LWT - Food Science and Technology 68 (2016) 44–51

Contents lists available at ScienceDirect

LWT - Food Science and Technology

journal homepage: www.elsevier.com/locate/lwt

Application of electrolyzed water for improving postharvest quality of mushroom

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ARTICLE INFO

Article history:
Received 26 July 2015
Received in revised form
5 December 2015
Accepted 9 December 2015
Available online 12 December 2015

Keywords:
Electrolyzed water
Mushroom
Quality
Browning index

ABSTRACT

This paper focused on the effectiveness of electrolyzed water (EW) at different concentrations (5, 25, 50 and 100 mg/L) combined with passive atmosphere packaging on the quality of mushroom. In order to understand the effect of EW on mushrooms, gas composition inside packages, weight loss, pH, whiteness and browning index, texture profile analysis (TPA), cap development, electrolyte leakage and FT-NIR analysis were performed during the twelve days of storage at 4 °C. Samples washed with 25 and 50 mg/L EW consumed O_2 lower than the other treatments. Mushrooms treated with 25 mg/L EW had a significantly lower electrolyte leakage values than untreated and 5 mg/L treated mushrooms. Mushrooms treated with 25 mg/L EW had the highest whiteness index and lowest browning index. EW treatments at the concentrations of 25 and 50 mg/L maintained the textural parameters and slowed down the weight loss better than other treatments. FT-NIR analysis supported the results obtained by weight loss and electrolyte leakage. In conclusion, the results of this research support the idea that combined use of EW treatment and passive modified atmosphere packaging can be used to extend the shelf life of mushrooms.

1. Introduction

Button mushroom (*Agaricus bisporus*) is one of the most common and widely consumed edible mushroom type due to their functional properties (Guan, Fan, & Yan, 2013). However, mushrooms lose their quality quickly after harvest in 1–3 days at ambient temperature (Oliveira, Sousa-Gallagher, Mahajan, & Teixeira, 2012a) because of their thin epidermal structure, high respiration rate, high moisture content (Mahajan, Oliveira, & Macedo, 2008) and high tyrosinase activity (Taghizadeh, Gowen, Ward, & O'Donnell, 2010). The critical quality indicators include browning, softening, (Yurttas, Moreira, & Castell-Perez, 2014) cap development, weight loss (Kim, Ko, Lee, Park, & Hanna, 2006) and free of mold growth (Mohapatra, Bira, Frias, Kerry, & Rodrigues, 2011). Therefore, different methods were reported such as electron-beam irradiation, (Mami, Peyvast, Ziaie, Ghasemnezhad, & Salmanpour, 2014) packaging with different films, (Taghizadeh et al., 2010) active papers with cinnamon oil, (Echegoyen & Nerín, 2015) modified atmosphere packaging, (Kim et al., 2006) washing with hydrogen peroxide (Sapers, Miller, Choi, & Cooke, 1999) and ozone (Yuk, Yoo, Yoon, Marshall, & Oh, 2007) to retain freshness of mushroom during shipping and marketing.

Electrolyzed water (EW) is a promising disinfectant which is generated by electrolysis of a salt solution (Vázquez-Sánchez, Cabo, & Rodríguez-Herrera, 2014). In contrast with other disinfectants, EW is not corrosive to organic materials and it reverts to ordinary water when diluted with tap water (Jemni et al., 2014). The effectiveness of EW depends on free available chlorine, presence of chlorine species and oxidation reduction potential (Al-Haq, Sugiyama, & Isobe, 2005). The use of EW on fresh produce has been officially approved by Japan and USA at a maximum 200 mg/L of free available chlorine (Lee et al., 2014). Previous studies have shown the effectiveness of EW on carrot, (Abadias, Usall, Oliveira, Alegre, & Viñas, 2008) spinach, (Guentzel, Liang Lam, Callan, Emmons, & Dunham, 2008) cabbage, (Koide, Takeda, Shi, Shono, & Atungulu, 2009) and broccoli (Martínez-Hernández et al., 2015).

Until now, EW has only been applied to the oyster mushroom (*Pleurotus ostreatus*) on the basis of microbiological point of view (Ding, Rahman, & Oh, 2011). Therefore this paper focused on white button mushroom (*Agaricus bisporus*) in order to determine the combined effect of passive modified atmosphere and electrolyzed water during cold storage.

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http://dx.doi.org/10.1016/j.lwt.2015.12.014
0023-6438/

2. Materials and methods

2.1. Materials

White button mushrooms *(Agaricus bisporus)* were purchased from a farm in Canakkale, Turkey and transported to the food engineering laboratory within 2 h. Subsequently, samples were sorted for similar size, maturity and color. Extremely large or small and damaged mushrooms were discarded. Then, mushrooms were divided into five groups. The first group was washed with water as an untreated and second, third, fourth and fifth group of samples were washed with electrolyzed water at concentrations of 5, 25, 50 and 100 mg/L free chlorine respectively for 3 min. After air drying, mushrooms (around 150 g) were packaged with MAP25 packaging machine in air conditions (21% O_2, 0.03% CO_2 and 79% N_2) to reach equilibrium state. Samples were stored at 4 °C for 12 days.

