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Storage temperature and type of cut affect the biochemical and physiological characteristics of fresh-cut purple onions

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ABSTRACT

Minimal processing of onion (*Allium cepa* L.) results in convenience and freshness in a single product. However, inappropriate storage of fresh-cut onion results in losses of nutritional and sensory characteristics. To further understand this phenomenon, we evaluated the effect of the storage temperature and type of cut on the quality of fresh-cut purple onions. Purple onions (cv. Crioula Roxa) were minimally processed using two types of cut (10 mm cubes and 3–5 mm thick slices) and stored at different temperatures (0, 5, 10 and 15 °C) with 85–90% relative humidity (RH) for 15 days. The following analyses were performed to evaluate the shelf life of the purple onion: pungency, total phenolic content, anthocyanin content, quercetin content, respiratory rate, color, soluble solids content, titratable acidity, pH, dryness and deterioration index (DDI), and decay index (DI). Fresh-cut onions stored at 0 °C showed less pungency, lower respiratory rate levels and less variation of total phenolic, anthocyanin and quercetin contents. In addition, the physicochemical aspects and appearance changed less with fresh-cut onions stored at 0 °C. Moreover, slicing enabled a higher stability of the physicochemical and biochemical aspects in comparison to dicing. Storage of slices at 0 °C allowed preservation for up to 15 days.

1. Introduction

Onions (*Allium cepa* L.) are mainly consumed in raw salads as a condiment or for seasoning. However, when preparing the onion bulbs for consumption, volatile compounds that cause irritations on contact with human nostrils and eyes are released. Another drawback is the onion's odor that can saturate the handler's hands for a period of time. One way to overcome these problems is the use of minimally processed onions, which makes the product more convenient and ready for consumption while maintaining its freshness.

At present, many fresh-cut vegetables, such as carrots, lettuce, leaf mixes, garlic, beets, broccoli, cabbage and cauliflower are commercially available in different types of cuts, including cubes, slices, matchsticks and shreds. With regard to consumption habits, the appearance and use of the final product must be considered to determine the type of cut that will be used for a fresh-cut food. This choice must be based on the knowledge of the vegetable's physiology and biochemistry to ensure that the products show the expected quality (Silva et al., 2011).

In Brazil and in other developing countries, the cold chain is not well established, especially during marketing. Interruption of the cold chain leads to significant loss in the quality and reduction of shelf-life of the product, which is most likely the main barrier for an increase in marketing and consumption of fresh-cut products in these countries.

Fresh-cut onions cut into 0.7 cm thick slices and stored at −2, 4 and 10 °C under modified atmospheres show yellowing, loss in firmness and an increase in microbial population growth with increasing temperatures (Liu and Li, 2006). At present, the effect of temperature on other quality attributes, in particular flavor and flavonoid content, has not yet been studied. Likewise, a comparison of the effects of the various types of cut has not been reported. Therefore, a study of this fresh-cut vegetable is necessary to understand the main changes in product quality and the resulting consequences for the consumer.

In the present study, we evaluated the effects of storage temperature and type of cut on the quality of fresh-cut purple onion. We also identified the main changes resulting from inadequate storage conditions to demonstrate that the use of an appropriate storage

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temperature may prolong the shelf-life of fresh-cut onions without significant loss of quality.

2. Materials and methods

2.1. Raw material

Purple onions (*A. cepa* L., cv. Crioula Roxa) produced in the municipality of Ituporanga in the State of Santa Catarina, Brazil were used in this study. After harvest, the onions were left in windrows to dry and cure for eight days. Their tops were then cut off, and the onions were sorted (with diameters from 50 to 80 mm) and placed in 20 kg plastic fiber bags. The onions were taken to the laboratory, subjected to a selection process discarding the damaged bulbs and subsequently stored at 10 °C for one day.

2.2. Minimum processing and storage conditions

The onions were subjected to minimal processing using two types of cuts as follows: 3–5 mm thick slices and 1.0 mm edge cubes. After processing, 100 g of diced and 200 g of sliced onion were weighed and placed into rigid polypropylene containers with $320.0 \pm 0.5\ cm^3$ and $1190.0 \pm 0.5\ cm^3$ capacity, respectively, these were then capped with a cover of the same material. The thicknesses of the polypropylene containers was 0.2 mm in the lateral dimension, 0.4 mm in the base and 0.35 mm in the cap. The cap was not an airtight gasket, allowing gas exchange with the atmosphere. The onions were stored in four different cold rooms at 0, 5, 10 or 15 °C and 85–90% relative humidity (RH) for 15 days. The experiment consisted of eight treatments (two types of cut and four storage temperatures). Each analysis was composed of four replications (using one container for each replication) with the exception of respiratory activity, which comprised five replications of 200 g per sample.

