Effect of controlled atmospheres on the quality of white onion (*Allium cepa* L)

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Abstract Onion is one of the oldest and most consumed crops in the world. Its quality deteriorates gradually during prolonged storage. In the present study, white onions of the variety “Sierra Blanca” were stored in a controlled atmosphere (CA) for 7 months. The color, total pungency, microbiological load and total carbohydrates were evaluated. Three treatments were applied: control treatment (CT), regular atmosphere at 2.5 °C without controlled relative humidity (RH); (T1)1% O₂ + 1% CO₂ at 2.5 °C and 60–75% RH and (T2)3% O₂ + 5% CO₂ at 2.5 °C and 60–75% RH. The statistical analysis showed a significant effect of the treatments and storage time in most of the variables analyzed. The CA managed to preserve the quality of the onion during the storage period while the control bulbs exhibited greater deterioration. These increased 2.9 times their level of pungency, had a higher microbial load and showed a very noticeable color change at the end of storage with respect to freshly harvested onions and those stored in a CA. They had a more yellow-green coloration. Both CA treatments were effective in

preserving onion quality, but a more positive effect for T1 than T2 was observed on most of the parameters evaluated.

Keywords *Allium cepa* · Controlled atmosphere · Pungency · Quality

Introduction

Onion (*Allium cepa* L) is one of the oldest and most consumed crops in the world. It is highly valued for its characteristic pungent flavor and is an essential ingredient for cooking in many regions of the world. Bulbs can be used in soups, sauces, condiments, medicine, as seasonings in the preparation of food and in the production of products with high added value as powders, flakes and salts. This vegetable is a seasonal crop, sometimes with overproduction (Nega et al. 2015). Onion is a vegetable of low perishability; however, during storage its quality deteriorates gradually. Its shelf life is influenced by several factors such as dry matter content, pungency, skin color, quality, duration of the dormancy period, fertilization, irrigation regime, duration of cultivation, treatment of sprouting suppressors and fungicides, as well as postharvest factors (harvest method and curing, storage and packaging). The success of preservation also depends on the variety, maturity, cultural practices, loss of moisture, sprouting and diseases caused by pathogens (Nega et al. 2015; Shivakumar and Chandrashekar 2014). Preservation is also influenced by climate conditions during the plant growth stage, by fertilization, especially nitrogen, and photoperiod. Producers, retailers and food companies follow different pre- and postharvest practices in order to protect onion quality during storage. This may include low temperatures, application of mitosis inhibitors and atmosphere with ethylene

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(Sharma et al. 2014). Another practice that can be used in onion conservation for long periods and that is environmentally friendly is controlled atmospheres. This technology is relatively expensive compared to regular storage but adds value to the crop by extending the product marketing period (Chope et al. 2007). However, many changes in the biochemical composition of the onion may occur during storage. These include changes in water content and in the concentration of flavor compounds. These variations may be different between varieties with different amounts of dry matter, soluble solids or pungency (Pöldma et al. 2012). The changes in the quality of the stored onion are due to the catabolism of substrates, mainly of carbohydrates and other phytochemicals. However, its storage offers mainly two advantages. First, it allows removal of the bulbs from adverse climatic conditions, diminishing the opportunity that they cause damage in the culture, and secondly, it provides the best conditions to regulate physiological and metabolic activity and predicts a pattern of future use (Sharma and Lee 2015).

The objective of the present work was to evaluate the behavior of some white onion quality parameters during storage in controlled atmospheres.

Materials and methods

Raw material and storage conditions

White onions (*Allium cepa* L cv. Sierra Blanca) were grown in the South Central region of the State of Chihuahua, Mexico. The vegetable was harvested in June 2014, cured in the field according to regional procedures, then stem and roots were cut. It was subjected to a selection process to standardize sizes and transported to the laboratory for storage in controlled atmospheres (CA). The storage was carried out under conditions of controlled temperature, relative humidity (RH) and atmosphere. Visibly flawless bulbs with an average weight of 196 g and an equatorial diameter of 7.51 cm were used for the study.

In the experiment, three treatments were applied. Controlled treatment (CT): onions were stored at 2.5 °C, regular atmosphere and without RH control. Treatment 1 (T1): onions were stored at $1.0 \pm 0.5\%$ O₂ and $1.0 \pm 0.5\%$ CO₂, 2.5 °C and 60–75% RH. Treatment 2 (T2): onions were stored at $3.0 \pm 0.5\%$ O₂ and $5.0 \pm 0.5\%$ CO₂, 2.5 °C and 60–75% RH. The concentration of the gases was monitored daily with a GCS-250 (Gas Control Systems, Inc, Model GS250, MI, USA) portable O₂/CO₂ analyzer as well as flow, which was obtained with a portable electronic meter (Agilent Technologies model 5067-0223, Wilmington DE, USA). Temperature and RH were also measured daily (Fisher Scientific portable hygrothermometer model

1,166,119, Friendswood TX, USA). The bulbs were distributed in batches of 94 kg for each of the treatments in CA and approximately 150 kg for the CT. Glass flasks of 20 L (12 for each treatment with 40 bulbs each) were used as storage chambers in the CA, which were maintained at a continuous flow of 2 mL/min of the gas mixture corresponding to each treatment. CT onions were stored in fruit and vegetable plastic crates (capacity 42 L). In each experiment, the bulbs were randomly sampled and their quality was analyzed at day zero and then at one-month intervals for 7 months. For the quality analysis, an experimental unit (EU) of five onions was used. For the seventh month of storage, there was no available sample of the control treatment so it was not possible to evaluate the quality of these bulbs in that month.