2.2. Preparation of electrolyzed water

Mixed oxidant brine system (MIOX Corporation, New Mexico, USA) was used to generate electrolyzed water. Electrolyte cell inside the equipment processed 1% NaCl solution for electrolysis of brine (Clevenger, Wu, DeGruson, Brazos, & Banerji, 2007). Then, stock solution of EW collected from vessel and diluted to 5, 25, 50 and 100 mg/L free chlorine. The N,N-diethyl-p-phenylenediamine (DPD) method was used to measure the amount of free chlorine in solutions by DR/2800 spectrophotometer (HACH, Co., USA).

2.3. The O_2 and CO_2 concentration in package headspace

Oxybaby (Hamburg, Germany) gas analyzer was used to determine gas concentrations inside the package of mushrooms. The needle of oxybaby was penetrated throughout adhesive septum which was placed on the package film for avoiding gas leakage and tearing of package film during analysis (Lu et al., 2009).

2.4. pH value

Around 20 g of samples were homogenized in a mixer and then centrifuged (Sigma 2–12K, Sartorious, Germany) at 5000 × g for 20 min (Jafri, Jha, Bunkar, & Ram, 2013). The pH values of mushrooms were determined by using Sartorius PP-50 pH meter (Goettingen, Germany).

2.5. Color

The cap color of ten mushrooms for each treatment was measured with Minolta CR-400 colorimeter (Minolta, Osaka, Japan). Standard white plate (CR-A43) was used to calibrate colorimeter. CIE color space coordinates L*(Lightness), a* (red-green) and b* (yellow-blue) were recorded by using SpectraMagic NX software. Browning index (BI) and whiteness index (WI) were calculated using following equations (Borchert et al., 2014):

$$BI = 100(x - 0.31)/0.17 \quad (1)$$

$$\text{Where } x = (a + 1.75L)/(5.645L + a - 3.012b) \quad (2)$$

$$WI = L - 3b + 3a \quad (3)$$

2.6. Weight loss

All packages were coded before the experiment. Subsequently, package weights of mushrooms were recorded at the beginning of storage and at each sampling day. Results were expressed as the percentage loss of initial package weight of samples (Koutsimanis, Harte, & Almenar, 2015).

2.7. Electrolyte leakage

Electrolyte leakage was measured by the method of Li et al. (2014) with some modifications. 1 g cap and 1 g stipe tissue were cut and put into 90 ml deionized water and incubated for 60 min at 25 °C. The electrical conductivity of this solution was measured before and after incubation. Then same solution was boiled for 25 min at 121 °C. Following equation was used to determine electrolyte leakage

$$E = (C_{60} - C_1)/C_T \times 100 \quad (4)$$

2.8. Texture profile analysis

Texture profile analysis (TPA) were performed on ten mushroom caps by using TAXT Plus texture analyzer (Stable Micro Systems, Surrey, England) with diameter probe. Following conditions were selected for TPA analysis: pre-test speed of 10 mm/s, test speed of 2 mm/s, post-test speed of 10 mm/s and strain of 30%. Then, force versus time figure were obtained by texture exponent software and firmness, cohesiveness, springiness, gumminess, chewiness parameters of the mushrooms were calculated by using same software.

2.9. Development stage

Cap opening criteria for veil was used to determine development stage. For scoring, seven point scale (where 1 = thight, 2 = stretched, 3 = less than half broken, 4 = greater than half broken, 5 = completely broken, 6 = cap open, 7 = extremely cap open) was used to monitor the development of cap opening (González-Fandos, Giménez, Olarte, Sanz, & Simón, 2000).

2.10. FT-NIR analysis

FT-NIR spectrometer (Bruker Optik, GmbH, Ettlingen Germany) was used to perform reflectance analysis of ten mushrooms for per treatment. Optical probe of FT-NIR spectrometer was placed on the cap surface of mushroom at a 90° angle (Paz, Sánchez, Pérez-Marín, Guerrero, & Garrido-Varo, 2009). Reflectance spectrum was obtained by the average of 64 scans corresponded to one sample between 400 and 12,000 cm^{-1} wavelengths.

2.11. Statistical analysis

SAS 9.4 statistical analysis software (SAS Institute, Inc., Cary, NC) was used to compare the main effect of storage time, different concentrations of EW and interaction effect (storage time × different concentrations of EW) on the postharvest quality of white button mushrooms by Two-way ANOVA and Tukey post hoc comparison test. Overall means were compared when the interaction effect was not found significant. Datas were shown as mean ± standard deviation.

3. Results and discussion

3.1. Gas composition inside package

Fresh produces are living structures and their respiration and transpiration processes continue after harvest depend on the food reserves and gases available (Sandhya, 2010). Respiration that affects the shelf life of products, is directly related to the amount of CO_2 produced and O_2 consumed inside the package (Singh, Langowski, Wani, & Saengerlaub, 2010). Fig. 1A shows that there has been a sharp decline regarding the amount of O_2 content inside package for all groups during the first 2 days of storage. Then reached a steady state between day 4 and 8. Samples washed with 25 and 50 mg/L EW consumed O_2 lower than the other treatments.