2.3. Biochemical analysis

The analysis of pungency was performed one day before processing (day −1) for initial characterization, at the processing day (day 0) and every three days, using the method described by Schwimmer and Weston (1961) and modified by Anthon and Barrett (2003). The results were expressed in micromoles of pyruvic acid per gram of fresh matter (fm).

The total phenolic content was determined using the methodology of Singleton and Rossi (1965), except that the extracting agent was replaced with distilled water. The results were expressed in gallic acid equivalents (GAE), i.e. milligram of gallic acid per 100 g of fm. The anthocyanin and quercetin contents were quantified by the method of Lees and Francis (1972), and the results were expressed as mg $100\ g^{-1}$. These analyses were performed at day zero and then every three days.

2.4. Physiological analyses

The determination of respiratory rate was performed daily. Fresh-cut onions were placed in 500 mL hermetic glass jars previously exposed to the temperature and humidity conditions of the experiments. The jars were periodically sealed for 1 h. A silicone septum was fitted to each jar lid through which 0.5 mL of gas sample was collected using a 1 mL syringe. Each collected sample was injected into a Thermo Electron Corporation gas chromatograph (model Trace GC Ultra) equipped with two flame ionization detectors (FIDs). The results were calculated based on the chromatographic analysis, the mass of onions in the jars and the period of time during which the jars remained sealed. The results were expressed as $mg\ kg^{-1}\ h^{-1}$ of CO_2.

The soluble solids content (%), titratable acidity (% of pyruvic acid) and pH were determined at day zero and at every three days, according to the methodology of AOAC (2010).

To evaluate the onion color, a Minolta Chroma Meter CR-400 colorimeter was used. The values of luminosity (L^*), chromaticity (C) and hue angle ($°h$) were determined at day zero and at every three days. Six slices were analyzed per replication, and two readings were performed for each slice. In the case of the diced onions, ten readings (five of the top cubes and five of the bottom cubes) were performed for each container.

The appearance was evaluated at day zero and at every three days, for 18 days, classifying the onions according to two indices. The dryness and deterioration index (DDI) was determined using the methodology of Miguel and Durigan (2007). A scale from 1 to 5 was used to classify DDI as follows: 1 = great (bright sample with typical coloration and turgid); 2 = good (bright with typical coloration and mild dryness); 3 = regular (strong smell but not unpleasant; more pronounced dryness); 4 = bad (intense dryness, tenderness, appearance of rot, atypical staining and moisture accumulation on the packaging); and 5 = very bad (dull and shriveled with rot and unpleasant smell). The decay index (DI) scale varied from 0 to 2 as follows: 0 (zero) = absence of visual rot; 1 = evidence of rot (superficial viscous aspect); and 2 = visible presence of rot (appearance of colonies).

2.5. Statistical analysis

The experimental design was completely randomized with an 8 × 6 factorial scheme (treatments × days of analysis). For pungency, DDI and DI analysis, the experimental design was 8 × 7 (treatments × days of analysis) and for respiratory rate, the experimental design was 8 × 16 (treatments × days of analysis), these designs was completely randomized too. The results obtained were subjected to analysis of variance (ANOVA), and the means were compared by Tukey's test ($p < 0.05$) using SAS statistical software (version 9.3; SAS Institute, Cary, NC, USA).

3. Results

3.1. Pungency, phenolic compounds and flavonoids are influenced by storage temperature and time

To determine the influence of storage temperature and time on the physiology of fresh-cut onion, we studied the most important changes in its characteristics through the evaluation of the main biochemical aspects of the onion. The pungency was influenced by storage temperature and time and by type of cut (Fig. 1). The sliced

