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Abstract

Cranberries are appreciated for their high amount of antioxidants such as flavonoids, anthocyanins, phenolic acids, carotenoids and vitamins. However, due to their sour and tart taste they request to be processed into sweeter dried fruits in order to be acceptable for the consumers. The aim of this work was to analyse the effect of ultrasound assisted osmotic dehydration on mass transfer parameters and on quality characteristics during storage of cranberries. Ultrasound treatment was performed at the frequency of 21 kHz for 30 min in three osmotic solutions - 61.5% sucrose, 30% sucrose with an addition of 0.1% of steviol glycosides and 40 % trehalose on cut in half cranberries. Afterwards, the cranberry samples were subjected to osmotic dehydration process at 40°C for 72 h. The osmodehydrated samples both with or without ultrasound pre-treatment were collected and stored at 10°C in climatic chamber in microperforated plastic bags (PLA) for 8 weeks. The weight reduction, dry matter, water activity, colour, and microbial analysis were performed after 1, 2, 4 and 8 weeks of storage. The obtained results indicated that ultrasound application significantly affected the mass transfer parameters during osmotic treatment, as well as it did the type of osmotic solution used. Thermal analysis showed the variations in sugar melting temperature and enthalpy as a result of osmotic treatment and storage. During the storage, a lower weight loss, and higher lightness was observed in US pre-treated samples. The sample that preserved the best chemico-physical and microbiological characteristics during storage was the one treated with 61.5% sucrose solution, due to its lowest water activity.

Keywords: cranberry, osmotic dehydration, shelf life, microbiology, water activity, colour

1. Introduction

Cranberries are considered as a rich source of many compounds which have a positive impact on human health. This fruit contains vitamins (A, C, E), minerals (potassium, sodium, selenium), fiber, lutein and beta-carotene. However, the most represented substances in cranberry fruit are polyphenols (Blumberg et al., 2013; McKay, Chen, Zampariello, & Blumberg, 2015; Neto, 2007; Nowacka, Fijalkowska, Dadan, et al., 2018; Teleszko, 2011). Unfortunately, fresh cranberries have a very sour and tart flavor that makes them rarely eatable as raw fruits. Although sugar is generally not desirable in the diet, according to American nutritional recommendations, its use is applied to improve the taste of products with highly valuable nutritional values to make them acceptable for the consumer (Blumberg et al., 2013; Kowalska & Olejnik, 2016; Nowacka et al., 2017a). Recently, different substances such as sweeteners or sweetness enhancer were proposed as an alternative to the use of sucrose. One of them is steviol glycoside, which is approximately 300 times sweeter than sucrose and it is highly appreciated for its technological purpose, since it is temperature and pH stable during the processing and storage (Periche, Castelló, Heredia, & Escriche, 2015).

To obtain appropriate sweetness of the final product, fresh cranberries are subjected to osmotic dehydration (OD) process (Nowacka, Fijalkowska, Wiktor, et al., 2018). OD is a widely used process carried out in hypertonic solution, usually sugars. During OD, a mass exchange occurs, in particular, water flows out from the fresh tissue into the surrounding solution and the osmotic substance enters the dehydrated tissue. The result is a partial dewatering impregnation, which allows an increase of the shelf-life of OD material (Goula, Kokolaki, & Daftsiou, 2017; Kaymak-Ertekin, F. & Sultanolu, 2000; Nowacka, Śledź, Wiktor, & Witrowa-Rajchert, 2014; Radojčin et al., 2015; Rząca, Witrowa-Rajchert, Tylewicz, & Rosa, 2009; Tylewicz et al., 2011). However, this process is long and often requires the acceleration of mass transfer using traditional methods as agitation and rotation or new techniques as for example ultrasound (Deng & Zhao, 2008; Fernandes, Oliveira, & Rodrigues, 2008; Goula et al., 2017; Nowacka, Tylewicz, Laghi, Dalla Rosa, & Witrowa-Rajchert, 2014). Ultrasound (US) is an air vibration in the frequency from 20 kHz to 100 kHz. In liquid medium it results in

compression and expansion of material, called "sponge effect", and formation of cavitation bubbles. The application of ultrasound may have an influence on physical and chemical properties of plant tissue due to creation of microscopic channels and formation of free radicals (Goula et al., 2017; Knorr, Zenker, Heinz, & Lee, 2004; McClements, 1995; Nowacka, Fijalkowska, Dadan, et al., 2018; Simal, Benedito, Sánchez, & Rosselló, 1998; Witrowa-Rajchert, Wiktor, Sledz, & Nowacka, 2014). Moreover, ultrasound coupled with thermal treatment leads to better bacterial inactivation in comparison to only thermal treatment (Zenker et al., 2003).

It is recognized that quality characteristics and physical properties of food may undergo changes during US treatment (Fernandes, Gallão, & Rodrigues, 2009; Fernandes, Oliveira, et al., 2008; Goula et al., 2017; Kentish & Ashokkumar, 2011; Nowacka, Fijalkowska, Dadan, et al., 2018; Rajewska & Mierzwa, 2017) and OD process (Fernandes, Gallão, & Rodrigues, 2009; Nowacka, Tylewicz, Romani, Dalla Rosa, & Witrowa-Rajchert, 2017b), but also during further storage (Wang, 2006). However, while changes due to process have received more attention, evolution of quality during storage of these type of product are seldom assessed. Thus, the aim of this study was to investigate the effect of ultrasound assisted osmotic dehydration on cranberries mass exchange parameters and on their quality parameters (dry matter, water activity, colour, thermal behaviour and microbial growth) during storage.

2. Material and methods

2.1. Sample preparation

Fresh swamp cranberry fruits (*Vaccinium oxycoccus*) were used in this research. The fruits were bought on the Polish market and stored at 4 ± 1°C until processing. The cranberries were cut with a sharp knife in the geometric centre of the fruit to break hard skin and consequently to facilitate mass transfers during processes (Nowacka et al., 2017a). Fruits were subjected to ultrasound treatment and then to osmotic dehydration process.

2.2. Sonication procedure (US)

50g of samples were placed in a beaker into OD solutions in ratio of 1:4 (fruit:solution) (Fernandes, Gallão, & Rodrigues, 2008; Tylewicz et al., 2011) in order to avoid changes in the solution concentration and then positioned in an ultrasonic bath MKD-3 (MKD Ultrasonics, Stary Konik, Poland, internal dimensions: 240x140x110 mm). Sonication was conducted for 30 minutes (Nowacka, Fijalkowska, Wiktor, et al., 2018) using frequency 21 kHz and the total power generated by sonotrodes 180 W, that corresponded to an intensity of 3.6 W/g. During treatments the fruits were covered by a net in order to prevent them from flowing to the surface. During the sonication in OD solutions, significant temperature changes (±1°C) were not observed. The treatment was conducted in two repetitions for each osmotic solution. After the sonication, beakers were transferred to a rotary shaker with controlled temperature to continue the osmotic dehydration process.

2.3. Osmotic dehydration (OD)

Osmotic dehydration was carried out in three different solutions at the temperature of 40°C:

1. 61.5% sucrose solution (SA)
2. 30% sucrose solution with 0.1% of steviol glycosides (STV)
3. 40% trehalose solution (T).

