and O₂ permeability of 33,000 mL/m² day atm under passive modified atmosphere packaging (MAP) conditions, and the others were not overwrapped with any kind of packaging film. Three different trays were used for each treatment in each sampling day. Every measurement was repeated at least three times. All the mushroom samples were stored at 4 °C ± 0.2 °C for 12 days in an incubator (Binder KB53, Binder GmbH, Tuttlingen, Germany). Mushrooms used in the experiments were categorized as follows: i) Control: Mushrooms not subjected to the SC solution and stored without any overwrapping material; ii) Control-P: Mushrooms not subjected to the SC solution and stored with a PVC overwrapping material; iii) SC-30: Mushrooms washed with the SC solution for 30 s and stored without any overwrapping material; iv) SCP-30: Mushrooms washed with the SC solution for 30 s and stored with a PVC overwrapping material; v) SC-60: Mushrooms washed with the SC solution for 60 s and stored without any overwrapping material; vi) SCP-60: Mushrooms washed with the SC solution for 60 s and stored with a PVC overwrapping material; vii) SC-120: Mushrooms washed with the SC solution for 120 s and stored without any overwrapping material and viii) SCP-120: Mushrooms washed with the SC solution for 120 s and stored with a PVC overwrapping material.

2.1 Colour analysis

The colour of the mushroom samples was measured in CIELab colour space where L* is the lightness component or luminance from black (0) to white (100), a* is a chromatic component from green (-120) to red (+120) and b* is a chromatic component from blue (-120) to yellow (+120) using a chroma meter (CR-400, Konica Minolta, Tokyo, Japan) equipped with a D₆₅ illuminant source. Prior to colour measurements, the chroma meter was calibrated with its white calibration tile (Y = 86.6, x = 0.3188 and

y = 0.3364). Total colour difference (ΔE*) values are calculated using Equation 1 (Borchert et al., 2014):

$$\Delta E^* = \sqrt{(L_i^* - L_f^*)^2 + (a_i^* - a_f^*)^2 + (b_i^* - b_f^*)^2} \quad (1)$$

where L_i^{*}, a_i^{*} and b_i^{*} are the initial colour values, and L_f^{*}, a_f^{*} and b_f^{*} are the final colour values.

2.2 Microbiological analysis

Twenty-five grams of mushrooms were aseptically weighed and homogenized using a stomacher (Bag Mixer 400VW, Interscience, Woburn, MA, USA) at high speed for 2 minutes with 225 mL of sterile peptone (0.1%, w/v) water (Oxoid, Basingstoke, UK). Serial dilutions (10⁻²-10⁻⁸) were made in serial dilution tubes by mixing 1 mL sample with 9 mL of 0.1% (w/v) sterile peptone water. *Pseudomonas* spp. were determined in King's B medium (Biolife Italiana, Milan, Italy) as given by King et al. (1954), following incubation at 25 °C for 48 h (Simón et al., 2005; Simón & González-Fandos, 2010). *Pseudomonas* spp. counts were determined by taking three separate trays for each treatment and each sampling point. Results were expressed as the average of three separate measurements in terms of log₁₀ CFU/g.

2.3 Texture measurements and weight loss

The firmness of the mushrooms was measured using a texture analyser (Lloyd TA1, Lloyd Instruments Ltd., West Sussex, UK) equipped with a load cell of 250 N. Cylindrical probe with a 12.5 mm diameter was used for the whole mushrooms. The probe speed was set to a constant speed of 2 mm/s, and the contact force was 0.5 N. Samples were penetrated to a depth of 5 mm. Force and time data were recorded with Llyod software, and the maximum force was expressed as the firmness (N) of the mushrooms. Results were reported as the average of nine measurements.

The weight loss of the mushroom samples was determined using a digital balance (Mettler Toledo, PB03-S, Columbus, OH, USA) with an accuracy of ±0.001 g. Triplicate measurements were done, and average value was reported as the weight loss. The weight loss (%) is given by Equation 2:

$$w_L (\%) = \frac{w_i - w_f}{w_i} 100 \quad (2)$$

where w_L is the weight loss (%), w_i is the initial weight (g) and w_f is the final weight (g) of the mushrooms.

2.4 Headspace gas composition analysis and pH

Oxygen (O₂) and carbon dioxide (CO₂) levels inside the packages were measured using a gas analyser (Check Mate-II, PBI Dansensor, Ringsted, Denmark). Samples were taken with a syringe inserted through a gas tight septum placed on the exterior of the film. Measurements were performed in triplicate, and results were reported as the average of triplicate measurements.