Du, Fu, Li, and Xia (2007) and Zhong, Wu, Wang, Wu, and Wei (2006) showed that respiration rate of green bell peppers and apricots decreased when they treated with chlorine dioxide gas that shows similar oxidising properties such as electrolyzed water. Therefore, its possible that 25 and 50 mg/L EW treatments damaged the membrane system of mushrooms primarily due to lipid oxidation. However, the CO_2 concentrations inside the package of 25 and 50 mg/L EW treated samples were above the optimal conditions for mushrooms (3–21% O_2 and 5–15% CO_2) (Sandhya, 2010). Because of the presence of high CO_2 in the package, it would be difficult to delineate the effect of EW treatment on the respiration rate of mushrooms; and this aspect needs further attention. In our study, no significant differences were found between untreated and 5 mg/L EW treatment during the storage. The amount of CO_2 inside the package of untreated and treated samples were increased during the storage as expected (Fig. 1B). Untreated samples and samples treated with 5 mg/L EW produced higher CO_2 levels during the storage. A possible explanation for this might be that low concentration of EW (5 mg/L) was not enough to slow down the respiration rate of mushroom. Our finding supported previous research of Das, Kim, and Choi (2011) who showed that similar O_2 and CO_2 levels were found inside the package of 0.1 mg/L EW treated and untreated iceberg lettuce. In addition, our results are in agreement with Rico et al. (2008) findings who reported that EW concentrations above 12 mg/L, slowed down the O_2 consumption and CO_2 production inside the package of lettuce. In our work, its possible that the EW concentrations of 25 and 50 mg/L suppressed the activities of respiratory enzymes to some extent.

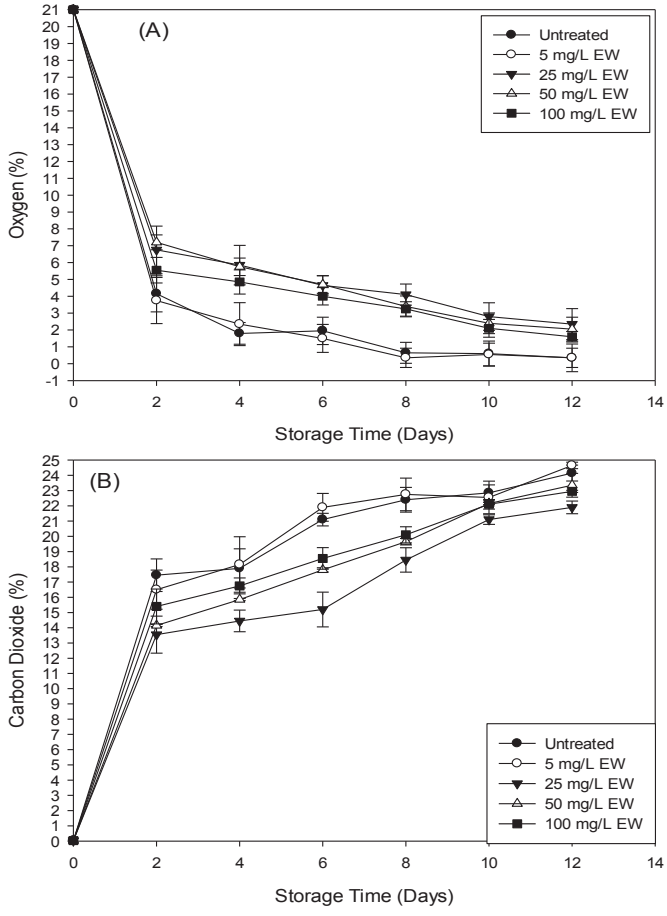

Fig. 1. Gas composition (A-O_2 and B-CO_2) inside the packages of untreated and EW treated mushrooms. Untreated (control mushrooms), 5 mg/L EW (Mushrooms immersed in electrolyzed water solution containing 5 mg/L free chlorine), 25 mg/L EW (Mushrooms immersed in electrolyzed water solution containing 25 mg/L free chlorine), 50 mg/L EW (Mushrooms immersed in electrolyzed water solution containing 50 mg/L free chlorine), 100 mg/L EW (Mushrooms immersed in electrolyzed water solution containing 100 mg/L free chlorine). Vertical bars denote standard deviation of three replicates.

3.2. pH values

Initial pH value of mushrooms was 6.92 which was a bit higher than the previous reported works (Borchert et al., 2014; Jaworska, Bernaś, Biernacka, & Maciejaszek, 2010). A significant decrease in the pH values of the samples was observed during the storage (Fig. 2). It's possible that production of organic acids by microorganisms resulted in decreases in pH values of mushrooms (Oliveira, Sousa-Gallagher, Mahajan, & Teixeira, 2012b). The lower changes were observed in the mushrooms treated with 25, 50 and 100 mg/L EW whilst higher changes were noticed in the untreated samples. This result may be explained by the fact that EW inhibited the growth of microorganism (Ding et al., 2011) leading to lower production of organic acids and less changes in pH values.

3.3. Color

The effect of EW treatments on whiteness and browning index

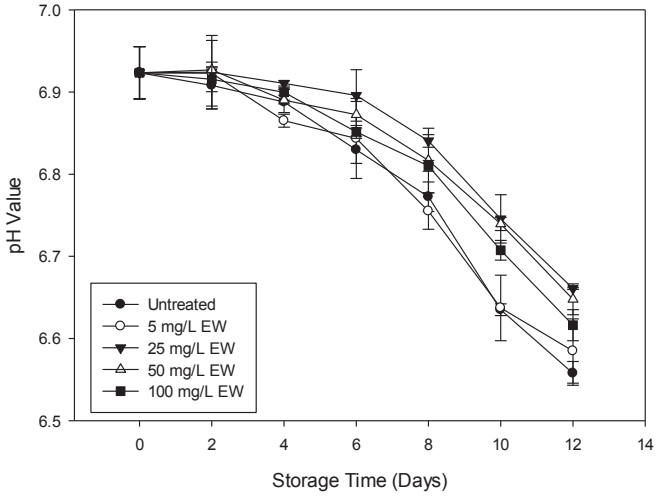

Fig. 2. Changes in pH values of untreated and EW treated mushrooms. Untreated (control mushrooms), 5 mg/L EW (Mushrooms immersed in electrolyzed water solution containing 5 mg/L free chlorine), 25 mg/L EW (Mushrooms immersed in electrolyzed water solution containing 25 mg/L free chlorine), 50 mg/L EW (Mushrooms immersed in electrolyzed water solution containing 50 mg/L free chlorine), 100 mg/L EW (Mushrooms immersed in electrolyzed water solution containing 100 mg/L free chlorine) Vertical bars denote standard deviation of three replicates.