SA solution is usually used for osmotic dehydration as standard solution (Ciurzyńska, Kowalska, Czajkowska, & Lenart, 2016). The solution of 30% of sucrose with addition of natural sweetener as steviol glycosides was used in order to reduce the sucrose content and keep similar sweetness. Steviol glycosides are up to 300 times sweeter than sucrose, thus the addition of 0.1% of steviol glycosides to a 30% sucrose solution provide a comparable sweetness to a 61.5% sucrose solution (Nowacka et al., 2017a). Trehalose solution was used as osmotic agent since it is able to improve the food structure and contribute to microbiological stability (Dermesonlouoglou, Zachariou, Andreou, & Taoukis, 2016). Solutions were prepared by dissolving the solutes into distilled water. The sucrose (Pfeifer & Langen Marketing Inc.) was used to prepare standard solutions. The steviol glycosides (Hortimex

Plus Inc.) with purity of 95,48% (63.43% of rebaudioside A, 22.85% of stevioside, 8.21% of rebaudioside C, 0.73% of dulcoside A and 0.26% of steviolbioside) and trehalose (Exacta+Optech Labcenter S.P.A) were used.

Due to high acidity of swamp cranberries, in order to obtain an acceptable taste of the product, the OD process was carried out till 72h of immersing in osmotic solution (Nowacka, Fijalkowska, Dadan, et al., 2018). The samples subjected to OD process obtained a sweet-sour taste, which is characteristic for processed cranberry fruits available on the market as jams, sauces or dried fruits.

After the treatment, the cranberries were rinsed with distilled water for 10 seconds and dried with absorbent paper for 5 seconds. The experiment was performed in duplicate for each solution. All examined samples are summarized in Table 1.

2.4. Storage conditions

After osmotic dehydration, samples were packed in micro-perforated plastic bags made from polylactid acid (PLA) and stored for 8 weeks in a climatic chamber at the temperature of 10°C. The chosen quality properties were analysed immediately after OD treatment (T0) and after the first (T1), second (T2), fourth (T4) and eighth (T8) week of storage. For each storage time two bags for each sample were analysed.

2.5. Analytical determinations

2.5.1. Mass transfer parameters

The mass transfer after 72 h of OD process was evaluated in terms of weight reduction (WR, kg·kg^{-1}), water loss (WL, kg·kg^{-1}) and solid gain (SG, kg·kg^{-1}) according to the following equations (Tylewicz et al., 2017):

$$WR = \frac{m_t - m_0}{m_0} \quad (1)$$

$$WL = \frac{m_t x_{wt} - m_0 x_{w0}}{m_0} \quad (2)$$

$$SG = \frac{m_t x_{STt} - m_0 x_{ST0}}{m_0} \quad (3)$$

where:

m_0 - initial weight before osmotic treatment (kg)

m_t - weight after a time t (kg)

x_{w0}- initial water mass fraction (kg·kg^{-1})

x_{wt} - water mass fraction after a time t (kg·kg^{-1})

x_{ST0} – initial total solids (dry matter) mass fraction (kg·kg^{-1})

x_{STt} – total solids (dry matter) mass fraction after a time t (kg·kg^{-1})

Moreover, weight reduction was also calculated for all the samples during the storage of 8 weeks, taking into account the weight of the samples at T0 and at each time of storage.

2.5.2. Moisture content

Moisture content was determined gravimetrically by drying the samples at 70°C until a constant weight was achieved (AOAC, 2002).

2.5.3. Water activity

Water activity (a_w) was determined using the device AquaLab Series 3TE (Decagon Devices Inc., Pullman, USA). The assay was performed in triplicate at room temperature (23±1°C).

2.5.4. Colour

Colour was analysed using a spectro-photocolorimeter (HUNTERLAB Color-FlexTM, A60-1010-615, Reston, Virginia) equipped with a 12 mm diameter sample holder. The following parameters were used: illuminant D65 (6500 K), observer 10°. Before each series of measurements, the instrument was calibrated with a black and white tile (L* = 93.47; a * = -0.83; b * = 1.33). The colour data were expressed, according to the CIE L*a*b* scale, in L* (lightness), a* (index of red) and b* (index of yellow). The final values were calculated as an average of nine measures. Moreover, the

hue angle (h°) and the total colour differences (ΔE) were calculated with the equation 4 and 5 respectively (Radojčin et al., 2015; Wiktor, Sledz, Nowacka, Rybak, & Witrowa-Rajchert, 2016):

$$h^o = tan^{-1}\frac{b^*}{a^*} \quad (4)$$

$$\Delta E = \sqrt{\left(\Delta L^*\right)^2 + \left(\Delta a^*\right)^2 + \left(\Delta b^*\right)^2} \quad (5)$$

where:

ΔL*, Δa*, Δb* is the differences of mean L*, a* and b* parameters, respectively, between fresh cranberries and osmodehydrated untreated and US treated samples.

2.5.5. Differential Scanning Calorimetry measurements (DSC)

The calorimetric analysis was performed to determine the temperature of sugars' decomposition using a DSC Q20 model differential calorimeter (TA Instrument, Germany) according to Panarese, Tylewicz, Santagapita, Rocculi, & Dalla Rosa (2012). The DSC was equipped with a cooling unit (TA-Refrigetated Cooling System90). The calibration of temperature and melting enthalpies was carried out with distilled water (T_m 0.0 °C) and indium (T_m 156.60 °C). For the calibration and for sample measurements the same heating rate was used, under a 50 mL/min dry nitrogen flow. About 20-30 mg of each sample were weighed in 50 µl aluminum capsules, closed and punctured just before the measurement. An empty capsule was used as a reference. The curves were obtained by heating the samples from 20 to 300 °C at a rate of 10 °C/min.

2.5.6. Microbiology assessment

The microbiological analyses were performed immediately after the osmotic treatment conducted for 72 hours (T0) and during the storage period (after 1, 2, 4, 8 weeks). In particular, the cell loads of mesophilic aerobic bacteria, yeasts and moulds were monitored in all samples over the storage, according to the procedure reported by Mannozzi et al. (2018). The results are the average of three independent samples for each condition.

195

196 **2.6. Statistical analysis**

197 Analysis of variance (ANOVA) was performed using Statistical 7.0 Statsoft software (Tulsa, UK)
198 using the Duncan test with a level of $p < 0.05$.

199

200 **3. Results and discussion**

201 **3.1. Mass transport balance during the OD treatment**

202 Table 2 shows the results of mass transfer parameters (weight reduction, water loss, solid gain)
203 involved during the OD treatment for 72 h at 40 °C. From the table it is possible to observe that the
204 highest weight reduction was observed for samples treated with sucrose (SA), followed by samples
205 treated with sucrose in combination with steviol glycoside (STV) and samples dehydrated with
206 trehalose (T). These differences were similar to the ones observed for the water loss from the samples.
207 In fact, the highest water loss was observed for samples treated with high concentration of sucrose.
208 This is due to the difference in osmotic pressure between food matrix and osmotic solution. SA
209 solution presented the higher concentration of sugar (61.5%) and was characterized by the lowest a_w
210 of about 0.867, while the solutions of STV and T presented the values of 0.976 and 0.965,
211 respectively.
212 In a study investigating the dehydration of apples, when sucrose and trehalose were used as osmotic
213 solution at the same a_w (0.96) lower water mass fraction (0.819 $g \cdot g^{-1}$) was observed in samples
214 dehydrated with sucrose solution against 0.838 $g \cdot g^{-1}$ observed for trehalose solution, indicating the
215 lower dewatering for the latest samples (Atarés, Chiralt, Corradini, & González-Martínez, 2009).
216 Also Tylewicz et al. (2017) observed that samples treated with trehalose solution at the same
217 concentration as sucrose (40% w/w) were characterized by a lower final dehydration level (at 120
218 min of OD) even if a higher initial rate of dehydration was observed.
219 As explained by Galmarini et al. (2011) at the same solute concentration, the a_w (which explains the
220 engine of transport) is lower in sucrose solution as well as its viscosity (which explains the molcular

diffusion). Therefore, the water transport is faster in samples dehydrated in sucrose than these dehydrated with trehalose.