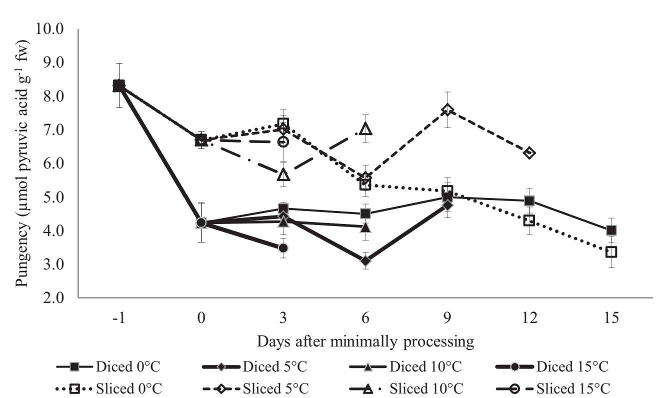

Fig. 1. Pungency of fresh-cut (diced or sliced) 'Crioula Roxa' onion stored at different temperatures and 85–90% RH for 15 days. Vertical bars represent the standard error ($n = 4$). −1 = before minimal processing.

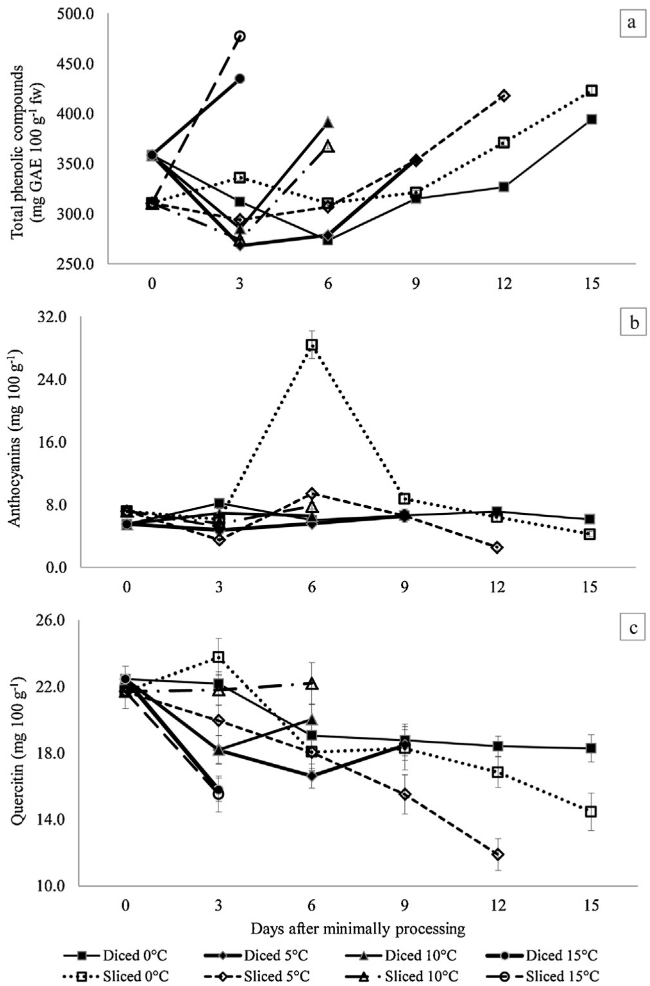

Fig. 2. Total phenolic compounds (a), anthocyanins (b) and quercetin (c) of fresh-cut (diced or sliced) 'Crioula Roxa' onion stored at different temperatures and 85–90% RH for 15 days. Vertical bars represent the standard error ($n = 4$).

onion stored at 0 °C showed less pungency compared to the other sliced onion treatments. In the general, dicing led to lower pyruvic acid content compared to slicing. Minimal processing (from day −1 to day 0) caused a reduction of 50 and 19% in the pungency content for cubes and slices, respectively. Moreover, a gradual loss of pungency occurred during storage, mainly for onion storage at 0 °C.

The results showed that the levels of phenolic compounds and anthocyanins changed depending on the storage temperature and time (Fig. 2). The onions stored at 15 °C had a higher content of phenolic compounds than those stored at other temperatures. An increase in phenolic compound contents was observed after 15 days of storage for both cut types. Slicing led to greater anthocyanin content in comparison to dicing. The onions stored at 0 °C had higher anthocyanin contents and a smaller loss of anthocyanins occurred during the storage period than with the onions kept at other temperatures (Fig. 2). Compared to day 0, a 48% increase of anthocyanin content for cubes on the third storage day was observed, and a 295% increase of anthocyanin content for slices was observed.