of mushrooms during storage are presented in Tables 1 and 2, respectively. Statistical analysis showed that interaction of EW concentration and storage time was not significant on WI and BI parameter whilst main effect of factors (EW concentrations and storage time) found significant. As expected, WI decreased and BI increased for untreated and treated samples throughout storage. However, no significant differences were found between the untreated and 5 mg/L EW treated mushrooms regarding WI and BI values. It is possible that low concentration of EW did not affect the enzymes responsible for browning. Mushrooms treated with 25 mg/L EW had the highest WI and lowest BI while the untreated samples had the lowest WI and highest BI ($p < 0.05$). Our findings are in agreement with the results of Borchert et al. (2014) who reported that a decrease of WI and increase of BI were correlated with the amounts of CO_2 and O_2 inside the packages of mushrooms.

3.4. Weight loss

Mushrooms lose their quality rapidly due to the water loss from their thin epidermal layer during storage (Khan et al., 2014). Weight loss of treated and untreated samples is shown in Table 3. A gradual increase was observed in weight loss of all mushrooms over time. The statistical analysis showed that there were no significant difference between untreated samples and samples treated with 5 mg/L EW. At the end of the storage, minimum weight losses of 0.271% and 0.276% were recorded in the samples treated with 25 mg/L and 50 mg/L EW. The highest weight loss of 0.497 was observed in untreated samples. In addition, no significant differences were found among the 25, 50 and 100 mg/L EW treated samples during the storage. In addition, it can be concluded that even at high concentrations (100 mg/L), EW may not damage to cell wall leading to increased the water loss. Our findings do not support the previous research of Hung, Bailly, Kim, Zhao, and Wang (2010) who reported that no significant differences were found on weight loss between untreated and 50 mg/L EW treated strawberry. Its possible that combined treatment of EW and Modified atmosphere packaging in our work may have led to the differences.

3.5. Electrolyte leakage

Electrolyte leakage can be used to determine the membrane and tissue integrity in fruit and vegetables (Li et al., 2014). This parameter increased in all samples during the storage (Table 4). Mushrooms treated with 25 mg/L EW had a significantly lower leakage values than untreated and 5 mg/L treated mushrooms at the end of the storage. Its possible that gas composition (high CO_2 and low O_2) inside the packages affected the cell membrane damage and senescence (Li et al., 2014; Li, Zhang, & Wang, 2008) of untreated and 5 mg/L EW treated samples. No statistically difference were found among the mushrooms treated with 25, 50 and 100 mg/L EW. Liu, Wang, Zhu, and Wang (2010) reported that browning of mushroom was not only related with enzymes but also membrane damage. In this study, positive correlation was also found between the electrolyte leakage and browning index of mushrooms.

3.6. Texture profile analysis (TPA)

Texture is an important parameter which is related with the structural and mechanical properties of food (Abbott & Harker, 2004). All of the measured TPA parameters of mushrooms such as firmness, cohesiveness, chewiness, gumminess and springiness decreased during storage.

In the literature, firmness is known to be related to cell turgor pressure, cell size, cell wall strength and intercellular adhesion in the cells (Aday & Caner, 2013). Fig. 3A shows the changes in firmness values of treated and untreated samples throughout storage. In general, 25 and 50 mg/L EW retarded the loss of mushroom firmness compared to other treatments. Untreated and 5 mg/L treated mushrooms had the lower firmness values during storage. It's possible that loss of turgor pressure in cells, weight and volume losses in tissue, protein denaturation and membrane solubilization (Jaworska & Bernaś, 2010) were higher in the untreated and 5 mg/L treated mushrooms. In addition, the creation of anaerobic conditions in the package of untreated and 5 mg/L treated mushrooms caused the production of ethanol in the tissue; affecting cell membrane integrity and the attendant effects on membrane leakage. This finding is correlated well with the results of weight loss. However, 25 and 50 mg/L EW treatments probably maintained the turgor pressure and preserved the structural integrity of cell wall.

The term springiness is associated with the elasticity of the foods (Aday & Caner, 2014). Springiness values decreased in untreated and treated mushrooms during storage (Fig. 3B). Changes in springiness depended on the concentration of EW. Untreated mushrooms had significantly lower springiness values than treated samples. These differences may be related with the moisture and solutes which were moved into intercellular space and maintained the hydrostatic pressures (Jaworska & Bernaś, 2010) because of the EW treatment.

Gumminess is defined as the required force to breakdown samples for swallowing (Aday, Temizkan, Buyukcan, & Caner, 2013). During the storage, samples treated with 25, 50 and 100 pm had higher gumminess values compared with untreated and 5 mg/L treated mushrooms (Fig. 3C). Possible explanation for this might be that high CO_2 and low O_2 concentration inside the packages destroyed the cell membrane structure (Li et al., 2008) of untreated

Table 1
The effect of EW treatments on whiteness index of mushrooms during storage.