Quality analysis

Color

This variable was measured using a Konica Minolta DP-400 portable colorimeter (Minolta Co. Ltd. Osaka Japan). Using the equipment, the coordinates of the CIELAB system (L*, a* and b*) were obtained on the surface of each onion (equatorial diameter) of the EU. Where, L* refers to the luminosity of the vegetable using a value of 100 when it is completely white and 0 when it is black; while a* and b* have no limits, but they have positive or negative values. The scale of a* moves from positive values (tends to red +) and negatives (tends to green –), and the scale of b* goes from yellow when it is more positive to blue when the value is more negative. With the obtained coordinates L* a* b* the color space CIE L* C* h° was also obtained. Where C* represents chroma or saturation of the color and h° is the hue angle representing the tone according to the angle on the 360° color wheel, with a red–purple tone at 0°, yellow at 90°, gray–green at 180° and blue at 270°, counterclockwise (McGuire 1992). The chroma was calculated by the following formula (McGuire 1992):

$$C^* = (a^{*2} + b^{*2})^{1/2}$$

The hue angle was obtained as follows (Petropoulos et al. 2015):

$$^{\circ}h = 180^{\circ} + [(\arctan(b^*/a^*)) / 6.2832] * 360$$

Due to $a^* < 0$ and $b^* > 0$. The color change (ΔE^*) was determined according to Korley et al. (2015) using the following formula:

$$\Delta E^* = [(L_0 - L^*)^2 + (a_0 - a^*)^2 + (b_0 - b^*)^2]^{1/2}$$

where L_0 , a_0 and b_0 are the initial values of the fresh onion, or before being stored, and L^* , a^* and b^* are the values obtained each month of storage. According to Chen and Mujumbar (2008), values of ΔE within a range of 0–0.5 indicate a change of color at the trace level, $\Delta E = 0.5$ –1.5 the change is light, $\Delta E = 1.5$ –3.0 the color change is perceptible, $\Delta E = 3.0$ –6.0 the color change is appreciable, $\Delta E = 6$ –12.0 the color change is large and $\Delta E \geq 12.0$ the color change is obvious.

Total pungency (pyruvic acid)

The level of onion pungency was measured by the pyruvic acid formed in the bulbs. The total pungency of the vegetable was determined according to the method reported by Schwimmer and Weston (1961). Quantification of the pyruvic acid was done by a standard curve of sodium pyruvate by preparing a stock solution at 0.1 M, from which dilutions were made from 0.010 to 0.20 $\mu\text{mol/mL}$. Absorbance was measured at 420 nm using a Jenway 6405 UV–Vis spectrophotometer (Jenway Ltd., Essex, UK). A dilution factor of 40X was used and the concentration of pyruvic acid was expressed in $\mu\text{mol/g}$ of fresh tissue.

Total carbohydrates

Total carbohydrates were determined using the Jenway 6405 UV–Vis spectrophotometer (Jenway Ltd., Essex, UK) at 490 nm. The phenol–sulfuric acid method was used according to the technique reported by Pozzo et al. (2005). For quantification, a standard curve from 0 to 1 μg glucose/mL was used and expressed as a percentage of total sugars.

Microbiological analysis

The presence of fungi, yeasts, aerobic mesophiles, total coliforms and *Escherichia coli* on the surface of the onion was determined by means of a rinse with 90 mL of 3 M[®] peptone water. This was done to evaluate microbiological growth on the external part of the vegetable by monitoring each month's growth. Petrifilm 3 M[®] ready-to-use media were used for the analysis. The count of fungi and yeasts was done within 3–5 days and incubated at 25 ± 2 °C. Bacterial counts were done at 48 h and incubated at 35 ± 2 °C. Analyses were done in duplicate. Results were reported as log₁₀ ufc/mL.

Data analysis

A completely randomized design was used for the study. The data were analyzed by analysis of variance to evaluate the effect of treatment and storage time on onion quality

parameters using the SAS statistical package (SAS Inst. Inc. Cary, NC). The means comparison was done using Duncan's test using the same statistical package. The means were accepted as significantly different at a confidence interval of 95% ($p \leq 0.05$). Results were reported as the mean $\pm$ SD.