Concerning the solid gain, the highest value was observed in samples treated with sucrose, followed by the samples treated with trehalose. Trehalose was found to have a higher effect on solid gain when used at the same concentration as sucrose (Tylewicz et al., 2017). In the present study, while a slightly but significantly higher water loss was observed for STV samples compared to T samples, the latter showed almost twice the solid gain.

Ultrasound pre-treatment led to a significant increase of weight reduction and water loss in all the samples. It is well known that ultrasound create microscopic channels which may ease moisture removal and increase the diffusivity of the water (Fernandes, Gallão, et al., 2008; Fernandes & Rodrigues, 2007; Nowacka et al., 2014). On the other side, for SA_US and T_US samples the US pre-treatment did not promote any differences for solid gain, while it caused a significant decrease in samples STV_US. This is probably because the solid gain comprises both soluble and insoluble solids (fruit matrix), and therefore any lysis effect in the tissue is accounted in this group.

3.2. Weight reduction and dry matter content during storage

Weight reduction and dry matter content of osmodehydrated cranberries throughout storage are shown respectively in Figure 1 and 2. Weight loss was generally in the range of 2-5%. The US pre-treatment led to a significantly lower weight loss in samples treated with SA and STV in comparison to the samples only osmodehydrated. The samples treated with sucrose solution both with or without US application presented the lowest weight loss, followed by samples treated by trehalose and then the samples treated with sucrose and steviol glycoside, which presented the highest weight loss. In general, the loss of weight during storage could be due to the water loss that resulted from surface water evaporation, and also by gravity mechanism that moves the liquid phase to the bottom of samples, leaving the tissue. Moreover, respiration and transpiration as well as the wounding stress during the processing of the fruits could cause the higher weight gain during the storage (Ferrari,

Sarantópoulos, Carmello-Guerreiro, & Hubinger, 2013). In fact, in the case of our study the weight loss was the highest in samples dehydrated with STV, which probably could still maintain the biological capacity to the cell respiration or even to ferment. Due to the higher dehydration during the process, samples treated with sucrose presented also the lower water content (Figure 2) compared to the other samples, that could be the reason for the lower loss of water during the storage.

As shown in Figure 2, the highest value of dry matter was observed for cranberries samples treated at 61.5% sucrose solution (around 0.5%). As already observed for mass transfer parameters, these samples were subjected to a higher dewatering and thus higher increase of the dry mater. During storage, a further (even if only slight) increase of dry mater was observed in all samples. Higher dry matter observed in SA_US and STV_US treated samples, in comparison to their controls, immediately after the treatment and at different period of storage was probably due to the partial destruction of the fruit peel allowing a higher penetration of sucrose into the tissue (Nowacka et al., 2017a).

3.3. Water activity

Figure 3 shows the water activity evolution for osmodehydrated cranberry samples with or without US pre-treatment during storage. The samples treated with SA presented the lowest a_w in comparison to the samples dehydrated with other solutions, because of the higher osmotic potential differences. The application of US did not change significantly the water activity of the samples at T0. Also, Stojanovic and Silva (2006) and Nowacka et al. (2017b) did not observed differences in water activity of ultrasound osmodehydrated blueberry and kiwifruit samples, respectively. An increase of water activity was observed at T1, while during further storage a slight but progressive decrease of water activity was noticed. The results are in accordance with the dry matter content, in fact the increase of solutes content during storage could lead to the decrease of water activity.

3.4. Colour changes during storage

Table 3 shows the changes of colour parameters of lightness (L*), red index (a*), yellow index (b*), hue angle (h°) and total colour differences (ΔE). During storage, until the fourth week a decrease of the L* parameter was observed for all samples. Cranberries dehydrated with ultrasound in trehalose solution (T_US) showed the lowest lightness value. Obtained data are in agreement with those reported in the literature, according to which the osmotic treatment leads to a decrease of the initial L* values. This phenomenon can be related to the modification of the surface layer of the product due to immersion in sugary solutions. This effect was noticed by Prinzivalli et al. (2006) in strawberry slices. As reported in the literature in the case of dehydrated apples and carrots, the pre-treatment with ultrasound leads to an increase in lightness (L*) compared to the untreated fruit (Fijalkowska, Nowacka, Wiktor, Sledz, & Witrowa-Rajchert, 2016). In our case, significantly higher values of L* for untreated and US treated samples were observed only at the 8th week of storage. Probably these colour changes were associated with loss of the anthocyanins during storage, which are responsible for red colour of cranberry fruits (Nowacka, Fijalkowska, Dadan, et al., 2018; Oszmiański, Wojdyło, Lachowicz, Gorzelany, & Matłok, 2016). This was also confirmed by the changes of a* parameter, which represent the red colour. In general, a decrease of a* and b* parameters was noted during storage, while the hue angle values, in the range of 16 to 28, indicating a red hue of the samples, did not show a real trend. In fact, they first decreased after one week and then started to increase till the fourth week, and then again decreased at eight week of storage.

In order to evaluate the colour alteration, the total colour differences was calculated. Generally, the value of ΔE higher than 2 is considered as a visible difference between the samples (Fijalkowska, Nowacka, & Witrowa-Rajchert, 2017). All samples were characterized by high values of ΔE in the range from 6 to 10 after the osmotic dehydration process and the total colour differences grow during storage till 4th week. In the 8th week of storage the decrease of ΔE was observed. The changes of colour are usually connected with the chemical compounds, which are responsible for the colour e.g. anthocyanins (Nowacka, Fijalkowska, Dadan, et al., 2018). In particular, red colour is one of the main indicators by which the consumer can assesses the quality of fresh cranberries. It makes the product

more or less attractive and it is the first characteristic that the consumer perceives (Kutyła-Olesiuk, Nowacka, Wesoły, & Ciosek, 2013; Nowacka, Fijalkowska, Wiktor, et al., 2018). The reduction of the red component of colour might be connected with the solubilization of pigments in the solution during osmotic treatment and the degradation of anthocyanins. Anthocyanins are particularly sensitive to osmotic dehydration, which may be the reason for the general reduction in colour (de Bruijn & Bórquez, 2014).

3.5. Thermal analysis DSC results

DSC measurements were performed to evaluate the melting of sugars introduced by OD in the samples and to evaluate any differences during storage. The melting temperature (Tm, °C) and enthalpy (ΔH, $J \cdot g^{-1}$) registered in the sample are reported in Figure 4 and Figure 5, respectively.

Melting of sucrose is known to occur in the temperature range of 206-232°C (Abd-Elrahman & Ahmed, 2009; Panarese, Tylewicz, Santagapita, Rocculi, & Dalla Rosa, 2012). In the present study, after the OD treatment a melting temperature of 211 °C was found, which is consistent with literature data previously reported.

The presence of steviol glycosides at 0.1% did not influence the melting temperature of the solution. In the case of trehalose, a melting peak with a temperature of 246 °C was observed. While about the crystallization of trehalose and its influence on glass transition there is a wide literature, its melting behaviour is not often studied. Raemy and Schweizer (1983) studied the melting properties of different sugars and indicated a melting temperature for trehalose of 235 °C, higher compared to sucrose one (215°C), which is similar to what we found in the present study.

