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REGULAR ARTICLE

Effect of prolonged storage in controlled atmospheres on the conservation of the onion (*Allium cepa* L.) quality

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ABSTRACT

The onion is a low perishability product, but in long-term storage, postharvest losses occur due to some phytopathological and sprouting factors. The aim of this study was to evaluate the effect of storage in controlled atmospheres (CA) on onion cultivar "Sierra Blanca" for seven months. The onions were subjected to three treatments: 1 % O_2 + 1 % CO_2 (T1), 3 % O_2 + 5 % CO_2 (T2), both at 2.5 °C and 60-75 % relative humidity (RH), and in environmental atmosphere (control treatment, CT) at 2.5 °C without controlled RH. Changes in enzymatic pyruvic acid (EPA) content, total soluble solids (TSS), dry matter (DM), firmness and sprouting during storage were evaluated. The results showed effect ($p \leq 0.05$) of treatment and storage time on all parameters. Changes in preserved bulbs in CA were minimal compared to those in the CT. The EPA was reduced on T1 onions while in T2 and CT onions it was increased at the end of storage. The TSS and firmness decreased in the three treatments, DM remained constant in T1 and T2 onions and in CT onions decreased in the sixth month by 19 %. T1 and T2 onions showed no sprouting, while CT onions, presented internal sprouts in 20 % of sampled bulbs, reaching 100 % from the third month till the end of storage. In conclusion, storage in CA is the best way to preserve the quality of onion "Sierra Blanca" for seven months, which is evidenced by the positive changes in quality.

Keywords: Controlled atmosphere; Onion; Sprouting; Pungency

INTRODUCTION

The technology of controlled atmospheres (CA) consists of storing fruits and vegetables in a refrigerated environment, in which the initial atmosphere (characterized by an approximate concentration of 21 % O_2 and 0.03 % CO_2) is replaced by an oxygen-poor and rich in carbon dioxide atmosphere, maintaining precise control of the concentration of these gases during storage (Graell and Ortiz, 2003). The metabolic activity in fruits and vegetables continues after the harvest, the CA are able to reduce the rate of respiration, inhibit the ethylene action and production, slow the ripening process and keep the nutritional quality of the products. If the processes of respiration, transpiration and ethylene production are not controlled and progress in an excessive way, they will cause the vegetables to ripen rapidly and their tissues will soften and wilt, considerably reducing its quality (Kader, 1994). Therefore, the CA delayed products senescence and they maintain their optimum state of maturation until consumption.

The scientific basis for application of CA in the storage of fruit and vegetables has been the subject of several investigations and it has evolved enormously, some of the science dates as far back as 200 years ago, but it was refined and applied commercially for the first time in the middle of the twentieth century (Thompson, 2010). Commercially this has been used for apples and pears because of its special adaptation to the CA conditions. But his effect has also been assessed in the conservation of other fruits such as the pitahaya (Magaña-Benítez et al., 2010); papaya (Martins and de Resende, 2013); mamey sapote (Martinez-Morales et al., 2004); blackberry (Brackmann et al., 2016); avocado, banana, mango and pineapple; and on a more limited basis in custard apple, lychee and rambutan (Kader,

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1994). It has also been used for the control of *Salmonella typhimurium* in the 'Cantaloupe' (Landa et al., 2009). In vegetables, it was applied to tomato storage (López et al., 2011), in spinach, in quality conservation and shelf life extension (Martinez-Damian and Cantwell de Trejo, 2002) and onions (Smittle, 1988; Yamashita et al., 2009). On these ones some research has been done in order to obtain their physicochemical characteristics and antioxidant capacity (Yalcin and Kavuncuoglu, 2014; Yang et al., 2004; Ng et al., 2000). In addition to, increase their shelf life and preserve their quality (Kaveri and Thirupathi, 2015; Põldma et al., 2012; Yoo et al., 2012; Melo et al., 2012, Chope et al., 2006; Uddin and MacTavish, 2003). During their collection, handling, transport, packaging and storage, onions are exposed to various treatments and environmental conditions that can affect their attributes of quality and physiological characteristics. These effects could be responsible for several reactions and stress, causing important biochemical changes on the bulb tissues (Benkeblia and Varoquaux, 2003). The onion classifies in a range of low perishability due to its low rate of respiration (Kader, 2002). In addition, after the harvest they enter into a natural state of dormancy what favors their preservation. Endogenous hormones control this phenomenon. It is variable depending on the cultivar and environmental factors, in particular the temperature, which can extend it or shorten it (Sharma et al., 2016). However, during storage, especially during long periods, losses of marketable bulbs are recorded by either sprouting, rooting, decay, weight-loss or phytopathological damage (González et al., 2005). Long-term storage also may affect significantly both physical appearance and chemical composition of dry bulbs (Sharma et al., 2014).