Treatments	Storage time (Days)							Overall
	0	2	4	6	8	10	12	
Untreated	56.40 ± 2.59	37.31 ± 0.10	34.88 ± 2.38	26.39 ± 0.61	23.63 ± 0.33	22.33 ± 1.80	21.47 ± 0.46	31.77 ± 12.06a
5 mg/L EW	56.40 ± 2.59	39.43 ± 1.43	35.56 ± 0.47	27.49 ± 0.41	23.99 ± 1.59	22.81 ± 0.99	21.40 ± 0.59	32.44 ± 12.08 ab
25 mg/L EW	56.40 ± 2.59	44.33 ± 1.67	39.98 ± 1.19	34.43 ± 1.49	31.38 ± 2.15	25.27 ± 0.73	25.08 ± 1.51	36.69 ± 10.85d
50 mg/L EW	56.40 ± 2.59	40.09 ± 1.19	38.42 ± 0.10	31.05 ± 0.83	30.18 ± 2.27	24.37 ± 1.39	24.01 ± 1.29	34.93 ± 10.93c
100 mg/L EW	56.40 ± 2.59	39.62 ± 3.30	36.16 ± 3.43	30.03 ± 2.42	28.08 ± 1.02	23.67 ± 0.31	23.22 ± 0.03	33.88 ± 11.29bc
Overall	56.40 ± 1.93A	40.16 ± 2.78B	37.00 ± 2.48C	29.88 ± 3.14D	27.45 ± 3.54E	23.69 ± 1.41F	23.04 ± 1.67F	

Untreated (control mushrooms), 5 mg/L EW (Mushrooms immersed in electrolyzed water solution containing 5 mg/L free chlorine), 25 mg/L EW (Mushrooms immersed in electrolyzed water solution containing 25 mg/L free chlorine), 50 mg/L EW (Mushrooms immersed in electrolyzed water solution containing 50 mg/L free chlorine), 100 mg/L EW (Mushrooms immersed in electrolyzed water solution containing 100 mg/L free chlorine).
a–c Means in the same column with different letters are significantly different ($p \leq 0.05$).
A–E Means in the same row with different letters are significantly different ($p \leq 0.05$) (Mean separation was performed by Tukey test).

Table 2
The effect of EW treatments on browning index of mushrooms during storage.

Treatments	Storage time (Days)							Overall
	0	2	4	6	8	10	12	
Untreated	13.20 ± 1.50	19.06 ± 0.43	22.38 ± 0.31	26.90 ± 1.521	28.16 ± 0.67	31.61 ± 0.39	32.36 ± 0.83	24.81 ± 6.74a
5 mg/L EW	13.20 ± 1.50	18.69 ± 0.09	22.10 ± 0.20	25.34 ± 0.717	28.05 ± 1.10	31.41 ± 0.07	32.05 ± 0.19	24.40 ± 6.64a
25 mg/L EW	13.20 ± 1.50	16.54 ± 0.64	19.05 ± 0.23	22.52 ± 0.893	24.41 ± 0.30	27.54 ± 0.01	28.29 ± 1.52	21.65 ± 5.46b
50 mg/L EW	13.20 ± 1.50	17.14 ± 0.35	19.54 ± 0.12	23.10 ± 0.002	25.38 ± 0.31	28.50 ± 0.72	31.00 ± 1.21	22.55 ± 6.11bc
100 mg/L EW	13.20 ± 1.50	17.14 ± 0.27	20.95 ± 0.15	23.48 ± 0.542	26.13 ± 0.03	29.08 ± 0.58	30.94 ± 0.89	22.99 ± 6.15c
Overall	13.20 ± 1.12A	17.71 ± 1.07B	20.80 ± 1.40C	24.27 ± 1.830D	26.43 ± 1.61E	29.63 ± 1.73F	30.93 ± 1.69G	

Untreated (control mushrooms), 5 mg/L EW (Mushrooms immersed in electrolyzed water solution containing 5 mg/L free chlorine), 25 mg/L EW (Mushrooms immersed in electrolyzed water solution containing 25 mg/L free chlorine), 50 mg/L EW (Mushrooms immersed in electrolyzed water solution containing 50 mg/L free chlorine), 100 mg/L EW (Mushrooms immersed in electrolyzed water solution containing 100 mg/L free chlorine).
a–c Means in the same column with different letters are significantly different ($p \leq 0.05$).
A–E Means in the same row with different letters are significantly different ($p \leq 0.05$) (Mean separation was performed by Tukey test).

Table 3
The effect of EW treatments on weight loss of mushrooms during storage.