No differences were observed during storage in the peaks of melting temperatures for all the samples. The enthalpy values are found to be proportional to the sugar contents. The initial values reported in Figure 5, of about 40, 27 and 19 $J \cdot g^{-1}$ respectively for SA, T and STV samples, reflect the impregnation levels reported in Table 2 for samples after 72 h of OD process. While for STV sample, no differences were observed when US was applied, for SA and T samples, an increase in the melting

enthalpy was observed. This difference may be attributed to the differences in mass transfer as shown by Table 2. Indeed, while water loss increased in STV sample after US application (increase of 8%, compared to 2 and 6% of respectively SA and T samples), solid gain decreased for of about 1.7%. Moreover, it could be possible that T and T_US samples suffer partial hydrolyzation of trehalose.

3.6. Microbial analysis

In Table 4 the results of total mesophilic aerobic bacteria and yeasts in cranberries samples during the shelf-life are reported. Osmotic dehydration improves the microbiological shelf-life since it leads to a reduction in water activity (Castelló, Igual, Fito, & Chiralt, 2009). In fact, even in our case study, the samples that reached lower water activity (SA; SA_US30) showed a better microbiological shelf-life over time. This is probably because of the high osmotic pressure of the SA solution which can enable longer shelf-life. Moreover, sucrose absorption has promoted an increase in the viscosity of the liquid phase, influencing the kinetics of the microbial growth, as reported in the case of kiwifruit by (Gianotti, Sacchetti, Guerzoni, & Dalla Rosa, 2001). According to the recommended microbiological criteria for fruits and vegetables, the maximum limits for the total mesophilic aerobic bacteria and yeasts/moulds are set to be 1×10^4 CFU/g and 1×10^2 CFU/g, respectively (Pascual and Calderón, 2000). As reported in Table 4, there were no significant differences between the samples pre-treated or not with ultrasound. However, the cell load of the total mesophilic aerobic bacteria, exceeded the maximum levels recommended by Pascual and Calderón (2000), after the first week of storage for the samples osmodehydrated in solutions with 30% sucrose + 0.1% stevia and 40% trehalose that were subjected to ultrasound pre-treatment. During the second week of storage this microbiological limit was also exceeded for samples osmodehydrated with sucrose + stevia and trehalose and not subjected to ultrasound pre-treatment, whereas for samples osmodehydrated with 61.5% of sucrose solution, with and without US pre-treatment, this limit was only exceeded after eighth weeks of storage. As regard to yeasts, the recommended cell load was superseded by all the samples at the beginning of the first week of storage, whereas for moulds the cell load exceeds only

for samples osmodehydrated with trehalose. During the fourth week of storage, the recommended cell load for moulds 1 x 10^2 CFU/g was superseded by all samples with the exception of those osmodehydrated with 61.5% sucrose that exceeded this limit only during the eighth week (data not shown) of storage. In fruits and vegetables, intercellular spaces play an important role in the penetration of microorganisms. In general, bacteria, yeast or mould cells are much smaller than plant cells, thus they can easily penetrate into the vegetable tissues (Alzamora et al., 2005).

Conclusions

The mass transfer parameters during OD treatment were significantly influenced by ultrasound application and the type of osmotic solution used. The highest water loss was observed in samples treated with sucrose and ultrasound (SA_US). During storage, ultrasound pre-treatment led to lower weight reduction in cranberry samples treated with any type of the solution in comparison to those without US pre-treatment. Moreover, during storage, the US pre-treatment promoted changes in the qualitative characteristics, in particular of colour leading to a higher lightness (L*) in comparison to the untreated fruit. The thermal analysis allowed the identification of the variations in melting temperatures and enthalpies as a result of osmotic treatment and storage.

The sample that preserved the best chemico-physical and microbiological characteristics during storage was the one treated with 61.5% sucrose solution, due to the lowest water activity. However, further studies are necessary in order to better understand the chemico-physical and physiological mechanisms underlying the highlighted changes.

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Figure Caption

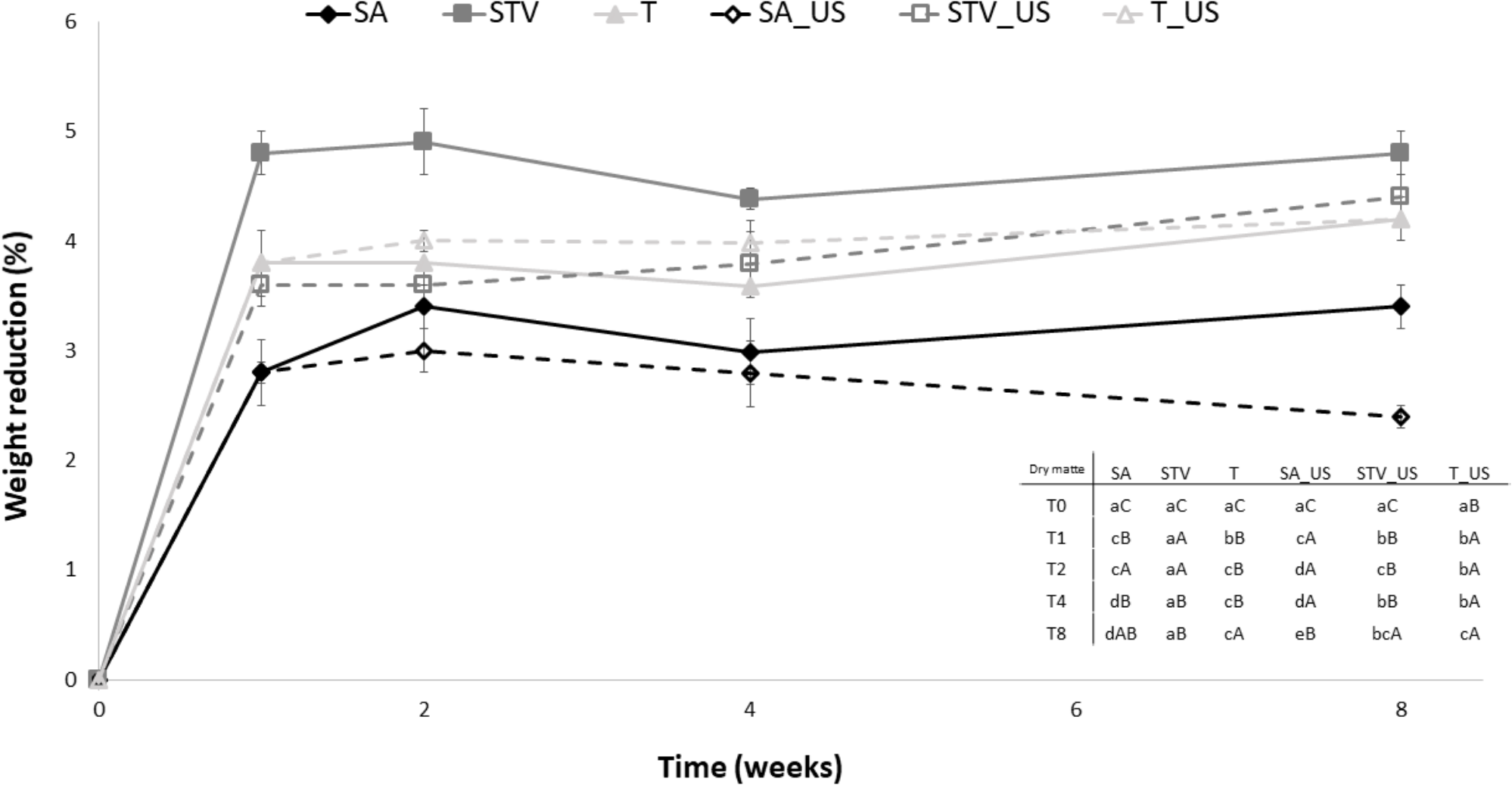
Figure 1. Weight reduction of osmodehydrated cranberries with or without US pre-treatment during storage at 10 °C. Different letters indicate statistical differences ($p < 0.05$) (lowercase letter within the same row indicate differences among different treatments for the same storage time, while capital letters within the same column indicate differences among different storage times for the same treatment).