Mushroom samples were homogenised using a kitchen type blender (MB450, Tefal, Cedex, France), and homogenised

mushrooms were filtered through a muslin cloth. The pH of the filtrate was measured using a digital pH meter (SevenEasy S20-K, Mettler Toledo, Columbus, OH, USA). Measurements were done in triplicate, and average value was given.

2.5 Statistical analysis

Experiments were performed using a completely randomized design. One-way analysis of variance (ANOVA) was performed using Matlab 7.12.0 (R2011a) software (MathWorks Inc., Natick, MA, USA) in order to analyse the data. Statistical differences between the treatment means were determined by post hoc analysis using Tukey's multiple range test. The differences between the means are regarded as statistically significant if the p-value ≤ 0.05 . Data were shown as mean \pm standard deviation.

3 Results and discussion

3.1 Effect of washing with SC solution and packaging on mushroom colour

Colour change in mushrooms is a crucial factor affecting the consumer's preference. The L* value of all the mushroom samples decreased while ΔE^* values increased during storage at 4 °C (Table 1). Previously conducted studies on *Agaricus bisporus* showed that L* value could be used as a criterion to determine the mushroom quality and shelf-life (Aguirre et al., 2008; Taghizadeh et al., 2010).

Mushrooms with L* value of lower than 80 would not be acceptable at wholesale level (Gao et al., 2014; Lagnika et al., 2014; Lopez-Briones et al., 1993). This grading criterion is the most widely used indicator to determine the mushroom shelf-life both in the industry and research (Aguirre et al., 2008).

Washing the mushrooms with the SC solution and packaging with the PVC film slowed down the colour change of the mushrooms

(Table 1). Similar results were also reported by Lu et al. (2007) who observed that the SC solution in concentration of 1 g/L effectively decreased the change in the L* value of apple slices. The initial L* value of the fresh mushrooms was 90.14. After 4 days of storage, the L* value of the control was significantly ($p \leq 0.05$) lower than the L* value of the fresh mushrooms while there was no significant difference ($p > 0.05$) in the L* value of SCP-120 as compared with the L* value of the fresh mushrooms after 8 days of storage. The L* value of SCP-120 after 12 days of storage was significantly ($p \leq 0.05$) higher than the L* value of the control on day 12th. This means that washing of the mushrooms with the SC solution and packaging with the PVC film retard browning and reduce the colour change of the mushrooms during 12 days of storage.

The browning and change in the colour of mushrooms is considered to occur due to polyphenol oxidase activity (Xu et al., 2016). Oxidation of phenolic compounds by polyphenol oxidase causes browning (Waliszewski et al., 2007). SC is a mixed type of inhibitor for polyphenol oxidase activity, the key enzyme responsible for browning reaction (Lu et al., 2006). SC inactivates mushroom tyrosinase, which is the major polyphenol oxidase responsible for browning in button mushrooms (Cliffe-Byrnes & O'Beirne, 2008). Therefore, the treatments with SC are responsible for slowing down the polyphenol oxidase activity of mushrooms. Lu et al. (2007) also found that SC was the effective inhibitor of polyphenol oxidase activity and enzymatic browning in apple slices.

After 12 days of storage, the highest L* and ΔE^* values were obtained for the SCP-60 and SCP-120. These results confirm that subjecting the mushrooms to the SC solution longer than 60 s does not have a significant ($p \leq 0.05$) effect on colour. Therefore, it was decided that SCP-60 was the most appropriate treatment to minimize the colour change in white button mushrooms.

Table 1. Effect of SC (sodium chlorite) washing on the colour of mushrooms stored at 4 °C for 12 days¹.