Treatments	Storage time (Days)				
	2	4	7	10	12
Untreated	0.07 ± 0.03Aa	0.14 ± 0.03Aa	0.27 ± 0.09Ba	0.43 ± 0.15Ca	0.49 ± 0.19Ca
5 mg/L EW	0.06 ± 0.03Aa	0.14 ± 0.06ABa	0.23 ± 0.07BCab	0.34 ± 0.06CDab	0.44 ± 0.03Dab
25 mg/L EW	0.03 ± 0.01Aa	0.11 ± 0.02ABa	0.15 ± 0.01ABab	0.21 ± 0.01Bb	0.27 ± 0.01Bb
50 mg/L EW	0.04 ± 0.01Aa	0.12 ± 0.03ABa	0.15 ± 0.04ABb	0.23 ± 0.04Bb	0.27 ± 0.07Bb
100 mg/L EW	0.04 ± 0.01Aa	0.12 ± 0.03ABa	0.18 ± 0.03Bab	0.24 ± 0.04Bb	0.29 ± 0.01Bb

Untreated (control mushrooms), 5 mg/L EW (Mushrooms immersed in electrolyzed water solution containing 5 mg/L free chlorine), 25 mg/L EW (Mushrooms immersed in electrolyzed water solution containing 25 mg/L free chlorine), 50 mg/L EW (Mushrooms immersed in electrolyzed water solution containing 50 mg/L free chlorine), 100 mg/L EW (Mushrooms immersed in electrolyzed water solution containing 100 mg/L free chlorine).
a–c Means in the same column with different letters are significantly different ($p \leq 0.05$).
A–E Means in the same row with different letters are significantly different ($p \leq 0.05$) (Mean separation was performed by Tukey test).

Table 4
The effect of EW treatments on electrolyte leakage of mushrooms during storage.

Treatments	Storage time (Days)						
	0	2	4	6	8	10	12
Untreated	18.19 ± 1.69Aa	42.50 ± 2.46Ba	52.25 ± 1.04BCa	60.95 ± 4.13CDa	67.94 ± 5.26Da	66.65 ± 1.10Da	70.62 ± 0.70Da
5 mg/L EW	18.19 ± 1.69Aa	42.42 ± 0.71Ba	49.57 ± 2.66BCa	56.31 ± 4.56CDab	62.64 ± 3.22DEab	64.62 ± 0.02DEa	68.69 ± 1.49Ea
25 mg/L EW	18.19 ± 1.69Aa	25.66 ± 2.23ABb	34.99 ± 2.16BCb	39.58 ± 4.95Ccd	52.86 ± 0.26Db	55.87 ± 2.44DEa	55.32 ± 3.03 Eb
50 mg/L EW	18.19 ± 1.69Aa	35.72 ± 4.57Bab	37.87 ± 3.62Bb	40.71 ± 4.61Bd	55.86 ± 5.08Cb	58.23 ± 2.19Ca	59.34 ± 4.14Cab
100 mg/L EW	18.19 ± 1.69Aa	34.48 ± 3.22Bab	41.97 ± 5.87BCab	46.66 ± 4.01CDbcd	54.42 ± 1.76DEb	61.23 ± 0.98Ea	63.43 ± 0.94Eab

Untreated (control mushrooms), 5 mg/L EW (Mushrooms immersed in electrolyzed water solution containing 5 mg/L free chlorine), 25 mg/L EW (Mushrooms immersed in electrolyzed water solution containing 25 mg/L free chlorine), 50 mg/L EW (Mushrooms immersed in electrolyzed water solution containing 50 mg/L free chlorine), 100 mg/L EW (Mushrooms immersed in electrolyzed water solution containing 100 mg/L free chlorine).
a–c Means in the same column with different letters are significantly different ($p \leq 0.05$).
A–E Means in the same row with different letters are significantly different ($p \leq 0.05$) (Mean separation was performed by Tukey test).

and 5 mg/L EW treated samples and resulted low gumminess values during storage.

Chewiness has come to be used to refer the required energy for mastication of foods (Aday, Buyukcan, & Caner, 2013). A sharp drop was observed in the chewiness value of untreated and treated mushrooms during storage (Fig. 3D). EW treatments at the concentration of 25, 50 and 100 mg/L maintained the chewiness values better than other groups.

Cohesiveness refers to strength of the internal bonds (Aday, Temizkan, et al., 2013). Cohesiveness values dropped sharply during the first 2 days of storage but then remained stable (Fig. 3E). Significant differences were observed between untreated and treated samples. Untreated mushrooms had lower values probably associated with the loss of polysaccharides and water in the cell walls.

Fracturability or brittleness described as the tendency of food to crack. In our work, fracturability was observed in all the samples during the first four days of the storage but after six days of storage some of the samples exhibited fracturability and some of the not. Therefore statistical analyses couldn't be performed and datas were not shown. Our results are in agreement with the work of Zivanovic, Busher, and Kim (2000) who showed that fracturability not occurred in the mushrooms with increment in storage time due to the deterioration.

3.7. Development stage

Development stage values for untreated and treated mushrooms are shown in Table 5. Statistical analysis showed that significant differences in cap development stage were observed among EW treated samples. The cap development of the mushrooms treated with 25 and 50 mg/L EW were higher than the other treated samples and untreated ones. It can be concluded that higher levels of CO_2 inside the packages of untreated and 5 mg/L EW treated samples retarted the cap development. Because CO_2 delayed the mycelial growth and morphogenesis (González-Fandos, Olarte, Giménez, Sanz, & Simón, 2001).