Although the temperature and type of cut did not cause any change in the quercetin content, the storage period affected the quercetin content as it decreased by 26% after 15 days of storage (Fig. 2). Thus, we concluded that the storage temperature and time affected the biochemical aspects of fresh-cut onions. A temperature of 0 °C resulted in the best preservation of the phenolic compounds and flavonoids present in the onion.

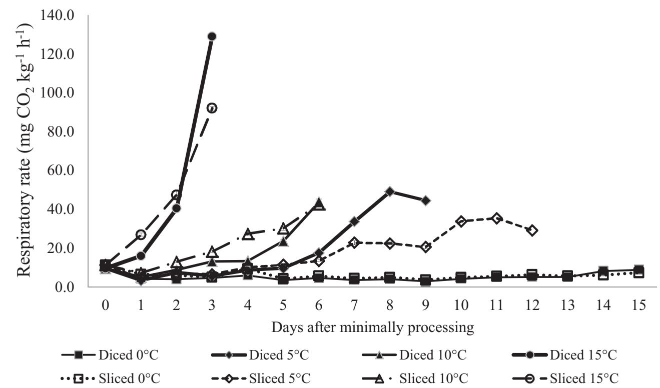

Fig. 3. Respiratory rate of fresh-cut (diced or sliced) 'Crioula Roxa' onion stored at different temperatures and 85–90% RH for 15 days. Vertical bars represent the standard error ($n = 5$).

3.2. Different storage temperatures affect the respiratory rate and physicochemical characteristics

The influence of temperature on the metabolism of fresh-cut products was evident when the respiratory rate was studied. The respiratory rate increased when the temperature increased regardless of the type of cut (Fig. 3). We observed that the onions stored at 15 °C had a respiratory rate eight times higher than the in those kept at 0 °C. Moreover, the use of a low storage temperature reduced the respiratory rate by 12%, on average, on the first storage day. A gradual increase of the respiratory rate occurred over time in all cases, except for the onions stored at 0 °C, which had a low respiratory rate throughout the entire storage period.

Other components present, such as soluble solids, and titratable acidity and appearance confirmed the metabolic changes. The results showed that higher storage temperature and cut intensity resulted in lower soluble solids contents (Fig. 4). The percentage of acidity and pH found in the fresh-cut onions varied with the storage temperature. At the end of shelf-life, there were increases in acidity. Onions stored at 15 °C, and diced onion at 10 °C, had the most rapid increases. Onions stored at 15 °C and diced onions at 10 °C also exhibited the lowest pH (Fig. 4). Dicing resulted in higher acidity and lower pH than slicing. During storage, a gradual increase in the percentage of acidity occurred, but the pH decreased during storage.

The results showed that the purple onion color was affected by storage temperature and type of cut. Sliced onions exhibited higher values of luminosity and hue angle as well as lower values of chromaticity, thereby leading to a fresher appearance than the diced onions (Fig. 5). During storage, the luminosity of diced onion decreased indicating a loss of sample brightness. The chromaticity gradually increased during the period between the processing day and the fifteenth day of storage with, on average, a total increment of approximately 50%. A statistically significant difference was not observed over time for the hue angle values.

The dryness and deterioration index (DDI) and the decay index (DI) increased gradually with the temperature increase and throughout storage regardless of the type of cut (Fig. 6). On average, whereas the onions kept at 0 °C scored approximately 2.3 and 0.4 in the DDI and DI scales, respectively, the onions stored 15 °C scored above 4 and 1.6 in the DDI and DI scales, respectively. The microbiological analysis of the samples undertaken by the Phytopathology Clinic of USP/ESALQ [Universidade de São Paulo – USP/Escola Superior de Agricultura "Luiz de Queiroz" – ESALQ]