Onions storability depend of various factors such as the cultivar, and pre-harvest and postharvest conditions. In general, long day cultivars are less susceptible to sprouting and post-harvest diseases than short day cultivars. Postharvest conditions and most importantly storage conditions (temperature, relative humidity and air composition) are essential factors for controlling and minimizing water losses, and consequently allowing for prolonging storage duration (Petropoulos et al., 2016b).

The onions commercial storage in a CA allows offering quality products to the market in times of short supply and high prices, satisfying the demand that exists throughout the year. Some researchers used this technology and obtained good results (Garba et al., 2014; Põldma et al., 2012). CA technology has been studied extensively on a wide range of products for approximately 50 years, the results showed considerable variations between each of them and each cultivar; therefore, the ideal combinations in O_2 and CO_2 needs to be determined experimentally for each case (Piña-Dumoulín et al., 2001).

The aim of the present study was to evaluate the effect of storage under two conditions of controlled atmosphere on various quality parameters of onion (*Allium cepa L*) cultivar "Sierra Blanca" stored for a period of seven months.

MATERIALS AND METHODS

Reagents

In this work, the following chemical reagents were used: Water (JT Baker. Avantor Performance Material S.A de C.V. Xalostoc Edo. de México); trichloroacetic acid crystal (JT Baker. Avantor Performance Material Inc. Center Valley, PA); 2,4-dinitrophenylhydrazine (Fermont. Chemicals Products Monterrey S. A de C.V. Monterrey N.L. México); sodium hydroxide (Macron Chemicals, Avantor Performance Material Inc, Suecia); and hydrochloric acid (JT Baker, Avantor Performance Material S.A de C.V. Xalostoc Edo. de México).

Sodium pyruvate (JT Baker, Avantor Performance Material Inc, China) was used to construct a standard curve.

Samples and storage conditions

For the study white onion (*Allium cepa* L.) cultivar "Sierra Blanca" (Gowan seeds S. A de C. V, Mexicali Mexico) was used, this cultivar was grown in the South Center of Chihuahua, Mexico. A local farmer donated the onions. The onions were harvested in June 2014, they were cured in the field in accordance with regional procedures, the foliage was removed leaving about 2 cm of stem and root, then outer layers and neck were allowed to dry perfectly. The bulbs were placed in polypropylene packaging with open tissue for transport. The onion was previously selected for uniform size before being transported to the laboratory to be stored in controlled atmospheres (CA). The experiment was carried out from June 2014 to January 2015.

CA storage was made at laboratory, for that, we developed a specific device, which distributes the gas mixture. CO_2 and nitrogen were obtained from commercial cylinders and oxygen was provided by compressed air generated by a commercial compressor.

Twenty L glass containers were used as storage chambers with airtight lids equipped with two tubes that functioned as the gas entrance and exit. The containers were connected to the gas distributor head to inject the desired gas mixture and were placed inside a refrigerator, which was protected against the entrance of light to prevent damage to the vegetable.

Three storage conditions were used in the study (treatments): 1) Control treatment (CT): The onion was stored in ambient air (approx. 21 % O_2, 0.03 % CO_2), without control of relative humidity (RH), 2) Treatment 1 (T1): 1± 0.5 % O_2 + 1± 0.5 % CO_2, 3) Treatment 2 (T2): 3± 0.5 % O_2 + 5± 0.5 % CO_2. The temperature used in the three treatments was 2.5 °C and RH to T1 and T2 was 60-75 %.

Prior to storage, it was verified that the onions were clean, healthy and flawless. After that, 40 bulbs were placed into each container. For storage in CA, twelve containers were used for each treatment and the CT onions were stored in fruits and vegetable plastic crates (capacity 42 L).

The storage chambers were connected to the gas distributor using rubber hoses made of latex (model 2020), and stayed with a continuous flow (2 mL/min) of the desired gas mixture, which passed through the container with silica gel or a humidifier, as this was required to maintain the relative humidity for storage.

Gas concentrations were measured with an O_2/CO_2 analyzer, (Gas Control Systems, Inc., Model GCS250, MI, USA). The gas flow was measured with a portable electronic meter (model 5067-0223 Agilent Technologies, Wilmington DE, USA) and relative humidity and temperature were measured with a portable digital hydro-thermometer (Fisher Scientific, model 1166119, Friendswood TX, USA). The measurements were made four times a day during the seven months of storage.

First, the quality of freshly harvested onions was evaluated; then, stored onions were evaluated every month. Each month random samples of bulbs were taken out from CA and left to balance with the laboratory environmental conditions for 3 to 5 h, other random samples were taken for quality assessment, and the same was done with the CT samples. The physicochemical analyses were carried out in triplicate; an experimental unit (EU) of five bulbs was used for analysis. In this study, a total of 280 bulbs were used for each treatment.