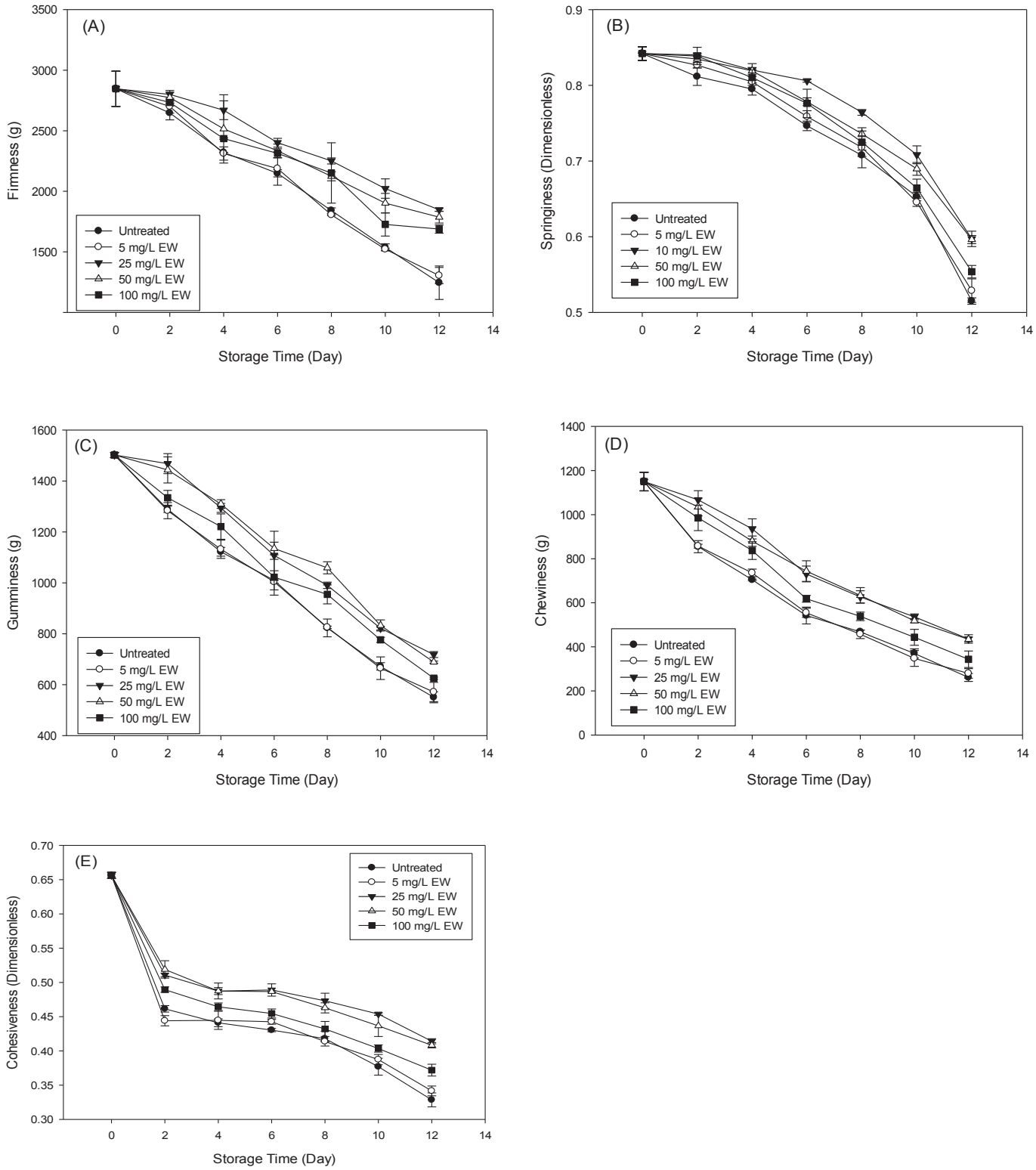

Fig. 3. Changes in TPA parameters (A-Firmness, B-Springiness, C-Gumminess, D-Chewiness, E-Cohesiveness) values of untreated and EW treated mushrooms. Untreated (control mushrooms), 5 mg/L EW (Mushrooms immersed in electrolyzed water solution containing 5 mg/L free chlorine), 25 mg/L EW (Mushrooms immersed in electrolyzed water solution containing 25 mg/L free chlorine), 50 mg/L EW (Mushrooms immersed in electrolyzed water solution containing 50 mg/L free chlorine), 100 mg/L EW (Mushrooms immersed in electrolyzed water solution containing 100 mg/L free chlorine). Vertical bars denote standard deviation of three replicates.

3.8. FT-NIR spectra

Near infrared spectroscopy is a non-destructive technique that gives information about the structure of food related with moisture (O–H bands) and sugars (C–H bands) (Aday & Caner, 2014). Fig. 4 shows the reflentance spectra of untreated and treated

Table 5
The effect of EW treatments on development stage of mushrooms during storage.

Treatments	Storage time (Days)						
	0	2	4	6	8	10	Overall
Untreated	4.12 ± 0.83	4.20 ± 0.44	4.11 ± 0.92	5.00 ± 0.53	4.88 ± 0.78	5.44 ± 0.52	4.66 ± 0.85bc
5 mg/L EW	3.37 ± 0.74	3.87 ± 0.83	4.25 ± 0.70	4.66 ± 0.50	4.77 ± 0.97	5.00 ± 0.50	4.35 ± 0.89b
25 mg/L EW	4.75 ± 0.46	4.87 ± 0.35	5.25 ± 0.70	5.50 ± 0.53	6.00 ± 0.75	6.37 ± 0.91	5.45 ± 0.84a
50 mg/L EW	4.62 ± 0.51	4.50 ± 0.53	5.12 ± 0.64	5.22 ± 0.66	6.00 ± 0.92	6.25 ± 0.88	5.28 ± 0.93a
100 mg/L EW	4.10 ± 0.73	4.00 ± 0.75	4.25 ± 0.70	5.00 ± 0.70	5.50 ± 0.53	6.00 ± 0.75	4.78 ± 1.00c
Overall	4.19 ± 0.80A	4.29 ± 0.70A	4.58 ± 0.86A	5.07 ± 0.63B	5.40 ± 0.93BC	5.78 ± 0.87C	