Figure 2. Dry matter content ($g \cdot g^{-1}$) of osmodehydrated cranberries with or without US pre-treatment during storage at 10 °C. Different letters indicate statistical differences ($p < 0.05$) (lowercase letter within the same row indicate differences among different treatments for the same storage time, while capital letters within the same column indicate differences among different storage times for the same treatment).

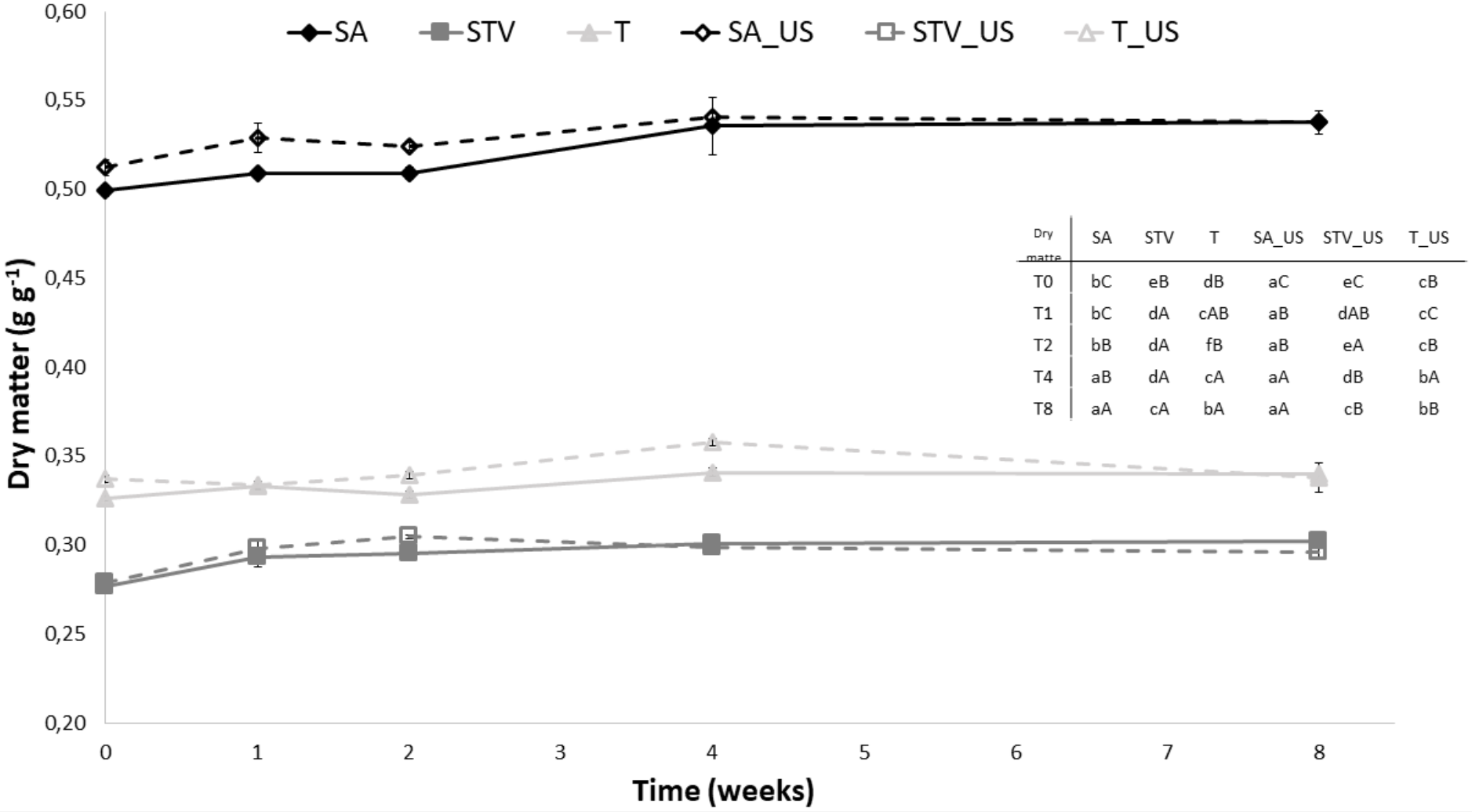
Figure 3. Water activity of osmodehydrated cranberries with or without US pre-treatment during storage at 10 °C. Different letters indicate statistical differences ($p < 0.05$) (lowercase letter within the same row indicate differences among different treatments for the same storage time, while capital letters within the same column indicate differences among different storage times for the same treatment).

Figure 4. The melting temperature (Tm, °C) of osmodehydrated cranberries with or without US pre-treatment during storage at 10 °C. Different letters indicate statistical differences ($p < 0.05$) (lowercase letter within the same row indicate differences among different treatments for the same storage time, while capital letters within the same column indicate differences among different storage times for the same treatment).

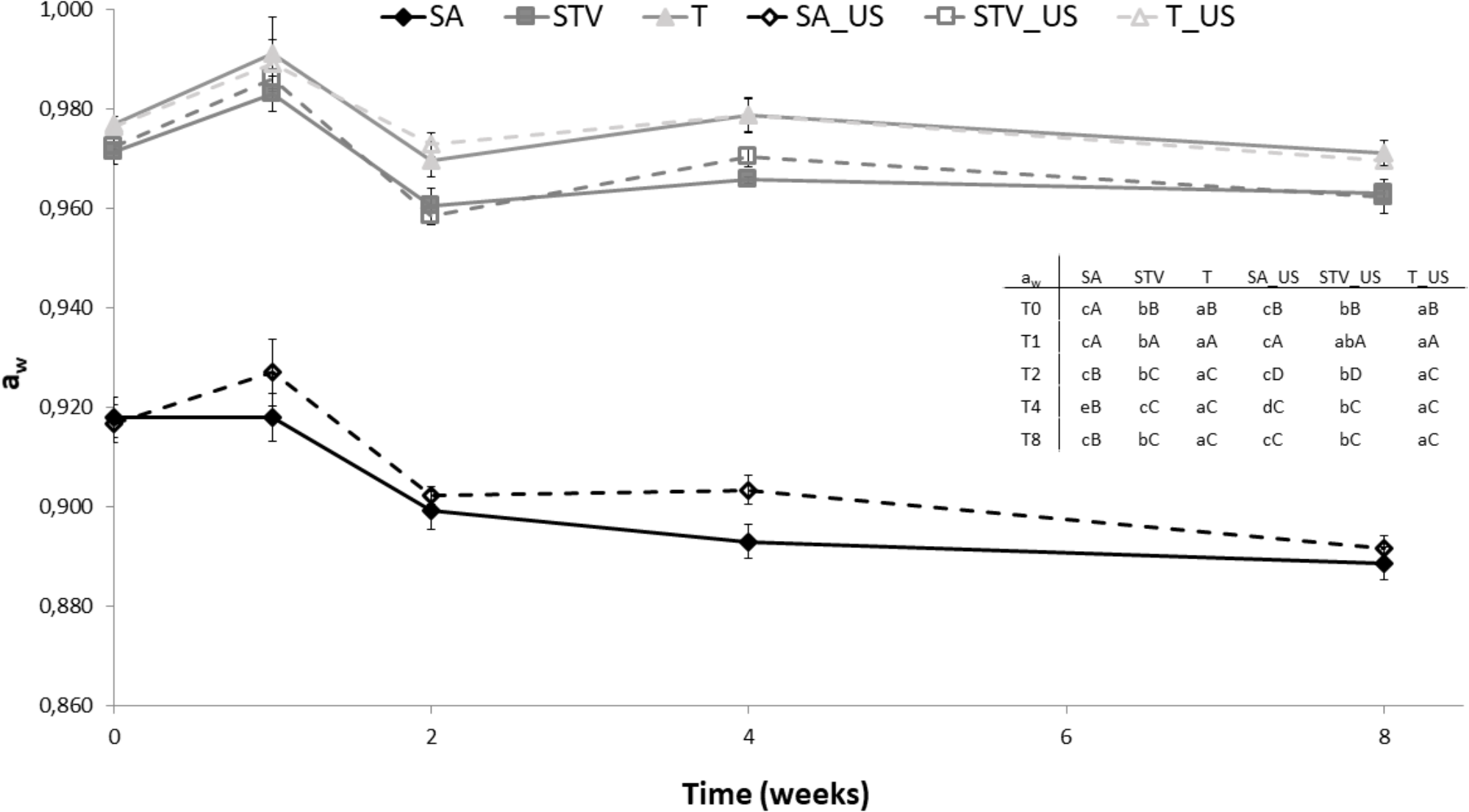
Figure 5. Melting enthalpy (ΔH, $J \cdot g^{-1}$) of osmodehydrated cranberries with or without US pre-treatment during storage at 10 °C. Different letters indicate statistical differences ($p < 0.05$) (lowercase letter within the same row indicate differences among different treatments for the same storage time, while capital letters within the same column indicate differences among different storage times for the same treatment).