Evaluation of the quality

Pungency (pyruvic acid)

The onion pungency level was measured through the pyruvic acid formed in the bulbs. The total pyruvic acid (TPA) content was determined as well as the native pyruvic acid (NPA) and enzymatic pyruvic acid (EPA) according to the reported method by Schwimmer and Weston (1961). The TPA was obtained by cutting every EU onions in cubes to obtain a compound sample, from this sample were taken in triplicate 20 g of onion and then they were processed in a blender with 20 mL of distilled water. The extract obtained was filtered using gauze and was left to stand for 10 min, then it was stirred to re-suspend solid tissue and a 0.5 mL aliquot was taken. It was mixed with 1.5 mL of 5 % trichloroacetic acid and left to stand for 1 h. After this, 18 mL of distilled water was added, and 1 mL of the solution was taken and placed in a test tube, then 1 mL of 2, 4-Dinitrophenylhydrazine and 1 mL of distilled water were added. After that, the tube with solutions was placed in a water bath at 37°C for 10 min, and then the reaction was stopped by adding 5 mL of NaOH 0.6 N.

Absorbance of each sample was measured with a spectrophotometer UV-Vis Jenway 6405 (Jenway Ltd., Essex, UK) set at 420 nm. The content of NPA was obtained following the same procedure as the TPA but on onion previously cooked in a microwave on high power in a time of 1 sec for each g of sample. The content of EPA was obtained by subtracting the NPA from the TPA.

A dilution factor of 40X was used and the concentration of pyruvic acid was expressed in µmoles/g FW (fresh weight).

The quantification was done through a sodium pyruvate standard curve preparing stock solution at 0.1 M, from which dilutions were made from 0.010-0.20 µmol/mL.

Total soluble solids

The total soluble solids (TSS) were determined using a digital refractometer (Atago, USA Inc.) and they were expressed in °Brix. For the measurement of this variable, EU onions were sliced just in the center, they were chopped in small cubes, they were mingled and a compound sample was obtained, from this sample a few juice drops were extracted and placed on the refractometer prism in order to obtain the direct reading.

Dry matter

EU onions were chopped and mixed; from this composite sample, 10 g were taken and dried in an oven (Felisa, model Fe-291, Feligneo S. A de C. V. Zapopan Jal. México) at 70 °C for 48 h to obtain a constant weight, then, the dry matter of fresh weight was determined as a percentage.

Sprouting percentage

EU onions were cut into halves through the equatorial diameter and those who presented internal sprouting were counted; the result was reported as a percentage based on the number of analyzed onions.

Firmness

Firmness was determined with a portable penetrometer (Wilson model 327 FT). The first onion layer was removed with the penetrometer knife and the whole vegetable was penetrated in two opposite points of the equatorial area of the bulb, then the average of the two measurements were taken, an 8 mm stainless steel punch was used.

Statistical analysis

A completely randomized design was used for research. An analysis of variance was performed to assess the effect of treatments and months of storage on the quality parameters of the onion using the statistical package SAS (SAS Inst. Inc. Cary, NC.). The means comparison was made through Duncan's test using the same statistical package. The means were accepted as significantly different at the 95 % of confidence intervals ($p \leq 0.05$). The results were reported as the mean ± standard deviation.

RESULTS AND DISCUSSION

Onions stored in controlled atmospheres (CA) (T1 and T2) managed to keep the characteristics of commercial quality during 7 months of conservation, not noted external sprouting and no issuance of roots. Similar results were found by Smittle (1988) on the onion cultivar "Granex" in which more than 99 % of the bulbs were marketable after 7 months of storage at 1 °C and 5 % CO_2 + 3 % O_2. As well as by Yamashita et al. (2009) who found that the concentration of 1 % O_2 and 1 % CO_2 to 1 °C and 80 % RH inhibited the sprouting and issuance of roots of onion bulbs stored by 196 days.

Pungency

The pungency is reported as enzymatically formed pyruvic acid (EPA). According to Yoo et al. (2016), the method used for the evaluation of the EPA is based on the measurement of pyruvic acid, which is formed when the onion cells are ruptured and the enzyme alliinase reacts with the flavor precursor namely S-alk (en) yl-l-cysteine sulfoxides (ACSOs).

Statistical analysis showed differences ($p \leq 0.05$) in the content of EPA between treatments, months of storage and the interaction between both factors.

The onion freshly harvested, prior to storage, showed in fresh tissue an EPA level of 1.187 ± 0.171 μmol/g FW. According to the scale used by The Sweet Onion Industry in USA, onion cultivar "Sierra Blanca" can be considered as a low pungency/sweet, since the value of pyruvic acid was less than 3 μmol/g FW (Russo et al., 2013).

In general, the obtained values place the CT onions with the higher EPA, followed by those stored at T2 and T1, which had the lower pungency (Fig. 1).