Untreated (control mushrooms), 5 mg/L EW (Mushrooms immersed in electrolyzed water solution containing 5 mg/L free chlorine), 25 mg/L EW (Mushrooms immersed in electrolyzed water solution containing 25 mg/L free chlorine), 50 mg/L EW (Mushrooms immersed in electrolyzed water solution containing 50 mg/L free chlorine), 100 mg/L EW (Mushrooms immersed in electrolyzed water solution containing 100 mg/L free chlorine).
a–c Means in the same column with different letters are significantly different ($p \leq 0.05$).
A–E Means in the same row with different letters are significantly different ($p \leq 0.05$) (Mean separation was performed by Tukey test).

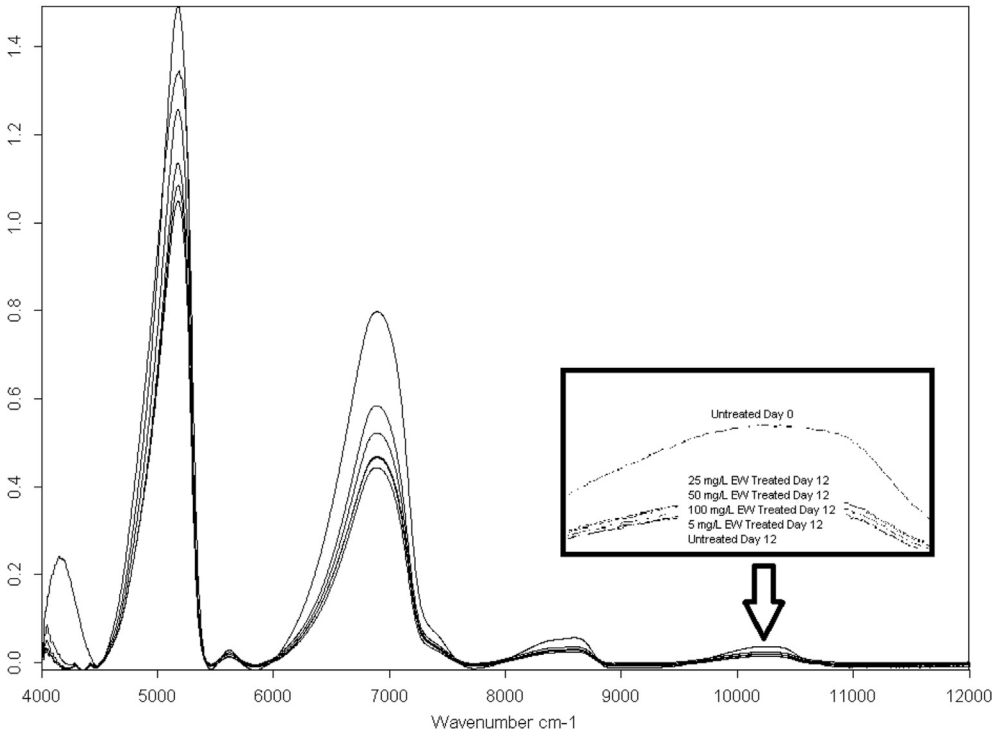

Fig. 4. FT-NIR spectra of untreated and EW treated mushrooms during storage. Untreated (control mushrooms), 5 mg/L EW (Mushrooms immersed in electrolyzed water solution containing 5 mg/L free chlorine), 25 mg/L EW (Mushrooms immersed in electrolyzed water solution containing 25 mg/L free chlorine), 50 mg/L EW (Mushrooms immersed in electrolyzed water solution containing 50 mg/L free chlorine), 100 mg/L EW (Mushrooms immersed in electrolyzed water solution containing 100 mg/L free chlorine).

mushrooms during storage. Peaks around 10,244 cm^{-1} provides information about the water (second O–H overtone) content of food (Di Egidio et al., 2009). At the beginning of study, fresh mushrooms had highest absorbance at 10244 cm^{-1} because of the high water content. However at the end of the storage, untreated samples had the lowest absorbance at same wavelength due the high water loss compared with other treated mushrooms. Similar results were obtained by the researchers who performed FT-NIR analysis on strawberry (Aday & Caner, 2014), cherry (Aday & Caner, 2010) and pineapple (Di Egidio et al., 2009). In addition, our findings correlate well with the results observed in weight loss section.

4. Conclusions

This study set out to determine the effectiveness of electrolyzed water on mushroom shelf life. This research has shown that EW at the concentrations of 25 mg/L and 50 mg/L maintained the quality of mushrooms better than other treatments. The second finding was EW treatment did not show any detrimental effect on mushrooms even at high concentration (100 mg/L) compared to untreated samples. Interestingly, lower values of cap development were observed in the untreated samples and samples treated with 5 mg/L EW due to the high carbon dioxide inside the packages. In conclusion, the results of this research support the idea that combined use of EW treatments at the concentrations of 25 mg/L and 50 mg/L and passive modified atmosphere packaging can be used to extend the shelf life of button mushrooms (*Agaricus bisporus*). Further experimental investigations are needed to determine the effect of EW on enzymes related to respiration, tissue softening and browning.

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