ITALUS HORTUS
Vol. 29 (2022), Pages 115-137
doi: 10.26353/j.itahort/2022.1.115137
Original Research Paper

Modified Atmosphere Packaging and low temperature storage extend marketability of cherimoya (*Annona cherimola* Mill.)

Ilenia Tinebra, Dario Scuderi, Gabriele Busetta, Eristanna Palazzolo, Luca Settanni and Vittorio Farina*

Department of Agricultural, Food and Forest Sciences. Università degli Studi di Palermo, viale delle Scienze, 90128, Palermo, Italy; ilenia.tinebra@unipa.it; dario.scuderi@unipa.it; gabriele.busetta@unipa.it; eristanna.palazzolo@unipa.it; luca.settanni@unipa.it
* Corresponding author: vittorio.farina@unipa.it; Tel.: +39-09123896090

Received: 15 November 2021; Accepted: 18 March 2022; Published: 29 April 2022

Abstract: Cherimoya is a subtropical fruit characterized by a delicious, sweet flavor and beneficial health properties, which found suitable growing conditions in the South of Italy. However, the marketing of this product is halted by its high perishability, which limits the shelf-life of the fresh fruit to few days after harvest and does not allow for commercialization beyond local markets. Studies have shown that storage of this fruit in controlled atmosphere, using Modified Atmosphere Packaging technologies, extended the post-harvest life of Cherimoya, but little is still known about the evolution of its sensory, nutraceutical and microbiological characteristics during such storage period. In this paper, we studied the effect of a 4-days long active-MAP (30% CO_2 – 10% O_2 – 60% N_2) storage period, associated with cold temperatures, on the physico-chemical, sensory, nutraceutical and microbiological quality traits of Italian-grown cherimoya fruits, compared with passive-MAP (Air composition, 21% O_2 + 1% CO_2 + 78% N_2) and simple cold storage. Active-MAP proved effective in delaying the reaching of the optimal consumption point until 10 days from harvest, besides showing absence of microbial growth until after 7 days from harvest. Both active- and passive-MAP treatments maintained better nutraceutical values than control until the end of the trial period, and sensory analysis confirmed that active-MAP treated fruits were at the optimal commercial stage after 10 days from harvest.

Keywords: MAP; headspace gas composition; shelf-life; tropical fruit; Sicily

1. Introduction

Cherimoya (*Annona cherimola* Mill.) is a fruit tree belonging to the family of *Annonaceae* (Calabrese, 1978; Schroeder, 1956), native to the Andean mountains, in the area now belonging to the nations of Ecuador and Peru. The fruit of *Annona cherimola* is a syncarpium consisting in the aggregation of many white fleshy fruitlets, originated from the growing together of many carpels, inserted in a spiral arrangement around a central pithy receptacle, each of which contains a dark brown to black colored seed (Cautín and Agustí, 2005; Palma et al., 1993; Scheldeman, 2002; Schroeder, 1956). However, studies have shown that the respiratory behavior of the *Annona* fruits is not affected by the aggregate nature of the fruit (Bruinsma and Paull, 1984; Pareek et al., 2011).

With a total cultivated area of around 3200 ha, Spain, particularly in the province of Granada, is the world's largest cherimoya producer, followed by Peru and Chile which are the world's top exporting countries (Pinto et al., 2005; Vanhove e Van Damme, 2013). A small, national market oriented area of less than 100 ha dedicated to the cultivation of cherimoya is present in the South of Italy, in the province of Reggio Calabria, where the fruit represents a local delicacy used for fresh consumption and transformation (Dattola et al., 2019; Gregorio et al., 2019). Also the northern coast of the island of Sicily showed climate characteristics that proved suitable for the cultivation of several tropical fruit

crops (Farina et al., 2017a) including cherimoya (Puccio et al., 2019).

Cherimoya fruits are rich in vitamin C and B6, besides being a major source of thiamine and riboflavin (Jamkhande et al., 2017). From the point of view of the nutritional value, cherimoya showed interesting characteristics, in particular with regards to its antioxidant and free radical scavenging effects, being the pulp of the fruit rich in acetogenins, phenols and flavonoids (Gentile et al., 2021; Gupta-Elera et al., 2011; Loizzo et al., 2012). Therefore, this can be considered a promising species for the introduction in the European fruit market, where consumers are increasingly aware of the effects of diet on their health (Altendorf, 2018). Modern consumers also show a marked preference for food that is grown closer to their final market, as this is considered more respectful of the environment, since the total distance that the food travels can be reduced (Testa et al., 2020; Van Passel, 2013). Moreover, yearly import volumes of exotic and tropical fruit have grown by around 50 million € in the last five years (CBI, 2020; Migliore et al., 2017; Sabbe et al., 2009).

All *Annona* species present some limitations to their commercial diffusion, mainly due to their little resistance to transport to distant markets and fast ripening rate after harvest, which limits significantly their shelf-life (Ludders, 2002; Pinto et al., 2005; Prieto et al., 2007; Siddiq et al., 2012). In facts, fruits of *Annona* are classified as climacteric, with an increase of respiratory activity and ethylene production after harvest (Biale and Barcus, 1970; Palma et al., 1993). When kept at room temperature (20 to 25 ±3 °C), cherimoya fruits reach full ripeness two to five days after harvest, and decay after 8 days (Alique and Zamorano, 2000; Lahoz et al., 1990; Manríquez et al., 2014; Sevillano et al., 2010). Thus, while representing an interesting economic opportunity for the growers in the Mediterranean area, Cherimoya fruits show some limitations to their marketability which can be overcome with the correct post-harvest treatments.

In the last years, research on how to postpone the decay of the fruits of this species were carried on, using a range of techniques and technologies (Alique et al., 1994; Benassi et al., 2003; Li et al., 2009; Liu et al., 2016; Montero et al,. 1995; Yonemoto et al., 2002), yet without simulating a possible supply chain of the product. Simple cold storage transportation, while commonly used for the shipping of fresh fruit (Eum et al., 2013), is not feasible for cherimoya for more than 6 days at 10 °C (Alique et al., 1994) as this species is particularly susceptible to chilling injury.

Among the various post-harvest technologies, Modified Atmosphere Packaging (MAP) was found to be successful in delaying the onset of cherimoya ripening process, extending storability of the fruit until 9, 14 and even 43 days from harvest (Alique, 1995; Alique and Oliveira, 1994; Palma et al., 1993), and alleviating chilling injury in *Annona* fruits (Lee et al., 2016). Still, these previous studies report little to no information about the effect of controlled atmosphere storage on the nutraceutical, sensory and microbiological quality of this fruit. MAP is a food post-harvest handling technology based on the dynamic process of alteration of gaseous composition inside a sealed package, determined by permeability of packaging film and respiration of the fruit inside it (Tinebra et al., 2021). The use of MAP reduces the respiration rate and activity of microorganisms and provides control of fruit and vegetable ripening, or browning, and ultimately extends the shelf life (Kader, 2002). Allowing the growers to put into practice a simple, low cost protocol for post-harvest handling of the cherimoya could facilitate the diffusion of this species on the European market, offering new opportunities for expanding the offer of tropical fruits, especially in the perspective of commercialization in markets where consumers are well informed about the beneficial effects of the consumption of fresh fruit and increasingly aware of the environmental costs of long-distance food transportation.

The goal of our study, so, was simulating a possible national to European scale, cold-stored transportation chain of fruits of Sicilian-grown cherimoya, preceded by a short MAP storage treatment, keeping particular attention to maintaining the fruit's safety and nutritional properties. Hence, physico-chemical, nutraceutical, microbiological and sensory quality characteristics of the fruits were analyzed in a period of 10 days from harvest.

2. Materials and Methods

2.1. Plant material

Cherimoya fruits of the cultivar "Fino de Jete" were harvested at commercial maturity in December 2020 from adult trees located in the varietal collection of the Department of Food, Agriculture and Forest Sciences (SAAF) of the Università degli Studi di Palermo, located in the city of Palermo, Sicily (38°06'N – 13°21'E), using skin color and fruit firmness as indexes of the maturity of the fruits (Berger and Galleti, 2004; Pinillos et al., 2008) (Figure 1). After harvest, fruits were immediately carried to the adjacent Postharvest Laboratory for being processed.