Results and discussion

Color

Table 1 shows the luminosity (L^*) obtained from the surface of onions stored in controlled atmospheres for 7 months. The statistical analyses showed an effect ($p \leq 0.05$) of the treatment, storage time and the interaction between both factors on the luminosity of the onions. Considering the value of all the months evaluated, on average the onions of T1 showed greater luminosity with a value of 98.212, followed by those of the T2 with 97.842 and the ones with the lowest value were the CT onions with 97.378. These results were higher than those obtained by Muniz et al. (2012) in “CNPH6400” and “Optima” onions. They are very close to the maximum value corresponding to white colors. Other authors have reported lower results in “Crioula Roxa” purple onions (Berno et al. 2014) and in “Roja Ocañera”, “Peruana Inca Alto del Pozo”, “Peruana Inca Abrego” and “Peruana Inca La Playa” red onions (Trujillo et al. 2016). Cardoso et al. (2016) also reported lower values of superficial L^* in “Bola Precoce” onions ($L^* = 67.96$ on average) to those obtained in the present work, reporting that curing had no effect on this parameter.

The onions stored in CA kept their luminosity practically constant throughout the conservation time. The only significant differences were observed in the value of L^* between the bulbs of T1 and T2 until the 7 month of storage, where the onions of T1 were brighter than those of T2. Teixeira and Durigan (2010) also reported that the luminosity of the guava “Pedro Sato” variety remained almost constant during storage in a controlled atmosphere at 1 kPa of O_2 at 12.5 °C. As for the CT onions, they showed a statistical difference in the value of L^* with respect to those stored in a CA after the fifth month of conservation (November), becoming less luminous at the end of storage (December). They had a reduction of 5.5% in the value of luminosity with respect to freshly harvested onions (June). These results are contrary to those obtained by Muniz et al. (2012) who observed an increase in the value of L^* during refrigerated storage of “CNPH6400” and “Optima” onions. These authors pointed out that the fresh mass affects the brightness of the vegetables, reporting a relationship between the loss of this and lower

Table 1 Luminosity and color coordinates a^* and b^* of onions stored in controlled atmospheres for 7 months

Month	Control treatment	(T1) (1% O ₂ + 1% CO ₂)	(T2) (3% O ₂ + 5% CO ₂)
<i>Luminosity (L)</i>			
0	98.71 ± 0.86aA	98.71 ± 0.86aA	98.71 ± 0.86aA
1	98.50 ± 1.05aA	98.09 ± 2.33aA	98.55 ± 0.89aAB
2	97.35 ± 1.43aA	98.32 ± 0.54aA	98.26 ± 0.62aAB
3	97.79 ± 0.84aA	97.21 ± 0.65aA	97.71 ± 0.81aABC
4	97.30 ± 1.43aA	98.01 ± 0.77aA	97.02 ± 0.94aBC
5	97.06 ± 1.53abA	98.79 ± 1.00aA	96.42 ± 2.16bBC
6	93.26 ± 1.27b B	97.62 ± 1.48aA	98.50 ± 0.83aAB
7	–	98.91 ± 0.80aA	97.66 ± 0.72bABC
Average**	97.37b	98.21a	97.84ab
<i>a*</i>			
0	– 1.82 ± 0.45ABC	– 1.82 ± 0.45A	– 1.82 ± 0.45A
1	– 2.36 ± 0.76aBC	– 1.77 ± 0.53aA	– 2.00 ± 0.32aA
2	– 1.36 ± 0.93aAB	– 1.09 ± 0.25aA	– 1.40 ± 0.37aA
3	– 1.08 ± 0.34aA	– 1.55 ± 0.90aA	– 1.33 ± 0.43aA
4	– 1.46 ± 1.00aAB	– 1.46 ± 0.23aA	– 1.62 ± 0.55aA
5	– 1.56 ± 0.46aABC	– 1.78 ± 0.50aA	– 1.87 ± 1.05aA
6	– 2.69 ± 1.39aC	– 1.76 ± 0.44aA	– 1.59 ± 0.52aA
7	–	– 1.49 ± 0.38aA	– 1.65 ± 0.41aA
Average	– 1.71a	– 1.59a	– 1.66 a
<i>b*</i>			
0	10.89 ± 0.81aC	10.89 ± 0.81aAB	10.89 ± 0.81aA
1	11.20 ± 1.51aC	10.59 ± 1.49aAB	11.00 ± 0.97aA
2	11.67 ± 0.72aBC	10.27 ± 0.99aB	10.96 ± 1.49aA
3	11.14 ± 0.57aC	11.70 ± 2.09aAB	10.82 ± 0.96aA
4	12.31 ± 2.22aBC	11.68 ± 0.64aAB	11.98 ± 1.09aA
5	13.79 ± 1.85aAB	12.13 ± 1.365aA	11.88 ± 1.55aA
6	15.92 ± 3.08aA	11.33 ± 0.65bAB	11.77 ± 1.08bA
7	–	11.65 ± 0.81aAB	11.81 ± 0.82aA
Average	12.20a	11.28b	11.38b

Mean ± SD (n = 5)

^{a,b,c}Different lowercase letters in the same row indicate a significant statistical difference ($p < 0.05$) between treatments within each month. ^{A,B,C}Different uppercase letters per column indicate a significant statistical difference ($p < 0.05$) between months of storage within each treatment. **Average of the total months of storage, different lowercase letters in the average indicate a significant statistical difference ($p < 0.05$) between treatments

values for the luminosity of the onions. In another study, Berno et al. (2014) reported a decrease in the value of L^* during the storage of “Crioula Roxa” onion slices, similar to what was observed in the present work.