Colour	Treatments	Storage time (day)			
		0	4	8	12
L*	Control	90.14 \pm 1.12 ^A	84.35 \pm 2.43 ^{Bb}	75.65 \pm 4.36 ^{Cf}	66.01 \pm 1.73 ^{Dc}
	Control-P		86.36 \pm 3.49 ^{Aab}	79.11 \pm 5.11 ^{Bef}	74.85 \pm 7.06 ^{Bb}
	SC-30		85.75 \pm 2.24 ^{Bab}	81.34 \pm 1.79 ^{Ced}	74.35 \pm 3.71 ^{Dabc}
	SCP-30		87.31 \pm 0.76 ^{Aab}	84.03 \pm 2.34 ^{Bbcd}	79.46 \pm 1.87 ^{Cab}
	SC-60		86.17 \pm 2.58 ^{ABab}	82.47 \pm 3.27 ^{Bcde}	76.78 \pm 2.67 ^{Cab}
	SCP-60		87.81 \pm 1.77 ^{Aba}	86.48 \pm 1.53 ^{Babc}	82.04 \pm 1.43 ^{Cab}
	SC-120		88.36 \pm 1.35 ^{Aba}	87.66 \pm 1.44 ^{Bab}	80.22 \pm 2.58 ^{Cab}
	SCP-120		89.37 \pm 2.39 ^{Aa}	89.11 \pm 0.97 ^{Aa}	82.65 \pm 5.30 ^{Ba}
	ΔE^*	Control		7.92 \pm 2.66 ^a	19.41 \pm 4.13 ^a
Control-P		–	5.56 \pm 3.20 ^{ab}	15.32 \pm 4.96 ^{ab}	20.31 \pm 6.18 ^{ab}
SC-30			6.06 \pm 2.20 ^{ab}	12.06 \pm 3.35 ^b	18.97 \pm 5.13 ^{abc}
SCP-30			3.34 \pm 1.39 ^b	7.45 \pm 2.73 ^c	12.75 \pm 1.87 ^{bc}
SC-60			5.11 \pm 2.62 ^{ab}	10.78 \pm 3.24 ^{bc}	16.52 \pm 3.87 ^{bc}
SCP-60			3.83 \pm 2.10 ^b	5.50 \pm 2.37 ^{cd}	11.13 \pm 1.93 ^c
SC-120			5.10 \pm 1.48 ^{ab}	6.81 \pm 1.62 ^c	15.45 \pm 2.97 ^{bc}
SCP-120			2.51 \pm 2.16 ^b	2.53 \pm 1.00 ^d	12.15 \pm 6.94 ^c

¹Values are expressed as mean \pm standard deviation (n = 9). Different uppercase letters (A-D) show that values in the same row within each group are significantly different ($p \leq 0.05$). Different lowercase letters (a-f) show that values in the same column within each group are significantly different ($p \leq 0.05$).

3.2 Effect of washing with SC solution and packaging on *Pseudomonas* spp. counts on mushroom

Pseudomonas spp. play a key role on the postharvest quality of the mushrooms. The initial count of *Pseudomonas* spp. on fresh mushrooms in this study was found to be $7.59 \log_{10}$ CFU/g which is in good agreement with the *Pseudomonas* spp. counts on mushrooms found in previous studies which ranged from 6.9 to $8.1 \log_{10}$ CFU/g at harvest time (Simón et al., 2005; Venturini et al., 2011). Washing the mushrooms with SC solution and packaging with the PVC film were found to be effective in reducing the *Pseudomonas* spp. counts (Table 2).

Similar results related to the inhibitory effect of SC solution on microorganisms were also reported for different food products. Allende et al. (2009) found that SC solution in concentration of 1 g/L reduced total aerobic mesophilic bacteria on the fresh-cut cilantro by $3 \log_{10}$ CFU/g. Wei et al. (2017) also found that SC solution caused a decrease in the total bacteria in strawberry by $2.9 \log_{10}$ CFU/g.

Pseudomonas spp. counts increased with the storage time. Washing the mushrooms with the SC solution resulted in the mushrooms with lower *Pseudomonas* spp. counts

Table 2. Effect of SC (sodium chlorite) washing on *Pseudomonas* spp. counts (\log_{10} CFU/g) on mushrooms stored at 4 °C for 12 days¹.

Treatments	Storage time (day)		
	4	8	12
Control	8.23 ± 0.46^a	9.34 ± 0.52^a	10.30 ± 0.59^a
Control-P	8.14 ± 0.45^a	8.43 ± 0.47^a	10.02 ± 0.58^{ab}
SC-30	5.49 ± 0.32^b	7.26 ± 0.41^b	9.08 ± 0.53^{ab}
SCP-30	5.32 ± 0.32^b	7.09 ± 0.40^b	8.76 ± 0.52^{bc}
SC-60	5.11 ± 0.31^b	5.92 ± 0.35^c	7.66 ± 0.46^{cd}
SCP-60	4.86 ± 0.30^b	5.58 ± 0.33^c	7.40 ± 0.44^{cd}
SC-120	4.81 ± 0.29^b	5.29 ± 0.31^c	6.89 ± 0.42^d
SCP-120	4.56 ± 0.28^b	5.28 ± 0.32^c	6.62 ± 0.41^d

¹Values are expressed as mean \pm standard deviation (n = 3), and different letters show that values within the same column are significantly different ($p \leq 0.05$).