During the storage period, CT bulbs showed an upward trend in the EPA concentration, they had an EPA content of 1.187 μmol/g FW at the beginning of storage and 2.43 μmol/g FW at six months storage (period in which CT sample was still available). This represents an increase

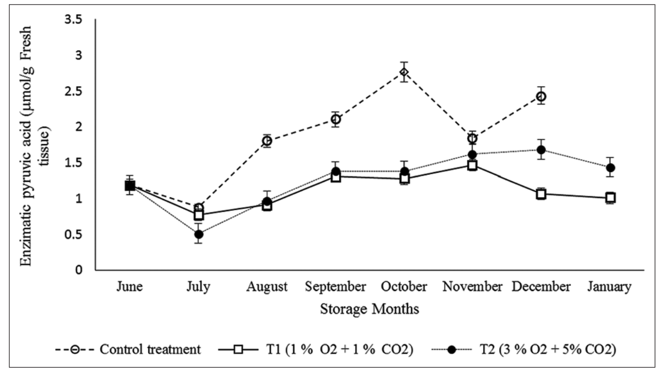

Fig 1. Enzymatic pyruvic acid of onion cultivar "Sierra Blanca" stored in controlled atmospheres at 2.5 °C and 60-75 % RH (n = 5; mean ± DE). (Control treatment: Sample not available for January).

of 104.71 % (increased 1.243 μmol/g FW). The same thing happened with the EPA content from the T2 onions, ranging from 1.187 μmol/g FW at the beginning to 1.436 μmol/g FW at the end of experiment, with an increase of 20.97 %. In the case of T1 bulbs, they maintained the levels of pungency with minor changes throughout the storage period, EPA concentration increased from the third month of storage, remained constant until the fifth month and then reduced in the sixth and seventh month, having no statistical differences in these two last months. Decreasing by 15.24 % at the end of storage compared to the initial value. In general, T1 had a positive effect on the pungency level during the seven months of storage due EPA content remained at low levels throughout the period of conservation. However, the effect was more evident after the fifth month where the T1 and T2 bulbs presented statistical difference in EPA concentration, at this point, the T1 bulbs pungency decreased and T2 bulbs pungency increased, possibly due to the effect of the atmosphere of each treatment on the onion's metabolic reaction.

The results showed a lower level of pungency in onions stored in CA that those stored in environmental atmosphere at the end of storage. The T1 bulbs decreased EPA content by 58.61 % and T2 bulbs in a 51.2 % compared with the EPA final value obtained in CT onions. These findings are in correspondence with those reported by Poldma et al. (2012) in "Hercules" and "Hyred" onion stored in a regular atmosphere and CA at 2 °C. Uddin and MacTavish (2003), also reported pungency decrees in onion cultivar "Hysam" stored 7 weeks on CA (treatment 2/2: 2 % O_2 and 2 % CO_2; treatment 2/8: 2 % O_2 and 8 % CO_2). These authors found that onions stored in regular atmosphere increased their total pyruvic acid content and those stored in CA decreased this parameter by 4.8 % and 13.5 % for 2/2 and 2/8 treatments respectively.

On the other hand, Sharma and Lee (2015) reported an EPA increase in onion cultivar "Sunpower", stored in refrigeration for nine months at different temperatures, similar to those results obtained in CT bulbs of this study.

The higher pungency level obtained in the CT bulbs must be mainly originated by the gaseous composition of the atmosphere under which they were stored. In this atmosphere, the wide availability of environmental oxygen favored a higher rate of respiration, accelerating the metabolic rate of the onion (Thompson, 2016). This reaction caused several changes in the biochemical content of onion, including an increase in the concentration of the onions flavor compounds, which are directly related to the pungency as the 1-propenyl cysteine sulfoxide (1-PrenCSO), Methyl cysteine sulfoxide (MCSO) and Propyl cysteine sulfoxide (PCSO) (Shivakumar and Chandrashekar, 2014).

By contrast, the lowest level of pungency in T1 and T2 onion bulbs is due to the effect of CA, in which, the rate of respiration and physiological changes in the vegetable are reduced (Chope et al., 2007), causing a decrease in concentration of the onion flavor compounds aforementioned. In accordance with Forney et al. (2009), the CA with low oxygen can inhibit the production of volatile compounds that contribute to the aroma and flavor of various fruits and vegetables, and a longer storage time greater inhibition may be.