The value of the coordinate of color, a^* , in all the treatments was negative, which means that there was a tendency of the onions towards a green color. Table 1 shows the results obtained from this parameter in onions stored in a CA for 7 months. Considering the average of the values obtained during all the months of storage, there was no statistical difference ($p \geq 0.05$) between treatments. However, the highest value of color a^* corresponded to CT ($a^* = -1.71$), followed by T2

($a^* = -1.66$) and then by T1 ($a^* = -1.59$). The control onions had a greener color than those treated in a CA. Similar results were obtained by Cardoso et al. (2016) in “Bola Precoce” onions, who reported that this parameter is affected by curing, obtaining a higher value ($a^* = -2.32$) for onions that were cured in the field than for those that were cured with artificial hot air ($a^* = -2.05$) and with artificially heated and dried air ($a^* = -1.76$). In another study, Trujillo et al. (2016) reported higher values than those obtained in the present work in “Roja Ocañera” ($a^* = 20.24$), “Peruana Inca Alto del Pozo” ($a^* = 21.85$), “Peruana Inca Abrego” ($a^* = 22.50$) and “Peruana Inca La Playa” ($a^* = 21.75$) onions.

On the other hand, a significant effect ($p \leq 0.05$) of the storage time was obtained in the coordinate of color a^* . On average, the onions of the three treatments tended to be greener in the month of July, that is to say the first month of being stored. Then this value decreased in the second month (August) and remained almost constant for the bulbs of T1 and T2 until the end of the seventh month of storage, while in the CT onions it increased significantly ($a^* = -2.69$) to the sixth month of storage.

The values of the coordinate of color b^* were positive for the three treatments. They showed a tendency towards yellow. Table 1 shows the values of this parameter. The statistical analysis showed a difference ($p \leq 0.05$) between treatments and storage time. On average, CT onions had the highest b^* value ($b^* = 12.20$), followed by T2 ($b^* = 11.38$) and then T1 ($b^* = 11.28$). However, the difference between the two treatments in controlled atmospheres was not significant. These results were greater than those reported by Trujillo et al. (2016) in “Roja Ocañera” ($b^* = 2.61$), “Peruana Inca Alto del Pozo” ($b^* = 2.40$), “Peruana Inca Abrego” ($b^* = 2.99$) and “Peruana Inca La Playa” ($b^* = -1.61$) onions. Likewise, our results were lower than those obtained by Cardoso et al. (2016) on the surface of “Bola Precoce” onions.

The storage time affected the value of b^* in the onions analyzed. In the CT bulbs, the value of b^* increased through the months of conservation. This increased from the first month of being stored, increasing up to 46% at the end of the conservation time with respect to the freshly harvested onions. On the other hand, the onions of T1 increased the value of b^* from the third month of storage (September), while those of T2 did so from the first month (July). The coloration of both remained almost constant throughout the storage time. They had much less increase at the end of storage than that obtained in the CT onions compared to the freshly harvested onions (with an increase of 6.9% for T1 and 8.4% for T2 without a significant difference between them). Muniz et al. (2012) also reported a trend towards light yellow coloration in “Optima” onions during their storage in refrigeration for 60 days.

Chroma defines the intensity or spectral purity of the color. It may go from the gray tones, pale, muted to the strongest and lively. It defines the degree of color, while hue angle is the tone or dye, and is characterized by the length of radiation wave and allows one color to be different from another (Mathias-Rettig and Ah-Hen 2014).

Table 2 presents the results of chroma and hue angle measurements on onions stored for 7 months in a CA. The statistical analysis showed a significant effect ($p \leq 0.05$) of the treatment and the storage time on the value of the chroma, while in the hue angle there was only a significant effect of the storage time but not of the treatment. CT onions had a higher average chroma value than those stored

in a CA showing a value of 12.349, while for T1 onions it was 11.404 and for those of T2 of 11.511. There was no significant difference between the CA treatments.

These values correspond to more neutral colors, according to Cardoso et al. (2016) who pointed out that the chroma defines the intensity of color, taking values close to zero for neutral colors and around 60 for bright colors. According to Petropoulos et al. (2015), the chroma depends on the variety and type of tissue of the onion. These authors reported different values of this parameter in fresh peel and pulp of “Vatikiotiko”, “Creamgold”, “Sivan F1” and “Red Cross” onions. The chroma values of the CT onions tended to increase throughout the storage time, showing an increase of 46.2% from the beginning to the end of the conservation. While in the bulbs of T1, there was no significant difference between the months of storage except for the second month (August), in which this parameter showed a reduction. It increased in the fifth month of storage (November). In the onions of T2, the results showed no significant difference in all the months of conservation. Berno et al. (2014) also reported a gradual increase in chromaticity in minimally processed onions stored in refrigeration for 15 days, obtaining an increase of this parameter of 50% at the end of the conservation period.