Figure 1. Representative sample of *Annona cherimola* Mill. cv "Fino de Jete" used in the experiment.

2.2. Experimental Design

After being carried to the laboratory, fruits were washed in sterilized water for two minutes and, subsequently, in a solution of distilled water and 200 ppm Ox-Virin (solution of hydrogen peroxide and peroxyacetic acid; 0,5% w/v) for 20 minutes. Later, they were also washed in a 100-ppm antioxidant ascorbic acid solution for two more minutes, then dried. Prior the beginning of the storage, a characterization of the physico-chemical and sensory aspects of the fruits was carried out on a sample of 30 fresh fruits, in order to assess the evolution of their characteristics over the storage time.

Fruits were randomly sorted in three groups, corresponding to the three experimental treatments, and later packed in low density polyethylene film bags (LDPE, Orved, S.p.A., Musile di Piave, Venezia, Italy) and stored at 10 ± 1 °C and 90 ± 5% RH in modified atmosphere conditions for 4 days. After that, all the bags were opened and fruits were kept at 10±1 °C and analyzed at three-days intervals (Day 4+0, 4+3, 4+6) for a simulated 6-day shelf-life period.

The experimental design was based on three treatments:

- CTR: open air (fruits stored in unsealed bags)
- AIR: 21% O_2 + 1% CO_2 + 78% N_2 (passive-MAP)
- MAP: 30% CO_2 + 10% O_2 + 60% N_2

Non-destructive monitoring of the weight loss and headspace gas composition was carried out with a two-day interval during the MAP storage period.

Each bag contained five fruits, and analyses were carried out in six replicates: therefore, six bags per treatment were analyzed at each evaluation time – for a total of 54 bags – so the experimental design consisted of 5 fruits × 6 bags × 3 treatments × 3 evaluation times, for a total of 270 fruits.

The high CO_2 percentage mixture for the MAP treatment was chosen in order to exploit the known bacteriostatic effect of the carbon dioxide and its residual effect on the shelf-life of cherimoya and other fruits (Alique, 1995; D'Aquino et al., 1998; Jayas and Jeyamkondan, 2002; Mathooko et al., 1993). At the same time, 10% a content of O_2 was kept to avoid anaerobic metabolism responsible for the formation of undesirable compounds such as acetaldehyde (Pesis et al., 2002; Rodov et al., 2000), and N_2 was chosen as filling gas to protect the fruits from mechanical damage during handling.

Modified atmosphere was obtained inside the sealed LDPE bags using a digitally controlled packaging machine (VM 16 Orved S.p.A, Musile di Piave, Venezia, Italy). Characteristics of the LDPE were the following: 90 μm thickness - 500 cm^3 volume films; permeation to CO_2 (cm^3 m^{-2} day^{-1}): 14000; Oxygen Transmission Rate (OTR): 7500 cm^3 m^{-2} day^{-1}; Water Vapour Transmission Rate (WVTR): 6.5 g m^{-2} day^{-1}.

2.3. Headspace gas composition

During storage in modified atmosphere conditions, the gas composition (oxygen and carbon dioxide) inside the bags of AIR and MAP treatments was determined using a gas analyzer (PBI Dansensor, Ringsted, Denmark) at two-days intervals. Gas analysis was performed inserting a needle attached to the gas analyzer through an adhesive seal fixed on the packaging material The results were obtained as % of O_2 and CO_2. All analyses were presented as mean ± standard deviation (SD) of six replicates.

2.4. Physico-chemical analyses

After the end of MAP storage, at three days intervals, the following parameters were measured on fruits of all treatments: weight of the fruits (g), using an electronic precision scale (Gibertini EU-C 2002 RS, Novate Milanese, Italy); firmness (N), using a hand-held penetrometer with an 8 mm probe (Fresh Produce Instruments, Moerkapelle, Netherlands); total soluble solids content (TSSC; °Brix) using a portable digital refractometer (Atago, Tokyo, Japan). All results are presented as mean ± standard deviation of five replicates.

2.5. Colorimetric analysis

Color of the skin and pulp was measured using a digital colorimeter (CR-400 Chroma Meter, Minolta, Japan) and calibration of the color meter was performed against a white tile background (Illuminants C: Y ¼ 89.53, x ¼ 0.3247, y ¼ 0.3198) prior to each measurement. Analyses were presented as mean ± standard deviation (SD) of five replicates.

Mean color difference (ΔE) between the colors at each evaluation time for the fruit of each treatment and the color of the fresh fruit measured at harvest was determined, according to the following equation:

$$\Delta E = \sqrt{(L^* - L_0^*)^2 + (a^* - a_0^*)^2 + (b^* - b_0^*)^2} \qquad \text{(eq. 1)}$$

where L*, a* and b* and L_0*, a_0* and b_0* represent the current and initial values of the color of the fruit. Mean Chroma (C*) values, which indicate the quantitative attribute of color intensity, and hue angle (h°), which is considered as the qualitative attribute of color, of the samples were calculated using equations 2 and 3, and then, a color table was created by converting the CIEL*a*b* color space into the red/green/blue (RGB) scale:

$$C^* = \sqrt{(a^2 + b^2)} \qquad \text{(eq. 2)}$$

$$h^\circ = \arctan\left(\frac{b^*}{a^*}\right) \qquad \text{(eq. 3)}$$

Browning index (B.I.) of the fruit pulp color during the simulated shipping period was determined visually assessing each fruit's degree of pulp browning according to the following scale: 0=no browning; 1=less than 1/4 browning; 2=1/4–1/2 browning; 3=1/2–3/4 browning; 4=more than 3/4 browning, and using the equation

$$\text{B.I.} = \left(\frac{1 \times N_1 + 2 \times N_2 + 3 \times N_3 + 4 \times N_4}{4 \times N}\right) \times 100 \qquad \text{(eq. 4)}$$

where N_x represents the number of fruits showing the relative degree of browning and N is the total number of fruits examined, as formulated by Wang et al. (Liu et al., 2016; Wang et al., 2005; Zhang et al., 2015).

2.6. Microbiological analyses

Twenty-five grams of all CTR, AIR and MAP fruit samples, at each sampling time, were transferred into sterile lateral filter bags (BagFilter® 400, Interscience, Saint Nom, Francia), added with 225 mL of Ringer's solution (Oxoid, Milan, Italy) and homogenized in a stomacher (BagMixer® 400, Interscience) for 2 min at the maximum speed (blending power 4). All homogenized samples were serially diluted applying a 1:10 dilution factor in the same isotonic solution used for the homogenization of the fruit samples. Cell suspensions were analyzed for the following microbial groups: total mesophilic microorganisms (TMM) on plate count agar (PCA), incubated at 30 °C for 72 h; total psychrotrophic microorganisms (TPM) on PCA, incubated at 7 °C for 7 d; members of the *Enterobacteriaceae* family on violet red bile glucose agar (VRBGA), after incubation at 37 °C for 24 h; yeasts on dichloran rose bengal chloramphenicol (DRBC) agar, after incubation at 28 °C for 48 h; molds on potato dextrose agar (PDA) supplemented with 0.1 g/L chloramphenicol to avoid bacterial growth, after incubation at 25 °C for 7 d. All media and supplements were purchased from Biotec (Grosseto, Italy). All plate counts were carried out in triplicate.

2.7. Content of Carbohydrates, Lipids, Proteins, Water and Ashes

The carbohydrate and protein content were evaluated as previously described, respectively using Anthrone's (Yemm e Willis, 1954) and Kjedahl's (Jung et al., 2003) methods. Ash and water contents were determined through the procedure described in AOAC (Williams, 1984). The content of lipids was calculated after lipid extraction with a gravimetric method, as previously described (Vigliante et al., 2019). All analyses were performed in triplicate and data were expressed as g per 100 g of pulp.