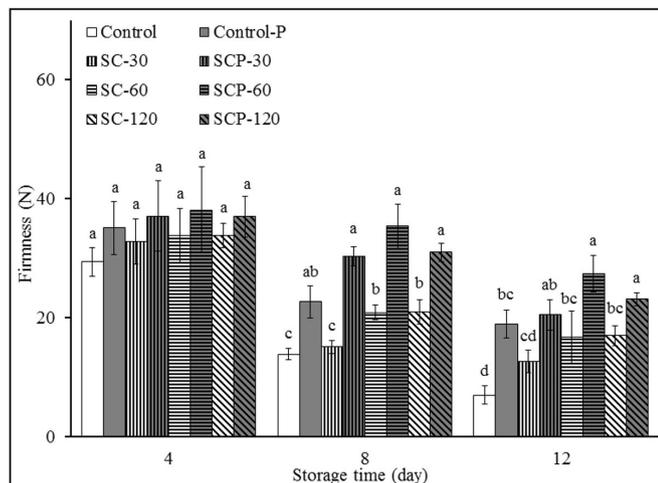


Figure 1. Change in firmness of mushrooms with storage time. Error bars represent the standard deviation of nine independent samples, and different letters show that values within the same storage day are significantly different ($p \leq 0.05$).

than the controls. After 8 days of storage, the number of *Pseudomonas* spp. on mushroom samples washed with the SC solution for 30, 60 and 120 s was lower than the initial number of *Pseudomonas* spp. on fresh mushroom. This indicates that SC is an effective antimicrobial agent and subjecting the mushrooms to the SC solution even for short times has a high inhibitory effect on the *Pseudomonas* spp.

The lowest *Pseudomonas* spp. counts on mushrooms were found for the SCP-120 at each sampling day. However, statistical analysis showed that there was no significant difference ($p > 0.05$) in the numbers of *Pseudomonas* spp. for the mushrooms subjected to the SC solution for 60 and 120 s regardless of overwrapped with the PVC film or not at any sampling day. In other words, treating the mushrooms with the SC solution for 60 or 120 s has the same inhibitory effect on the *Pseudomonas* spp. irrespective of packaging throughout 12 days of storage.

3.3 Effect of washing with SC solution and packaging on mushroom texture and weight loss

The firmness of the mushrooms is often one of the most important quality parameters considered by the consumers, and it is related to change in weight loss (Gao et al., 2014). The initial firmness of the fresh mushrooms was found to be 40 N, and the firmness decreased with the storage time (Figure 1). In other words, all the mushroom samples softened during 12 days of storage at 4 °C. One of the important reasons of the softening is the degradation of cell walls in mushrooms caused by bacterial enzymes and microorganisms especially *Pseudomonas* spp. that breaks down the intracellular matrix (Gao et al., 2014). The other important reason of the softening is shrinkage of the cell due to loss of water (dehydration). The firmness of the mushrooms washed with the SC solution was higher than the firmness of the control samples. The tendency in the bacteria-induced softening and the softening due to the loss of water could be slowed down with the aid of the SC washing treatments.

The firmness of all the mushroom samples treated with the SC solution and packed with the PVC film were significantly ($p \leq 0.05$) higher than the firmness of the mushrooms solely treated with the SC solution and the controls after 8 days of storage (Figure 1). This means that the SC washing of the mushrooms combined with the packaging retards softening of the mushrooms during storage. Similar results regarding the effect of packaging material on the firmness of mushrooms were also reported by González-Fandos et al. (2000) who found that the change in the firmness values of the mushrooms was delayed by packaging the mushrooms with the PVC film that increases the CO_2 level in the package and decreases the respiration rate. After 12 days of storage, the firmness value of the control decreased to 7 N while the firmness values of SCP-60 and SCP-120 were 27.4 N and 23.1 N, respectively. In other words, the decrease in the firmness of SCP-60 was lower than the decrease in the firmness of SCP-120. This indicated that subjecting the mushrooms to the SC solution longer than 60 s has an adverse effect on the firmness of the mushrooms. Therefore, SCP-60 was found to be the most appropriate treatment to minimize the change in the firmness of mushrooms.

Dehydration is important and directly affects the mushroom quality because mushrooms lose water from their epidermal layer during the postharvest storage (Khan et al., 2014). Weight loss increased with the storage time for all the mushroom samples (Figure 2). The maximum weight loss occurred in the control and reached almost 40% after 12 days of storage. There was a significant difference ($p \leq 0.05$) between the weight loss of control and SC-60 and SC-120 over the entire storage period. This means that subjecting the mushrooms to the SC solution longer than 30 s has reduced the weight loss. When the mushrooms were packed with the PVC film, weight loss was significantly ($p \leq 0.05$) reduced as compared with the unpacked mushrooms treated with the SC solution over the entire storage period. Similar results were also reported by Oz et al. (2015) who found that packaging slowed down the dehydration of the mushrooms. After 12 days of

storage, the weight loss for the mushroom samples packed with the PVC film was less than 10%. This reveals that the PVC film acts as a good barrier against water loss from the mushrooms.