The hue angle values were in the range of 95.50–101.98 (Table 2), which denotes a yellowish color for the onions analyzed, possibly due to the greenish coloration that the bulbs presented on their surface in the three treatments. Ahmed et al. (2015) reported that the exposure of the onions to direct sunlight increased the percentage of bulbs with green color of the “Fadasi”, “KamLeen Yellow” and “Baftaim” varieties due to chlorophyll biosynthesis. This may explain the coloration of the onions analyzed in the present study, which were cured directly in the field and exposed to direct sunlight. During storage, they continued to be exposed to artificial light during the measurement of the concentration of gases inside of the cameras (glass bottles of 20 L).

Statistical analysis showed no differences in the hue angle between treatments but did show a difference between months of storage. In CT onions, this parameter decreased from the second month of storage, then remained practically constant until the sixth month of storage. It then increased again to levels similar to that shown in fresh onions. In the onions of T1 and T2, this parameter also showed a downward trend from the second month of storage and remained almost constant until the end of the conservation period. Similar results were obtained by Viškelis et al. (2012), who did not observe a significant change in hue angle during the storage of green onions of the “Parade” variety stored for 20 days at 0 °C and 10% CO₂. However, their hue angle values were higher than

Table 2 Chroma and hue angle of onions stored in controlled atmospheres for 7 months

Month	Control treatment	(T1) (1% O ₂ + 1% CO ₂)	(T2) (3% O ₂ + 5% CO ₂)
<i>Chroma</i>			
0	11.05 ± 0.86aC	11.05 ± 0.86aAB	11.05 ± 0.86aA
1	11.47 ± 1.53aBC	10.74 ± 1.53aAB	11.18 ± 0.97aA
2	11.78 ± 0.72aBC	10.33 ± 1.00aB	11.05 ± 1.53aA
3	11.19 ± 0.60aC	11.82 ± 2.16aAB	10.90 ± 0.99aA
4	12.41 ± 2.33aBC	11.77 ± 0.66aAB	12.10 ± 1.12aA
5	13.88 ± 1.86aAB	12.26 ± 1.40aA	12.04 ± 1.68aA
6	16.16 ± 3.27aA	11.48 ± 0.63bAB	11.88 ± 1.14bA
7	–	11.76 ± 0.85aAB	11.93 ± 0.85aA
Average*	12.34a	11.40b	11.51b
<i>Hue angle</i>			
0	99.42 ± 1.86aAB	99.42 ± 1.86aA	99.42 ± 1.86aAB
1	101.98 ± 3.41aA	99.38 ± 2.10aA	100.34 ± 1.83aA
2	96.65 ± 4.51aB	96.06 ± 1.03aB	97.22 ± 0.93aAB
3	95.51 ± 1.44aB	97.38 ± 3.33aAB	96.95 ± 1.88aB
4	96.31 ± 3.22aB	97.11 ± 0.91aAB	97.65 ± 2.26aAB
5	96.50 ± 1.81aB	98.25 ± 1.72aAB	98.63 ± 3.81aAB
6	99.23 ± 2.80aAB	98.88 ± 2.38aAB	97.57 ± 1.72aAB
7	–	97.21 ± 1.51aAB	97.94 ± 1.74aAB
Average	97.86a	97.96a	98.23a

Mean ± SD (n = 5)

^{a,b,c}Different lowercase letters in the same row indicate a significant statistical difference ($p < 0.05$) between treatments within each month. ^{A,B,C}Different uppercase letters per column indicate a significant statistical difference ($p < 0.05$) between months of storage within each treatment. *Average of the total months of storage, different lowercase letters in the average indicate a significant statistical difference ($p < 0.05$) between treatments

those obtained in the onions analyzed in the present work. According to Petropoulos et al. (2015), the hue angle depends on the variety and type of onion tissue. These authors reported different values of this parameter in fresh peel and pulp of “Vatikiotiko”, “Creamgold”, “Sivan F1” and “Red Cross” onions.

The color changes (ΔE) induced by storage are presented in Table 3. Statistical analysis showed an effect ($p \leq 0.05$) of the treatment, storage time and the interaction between both factors. On average, the CT onions had the highest ΔE , followed by those of T1 and finally those of T2, with no differences between the CA treatments. The storage time had a very significant effect on the ΔE of the CT onions, which showed an upward trend from the first month of storage. The change is very appreciable (ΔE 6.0–12) in the fifth month of storage, according to the scale reported by Chen and Mujumbar (2008). Based on this same scale, the onions conserved in a CA also showed a perceptible change in their color (ΔE 1.5–3.0), observing a tendency to increase throughout the months of conservation. They then decrease at the end of the experiment. Results similar to those found in CT onions were reported by Petropoulos et al. (2016) in “Sivan F1”, “Red Cross”,

“Vatikiotiko” and “Creamgold” onions stored 260 days at 5 and 25 °C. The biggest change being for the higher temperature and for the “Sivan F1” variety (ΔE 6.0–12). Modified atmospheres also induced a detectable ΔE (ΔE 1.45) in “Parade” green onion stored for 20 days at 0 °C and 10% CO₂ (Viškelis et al. 2012).