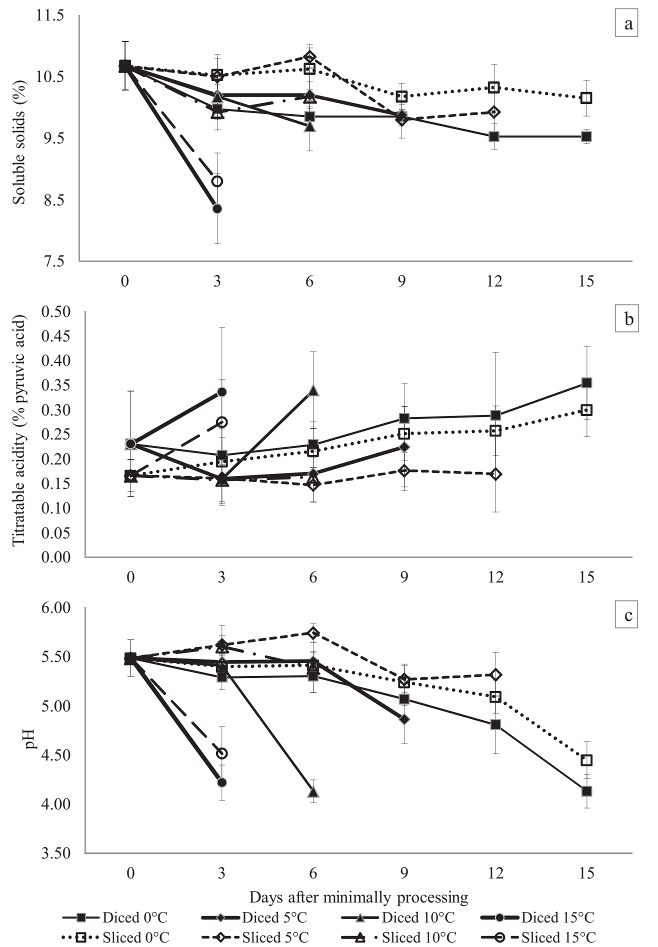

Fig. 4. Soluble solids (a), titratable acidity (b) and pH (c) of fresh-cut (diced or sliced) 'Crioula Roxa' onion stored at different temperatures and 85–90% RH for 15 days. Vertical bars represent the standard error ($n = 4$).

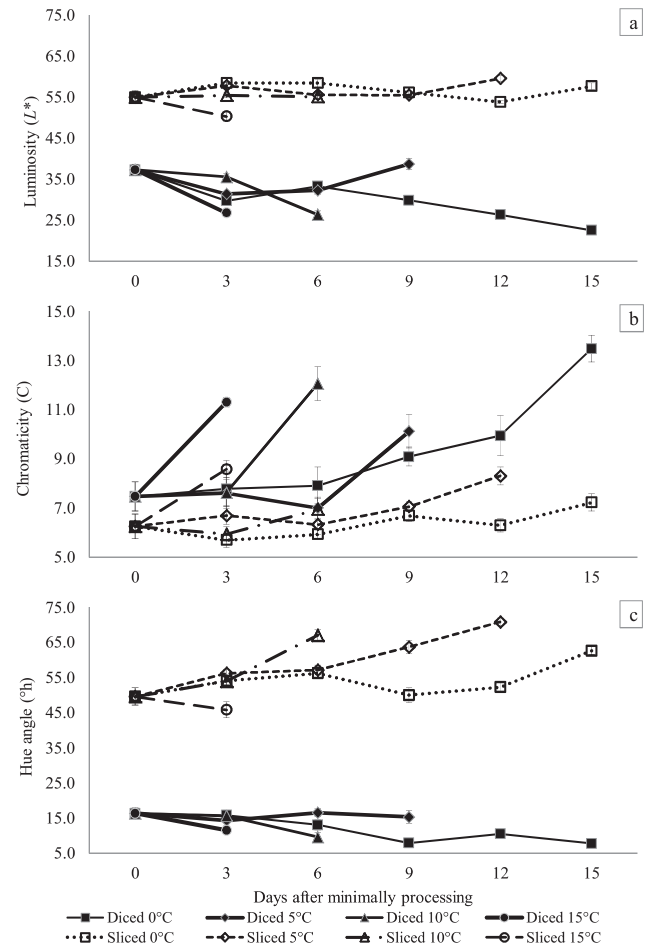

Fig. 5. Evaluation color of fresh-cut (diced or sliced) 'Crioula Roxa' onion stored at different temperatures and 85–90% RH for 15 days. Vertical bars represent the standard error ($n = 4$).

indicated the presence of the bacterium *Burkholderia cepacia* (synonym of *Pseudomonas cepacia*) as the main agent causing DI, which was also related to the bacterial rot in the scales, as is common in onions.

The storage temperature affected the quality of fresh-cut onion. Lower storage temperatures resulted in lower onion metabolism and, consequently, smaller effects on onion quality.

4. Discussion

Our purpose was to evaluate the effect of different storage temperatures and cut type on the biochemical aspects and quality attributes of fresh-cut onion. In addition, we aimed to identify the main changes resulting from inadequate storage conditions. We found that temperature, cut type and storage time directly affected the biochemical characteristics of the onion.