Yoo et al. (2012) likewise established that the pungency increase during bulbs storage is due to the increase in the content of the flavor precursors from the hydrolysis of ɣ-glutamyl peptides by ɣ-glutamil trans peptidase enzyme, especially close to sprouting times. According to this author, this reuse of storage resources is essential and unavoidable to the growth of new leaves or tissue, and for the regrowth of onion bulbs, but in sweet onions, this increased level of pungency during storage, is considered an unfavorable change. However, the increase in the level of pungency of onion bulbs cultivar "Sierra Blanca" observed in the present study (mainly in the TC and T2 bulbs), did not significantly affect the quality of the onion. Pungency values are still within the range in which the onion is considered sweet, according to the classification issued by the Sweet Onion Industry in Georgia USA (Dhumal et al., 2007) which is desirable according to the market demands. This result could also be a result of the temperature used in the present study (2.5 °C). Other authors have reported that this temperature achieved a better preservation of the postharvest onion quality (Sohany et al., 2016). Meanwhile Ahmed et al. (2015) reported that the ideal temperature to preserve the onion quality is close to 0°C.

The EPA levels obtained in the present study, both prior to the CA onion storage as well as at the end, were substantially lower than those results reported by Sharma and Lee (2015) in onion cultivar "Sunpower" stored at 4, 5 and 25 °C. These authors noted that pyruvic acid concentration in onions depends on several factors such as dry matter, sugar content, cultivars, maturity and sulphur nutrition. In another study, Randle and Bussard (1993) also reported higher levels of EPA to those found in the present study in different cultivars like "Sweet Georgia", "Sweet Tex" and "Sweet Vidalia" considered sweet. The results were also much lower than those values obtained by Mallor et al. (2011a) in eight lines of Spanish onion "Fuentes de Ebro". While Crowther et al. (2005) reported a similar result in onion cultivar "UK Sweet".

Various factors have an influence on the level of pungency in onions, such as the genetic potential and the environment in which it develops. Therefore, the intensity in flavor of the vegetable can be increased within the cultivar by lower irrigation rates, high temperatures during its growth and development, and high fertilization in sulphur (Randle, 1997). In this regard, Coolong and Randle (2003) found that when the onions cultivar "Granex 33" were grown at a temperature of 15.6 °C its pungency level was 3.8 μmol/g FW of pyruvic acid, and at 32.2 °C the pungency was 7.1 μmol/g FW.

In general, pungency results obtained for onion cultivar "Sierra Blanca" are favorable since the soft onion or sweet onion is very popular in some markets such as the United States, there is also a growing interest in improving and producing this type of onion in the industry (Yoo et al., 2012).

Total soluble solids

The statistical analysis showed differences ($p \leq 0.05$) in the content of total soluble solids (TSS) between treatments, months of storage, and the interaction between both factors.

Total soluble solids are defined as the total of all the solids that are dissolved in water, including sugars, salts, proteins and organic acids; therefore, the reading obtained in the refractometer is the sum of all of them (Chope et al., 2006).

The TSS content is an important quality parameter and is related to the degree of conservation of the onion. To higher soluble solids content, greater is the percentage of dry matter and therefore the bulbs are better preserved (Mallor, 2008).

The freshly harvested onion presented a level of TSS of 12.200± 0.787 °Brix, which decreased considerably during storage, both in the CT onions as in the ones in the CA (Fig. 2). This result is higher than that obtained by Malek

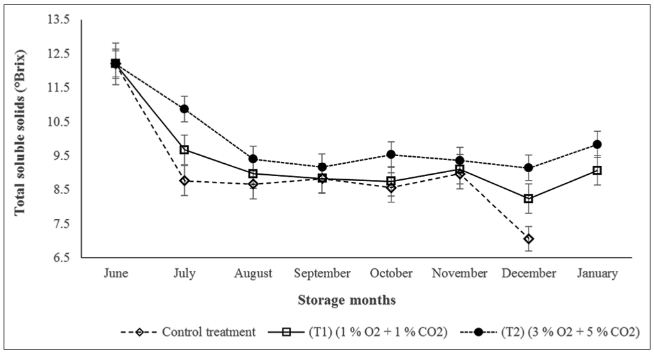

Fig 2. Total soluble solids of onion cultivar "Sierra Blanca" stored in controlled atmospheres at 2.5 °C and 60-75 % RH (n = 5; mean ± DE). (Control treatment: Sample not available for January).

and Heidarisoltanabadi (2015) in Spanish sweet onion cultivars.

The largest reduction occurred in the first month of storage for the three treatments, most notably for CT bulbs ($p \leq 0.05$) and with smaller reductions for T2, then all three maintained their concentration practically constant and without statistical difference ($p \geq 0.05$) among them up to the sixth month of storage. From this point TSS concentration of CT bulbs decreased dramatically, showing a reduction of 42 % compared to freshly harvested onions, while T2 bulbs decreased by 19 % and those of T1 by 25% at seven months of conservation without statistical difference between them, indicating the positive effect of the CA in the greater conservation of this quality parameter.