Total pungency (pyruvic acid)

The pungency is an important quality feature of onion. Abrameto et al. (2010) described the measurement of pyruvic acid as a model compound to analyze this parameter. Statistical analysis showed a difference ($p \leq 0.05$) between treatments, months of storage and the interaction between both factors on the total pungency level of the onion. The CA had a retarding effect on the development of this parameter, as seen in Fig. 1. The onions of the CT presented an average of 2.3 μmol of pyruvic acid/g of fresh onion, followed by the T2 bulbs with 1.65 μmol of acid pyruvic/g and finally those of T1 with 1.5 μmol of pyruvic acid/g. These results are lower than those reported by Anthon and Barrett (2003) on “Sweet Vidalia” and “Sweet Melody” onions, and for

Table 3 Color change (ΔE) of onions stored in controlled atmospheres for 7 months

Month	Control treatment	(T1) (1% O ₂ + 1% CO ₂)	(T2) (3% O ₂ + 5% CO ₂)
1	1.80 ± 0.68aB	1.927 ± 1.53aAB	1.801 ± 0.62aB
2	2.24 ± 1.01aB	1.92 ± 0.51aAB	2.04 ± 0.77aB
3	1.98 ± 1.00aB	3.02 ± 1.33aA	2.05 ± 1.09aB
4	3.12 ± 1.64aB	1.95 ± 0.72aAB	2.26 ± 1.76bB
5	3.82 ± 2.10aB	2.13 ± 1.27aAB	3.88 ± 1.31abA
6	7.99 ± 1.95aA	2.07 ± 0.98bAB	1.10 ± 0.55bB
7	–	1.14 ± 0.48aA	1.90 ± 0.60aB
Average*	3.17a	2.18b	2.02b

Mean ± SD (n = 5)

^{a,b,c}Different lowercase letters in the same row indicate a significant statistical difference ($p < 0.05$) between treatments within each month. ^{A,B,C}Different uppercase letters per column indicate a significant statistical difference ($p < 0.05$) between months of storage within each treatment. *Average of the total months of storage, different lowercase letters in the average indicate a significant statistical difference ($p < 0.05$) between treatments

Fig. 1 Total pungency of onions stored in controlled atmospheres for 7 months. ^{abc}Different letters indicate a significant statistical difference ($p < 0.05$) between treatments within each month (control samples not available for the seventh month)

those found by Coolong and Randle (2003) on “Granex 33” onions, who observed that the level of pungency tends to increase with the temperature of growth of the crop. Likewise, the onion analyzed in the present work is classified as sweet because it contains 0–3 μmol of pyruvic acid/g according to Dhumal et al. (2007). These low pungency onions are preferred for fresh consumption in countries such as the United States of America, Japan and many European countries (Mallor et al. 2011).

The storage time had a significant effect on the level of the pungency of the onions of the CT. This showed an upward trend throughout the months of conservation with a range from 1.24 to 3.07 μmol of pyruvic acid/g fresh wt. It reached its maximum concentration in the fourth and fifth months of storage with an increase of 2.9 times its concentration with respect to freshly harvested onions. This same trend was observed in the bulbs preserved in CA. However, the increase was much lower than that obtained in the bulbs of the CT. The change was more noticeable in

the onions of T2, which showed a range from 1.25 to 1.99 μmol of pyruvic acid/g fresh wt with the highest concentration in the sixth month of conservation (December). The onions of T1 also showed an increase in their pungency level with a range from 1.25 to 1.77 μmol of pyruvic acid/g fresh wt, reaching its highest concentration in the fifth month of storage (November). It then reduced it to levels like those obtained in freshly harvested onion at the end of storage.

An increase in pungency due to onion storage has been previously reported (Uddin and MacTavish 2003; Sharma and Lee 2015). Abayomi and Terry (2009) also observed an increase in the pungency level in onions of “SS1” and “Renata” varieties stored in CA (4 °C, 3.03 kPa of CO₂ and 5.05 kPa of O₂) for 31 and 8 months, respectively. This increase was associated with the breakdown of dormancy and initiation of sprouting even when buds were not visible. It was also related to the change in dry matter content due to weight loss and tissue dehydration during prolonged storage of the vegetable (Sharma and Lee 2015). Likewise, it has been seen that the increase in the concentration of alk(en)yl cysteine sulfoxide compounds that occurs during conservation influences this parameter (Kopsell et al. 1999; Shivakumar and Chandrashekar 2014).