Storage at lower temperatures led to a longer shelf-life and, consequently, a lower pyruvic acid content due to its higher consumption as a metabolic substrate. The consumption of acids as a metabolic substrate of respiration is associated with the reduction in pungency over the storage period. Likewise, the reduction of pungency resulting from minimal processing was most likely due to cell disruption caused by the peeling, cutting and sanitation procedures through the volatilization, leakage and leaching of the substances responsible for the pungency (Schwimmer and Weston, 1961; Anthon and Barrett, 2003; Lanzotti, 2006; Brecht et al., 2007; Bhat et al., 2010). Similarly to the findings of Miguel and Durigan (2007), we verified that a higher intensity of cut caused more acid leaching, and thus, less pungency. However, we believe that the decrease in pungency is not an obstacle for the consumption of this product because the demand for onion bulbs with lower pyruvic acid concentrations is increasing (Vilela et al., 2005).

The increase in the total phenolic content observed was most likely associated with the vegetable defense strategy against oxidative stress (Silva et al., 2010). To minimize the stress caused by minimal processing, the product must be kept at low temperatures to reduce its metabolism and, consequently, the changes in the content of these compounds (Brecht et al., 2007; Siddiq et al., 2013).

We observed that storage at 0 °C resulted in higher anthocyanin contents. We postulated that this fact may result from an increase in anthocyanin biosynthesis as a response against the stress caused by the low storage temperature and the cutting process because anthocyanins can increase the tolerance of the vegetable to the refrigeration temperature (Ferreres et al., 1996; Gould and Lister, 2006). Therefore, a considerable increase in the anthocyanin content occurred during the third and sixth day for cubes and slices, respectively. The response was faster in the case of cubes due to the higher level of stress (Fig. 2).

The quercetin levels decreased during the storage period, which can be attributed to the antioxidant function that this compound has in plant tissues (Lakhanpal and Rai, 2007; Bentz, 2009). Other studies have also shown a reduction of quercetin content in fresh-cut onions during storage (Price and Rhodes, 1997; Price et al.,