Melo et al. (2012) reported a similar behavior in TSS content in onions of cultivars "Beta Crystal" and "Optima", maintained at 5 °C and 60 % of RH for two months. Both cultivars decreased its concentration of TSS in the study, but the effect was more pronounced for "Beta Cristal", similar to the behavior of CT onions of present study. Meanwhile, Chope et al. (2006) found differences in the pattern of change in TSS content in onion cultivar "Renate", "Ailsa Craig" and "SS1", stored in CA with 3.03 kPa CO_2 and 5.05 kPa O_2 at 2 °C by 230, 129 and 81 days respectively. In contrast to found in the present study, these authors reported an increase in the concentration of TSS since the start of the storage until the first 40 days in the three cultivars tested. Subsequently they did not observe any significant change in the concentration of TSS in onion cultivars"Renate" and "Aisla Craig" stored for 111 days and cultivar "SS1"stored for 53 days". Similar to results found in the present study.

In general it was found that T2 onions had higher TSS content, followed by T1 and lastly CT onions (9.9207, 9.3885 and 8.9792 °Brix respectively) ($p \leq 0.05$).

Although the TSS content of onion was reduced during storage, the average range obtained from the three treatments (TC, T1 and T2) can be considered acceptable for onion, due to they are within the range of TSS reported by other authors for this crop (Petropoulos et al., 2016a; Mallor et al., 2011b; Chope et al., 2007). These results were higher than those values reported by Malek and Heidarisoltanabadi (2015) in Spanish sweet onion cultivars. Moreover, exceed the values obtained by Mallor et al. (2011a) in sweet onion "Fuentes de Ebro". On the other hand, the results are lower than those values reported by Sohany et al. (2016) in red onion. Some authors report that the content of TSS in onion is dependent of the cultivar (Insani et al., 2016) and some practices of postharvest handling as curing (Nega et al., 2015), as well as the time and type of storage, among others (Malek and Heidarisoltanabadi, 2015).

The onion soluble solids consist mainly of glucose, fructose, sucrose and polymers of fructans. The latter are an important source of fiber, which helps digestion, working as a prebiotic that stimulates the growth of beneficial bifidobacteria in the colon. In addition, its consumption is associated with a lower incidence of colorectal cancer, as well as with the decrease of cholesterol, phospholipids and triglycerides (Raines et al*.,* 2009; Havey et al., 2004).

According to Benklebia et al. (2005), the sugar metabolism is closely linked to the dormancy and sprouting rate of onion and its quantitative variations are the most important biochemical change during long periods of conservation. While Chope et al. (2012) indicates that changes during storage are related to respiration and re-mobilization of carbohydrates to provide energy for the development of sprouts. This may be the reason for the sudden reduction of TSS in the CT onions at the 6 months of conservation since they presented internal sprouts in 100 % of the bulbs tested at the end of the storage.

Dry matter

The content of dry matter (DM) obtained from CT onions and onions stored in CA for seven months shown in Fig. 3.

Dry matter in onions consists mainly of fiber, starch and sugars; these include the non-structural carbohydrates like fructose and glucose, non-reducing sugars such as glucose, and the fructans. Together, these carbohydrates constitute approximately 60-80 % of the DM content (Sharma et al., 2015). The DM is an important quality factor and determines the main uses of the onions bulbs, so those who have high amounts are suitable for dehydrating and have better quality for conservation and industry of frying (Gashua et al., 2014; Hansen, 1999).

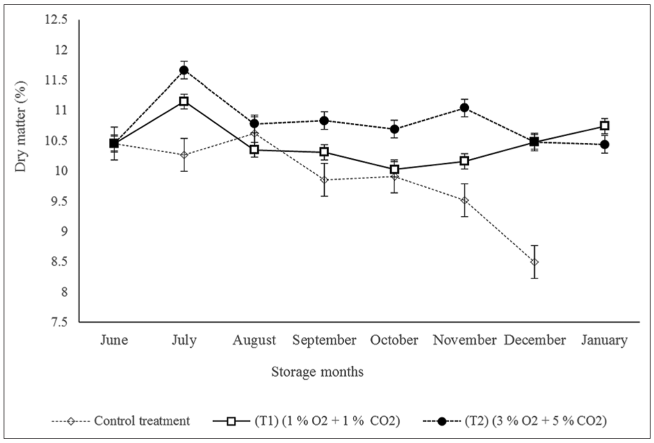

Fig 3. Dry matter of onion cultivar "Sierra Blanca" stored in controlled atmospheres at 2.5°C and 60-75 % RH (n = 5; mean ± DE). (Control treatment: Sample not available for January).

Statistical analysis showed differences ($p \leq 0.05$) in the content of DM between treatments and months of storage but not in the interaction between both factors.

The freshly harvested onion had a DM content of 10.45%. This concentration tended to increase in the first month of storage, both in onions from T1 and T2, then slightly reduced (7.1 % and 7.5 %, respectively) to the second month and remain without a statistical difference ($p \geq 0.05$) for the remaining months. There was no statistical difference between these treatments at the end of storage.