2.8. Mineral Content

The contents of K, Na, Ca, Mg, Fe, Cu, Mn, and Zn were determined by atomic absorption spectroscopy following wet mineralization, and using the instrumental condition as previously described (Farina et al., 2017b). Briefly, the samples were digested, and approximately 100 mg of dried sample was weighed and incubated with 9 mL of 65% (*w/v*) HNO_3, and 1 mL of 30% (w/v) H_2O_2 were added. The temperature was set at 200 °C for 20 min. Once cooled, the digested samples were diluted to a final volume of 50 mL with distilled H_2O. All measurements were performed using an Agilent 4200 MP-AES

fitted with a double-pass cyclonic spray chamber and OneNeb nebulizer. The calibration standards were prepared by diluting a 1000 mg/L multi-element standard solution (Sigma Aldrich and Scharlab S.L.) in 1% (*v/v*) HNO_3. Finally, P was determined using a colorimetric method (Zhao et al., 2009). All analyses were performed in triplicate and data were expressed as mg per 100 g.

2.9. Vitamin Content

Retinol (Vit. A), Riboflavin (Vit. B2), Thiamine (Vit. B1), and Ascorbic Acid (Vit. C) were extracted and determined according to previously reported methods. Briefly, Vit. A was extracted and quantified using a commercial kit (Vitamin A Food ELISA Kit, Crystal Chem, NL) and following the manufacturer's instructions. Vit. B1 and Vit. B2 were respectively extracted using 0.1 N HCl (Ollilainen et al., 1993) or a solution of 1% (*v/v*) H_2SO_4 (Bueno-Solano et al., 2009). Quantification was performed via HPLC equipped with a fluorimetric detector (Bueno-Solano et al., 2009; Ollilainen et al., 1993). Finally, Vit. C was extracted with 10 mL of 1% (*v/v*) HPO_3 for 45 min from dried extract, previously prepared (Gentile et al., 2019). After filtration, 1 mL was mixed with 9 mL of $C_{12}H_7NCl_2O_2$ and the absorbance was measured at 515 nm against a blank after 30 min. Vitamin C was quantified using a calibration curve of authentic L-ascorbic acid (0.02–0.12 mg/100 g). All analyses were performed in triplicate and data were expressed as mg per 100 g.

2.10. Sensory Analysis

Sensory analysis was conducted on the fruits at three-day intervals after the opening of the packages, corresponding with evaluation times 4+0, 4+3, 4+6. Sensory evaluation was performed by a team of 30 judges (sixteen women and fourteen men aged between 20 and 56 years) with a good background and knowledge of the details of this kind of food evaluation, in accordance to the guidelines of UNI10957:2003 legislation (Gianguzzi et al., 2017; Mazzaglia et al., 2010; Sortino et al., 2020). Each judge was provided with a piece of at least 20 g from a fruit from each sample to be evaluated and water was offered between tastings to rinse the mouth.

Preliminary meetings took place to choose 23 qualitative descriptors for the definition of the sensory profile, generated on the basis of citation frequency (>60%) (Gentile et al., 2021; Puccio et al., 2019): Visual Appearance (VA); Skin Color (SC); Firmness (F); Fruit Odor (OF); Odor of Exotic Fruit (OEF); Odor of Cherimoya (OC); Odor of Medicine (OM); Herbaceous Odor (OH); Flesh Color (FC); Sweetness (S); Acid (A); Juicy (J); Astringent (AS); Pungent/Fermented (P); Herbaceous Flavor (FH); Bitter (B); Flavor of Cherimoya (FC); Texture (T); Flavor of Fruit (FF); Flavor of Exotic Fruit (FEF); Flavor of Fermented Fruit (FFER); Floury (FL).

2.11. Statistical analysis

Analysis of variance was applied to all the variables studied. The mean values obtained in the different categories were compared by one-way ANOVA, and significant differences among means at $p < 0.05$ were determined by Tukey's test. All statistical analysis was conducted using SigmaPlot software version 12.0 (Systat Software, Inc., San Jose, CA, USA).

3. Results and Discussion

3.1. Headspace Gas Composition

Figure 2 reports the relative compositions of O_2 and CO_2 within the packages during the modified atmosphere storage at 10±1 °C.

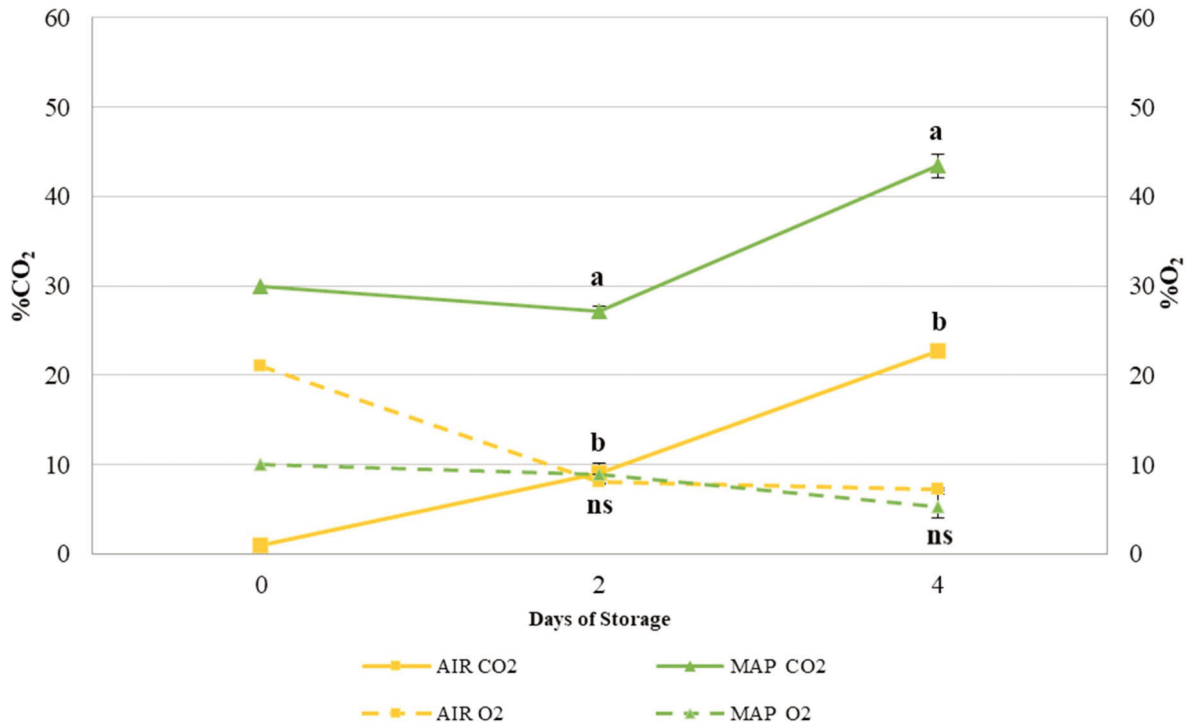

Figure 2. Carbon dioxide (%CO_2) and oxygen (%O_2) content within the sealed bags throughout the MAP storage (0, 2 days of storage). All values are shown as mean ± S.D. (n = 6). Different letters at each evaluation time indicate significant difference between the treatments for Tukey's HSD test ($p < 0.05$). "ns" indicates there is no significant difference between any two treatments for Tukey's HSD test ($p < 0.05$). Figure shows the differences between the treatments AIR: 21% O_2 + 1% CO_2 + 78% N_2 (passive-MAP); and MAP: 30% CO_2 + 10% O_2 + 60% N_2.

Results show an increase in CO_2 concentration for both treatments and a simultaneous decrease of O_2 concentration. This increase was sudden for AIR treatment and followed a linear trend. This was reflected also in the O_2 concentration, which decreased from about 20 to 10% in the first 2 days of storage. The increase in CO_2 concentration for MAP treatment, instead, begun only after the first 2 days of storage. Similarly, the O_2 concentration stayed at the original values after the first interval.

Many literature sources described the post-harvest behavior of cherimoya as peculiar, highlighting the presence of two CO_2 production peaks after harvest (Kader, 1986; Kosiyachinda and Young, 1975; Moreno and De La Plaza, 1982; Palma et al., 1993; Paull and RE, 1982; Wang, 1990). Our analysis observed a first CO_2 concentration peak happening simultaneously at 4 storage days for both AIR and MAP treatments. CO_2 concentration was the highest within the sealed packages of the MAP treatment, and this is in accordance with what has been observed on cherimoya stored at low temperature and high CO_2 compared with passive-MAP by other authors (Alique, 1995; De la Plaza and Muñoz-Delgado, 1980).