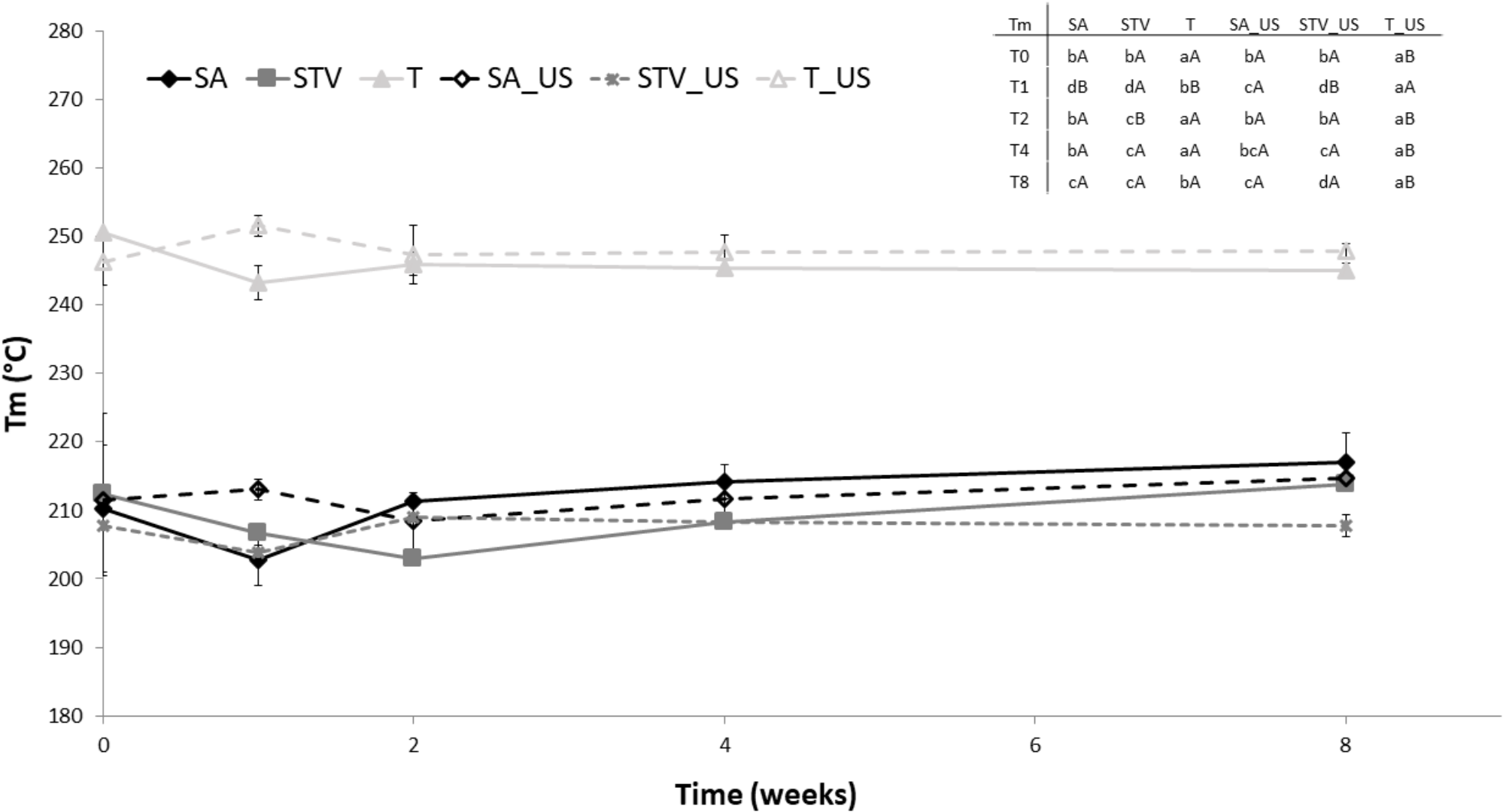
Dry matte	SA	STV	T	SA_US	STV_US	T_US
T0	aC	aC	aC	aC	aC	aB
T1	cB	aA	bB	cA	bB	bA
T2	cA	aA	cB	dA	cB	bA
T4	dB	aB	cB	dA	bB	bA
T8	dAB	aB	cA	eB	bcA	cA