In CT onions, the results showed that DM decreased drastically with the storage time from the first month, showing a reduction close to 19 % at the end of storage with respect to freshly harvested onion. Hansen (1999) obtained similar results in the onion cultivar "Hyduro" stored in 1 °C and 75-80 % RH for seven months. However, the reduction at the end of the storage was greater (40 %) than the one obtained in this research, which is attributed to the respiration rate of the vegetable. This same behavior was observed by Chope et al. (2007) in the onion cultivar "Carlos", "Hysam", "Red Baron", "Renate" and "SS1" stored during 243 days at 4 °C, 109 days at 12 °C and 98 days at 20 °C respectively.

The decrease in the content of DM from TC onions is mainly due to the effect of environmental gaseous composition on the metabolic activity of onion. As stated above, in this atmosphere, there is greater availability of oxygen, allowing TC bulbs a higher respiration rate than that obtained in AC by T1 and T2 bulbs (Thompson, 2016). The increase in respiration rate is proportional to the storage time and the damage in the postharvest onion quality (Garba et al., 2014). This increased respiratory rate results in higher oxygen consumption and an increase in the catabolism of carbohydrates (Shivakumar and Chandrashekar, 2014) which induces a reduction of DM content. This also causes the onion dormancy breakdown which may be delayed with the use of CA, the end of this process is indicated by the appearance of inner sprouts in onion (Sharma et al., 2014), which in CT onions happened at the third month of storage.

The onset of sprouting increases the metabolic rate of the onion, which implies a high-energy requirement that is provided by the substrate stored in the bulbs, which form the DM, so that this parameter is reduced, this feature depends primarily on the growing conditions and of the onion genotype (Petropoulos et al., 2016a).

Another factor that could have influenced the reduction of DM in the CT onions was the RH because it was not controlled during storage. According to Sharma and Lee (2015) this factor together with the temperature are the most important parameters that influence the onion DM content.

According to Sinclair et al. (1995) based on the content of DM, the onions can be classified into cultivars to market fresh (7-15 % DM) and dehydrate (16-22 % DM). Taking this into consideration, the onion of this study must be destined for the fresh market.

Comparable DM values were reported previously for fresh market onion (Insani et al., 2016).

Sprouting percentage

Onion post-harvest sprouting is one of the major physiological factors that limit its shelf life. This can be prevented through the use of a proper temperature. The optimum temperature for sprouting is around 15 °C, but this value changes from a cultivar to another (Komochi, 1990). Sprouting occurs when the leaf primordia which are formed on stored bulbs, develop green leaves instead of cataphylls, which is longer and finally protrude from the neck of the bulb (Sharma et al., 2016).

In the present study, there was no visible external sprouting present in neither analyzed onions of the three treatments (CT, T1 and T2) throughout the period of storage. However, internal sprouting was found in CT onions. Sprouts were observed in the third month of storage by 20% of bulbs sampled and it was increasing up to 100% of onions analyzed in the sixth month of conservation (Table 1). Similar results were obtained by Ernst et al. (2003) in onion cultivar "Sherpa", stored for 36 weeks at 2 °C at CA under different concentrations of oxygen (0.5, 1.0, and 21 %) and less than 0.3 % CO_2. Sharma and Lee (2015) meanwhile reported the presence of visible sprouts in the onion cultivar "Sunpower", after 7 storage months at 4 °C.

According to Komochi (1990), at the time of being harvested, the onion is usually dormante and depending on the genotype and storage conditions, the growth of sprouts starts after a certain period of conservation. Chope et al. (2012) reported that during the post harvest storage there is a gradual change in the levels of growth regulators which inhibitors levels are reduced and promoters increased. Qadir et al. (2007) found that sprouting in onions is initiated by the induction of cytokinins with the reduction of the concentration of abscisic acid and stress, due to wounds, cold or heat shock.

According to Sharma et al. (2016) the end of the dormancy of onion happens when the first inner sprout appear in the bulbs, but commercial storage life and market value of the onion continue until there is visible sprout growth and rooting. In the present study the onions stored in CA did not reach to break their dormancy, since they issued no sprouts during the 7 months of storage. While the CT onions broke their dormancy at three months of storage under refrigeration at 2.5 °C with 20 % of sampled onions containing internal sprouts. Bufler (2009) reported a shorter time (7 weeks) in the onset of sprouting in onion cultivar "Copra" stored at 18 °C in air, while those treated with ethylene to delay sprouting up to 18 weeks. Yoo and Pike (1996) inhibited sprouting in onions cultivar "Texas grano 1015Y", storing at 4 °C and 11 °C with 1 % O_2.