3.2. Physico-chemical analyses

3.2.1. Fruit Weight Loss

The bags containing the cherimoya fruits were weighed at each evaluation time, both during the modified atmosphere storage period and after the opening of the packages (Figure 3). No significant difference between weight losses was observed in the 4 days storage period. At the end of the simulated

shipping period, weight loss was very contained for all treatments, reaching a maximum value of 1.2% of the fresh fruit mass in the CTR fruits after 4-days storage and 6 days shipping simulation.

Fruit treated with MAP had a maximum weight loss of about 1%, higher than fruit treated with AIR (0.30%). This is probably related to the modification of the atmosphere inside the package and thus the levels of O_2 and CO_2 reached and the maintenance of a high humidity environment for the goods inside the plastic film, as reported by Kader et al. (1989). The modified moisture atmosphere maintains the freshness of the fruit (Tugwell e Chvyl, 1996) and, therefore, may reduce weight loss caused by water loss. Thise results can likely be considered an effect of the storage temperature of 10 °C on the fruits, as other studies on cherimoyas kept at room temperature (20±2 °C) recorded weight losses up to 10% of the fresh fruit mass after 5 days from harvest (Cordeiro et al., 2013; Yonemoto et al., 2002).

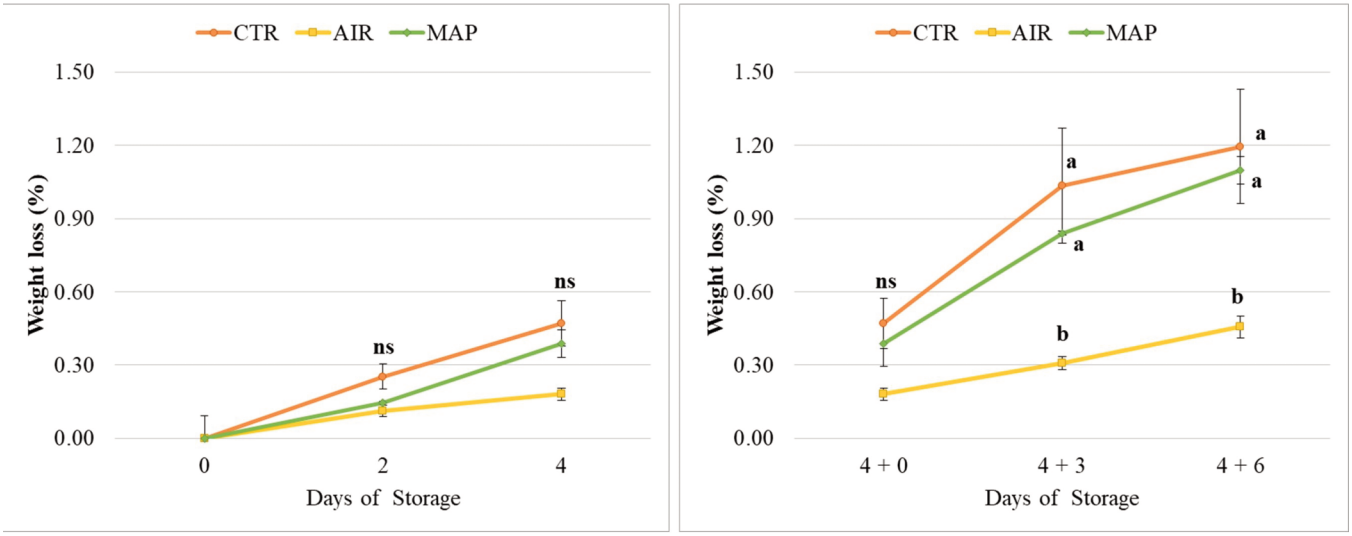

Figure 3. Weight Loss during (a) MAP storage (0, 2, 4 days of storage) and (b) simulated shipping period (4+0, 4+3, 4+6). All values are shown as mean ± S.D. (n = 6). Different letters at each evaluation time indicate significant difference between the treatments for Tukey's HSD test ($p < 0.05$). "ns" indicates there is no significant difference between any two treatments for Tukey's HSD test ($p < 0.05$). Figure shows the differences between CTR: open air (fruits stored in unsealed bags); AIR: 21% O_2 + 1% CO_2 + 78% N_2 (passive-MAP); MAP: 30% CO_2 + 10% O_2 + 60% N_2

3.2.2. Firmness

Fruit firmness generally decreases rapidly in cherimoya as a result of several physiological processes that take place in the course of ripening (Cordeiro et al., 2013), and it is one of the most important parameter consumers use to evaluate the ripeness degree of cherimoya, this being a fruit which does not show a marked change of color at maturity (Berger e Galleti, 2004; Pareek et al., 2011). Cherimoya fruits are generally assumed ready for consumption when they have flesh firmness values below 60 N (Shen et al., 2009).

Measurement on the fresh fruits showed an average firmness level of 108 N at harvest, which is considered to be corresponding to a fruit with optimum quality (Pinillos et al., 2008). CTR fruits were the ones which showed the most important softening, reaching a value of 40 N at the end of the 10 days of storage. MAP and AIR fruits, on the other hand, kept firmness values above 80 N until the end of the storage period (Figure 4). Although the differences between AIR and MAP treatments are often not significant, flesh firmness show better values for MAP fruits. This can be considered an index of the ripening of CTR fruits, as firmness has been observed to decrease rapidly after the onset of ethylene production (Manríquez et al., 2014), which happens after the climacteric maximum that could be observed only in CTR fruits.

Compared to other studies on cherimoyas kept at room temperature (20±2 °C) or at 10 °C without controlled atmosphere (Cordeiro et al., 2013; Manríquez et al., 2014; Pareek et al., 2011; Shen et al., 2009), all the fruits in our study showed a better retention of their firmness. Moreover, also the storage in controlled atmosphere seems to have an effect on maintaining the firmness of the fruits of our study (Alique, 1995), as untreated CTR fruits performed significantly worse than those of the two AIR and MAP treatments.

Another factor involved in the decline of desirable texture is the loss of water, which leads to a decrease in weight, turgidity and crispness (Cortellino et al., 2015). Softening can be caused by the hydrolysis of protopectins into water-soluble pectins, decrease in cellulose crystallinity, thinning of cell walls, diffusion of sugar into intercellular spaces, and the movement of ions from the cell wall (Toivonen e Brummell, 2008). Varoquaux and Wiley, (1994) reported that modified atmospheres can limit the loss of compartmentalization within cells and the interaction of enzymes, such as polygalacturonases and pectin esterases, with their substrates. Many studies have also shown that the decrease in firmness during storage is strongly dependent on the availability of oxygen, mainly from the packaging atmosphere but also from the permeability of the plastic packaging material (Cortellino et al., 2015).

In other studies, increases in fruit firmness have been reported with the application of a high level of carbon dioxide (Harker et al., 2000; Lee et al., 2002), in addition to the improvement in firmness observed when strawberry fruits are kept at low temperatures (Watkins et al., 1999). This can be seen as a satisfying result from the point of view of the postharvest management of the fruits: firmer fruits, in facts, are less subject to manipulation damage and can thus be handled more easily and provided to the stores in a condition more appreciated by the consumer (Pareek et al., 2011).