Other authors, such as Uddin and MacTavish (2003), have reported a decrease in the level of pungency during storage in a CA (2% O₂ + 2% CO₂ and 2% O₂ + 8% CO₂) for “Hysam” onions. This was associated with a reduction in the precursors of alkyl (en)yl cysteine sulfoxide compounds present prior to cell disruption, to a decrease in the enzymatic activity or to changes in the individual precursors. This same behavior was observed by Pöldma et al. (2012) in “Hercules”, “Hyred” and

“Exhibition” onions stored in an atmosphere with 1% O₂, 5% CO₂ and 2 °C for more than 8 months.

Microbiological analysis

The results of the microbiological analysis on the surface of the onion are presented in Table 4. The statistical analysis showed a difference ($p \leq 0.05$) between treatments, storage time and in the interaction between both factors on the counting of mesophilic aerobic bacteria, total coliforms, fungi and yeasts. The bacterium *Escherichia coli* was not found in any of the samples analyzed. This bacterium is indicative of fecal contamination and

normally only inhabits the human or animal intestine. This is considered an excellent indicator of the presence of other microbes that can cause diseases such as cholera, typhoid fever, shigellosis, amebiasis and hepatitis (Rivera-Jacinto et al. 2009). Due to the absence of this bacterium, the analyzed onions can be considered of good sanitary quality and submitted to good management during production. This microorganism can reach the vegetable from various sources such as irrigation water, fertilizers, or by the personnel who manipulate it.

Mesophilic organisms are also indicators of food quality and reflect whether the sample was exposed to some type of contamination and if there are favorable conditions for

Table 4 Microbiological counts from the surface of whole onions stored in controlled atmospheres for 7 months

Month	Control treatment	(T1) (1% O ₂ + 1% CO ₂)	(T2) (3% O ₂ + 5% CO ₂)
<i>Fungi and yeasts log 10 (ufc/mL)</i>			
0	0.00 ± 0.00a C	0.00 ± 0.00aE	0.00 ± 0.00aB
1	1.00 ± 1.41aC	0.00 ± 0.00bE	0.00 ± 0.00bB
2	3.00 ± 0.00bB	3.30 ± 0.0 aC	0.00 ± 0.00cB
3	6.00 ± 0.00aA	2.00 ± 0.00cD	5.06 ± 0.02bA
4	4.03 ± 0.05aB	2.15 ± 0.21bD	0.00 ± 0.00cB
5	–	5.00 ± 0.00aA	5.00 ± 0.00aA
6	–	4.38 ± 0.00aB	0.00 ± 0.00bB
7	–	0.00 ± 0.00bE	1.00 ± 1.41aB
Average*	2.81a	2.10b	1.38c
<i>Mesophilic aerobic bacteria log 10 (ufc/mL)</i>			
0	5.12 ± 0.03aB	5.12 ± 0.03aA	5.12 ± 0.03aB
1	4.79 ± 0.29aB	3.95 ± 0.06bCD	4.01 ± 0.08bD
2	6.00 ± 0.14aA	4.43 ± 0.05bB	4.34 ± 0.02bC
3	6.20 ± 0.03aA	4.93 ± 0.02bA	6.16 ± 0.02aA
4	4.31 ± 0.01aC	3.80 ± 0.28abD	3.45 ± 0.21b E
5	–	0.00 ± 0.00bE	4.00 ± 0.00aD
6	–	3.99 ± 0.12bCD	4.53 ± 0.12aC
7	–	4.15 ± 0.06aC	3.84 ± 0.08aD
Average	5.29a	3.80c	4.43b
<i>Total coliforms log 10 (ufc/mL)</i>			
0	3.07 ± 0.10a E	3.07 ± 0.10aAB	3.07 ± 0.10aD
1	3.30 ± 0.03aD	2.30 ± 0.00bBC	0.00 ± 0.00cE
2	5.58 ± 0.01a A	1.00 ± 1.41abDE	2.96 ± 0.26 bD
3	5.31 ± 0.16bB	3.52 ± 0.08cAB	5.80 ± 0.08aA
4	4.05 ± 0.01aC	3.35 ± 0.01bAB	0.00 ± 0.00cE
5	–	4.00 ± 0.00aA	0.00 ± 0.00bE
6	–	2.00 ± 0.00bCD	3.68 ± 0.02aB
7	–	0.00 ± 0.00bE	3.35 ± 0.04aC
Average	4.26a	2.40b	2.35b

Mean ± SD (n = 5)

^{a,b,c}Different lowercase letters in the same row indicate a significant statistical difference ($p < 0.05$) between treatments within each month. ^{A,B,C}Different uppercase letters per column indicate a significant statistical difference ($p < 0.05$) between months of storage within each treatment. *Average of the total months of storage, different lowercase letters in the average indicate a significant statistical difference ($p < 0.05$) between treatments

the multiplication of microorganisms that cause disease or pathogens, as well as the presence of organic matter (García-Gómez et al. 2002). The analysis of fungi and yeasts, aerobic mesophiles and total coliforms showed great variability in the counts of these microorganisms through the months of storage in onions of the three treatments evaluated. On average, the CT onions had higher fungal and yeast counts as well as aerobic mesophiles and total coliforms than those of T1 and T2; while comparing the latter, the bulbs of T2 had the highest count of aerobic mesophiles. The above denotes the effect of the atmosphere on microbial growth, indicating greater development in atmospheres with higher oxygen contents. This effect was also reported by Baskaran et al. (2015) on minimally processed onions stored in a modified atmosphere, suggesting an effect of the composition of the gas on growth of these microorganisms on the vegetables.