3.4 Effect of washing with SC solution and packaging on headspace gas composition and pH

O₂ and CO₂ concentrations inside the packages were measured immediately after the mushrooms were packed. O₂ levels in the packages decreased while CO₂ levels increased with the storage time because of the high respiration rate and the gas permeability properties of the PVC film (Gantner et al., 2017). There was no significant difference ($p > 0.05$) in gas composition values of the packaged mushroom samples. The rate of change in O₂ and CO₂ levels inside the packages was high during the first 4 days of storage, and then the rate of change of O₂ and CO₂ was diminished and levelled off. This means that the respiration rate of the mushrooms in the first 4 days was high and then the respiration rate decreased due to an increase in the CO₂ levels inside the packages. Similar results were also reported by Lagnika et al. (2011) who observed that an increase in CO₂ levels inside the packages caused an inhibitory effect on the respiration rate of mushrooms stored under MAP at 4 °C. The concentration of O₂ inside the packages decreased to around 15% while the CO₂ concentration increased to about 4% after 12 days of storage (Figure 3).

pH is important during storage because it affects stability and shelf-life of foods. The initial pH value of the fresh *Agaricus bisporus* was found to be 6.65 which is in good agreement with the pH values (6.50-6.92) reported for fresh *Agaricus bisporus* (Aday, 2016; Masson et al., 2002). The pH values of the mushroom samples varied between 6.58 and 6.85 during 12 days of storage at 4 °C (Figure 4). There was no significant difference ($p > 0.05$) in pH values of the mushrooms stored at 4 °C for 12 days. This means that washing the mushrooms with the SC solution or packaging with the PVC film has not any effect on the pH values of the mushrooms stored at 4 °C for 12 days.

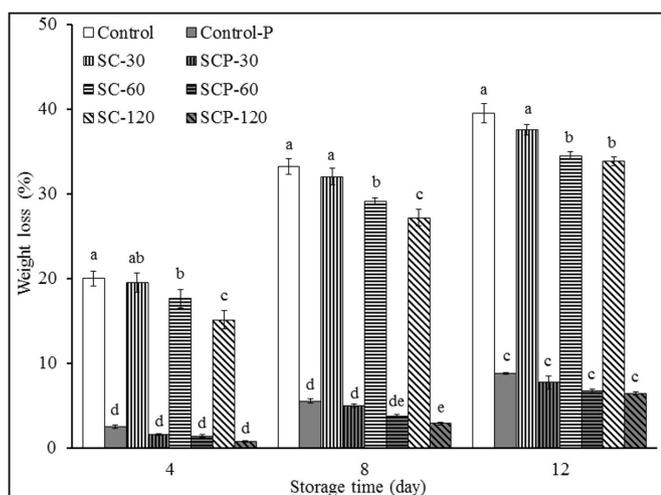


Figure 2. Change in weight loss of mushrooms with storage time. Error bars represent the standard deviation of three independent samples, and different letters show that values within the same storage day are significantly different ($p \leq 0.05$).

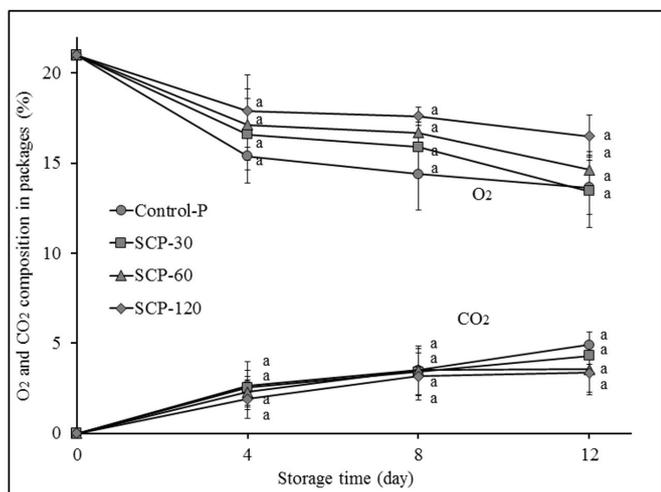


Figure 3. Change in gas composition inside packages with storage time. Error bars represent the standard deviation of three independent samples, and different letters show that values within the same storage day are significantly different ($p \leq 0.05$).