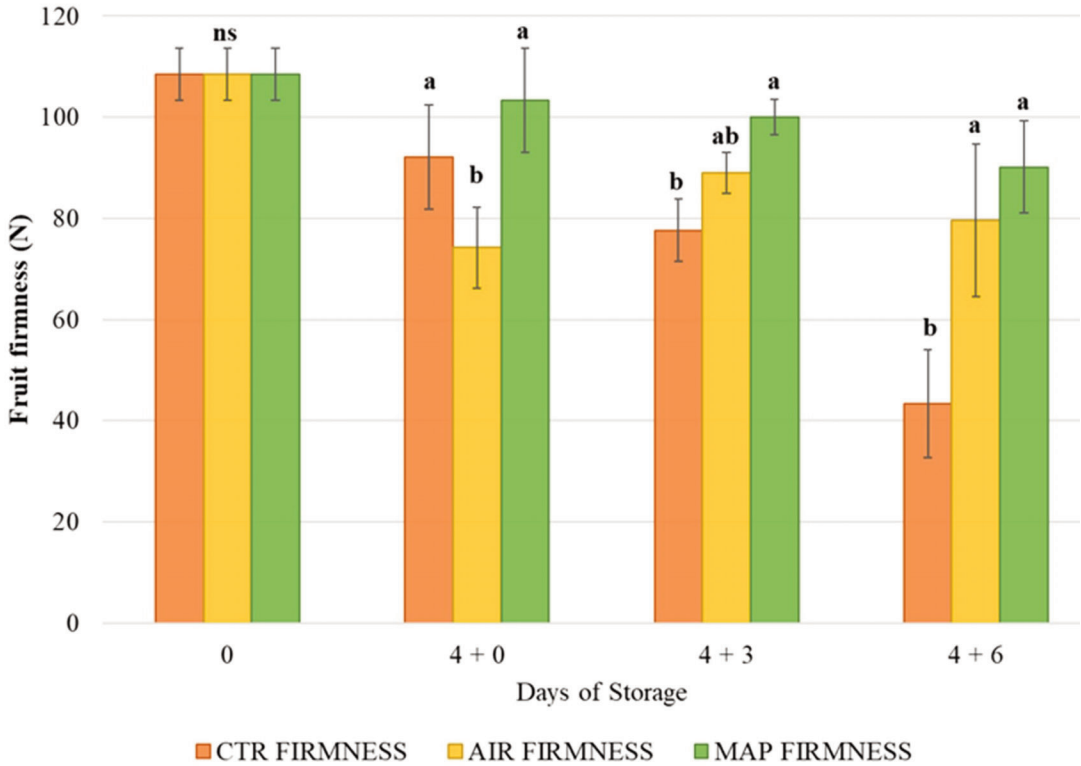

Figure 4. Evolution of Fruit Firmness on the fresh fruit and during simulated shipping period (4 + 0 , 4 + 3, 4 + 6). All values are shown as mean ± S.D. (n = 6). Different letters at each evaluation time indicate significant difference between the treatments for Tukey's HSD test ($p < 0.05$). "ns" indicates there is no significant difference between any two treatments for Tukey's HSD test ($p < 0.05$). Figure shows the differences between CTR: open air (fruits stored in unsealed bags); AIR: 21% O_2 + 1% CO_2 + 78% N_2 (passive-MAP); MAP: 30% CO_2 + 10% O_2 + 60% N_2.

3.2.3. Total Soluble Solids Content

Total soluble solids content increased in all treatments, with different rates (Figure 5). After 4 days in modified atmosphere storage, fruits of the MAP treatment had the smallest increase in the sugar content, with a TSSC value of 8.33 °Brix, while fruits from both CTR and AIR treatments had already reached values above 10 °Brix (12.18 and 13.83 °Brix, respectively). After 3 days of simulated shipping period, values of TSSC for all treatments were between 12 and 15 °Brix, with values for the MAP treatment fruits showing a significant increase. After 6 days from the opening of the packages, so at 10 days from harvest, CTR fruits were the only ones having TSSC close to 20 °Brix, a value which indicates that cherimoya fruits are ready for consumption (Palma et al. 1993). Fruits from both AIR and MAP treatments, on the same date, had the same TSSC content of 13.70±0.1 °Brix, indicating that they were still not ready for consumption and needed a longer time for reaching the optimal ripeness degree. As already seen for firmness, the differences between AIR and MAP treatment, although are often not significant, show better values for MAP fruits.

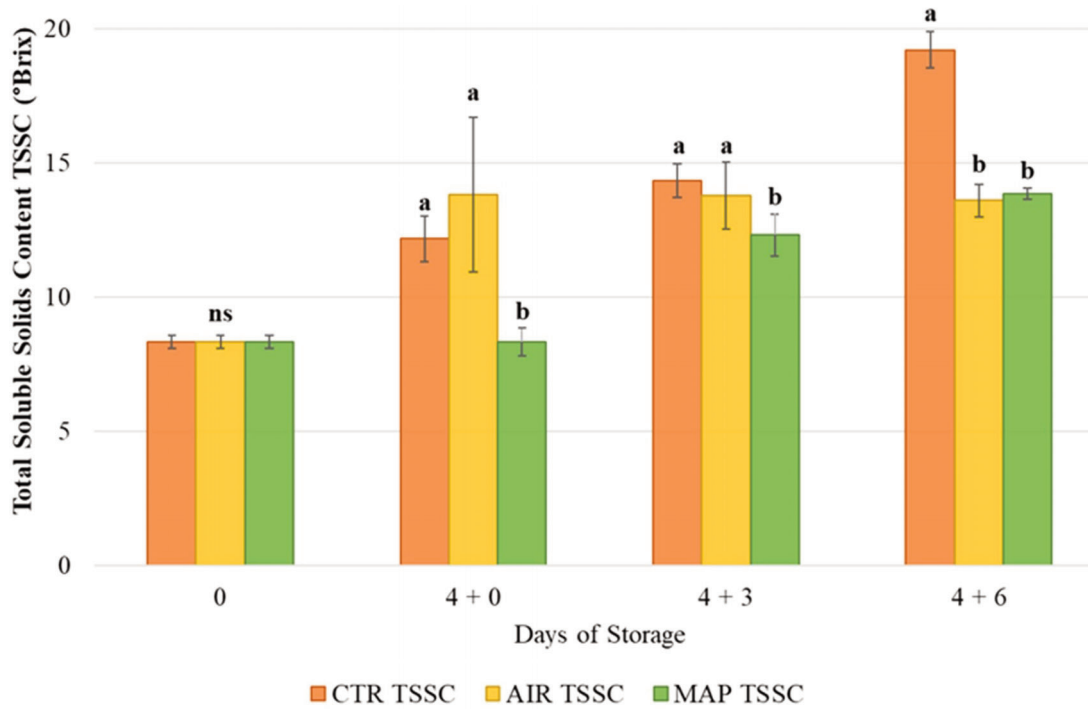

Figure 5. Total Soluble Solids content on the fresh fruit and during simulated shipping period (4 + 0 , 4 + 3, 4 + 6). All values are shown as mean ± S.D. (n = 6). Different letters at each evaluation time indicate significant difference between the treatments for Tukey's HSD test ($p < 0.05$). "ns" indicates there is no significant difference between any two treatments for Tukey's HSD test ($p < 0.05$). Figure shows the differences between CTR: open air (fruits stored in unsealed bags); AIR: 21% O_2 + 1% CO_2 + 78% N_2 (passive-MAP); MAP: 30% CO_2 + 10% O_2 + 60% N_2.

In particular, we observed that fruits of the MAP treatment maintained the initial TSSC value after the modified atmosphere storage period, and this increased only after the opening of the packages, suggesting that the MAP gas mixture halted the ripening of the fruits. AIR fruits, instead, showed an increase in their TSSC during modified atmosphere storage similar to the one of the CTR fruits, but, after the opening of the packages, did not further increase their soluble sugar content. Alique (1995) reported a similar result after monitoring cherimoya fruits stored for short periods in high (20%) CO_2 atmosphere. In facts, the author reported that fruits subjected to this treatment exhibited higher sweet-

ness than those left in passive-MAP conditions or in open air and ascribed this difference to a probable inhibition of ethylene production, and the subsequent processes leading to senescence, due to the high CO_2 percentage in the packages.

3.3. Colorimetric Analysis

Table 1 reports the results of the colorimetric analyses performed on the fruits at all evaluation times. It emerged that no significant difference was present among the treatments for any parameter of the CIELab color space over the course of the evaluation, confirming that appearance of the Modified Atmosphere treated fruits varied similarly to the untreated ones. Skin color change in all treatments was also more limited than that observed by Del Cura et al. (Cura et al., 1996) in cherimoyas treated with 20% CO_2 atmosphere.

Table 1. Color Difference (ΔE), Chroma (C*), and hue angle (h°) values of the skin and flesh color on the fresh fruit and during simulated shipping period (4 MAP + 0 S, 4 MAP + 3 S, 4 MAP + 6 S). Table shows the differences between CTR: open air (fruits stored in unsealed bags); AIR: 21% O_2 + 1% CO_2 + 78% N_2 (passive-MAP); MAP: 30% CO_2 + 10% O_2 + 60% N_2. Different letters at each evaluation time indicate significant difference between the treatments for Tukey's HSD test ($p < 0.05$). "ns" indicates there is no significant difference between any two treatments for Tukey's HSD test ($p < 0.05$).