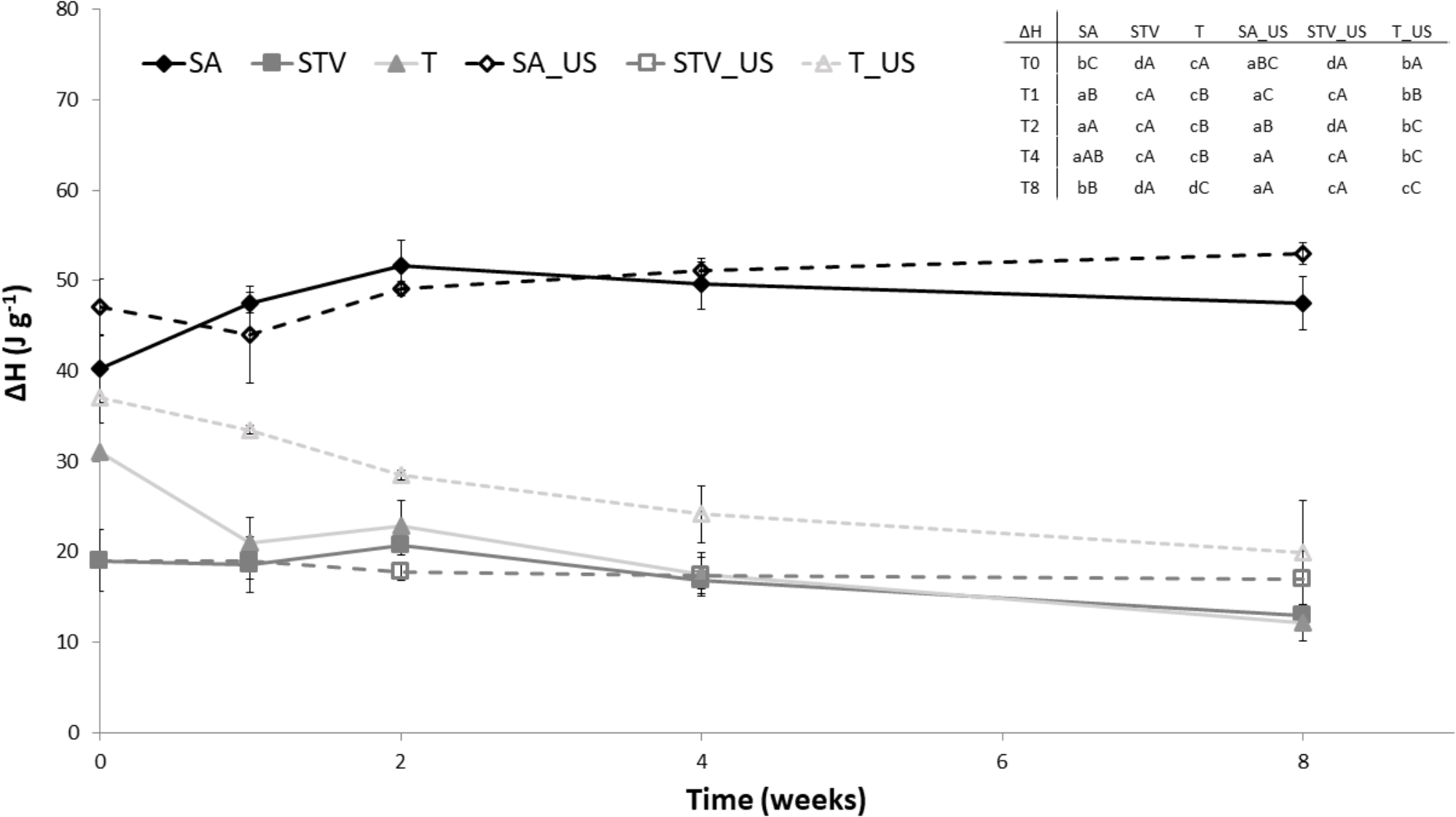
Dry matte	SA	STV	T	SA_US	STV_US	T_US
T0	bC	eB	dB	aC	eC	cB
T1	bC	dA	cAB	aB	dAB	cC
T2	bB	dA	fB	aB	eA	cB
T4	aB	dA	cA	aA	dB	bA
T8	aA	cA	bA	aA	cB	bB



a_w	SA	STV	T	SA_US	STV_US	T_US
T0	cA	bB	aB	cB	bB	aB
T1	cA	bA	aA	cA	abA	aA
T2	cB	bC	aC	cD	bD	aC
T4	eB	cC	aC	dC	bC	aC
T8	cB	bC	aC	cC	bC	aC



Tm	SA	STV	T	SA_US	STV_US	T_US
T0	bA	bA	aA	bA	bA	aB
T1	dB	dA	bB	cA	dB	aA
T2	bA	cB	aA	bA	bA	aB
T4	bA	cA	aA	bcA	cA	aB
T8	cA	cA	bA	cA	dA	aB



ΔH	SA	STV	T	SA_US	STV_US	T_US
T0	bC	dA	cA	aBC	dA	bA
T1	aB	cA	cB	aC	cA	bB
T2	aA	cA	cB	aB	dA	bC
T4	aAB	cA	cB	aA	cA	bC
T8	bB	dA	dC	aA	cA	cC

Table 1. Abbreviations of examined cranberry samples

Abbreviations	Sample description
SA	cranberries subjected to osmotic dehydration with 61.5% sucrose solution
STV	cranberries subjected to osmotic dehydration with 30% sucrose solution with addition 0.1% of steviol glycosides
T	cranberries subjected to osmotic dehydration with 40% trehalose solution
SA_US	cranberries subjected to 30 min ultrasound treatment and then osmotic dehydration with 61.5% sucrose solution
STV_US	cranberries subjected to 30 min ultrasound treatment and then osmotic dehydration with 30% sucrose solution with addition 0.1% of steviol glycosides
T_US	cranberries subjected to 30 min ultrasound treatment and then osmotic dehydration with 40% trehalose solution

Table 2. Weight reduction ($kg \cdot kg^{-1}$), water loss ($kg \cdot kg^{-1}$), solid gain ($kg \cdot kg^{-1}$) of osmodehydrated cranberries with or without US pre-treatment after 72 h of osmotic dehydration in sucrose (SA) sucrose + steviol glycoside (STV) and trehalose (T) solutions

Samples	Weight reduction	Water loss	Solid gain
SA	0.402 ± 0.002^{b}	0.586 ± 0.002^{b}	0.184 ± 0.002^{a}
STV	0.234 ± 0.001^{d}	0.332 ± 0.001^{e}	0.098 ± 0.001^{c}
T	0.172 ± 0.001^{f}	0.328 ± 0.001^{f}	0.156 ± 0.001^{b}
SA_US	0.424 ± 0.002^{a}	0.605 ± 0.002^{a}	0.182 ± 0.002^{a}
STV_US	0.299 ± 0.001^{c}	0.381 ± 0.001^{c}	0.081 ± 0.001^{d}
T_US	0.189 ± 0.001^{e}	0.345 ± 0.001^{d}	0.156 ± 0.001^{b}

Different letters within the same column indicate statistical differences ($p < 0.05$).

Table 3. Colour parameters L*, a*, b*, hue angle h° and total colour differences (ΔE) of osmodehydrated cranberries with or without US pre-treatment during storage storage at 10 °C