According to Chitarra and Chitarra (2005) the low temperatures have a positive effect on dormancy and sprouting in bulbs and tubers due to a reduction in their metabolic activities.

Firmness

The onion firmness is an attribute that is directly related to the freshness and crispness index of the vegetable (González et al., 2012).

The statistical analysis showed differences ($p \leq 0.05$) in the onion firmness between treatments, within months of storage and the interaction between both factors.

Table 1: Percentage of onions with internal sprouting during storage in CA for seven months

Storage months	% Internal sprouting in onions		
	Control treatment	T1 (1% O_2+1% CO_2)	T2 (3% O_2+5% CO_2)
June	0	0	0
July	0	0	0
August	0	0	0
September	20	0	0
October	60	0	0
November	100	0	0
December	100	0	0
January	Na	0	0

Na=sample not available (n=5)

The freshly harvested onion presented a firmness of 76.2 N, which tended to decrease during storage in both, CT onions and those stored in CA (Fig. 4).

During the first two months of storage, the firmness of T1 and T2 onions remained virtually constant, being slightly lower in T1 onions with respect to T2 onions. After, this behavior changed and bulbs of both treatments reduced this parameter from the third month of storage. One major change was observed in T2 bulbs, which had less firmness than T1 onions until the end of the storage, although this difference was not statistically significant ($p \geq 0.05$).

On the other hand, CT onions reduced its firmness more drastically than those onions maintained on CA since the very first month of storage under refrigeration, showing a decrease of a 27.5 % at the end of the storage (6 months) with respect to the freshly harvested onion. While T1 and T2 onions decreased by 17.44 % and 19.99 %, respectively, after seven months.

A similar behavior was reported by Chope et al. (2007) who observed a decrease in onion firmness cultivar "Carlos", "Renata" and "SS1" stored in air and CA (5 kPa CO_2 and 3 kPa O_2) for 42 days. In addition, Chope et al. (2006) observed this pattern in onion cultivar "Renata", "Ailsa Craig" and "SS1" stored during 230, 129 and 81 days respectively in CA (3.03 kPa CO_2 and 5.05 kPa O_2). In contrast, Melo et al. (2012) reported that the onion firmness in cultivar "Beta Cristal" remained constant during 60 days of storage at 5 °C, while in cultivar "Optima" increased. The decrease in firmness during storage is related to biochemical reactions of cell wall degradation during the process of ripening and senescence of horticultural products (Melo et al., 2012).

CONCLUSIONS

The two treatments of CA managed to inhibit onion sprouting by 100 % in seven months of storage, while

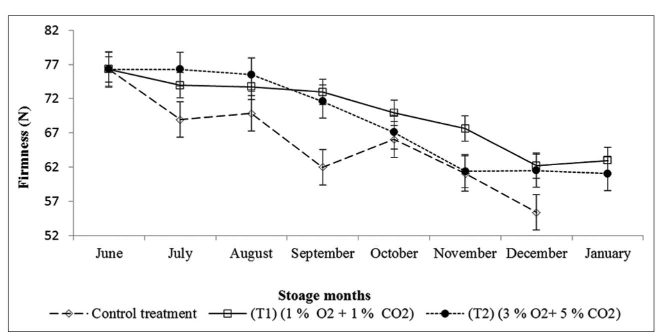

Fig 4. Firmness of onion cultivar "Sierra Blanca" stored in controlled atmospheres at 2.5 ° C and 60-75 % RH (n = 5; mean ± DE). (Control treatment: Sample not available for January).

onions stored in air (CT) had internal sprouting at the third month of conservation. Onions stored in CA showed minimal changes in most of the evaluated parameters. The pungency increased in T2 (3 % O_2 + 5 % CO_2) onions and decreased in T1 (1 % O_2 + 1 % CO_2) onions. The firmness and soluble solids decreased, and dry matter remained constant during the seven months of storage in both treatments onions, while CT bulbs increased the pungency at six months of storage and significantly reduced soluble solids, dry matter and firmness. Therefore, it is considered that CA storage is the best way to preserve the quality of onion cultivar "Sierra Blanca" for a period of seven months. In addition, the results suggest that in general, the cultivar in study responds satisfactorily to both conditions of controlled atmospheres. However, more research is required regarding the evaluating of other quality parameters.

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Authors contributions

All authors contributed extensively to the work presented in this manuscript. C. Chávez-Mendoza.: Designed and performed research, performed statistical analysis and data interpretation and wrote and revised the manuscript. M. V. Vega-Garcia.: Contributed to research design, participated in experiments and reviewed the manuscript. I. J. Gonzalez-Rios and A. Guevara-Aguilar.: Performed chemical analyses. E. Sanchez, S. M. Alvarado-Gonzalez and M.A. Flores-Cordova contributed to the development of experimental part and revised the manuscript. All authors read and approved the final manuscript.

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