	Skin color											
	Fresh			4 MAP + 0 S			4 MAP + 3 S			4 MAP + 6 S		
	ΔE	C*	h°	ΔE	C*	h°	ΔE	C*	h°	ΔE	C*	h°
CTR	0.00	27.61	-1.18	2.84b	35.43ns	-1.25ns	2.89b	35.03a	-1.24ns	3.28b	30.84b	-1.24ns
AIR	0.00	27.61	-1.18	6.43a	35.21ns	-1.33ns	4.97a	36.04a	-1.36ns	2.88c	31.99b	-1.26ns
MAP	0.00	27.61	-1.18	2.56b	35.21ns	-1.22ns	1.73c	30.75b	-1.21ns	4.06a	35.56a	-1.35ns
	Flesh color											
	Fresh			4 MAP + 0 S			4 MAP + 3 S			4 MAP + 6 S		
	ΔE	C*	h°	ΔE	C*	h°	ΔE	C*	h°	ΔE	C*	h°
CTR	0.00	3.66	0.09	1.38b	13.26b	-1.48ns	3.71a	14.87b	-1.51ns	5.66a	18.33b	-1.56ns
AIR	0.00	3.66	0.09	3.95a	15.44a	-1.54ns	3.74a	16.96a	-1.53ns	3.69b	20.45a	-1.56ns
MAP	0.00	3.66	0.09	4.37a	15.74a	-1.49ns	2.06b	16.58a	-1.51ns	2.63c	18.25b	-1.56ns

After 4 days of storage + 6 shelf-life days, it emerged that the largest change in flesh color was found in the untreated CTR fruits (ΔE = 5.66), while the AIR fruit were the ones that showed the smallest difference in skin color (ΔE = 2.88).

It is suggested that pulp and skin darkening is a symptom of increased activity of polyphenol oxidases on phenolic compounds that exist in skin and pulp (Pareek et al., 2011). Lower accumulation of total phenolics with post-harvest storage can be explained by reduced activity of polyphenol oxidases and peroxidase, which are involved in the oxidation of phenolic compounds (Pareek et al., 2011). Figure 6 describes the evolution over time of the browning index (B.I.) calculated for the fruits of the different treatments. As expected, untreated CTR fruits were the ones where the impact of the browning on the appearance of the fruits was the highest. In the fruits subjected to controlled atmosphere storage of the treatments AIR and MAP, the impact of browning was more limited, but the best results were obtained with the AIR treatment, where B.I. was below 50% during the whole storage period of the trial. This is an interesting result, considering that many techniques have been tried to control enzymatic browning of the pulp of cherimoya (Abufon, 1985; Mastrocola et al., 1998; Palma et al., 1993; Prieto et al., 2007) which requires more intensive manipulation of the fruits and their storage environment.

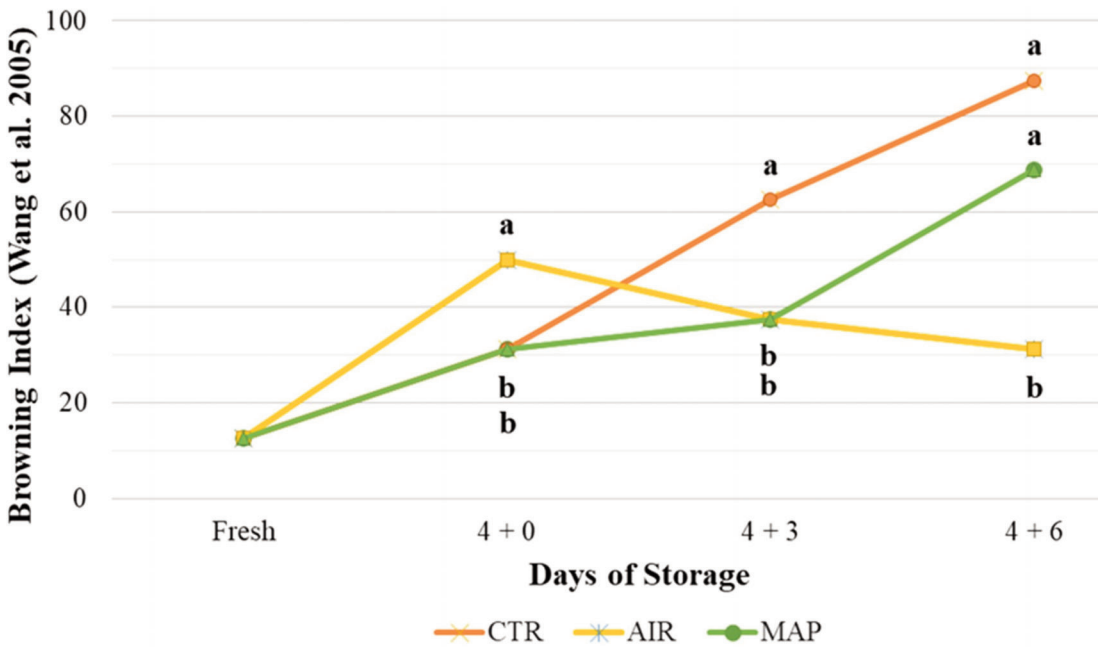

Figure 6. Evolution over storage time of the Browning Index of the fruits at each evaluation time (Fresh fruit; 4 MAP + 0 S.; 4 MAP + 3 S.; 4 MAP + 6 S.) calculated according to Wang et al., 2005. Figure shows the differences between CTR: open air (fruits stored in unsealed bags); AIR: 21% O_2 + 1% CO_2 + 78% N_2 (passive-MAP); MAP: 30% CO_2 + 10% O_2 + 60% N_2.

3.4. Microbiological analyses

The results of the microbiological investigation on cherimoya fruits subjected to different treatments (CTR, AIR and MAP) are reported in Table 2. None of the samples analyzed revealed the presence of detectable levels of molds, responsible for the microbiological spoilage of fruits and vegetables due to the generation of off-flavours, discoloration and rotting (Filtenborg et al., 1996; Rico-Munoz et al., 2019).

Table 2. Microbial loads of the cherimoya fruit samples of the Control (CTR), passive-MAP (AIR) and active-MAP (MAP) treatments tested on different substrates: Plate Count Agar (PCA); Violet Red Bile Glucose Agar (VRBGA); Dichloran Rose Bengal Chloramphenicol (DRBC); Potato Dextrose Agar (PDA). Results are expressed as log CFU/g. Different letters indicate significant differences between treatments for the same evaluation date. "ns" indicate no significant difference between treatments.

Samples	PCA 30°C	PCA 7°C	VRBGA	DRBC	PDA
		Day 0 (4+0)			
CTR	<2 a	<2 a	<2 a	<2 a	<2 a
AIR	<2 a	<2 a	<2 a	<2 a	<2 a
MAP	<2 a	<2 a	<2 a	<2 a	<2 a
p value[b]	ns	ns	ns	ns	ns
		Day 3 (4+3)			
CTR	3.35 ± 0.21 a	3.07 ± 0.18 a	3.12 ± 0.23 a	3.20 ± 0.12 a	<2 a
AIR	3.51 ± 0.11 a	2.95 ± 0.21 a	3.04 ± 0.13 a	3.34 ± 0.19 a	<2 a
MAP	<2 b	<2 b	<2 b	<2 b	<2 a
p value	<0.0001	<0.0001	<0.0001	<0.0001	ns
		Day 6 (4+6)			
CTR	5.73 ± 0.17 a	5.37 ± 0.18 a	5.15 ± 0.14 a	5.37 ± 0.23 a	<2 a
AIR	5.43 ± 0.12 a	5.09 ± 0.13 a	5.13 ± 0.11 a	5.40 ± 0.18 a	<2 a
MAP	4.15 ± 0.20 b	4.03 ± 0.10 b	3.84 ± 0.21 b	4.01 ± 0.13 b	<2 a
p value	<0.0001	<0.0001	<0.0001	<0.0001	ns

According to the Tukey's test, statistically significant differences among treatments appeared after 3 days of storage when CTR and AIR fruit samples showed levels of TMM, TPC, yeasts and members of *Enterobacteriaceae* family of about 10^3 CFU/g, while these microbial groups were below the detection limit in MAP fruits. This trend was due to the exposition of CTR and AIR fruits to the high percentage of oxygen which is the most important gas involved in food deterioration (especially fruits and vegetables); oxygen acts as final electron acceptor during aerobic respiration of spoilage microorganisms (Soltani et al., 2015). However, after 6 days of storage, all microbial groups considered in the investigation became detectable also in MAP cherimoya fruits even though their cell densities were about 2 Log cycles lower than those found for CTR and AIR fruits. These results confirmed the observation of Martínez-Ferrer et al. (2002) who reported that low concentrations of oxygen in MAP are correlated with a slow microbial growth. From the microbiological point of view, this study showed that the application of MAP and low temperatures are not able to arrest the microbial growth but are effective to slow down significantly their development.