	L*				
	T0	T1	T2	T4	T8
SA	21 ± 3 ^{aA}	17 ± 1 ^{aAB}	17 ± 1 ^{aAB}	15 ± 1 ^{abB}	24 ± 3 ^{abA}
STV	17 ± 1 ^{bB}	16.6±0.4 ^{aB}	15 ± 1 ^{aB}	15 ± 2 ^{abB}	21.8 ± 0.1 ^{bA}
T	18 ± 2 ^{abB}	18 ± 2 ^{aAB}	15 ± 3 ^{aB}	13 ± 3 ^{abB}	22 ± 1 ^{abA}
SA_US	20 ± 3 ^{abB}	18 ± 1 ^{aB}	17 ± 2 ^{aB}	16 ± 2 ^{aB}	25 ± 1 ^{aA}
STV_US	18 ± 2 ^{abB}	17 ± 1 ^{aB}	19 ± 3 ^{aAB}	14 ± 3 ^{abB}	22.2 ± 0.3 ^{abA}
T_US	19 ± 2 ^{abB}	19 ± 1 ^{aBC}	15 ± 2 ^{aC}	10.2 ± 0.5 ^{bD}	23 ± 1 ^{abA}
	a*				
	T0	T1	T2	T4	T8
SA	26 ± 2 ^{aA}	24 ± 1 ^{aA}	24 ± 2 ^{aA}	28 ± 3 ^{aA}	18 ± 1 ^{abB}
STV	25 ± 2 ^{abA}	21 ± 1 ^{aBC}	22 ± 2 ^{aAB}	24 ± 2 ^{aAB}	17.6 ± 0.1 ^{abC}
T	25 ± 2 ^{abAB}	21 ± 3 ^{aBC}	23 ± 3 ^{aABC}	27 ± 2 ^{aA}	19 ± 2 ^{aC}
SA_US	24 ± 1 ^{abB}	22 ± 2 ^{aB}	25 ± 2 ^{aAB}	29 ± 2 ^{aA}	18 ± 1 ^{abC}
STV_US	23 ± 2 ^{bA}	21 ± 2 ^{aA}	22 ± 2 ^{aA}	25 ± 3 ^{aA}	15 ± 1 ^{bcB}
T_US	25 ± 2 ^{abA}	23 ± 2 ^{aAB}	20 ± 1 ^{aB}	28 ± 1 ^{aA}	14 ± 1 ^{cC}
	b*				
	T0	T1	T2	T4	T8
SA	12 ± 1 ^{aB}	10 ± 1 ^{aAB}	10 ± 2 ^{aAB}	15 ± 2 ^{aA}	8.3± 1 ^{abC}
STV	10 ± 1 ^{abAB}	6 ± 1 ^{bC}	8 ± 4 ^{aABC}	11 ± 4 ^{aA}	6.4± 0.4 ^{bcdBC}
T	11 ± 2 ^{abAB}	6 ± 2 ^{bC}	8 ± 1 ^{aBC}	13 ± 1 ^{aA}	7 ± 1 ^{abcBC}
SA_US	11 ± 1 ^{abB}	9 ± 1 ^{abBC}	11 ± 1 ^{aBC}	15 ± 1 ^{aA}	9 ± 1 ^{aC}
STV_US	9 ± 2 ^{bAB}	8 ± 1 ^{abAB}	8 ± 2 ^{aAB}	12 ± 2 ^{aA}	5 ± 1 ^{cdB}

T_US	10 ± 3 ^{abA}	9 ± 1 ^{abAB}	8 ± 1 ^{aAB}	12 ± 2 ^{aA}	4.6 ± 0.2 ^{dB}

h°

	T0	T1	T2	T4	T8
SA	25 ± 2 ^{aB}	23 ± 1 ^{aB}	23 ± 1 ^{aB}	28 ± 2 ^{aA}	24 ± 2 ^{abAB}
STV	21 ± 2 ^{abAB}	16 ± 2 ^{aB}	19 ± 1 ^{aAB}	23 ± 6 ^{aA}	20 ± 1 ^{cdAB}
T	23 ± 3 ^{abA}	17 ± 5 ^{aB}	18 ± 2 ^{aAB}	25 ± 2 ^{aA}	21.6 ± 0.1 ^{bcAB}
SA_US	25 ± 2 ^{bAB}	22 ± 2 ^{aB}	23 ± 3 ^{aAB}	27.9 ± 0.3 ^{aA}	25 ± 1 ^{aAB}
STV_US	21 ± 3 ^{abA}	21 ± 2 ^{aA}	20 ± 4 ^{aA}	24 ± 2 ^{aA}	19 ± 1 ^{cdA}
T_US	21 ± 3 ^{bA}	21 ± 2 ^{aA}	21 ± 1 ^{aA}	24 ± 3 ^{aA}	18 ± 1 ^{dA}

ΔE

	T0	T1	T2	T4	T8
SA	6 ± 2 ^{bC}	8 ± 1 ^{bC}	8 ± 2 ^{aC}	21.3 ± 0.3 ^{aA}	14 ± 1 ^{cB}
STV	8 ± 2 ^{abC}	13 ± 2 ^{aB}	11 ± 2 ^{aB}	22.0 ± 0.6 ^{aA}	14.9 ± 0.2 ^{bcB}
T	8 ± 3 ^{abC}	13 ± 2 ^{aB}	11 ± 2 ^{aBC}	21.0 ± 0.4 ^{aA}	14 ± 2 ^{cB}
SA_US	8 ± 1 ^{abC}	10 ± 2 ^{abC}	7 ± 3 ^{aC}	21.1 ± 0.1 ^{aA}	14 ± 1 ^{bcB}
STV_US	10 ± 3 ^{aB}	11 ± 2 ^{abB}	11 ± 3 ^{aB}	21 ± 1 ^{aA}	17 ± 2 ^{abA}
T_US	8 ± 2 ^{abC}	9 ± 1 ^{abC}	13 ± 2 ^{aB}	21.0 ± 0.2 ^{aA}	19 ± 1 ^{aA}

Different letters indicate statistical differences ($p < 0.05$) for each colour parameter (lowercase letter within the same column indicate differences among different treatments for the same storage time, while capital letters within the same row indicate differences among different storage times for the same treatment).

Table 4. Mesophilic aerobic bacteria and yeast of osmodehydrated cranberries with or without US pre-treatment during storage storage at 10 °C

	Mesophilic aerobic bacteria log CFU/g				
	T0	T1	T2	T4	T8
SA	2.2 ± 0.2^{a}	3.3 ± 0.3^{b}	2.9 ± 0.2^{d}	2.9 ± 0.3^{c}	4.9 ± 0.2^{c}
STV	2.4 ± 0.2^{a}	3.8 ± 0.2^{b}	5.4 ± 0.3^{c}	7.9 ± 0.2^{a}	8.0 ± 0.3^{a}
T	2.0 ± 0.3^{a}	4.8 ± 0.2^{a}	6.0 ± 0.2^{b}	7.2 ± 0.2^{b}	8.2 ± 0.2^{a}
SA_US	2.5 ± 0.3^{a}	1.5 ± 0.3^{c}	2.8 ± 0.2^{d}	2.9 ± 0.2^{c}	5.5 ± 0.2^{b}
STV_US	2.0 ± 0.3^{a}	5.1 ± 0.2^{a}	6.7 ± 0.1^{a}	7.9 ± 0.3^{a}	8.6 ± 0.4^{a}
T_US	2.5 ± 0.2^{a}	5.2 ± 0.3^{a}	7.0 ± 0.3^{a}	7.4 ± 0.3^{ab}	8.4 ± 0.3^{a}
	Yeast log CFU/g				
	T0	T1	T2	T4	T8
SA	2.6 ± 0.2^{a}	1.5 ± 0.2^{c}	2.7 ± 0.12^{d}	1.9 ± 0.5^{c}	4.9 ± 0.2^{b}
STV	2.7 ± 0.2^{a}	3.1 ± 0.2^{b}	5.3 ± 0.2^{c}	7.9 ± 0.3^{a}	8.3 ± 0.3^{a}
T	1.9 ± 0.2^{c}	4.6 ± 0.3^{a}	6.1 ± 0.2^{b}	7.1 ± 0.2^{b}	8.1 ± 0.4^{a}
SA-US	2.1 ± 0.2^{bc}	1.0 ± 0.4^{c}	2.1 ± 0.2^{e}	2.8 ± 0.3^{c}	5.2 ± 0.2^{b}
STV-US	1.9 ± 0.2^{c}	4.6 ± 0.3^{a}	6.6 ± 0.2^{a}	7.8 ± 0.3^{a}	8.2 ± 0.3^{a}
T-US	2.5 ± 0.2^{ab}	5.2 ± 0.3^{a}	6.8 ± 0.3^{a}	7.3 ± 0.3^{ab}	8.3 ± 0.3^{a}

Different letters within the same column indicate statistical differences ($p < 0.05$).