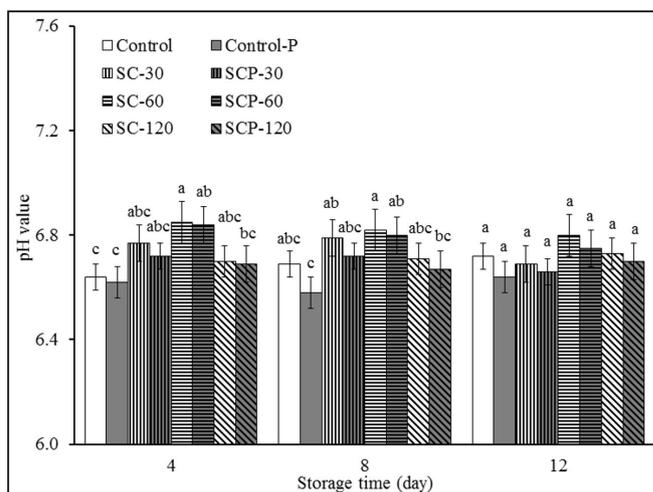


Figure 4. Change in pH of mushrooms with storage time. Error bars represent the standard deviation of three independent samples, and different letters show that values within the same storage day are significantly different ($p \leq 0.05$).

4 Conclusion

Treating the mushrooms with the SC solution had beneficial effects on maintaining the postharvest quality and reducing the *Pseudomonas* spp. counts. Washing the mushrooms with the SC solution and packaging with the PVC film slowed down the colour change of the mushrooms. The firmness of the mushrooms washed with the SC solution was higher than the firmness of the control, but treating the mushrooms with the SC solution longer than 60 s had an adverse effect on the mushroom firmness. Among different treatments used in our study, mushrooms washed with the SC solution for 60 s and stored at 4 °C with a PVC overwrapping material were found to be the most appropriate treatment to minimize the change on the postharvest quality of mushrooms. PVC film reduced the water loss and decreased the respiration rate of the mushrooms. Washing the mushrooms with the SC solution resulted in the mushrooms with lower *Pseudomonas* spp. counts than the controls. SC was an effective antimicrobial agent and subjecting the mushrooms to the SC solution for short period of times had a high inhibitory effect on the *Pseudomonas* spp. Washing the mushrooms with the SC solution could be used by the mushroom processors as an alternative to other postharvest treatments used for the mushrooms. The change on the postharvest quality of mushrooms could be minimized and mushroom shelf-life could be prolonged by the SC washing and packaging.

Acknowledgements

This work was financially supported by the Gebze Technical University through Scientific Research Project (BAP) 2015 A-40. Dr. Fatih Tarlak would like to thank The Scientific and Technological Research Council of Turkey (TUBITAK) for granting PhD scholarship (2211-C).