3.5. Proximate Composition

The proximate composition (moisture, protein, fat, total sugars, raw fiber and ash) of cherimoya fruits immediately after harvest and during storage is presented in Table 3. During the storage period of the fruit, for all three treatments, a non-significant decrease in moisture content from about 79% at harvest to an average value of 74% at day 10 of storage was observed. MAP treatment maintained the moisture content better, with a decrease from an initial value of 79.30% to 77.56%. The maintenance of moisture content is very important in fruits as it makes the fruit juicier and more palatable for the consumer (Othman et al., 2014). The slight decrease that was noticed could be due to the process of respiration of the fruit and the consequent loss of water (Lakshminarayana et al., 1970).

Major differences between the untreated (CTR) fruits and those subjected to Modified Atmosphere Packaging (AIR or MAP) could be found only when observing the content in proteins and in raw fibers (Table 3). Fruits from the CTR treatment, in facts, had a lower content in proteins, and a higher one in raw fibers, at all evaluation times.

Table 3. Results of the proximate composition analysis on the fruits of cherimoya fruit samples of the Control (CTR), passive-MAP (AIR) and active-MAP (MAP) treatments on fresh fruit and during simulated shipping period (4 MAP + 0 S, 4 MAP + 3 S, 4 MAP + 6 S). Results are expressed as % (moisture content) and g/100g of pulp (all other parameters). Different letters indicate significant differences between treatments for the same evaluation date. "ns" indicate no significant difference between treatments.

Treatment	Days of Storage	Moisture content	Protein content	Fat content	Sugar content	Raw fiber content	Ash
Fresh Fruit	0	79.30 ± 0.9	1.78 ± 0.1	0.15 ± 0.01	12.58 ± 0.9	5.35 ± 0.2	0.73 ± 0.01
CTR	4 MAP + 0 S	79.63 ± 0.6 ns	1.51 ± 0.1b	0.19 ± 0.01 ns	12.79 ± 0.2 a	5.15 ± 0.1 a	0.60 ±0.1 ns
	4 MAP + 3 S	75.73 ± 2.2 b	1.59 ± 0.2 b	0.23 ± 0.01ns	13.78 ±0.3 ns	4.00 ± 0.1 a	0.62 ± 0.1 ns
	4 MAP + 6 S	72.88 ± 0.3 b	1.40 ± 0.1 b	0.18 ± 0.01 b	12.50 ± 1.0 b	3.81 ± 0.4 a	0.68 ± 0.1 ns
AIR	4 MAP + 0 S	78.37 ± 0.6 ns	1.67 ± 0.1 a	0.20 ± 0.01 ns	11.85 ± 0.8 b	4.95 ± 0.4 a	0.54 ± 0.01 ns
	4 MAP + 3 S	78.18 ± 2.2 a	1.56 ± 0.1b	0.21 ± 0.01ns	14.90 ± 1.4 ns	2.11 ± 0.1 b	0.59 ± 0.01 ns
	4 MAP + 6 S	72.75 ± 1.5 b	1.56 ± 0.1a	0.25 ± 0.01 b	14.25 ± 0.5 a	2.93 ± 0.1 b	0.69 ± 0.01 ns
MAP	4 MAP + 0 S	78.44 ± 0.4 ns	1.57 ± 0.1b	0.19 ± 0.01 ns	13.01 ± 1.3 a	4.32 ± 0.1 b	0.70 ± 0.1 ns
	4 MAP + 3 S	78.96 ± 0.7 a	1.69 ± 0.1a	0.24 ± 0.01 ns	12.74 ± 1.5 ns	2.35 ± 0.1 b	0.68 ± 0.1 ns
	4 MAP + 6 S	77.56 ± 0.6 a	1.53 ± 0.1a	0.25 ± 0.01 b	11.41 ± 1.0 b	2.74 ± 0.5 b	0.63 ± 0.1 ns

Fat content represents the true fat and other materials such as phospholipids, sterols, essential oils and fat-soluble pigments in the fruit. There were no significant differences in the average fat content of the cherimoya fruits analyzed for all treatments. It increased during the storage period, from an initial value of 0.15±0.03 g/100 g to a maximum value of 0.25±0.03 g/100 g. The low level of fat suggests that these fruits are not a good source of energy (Boakye, 2013) and are recommended for weight loss or maintenance, nutrient supply and lowering blood pressure (Asgary et al., 2014).

Ash is the inorganic residue remaining after heating removal of all the water and organic matter that provides a measure of the total amount of minerals in a food (Othman et al., 2014). The main purpose of ash determination is to assess the quality of the food materials. High total ash content for a food material indicates the presence of adulterants (Mbogo et al., 2010). The ash content for cherimoya fruit at harvest was 0.73±0.03 g/100g and this value did not change significantly throughout the experiment in all three treatments.

3.6. Vitamin and Mineral Content

Vitamin C has been observed to be the most abundant vitamin in the pulp of cherimoya fruits (Gupta-Elera et al., 2011; Jamkhande et al., 2017). Its content was above 30mg/100g for the fruits of all treatments throughout the period of the experiment. However, cherimoya seems to be prone to losses of vitamin C during storage, just like other green-colored foodstuffs (Lee and Kader, 2000; Spínola et al., 2013). After 4 days of storage + 6 days of simulated shipping period, in facts, fruits of all treatments had lost about 10mg/100g of vitamin C, and no significant difference was found between the treatments at that time.

Controlled atmosphere, however, seems to have helped preserve a small content of vitamin A (retinol), which is widely recognized as an important factor in the maintenance of healthy cells and tissues (Ross, 2010), in the pulp of the fruits of the treatments AIR and MAP. On the other hand, it could only be found in traces in untreated CTR fruits, already at the end of the 4-days period of MAP storage. No major changes, instead, were observed in the contents of vitamins B1 and B2 over the course of the experiment, even though untreated CTR fruits seem to have better preserved their content in the pulp (Figure 7).

The values of K, Na, Ca, Mg and P remained high throughout the storage period (Table 4). Potassium and sodium are the predominant mineral elements in the fruit. They remained high in all three treatments and in particular, the MAP treatment maintained high levels of Na until the tenth day of storage. Cherimoya fruit can, therefore, contribute significantly to the daily amount of sodium required by the body, as the RDA value for adult sodium is only 500 mg/day (Ganesan et al., 2020).

Calcium levels were slightly lower than those reported for other cherimoya varieties (Djarot e Badar, 2017), and remained equal to, or slightly above, the harvest level (9 mg/100g) throughout the storage period. The content of iron, copper and manganese in cherimoya fruits remained at very low values throughout the storage period (Table 4). The zinc level in the cherimoya fruits remained at values of about 4.00 mg/100g and no significant differences were observed between treatments (Table 4). The zinc level found was well below the FAO and WHO permissible level of 6 mg/100 g (Ganesan et al., 2020).

3.7. Sensory Analysis

Fruits at harvest were considered too firm by the judges and did not reach high scores for the positive descriptors, while they had higher scores for descriptors such as herbaceous odor, herbaceous flavor, and bitter. This can be explained by the fact that the fruits were harvested at commercial maturity rather than physiological maturity, in order to simulate a supply chain handling.