Total carbohydrates

For determination of total carbohydrates, the method of Dubois et al. (1956) was used, which has been shown to be simple, stable and reproducible, managing to shorten the time needed for the determination of carbohydrates compared with other colorimetric methods (López-Legarda et al. 2017). The total carbohydrate contents obtained in the evaluated onions are presented in Table 5. On average, there was a statistical difference ($p \leq 0.05$) between treatments, storage time and the interaction between both factors. In general, the CT bulbs showed the lowest content of total carbohydrates with 3.422%, followed by those of T2 with 4.466% and then those of T1 with 4.590%. There was no significant difference between CA treatments. The results obtained from freshly harvested onions or at the

beginning of the storage (2.540%) were higher than the one reported by Pozzo et al. (2005) in onions of the varieties, “Cobrizza INTA” (1.77%), “Valcatorce INTA” (2.19%), “Navideña INTA” (1.39%) and “Valuno INTA” (1.21%) at the start of storage for 4 months.

In general, an increase in the total carbohydrate content of the onion was observed during storage, being more evident in bulbs stored in a CA. In the CT bulbs, the highest values were presented in the second, fourth and fifth months of storage. In the remaining months, the difference between them was not significant. Likewise, in T1 the maximum value was presented in the second month of storage and in the remaining months the total carbohydrate content was statistically equal. In the T2 bulbs, more fluctuation in the value of this parameter was obtained, the highest concentration being observed in the fifth month of storage. Similar results were reported by Pozzo et al. (2005), who found an increase in total sugars in all varieties evaluated during storage for four months at room temperature, as happened in the present study. In this regard, Havey et al. (2004) reported that the increase of sugars in onions with high solids contents might be due to the high availability of sucrose for the synthesis of fructans, which accumulate in the bulbs and reduce water content, thus increasing the concentration of soluble sugars in the vegetable. The increase of total sugars during storage in a CA has also been seen in other vegetables. Loyola et al. (2003) also reported a higher content of these compounds in potatoes of the “Ranger Russet” variety stored in a regular atmosphere compared to those maintained with an atmosphere of 5% of CO₂ and 12% of O₂.

Table 5 Total carbohydrate content (%) of onions stored in controlled atmospheres

Month	Control treatment	(T1) (1% O ₂ + 1% CO ₂)	(T2) (3% O ₂ + 5% CO ₂)
0	2.54 ± 0.80aB	2.54 ± 0.80aB	2.54 ± 0.80aC
1	4.60 ± 0.63aA	4.43 ± 0.54aB	4.50 ± 1.26aAB
2	2.87 ± 0.28bB	7.88 ± 2.67aA	5.53 ± 0.50abAB
3	4.43 ± 1.12aA	3.21 ± 0.64aB	3.62 ± 0.55aBC
4	4.94 ± 1.04aA	4.77 ± 0.755aB	4.70 ± 1.36aAB
5	2.42 ± 0.66bB	4.31 ± 0.71aB	6.06 ± 1.19aA
6	2.13 ± 0.53aB	4.60 ± 2.23aB	3.74 ± 0.40aBC
7	–	5.01 ± 1.58aB	5.01 ± 1.55aAB
Average*	3.42b	4.59a	4.46a

Mean ± SD (n = 5)

^{a,b,c}Different lowercase letters in the same row indicate a significant statistical difference ($p < 0.05$) between treatments within each month. ^{A,B,C}Different uppercase letters per column indicate a significant statistical difference ($p < 0.05$) between months of storage within each treatment. *Average of the total months of storage, different lowercase letters in the average indicate a significant statistical difference ($p < 0.05$) between treatments

Conclusion

The controlled atmospheres managed to conserve the quality of “Sierra Blanca” onions during 7 months of storage. Both T1 (1% O₂ + 1% CO₂, 2.5 °C and 60–75% RH) and T2 (3% O₂ + 5% CO₂ at 2.5 °C and 60–75% RH) conserved the luminosity of the vegetable and induced smaller changes in color (ΔE) with respect to the CT and freshly harvested onions. They also delayed the development of total pungency and presented lower microbial loads. However, they had higher total carbohydrate contents. The CT onions exhibited a greater deterioration in their quality during the conservation time, they increased their pungency level, showed a reduction in their brightness value, increased the green and yellow coloration and presented a very noticeable color change at the end of storage compared to onions freshly harvested or preserved in CA. Both CA treatments were effective in preserving onion quality, but a more positive effect of T1 than T2 was observed on most of the parameters evaluated.

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