References

- Aday, M. S. (2016). Application of electrolyzed water for improving postharvest quality of mushroom. *Lebensmittel-Wissenschaft + Technologie*, 68, 44-51. <http://dx.doi.org/10.1016/j.lwt.2015.12.014>.
- Aguirre, L., Frias, J. M., Barry-Ryan, C., & Grogan, H. (2008). Assessing the effect of product variability on the management of the quality of mushrooms (*Agaricus bisporus*). *Postharvest Biology and Technology*, 49(2), 247-254. <http://dx.doi.org/10.1016/j.postharvbio.2008.01.014>.
- Allende, A., McEvoy, J., Tao, Y., & Luo, Y. (2009). Antimicrobial effect of acidified sodium chlorite, sodium chlorite, sodium hypochlorite, and citric acid on *Escherichia coli* O157:H7 and natural microflora of fresh-cut cilantro. *Food Control*, 20(3), 230-234. <http://dx.doi.org/10.1016/j.foodcont.2008.05.009>.
- Borchert, N. B., Cruz-Romero, M. C., Mahajan, P. V., Ren, M., Papkovsky, D. B., & Kerry, J. P. (2014). Application of gas sensing technologies for non-destructive monitoring of headspace gases (O₂ and CO₂) during chilled storage of packaged mushrooms (*Agaricus bisporus*) and their correlation with product quality parameters. *Food Packaging and Shelf Life*, 2(1), 17-29. <http://dx.doi.org/10.1016/j.fpsl.2014.05.001>.
- Brennan, M., Le Port, G., & Gormley, R. (2000). Post-harvest with citric acid or hydrogen peroxide to extend the shelf life of fresh sliced mushrooms. *Lebensmittel-Wissenschaft + Technologie*, 33(4), 285-289. <http://dx.doi.org/10.1006/fstl.2000.0657>.
- Cliffe-Byrnes, V., & O'Beirne, D. (2008). Effects of washing treatment on microbial and sensory quality of modified atmosphere (MA) packaged fresh sliced mushroom (*Agaricus bisporus*). *Postharvest Biology and Technology*, 48(2), 283-294. <http://dx.doi.org/10.1016/j.postharvbio.2007.10.012>.
- Doymaz, I. (2014a). Infrared drying of button mushroom slices. *Food Science and Biotechnology*, 23(3), 723-729. <http://dx.doi.org/10.1007/s10068-014-0098-0>.
- Doymaz, I. (2014b). Drying kinetics and rehydration characteristics of convective hot-air dried white button mushroom slices. *Journal of Chemistry*, 2014, 453175. <http://dx.doi.org/10.1155/2014/453175>.
- Gantner, M., Guzek, D., Pogorzelska, E., Brodowska, M., Wojtasik-Kalinowska, I., & Godziszewska, J. (2017). The effect of film type and modified atmosphere packaging with different initial gas composition on the shelf life of white mushrooms (*Agaricus bisporus* L.). *Journal of Food Processing and Preservation*, 41(1), e13083. <http://dx.doi.org/10.1111/jfpp.13083>.
- Gao, M., Feng, L., & Jiang, T. (2014). Browning inhibition and quality preservation of button mushroom (*Agaricus bisporus*) by essential oils fumigation treatment. *Food Chemistry*, 149, 107-113. <http://dx.doi.org/10.1016/j.foodchem.2013.10.073>. PMID:24295683.
- González-Fandos, E., Giménez, M., Olarte, C., Sanz, S., & Simón, A. (2000). Effect of packaging conditions on the growth of microorganisms and the quality characteristics of fresh mushrooms (*Agaricus bisporus*) stored at inadequate temperatures. *Journal of Applied Microbiology*, 89(4), 624-632. <http://dx.doi.org/10.1046/j.1365-2672.2000.01159.x>. PMID:11054166.
- Khan, Z. U., Aisikaer, G., Khan, R. U., Bu, J., Jiang, Z., Ni, Z., & Ying, T. (2014). Effects of composite chemical pretreatment on maintaining quality in button mushrooms (*Agaricus bisporus*) during postharvest storage. *Postharvest Biology and Technology*, 95, 36-41. <http://dx.doi.org/10.1016/j.postharvbio.2014.04.001>.
- King, E. O., Ward, M. K., & Raney, D. E. (1954). Two simple media for the demonstration of pyocyanin and fluorescein. *The Journal of Laboratory and Clinical Medicine*, 44(2), 301-307. PMID:13184240.
- Lagnika, C., Zhang, M., & Wang, S. (2011). Effect of high argon pressure and modified atmosphere packaging on the white mushroom (*Agaricus bisporus*) physico-chemical and microbiological properties. *Journal of Food and Nutrition Research*, 50, 167-176.
- Lagnika, C., Zhang, M., Nsor-Atindana, J., & Bashari, M. (2014). Effects of ultrasound and chemical treatments on white mushroom (*Agaricus bisporus*) prior to modified atmosphere packaging in extending shelf-life. *Journal of Food Science and Technology*, 51(12), 3749-3757. <http://dx.doi.org/10.1007/s13197-012-0904-8>. PMID:25477641.
- Lopez-Briones, G., Varoquaux, P., Bureau, G., & Pascat, B. (1993). Modified atmosphere packaging of common mushroom. *International Journal of Food Science & Technology*, 28(1), 57-68. <http://dx.doi.org/10.1111/j.1365-2621.1993.tb01251.x>.
- Lu, S., Luo, Y., & Feng, H. (2006). Inhibition of apple polyphenol oxidase activity by sodium chlorite. *Journal of Agricultural and Food Chemistry*, 54(10), 3693-3696. <http://dx.doi.org/10.1021/jf0518103>. PMID:19127746.
- Lu, S., Luo, Y., Turner, E., & Feng, H. (2007). Efficacy of sodium chlorite as an inhibitor of enzymatic browning in apple slices. *Food Chemistry*, 104(2), 824-829. <http://dx.doi.org/10.1016/j.foodchem.2006.12.050>.
- Masson, Y., Ainsworth, P., Fuller, D., Bozkurt, H., & İbanoğlu, Ş. (2002). Growth of *Pseudomonas fluorescens* and *Candida sake* in homogenized mushrooms under modified atmosphere. *Journal of Food Engineering*, 54(2), 125-131. [http://dx.doi.org/10.1016/S0260-8774\(01\)00193-5](http://dx.doi.org/10.1016/S0260-8774(01)00193-5).