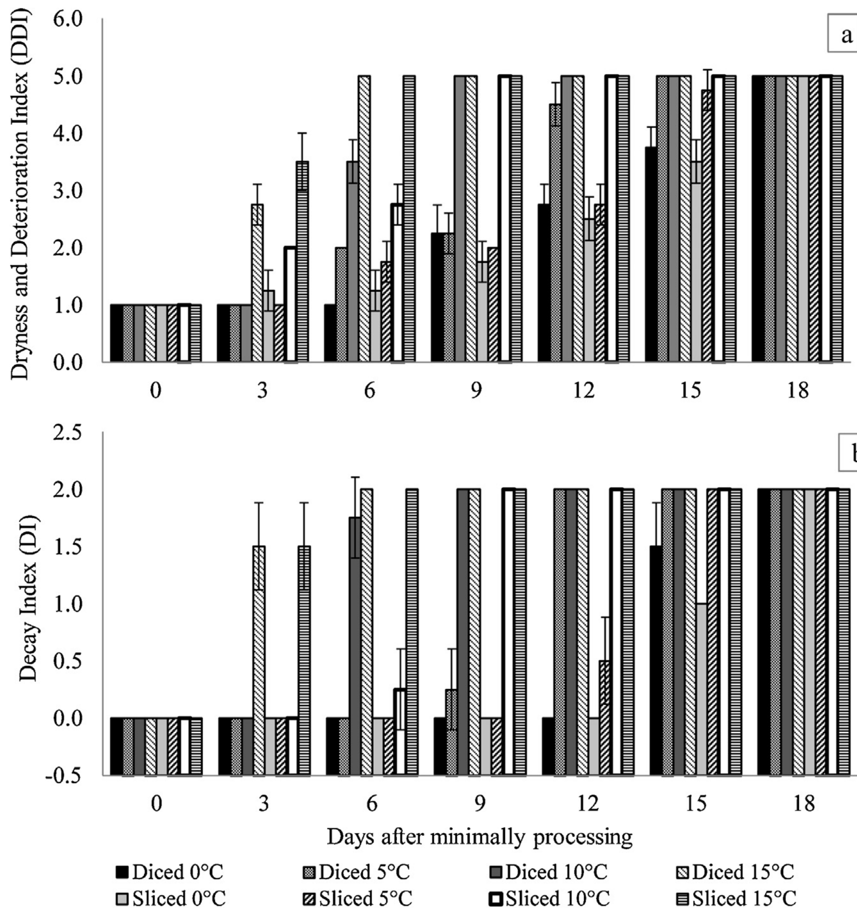

Fig. 6. Visual quality index of fresh-cut (diced and sliced) 'Crioula Roxa' onions stored at different temperatures at 85–90% RH for 18 days. Vertical bars represent the standard error ($n = 4$). DDI scale: 1 = great (bright sample with typical coloration and turgid); 2 = good (bright sample with typical coloration and mild dryness); 3 = regular (strong smell but not unpleasant; more pronounced dryness); 4 = bad (intense dryness, tenderness, appearance of rot, atypical staining and moisture accumulation on the packaging); and 5 = very bad (dull and shriveled with rot and unpleasant smell). DI scale: 0 (zero) = absence of visual rot; 1 = evidence of rot (superficial viscous aspect); 2 = visible presence of rot (appearance of colonies).

1997). Despite this decrease, the fresh-cut onion still contained high quercetin levels when compared to other non-processed products (USDA, 2011), thus demonstrating that minimal processing still retains onion as one of the vegetables with significant quercetin levels.

We observed that the reduction of storage temperature led to a decrease of the respiratory rate of the fresh-cut onions, which prolonged the product shelf-life. Previous studies have reported that temperature is one of the main factors that has to be controlled to extend the shelf-life of various fresh-cut products (Caleb et al., 2012; Zhan et al., 2012; Ayub et al., 2013; Waghmare et al., 2013).

We observed that an accelerated metabolism in the onions kept at 15 °C resulted in a consumption of soluble solids, increase of acidity and reduction of pH. Soluble solids are used as energy reserves over time (Brecht et al., 2007). A decrease in soluble solids may also be related to damage caused in the cell structure by the cutting process, thus causing part of its content to be eliminated (Toivonen and DeEll, 2002), which may be the reason for the larger decrease in soluble solids content for the diced onions. Because the acidity and pH are related to the organic acid content, greater stress caused by the type of cut and high temperature results in a larger production of these acids, and consequently, an increase in acidity and reduction of pH. This relationship was also confirmed by the increased phenolic compound content during storage.

The color change may be explained by particular response found in purple onion. During storage and especially at the end of the product shelf-life, the anthocyanins that were present in the last cell layer of the epidermal tissue migrated to other cells that did not contain the pigment, thus turning the onions pinkish. This migration occurred more intensely in the diced onions, indicating that the intensity of the cut affected the process. This phenomenon influenced the three color parameters. In addition, the onset of translucency was observed during storage, especially for the sliced onion. The diced onion exhibited the largest loss of surface water due to the larger exposed surface area and more damaged cells. The translucency and loss of surface water may also have led to a difference in the color parameters between the different types of cut and throughout the storage period. The yellowing and translucency are the main changes of visual quality observed in fresh-cut onion (Blanchard et al., 1996; Liu and Li, 2006). The decrease of hue angle values and the change in chromaticity may be indicative of the yellowing process, which is a result that has also been found in other studies (Miguel and Durigan, 2007).

One of the main factors observed in the appearance of the onion was the adulteration of color and gradual deterioration of the product appearance. Thisdeterioration was characterized by the presence of surface viscosity due to the development of microorganisms and by the accumulation of water in the container. These features took a longer time to become visible in the onions that were kept at reduced temperature and cut into slices. We believe that microbiological monitoring is required for a better evaluation of the parameters analyzed in this study, with the aim of determining the period of time that the product can be used without compromising consumer food safety.

Our results showed that the storage temperatures and type of cut differently affected the fresh-cut onion. Product degradation was intensified with the increase of temperature and intensity of cut. Thus, low temperatures and lower levels of damage contribute to a longer preservation of quality attributes.

In summary, onions that were stored at 0 °C showed a smaller variation in the levels of phenolic compounds and flavonoids as well as lower respiratory rates, which resulted in higher soluble solids content, higher pH, lower acidity, less changes in color and a better overall appearance, thereby enabling preservation for up to 15 days. Slicing also led to less variation of the aforementioned aspects due to less damage caused to the cell structures.

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