- Moradian, S., Almasi, H., & Moini, S. (2018). Development of bacterial cellulose-based active membranes containing herbal extracts for shelf life extension of button mushrooms (*Agaricus bisporus*). *Journal of Food Processing and Preservation*, 42(3), e13537. <http://dx.doi.org/10.1111/jfpp.13537>.
- Oz, A. T., Ulukanlı, Z., Bozok, F., & Baktemur, G. (2015). The postharvest quality, sensory and shelf life of *Agaricus bisporus* in active map. *Journal of Food Processing and Preservation*, 39(1), 100-106. <http://dx.doi.org/10.1111/jfpp.12301>.
- Sedaghat, N., & Zahedi, Y. (2012). Application of edible coating and acidic washing for extending the storage life of mushrooms (*Agaricus bisporus*). *Food Science & Technology International*, 18(6), 523-530. <http://dx.doi.org/10.1177/1082013211433075>. PMID:23175781.
- Simón, A., González-Fandos, E., & Tobar, V. (2005). The sensory and microbiological quality of fresh sliced mushroom (*Agaricus bisporus* L.) packaged in modified atmospheres. *International Journal of Food Science & Technology*, 40(9), 943-952. <http://dx.doi.org/10.1111/j.1365-2621.2005.01028.x>.
- Simón, A., & González-Fandos, E. (2010). Effect of washing with citric acid or sodium hypochlorite on the visual and microbiological quality of mushrooms (*Agaricus bisporus* L.). *Journal of Food Quality*, 33(s1), 273-285. <http://dx.doi.org/10.1111/j.1745-4557.2010.00322.x>.
- Singla, R., Ganguli, A., & Ghosh, M. (2012). Physicochemical and nutritional characteristics of organic acid-treated button mushrooms (*Agaricus bisporus*). *Food and Bioprocess Technology*, 5(2), 808-815. <http://dx.doi.org/10.1007/s11947-010-0457-7>.
- Taghizadeh, M., Gowen, A., Ward, P., & O'Donnell, C. P. (2010). Use of hyperspectral imaging for evaluation of the shelf-life of fresh white button mushrooms (*Agaricus bisporus*) stored in different packaging films. *Innovative Food Science & Emerging Technologies*, 11(3), 423-431. <http://dx.doi.org/10.1016/j.ifset.2010.01.016>.
- U. S. Food and Drug Administration – FDA. (2019). *Department of health and human services; secondary direct food additives permitted in food for human consumption*. USA: FDA.
- Venturini, M. E., Reyes, J. E., Rivera, C. S., Oria, R., & Blanco, D. (2011). Microbiological quality and safety of fresh cultivated and wild mushrooms commercialized in Spain. *Food Microbiology*, 28(8), 1492-1498. <http://dx.doi.org/10.1016/j.fm.2011.08.007>. PMID:21925034.
- Waliszewski, K., Pardio, V., & Ovando, L. (2007). Control of polyphenol oxidase activity in banana slices during osmotic dehydration. *Drying Technology*, 25(2), 375-378. <http://dx.doi.org/10.1080/07373930601120613>.
- Wani, B. A., Bodha, R. H., & Wani, A. H. (2010). Nutritional and medicinal importance of mushrooms. *Journal of Medicinal Plants Research*, 4(24), 2598-2604. <http://dx.doi.org/10.5897/JMPR09.565>.
- Wei, W., Wang, X., Xie, Z., Wang, W., Xu, J., Liu, Y., Gao, H., & Zhou, Y. (2017). Evaluation of sanitizing methods for reducing microbial contamination on fresh strawberry, cherry tomato, and red bayberry. *Frontiers in Microbiology*, 8, 2397. <http://dx.doi.org/10.3389/fmicb.2017.02397>. PMID:29259594.
- Xu, Y., Tian, Y., Ma, R., Liu, Q., & Zhang, J. (2016). Effect of plasma activated water on the postharvest quality of button mushrooms, *Agaricus bisporus*. *Food Chemistry*, 197(Pt A), 436-444. <http://dx.doi.org/10.1016/j.foodchem.2015.10.144>. PMID:26616972.
- Zalewska, M., Marcinkowska-Lesiak, M., & Onopiuk, A. (2018). Physicochemical properties of white button mushrooms (*Agaricus bisporus*) as affected by coating. *Journal of Food Processing and Preservation*, 42(2), e13419. <http://dx.doi.org/10.1111/jfpp.13419>.