After the 4 days of storage, similar results were found in the fruits of the MAP treatment, while fruits of AIR and CTR showed some changes and received low to medium scores in all descriptors,

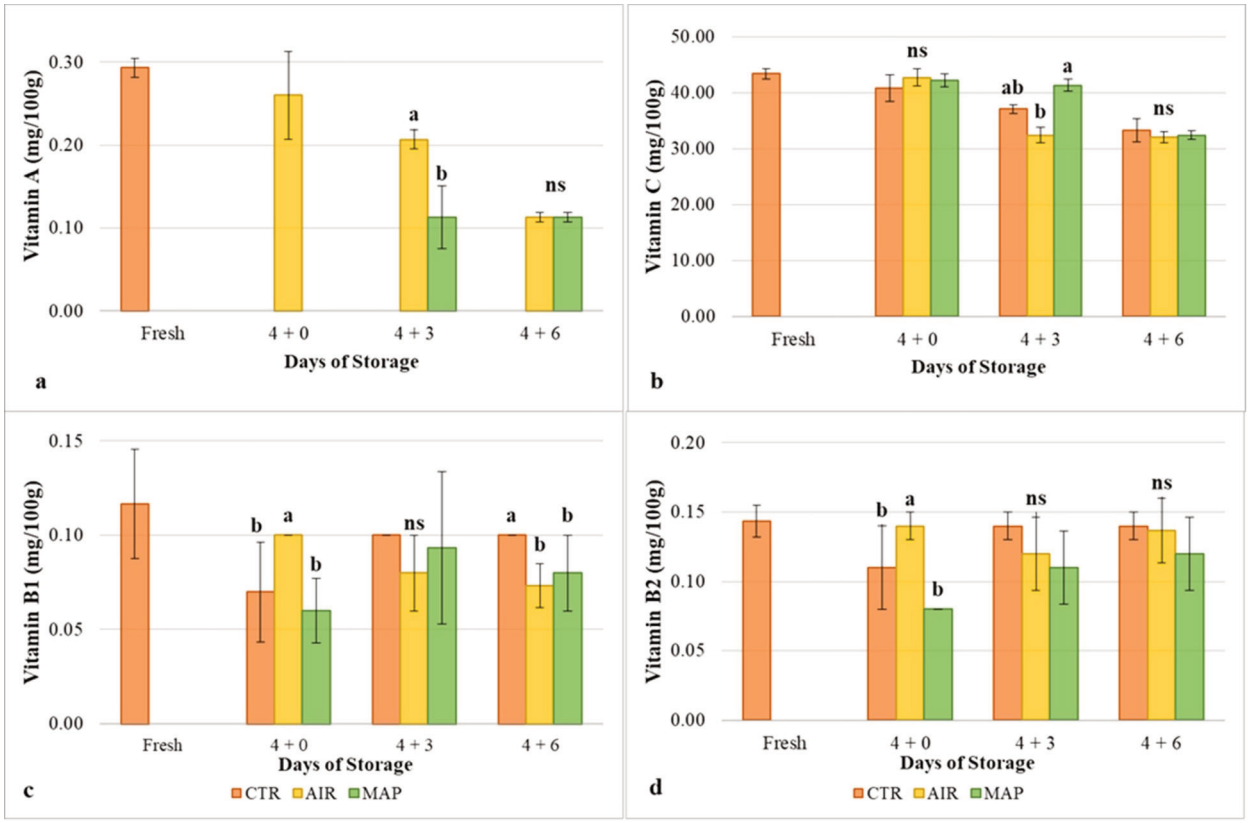

Figure 7. Vitamin A (a), Vitamin C (b), Vitamin B1 (c) and Vitamin B2 (d) content of the fruits of the samples of the Control (CTR), passive-MAP (AIR) and active-MAP (MAP) treatments during simulated shipping period (4+0, 4+3, 4+6). Where columns are missing, the substance was only found in traces. Different letters at each evaluation time indicate significant difference between the treatments for Tukey's HSD test ($p < 0.05$). "ns" indicates there is no significant difference between any two treatments for Tukey's HSD test ($p < 0.05$). Figure shows the differences between CTR: open air (fruits stored in unsealed bags); AIR: 21% O_2 + 1% CO_2 + 78% N_2 (passive-MAP); MAP: 30% CO_2 + 10% O_2 + 60% N_2.

Table 4. Mineral composition (mg/100g) of the samples of the Control (CTR), passive-MAP (AIR) and active-MAP (MAP) treatments on fresh fruit and during simulated shipping period (4 MAP + 0 S, 4 MAP + 3 S, 4 MAP + 6 S). at harvest and over the course of the simulated shipping period. Different letters indicate significant differences between the treatments in the same evaluation time. "ns" indicates no significant difference between treatments at the given time.

Treatment	Days of storage	K	Na	Ca	Mg	P	Cu	Mn	Zn	Fe
Fresh	0	304 ± 34.6	19 ± 5.0	9 ± 1.1	10 ± 0.5	31 ± 6.0	1 ± 0.6	1 ± 0.3	4 ± 0.3	0.4 ± 0.01
CTR	4 MAP + 0 S	278 ± 3.6ns	18 ± 4.7ns	9 ± 1.0ns	9 ± 1.1ns	24 ± 2.5b	1 ± 0.2ns	1 ± 0.1ns	3 ± 0.1ns	0.3 ± 0.01ns
	4 MAP + 3 S	257 ± 28.0b	23 ± 1.0a	8 ± 2.0ns	8 ± 1.0ns	18 ± 5.0b	1 ± 0.4ns	1 ± 0.3ns	4 ± 0.9ns	0.2 ± 0.01ns
	4 MAP + 6 S	273 ± 13.0b	20 ± 1.0ns	10 ± 1.0ns	10 ± 1.0ns	31 ± 2.0a	1 ± 0.9ns	1 ± 0.1ns	5 ± 1.0ns	0.3 ± 0.01ns
AIR	4 MAP + 0 S	273 ± 13.2ns	20 ± 7.0ns	10 ± 1.0ns	10 ± 1.0ns	31 ± 2.0a	1 ± 0.9ns	1 ± 0.1ns	5 ± 0.4ns	0.3 ± 0.01ns
	4 MAP + 3 S	279 ± 36.9 a	21 ± 9.6a	9 ± 1.7ns	9 ± 2.5ns	28 ± 3.0a	2 ± 0.7ns	1 ± 0.1ns	5 ± 0.4ns	0.3 ± 0.01ns
	4 MAP + 6 S	285 ± 4.7a	17 ± 1.1ns	9 ± 1.1ns	10 ± 2.0ns	22 ± 2.0b	2 ± 0.7ns	1 ± 0.1ns	5 ± 0.4ns	0.3 ± 0.01ns
MAP	4 MAP + 0 S	269 ± 20.5ns	22 ± 9.6ns	9 ± 1.7ns	9 ± 2.5ns	28 ± 3.0a	2 ± 0.7ns	1 ± 0.1ns	5 ± 0.5ns	0.3 ± 0.01ns
	4 MAP + 3 S	278 ± 3.6a	18 ± 4.7b	9 ± 1.0ns	9 ± 1.1ns	24 ± 2.5a	1 ± 0.2ns	1 ± 0.1ns	3 ± 0.0ns	0.3 ± 0.01ns
	4 MAP + 6 S	285 ± 4.7a	17 ± 1.1ns	9 ± 1.1ns	10 ± 2.0ns	22 ± 2.0b	2 ± 0.7ns	1 ± 0.1ns	5 ± 0.4ns	0.3 ± 0.01ns

showing a lack of taste of the fruits, linked to an incomplete maturation of the fruits (Pareek et al., 2011). On day 4+3, the only significant differences were found in the descriptors herbaceous odor and texture: in particular, the latter was considered very low by the judges in the CTR fruits, and this can be linked to the ripening processes taking place in them. At the end of the MAP storage + shelf-life period, after 10 days from harvest, only the untreated CTR fruits were finally considered good by the panelists, who assigned scores above 6 to descriptors such as odor of exotic fruit, sweet, flavor of cherimoya, flavor of fruit, and flavor of exotic fruit (Figure 8). This was supported by the physico-chemical analyses, which showed that only the fruits of this treatment reached a ripeness degree suitable for consumption.

On day 4+6, fruits of the AIR treatment, despite showing an attractive appearance, recorded high scores for negative descriptors such as odor of medicine and herbaceous odor, while MAP fruits had scores below 6 for almost all descriptors, indicating they could not still be considered at the optimal commercial ripeness stage (Figure 8). Therefore, these fruits seem more suitable for a placement on markets more distant than the local ones.

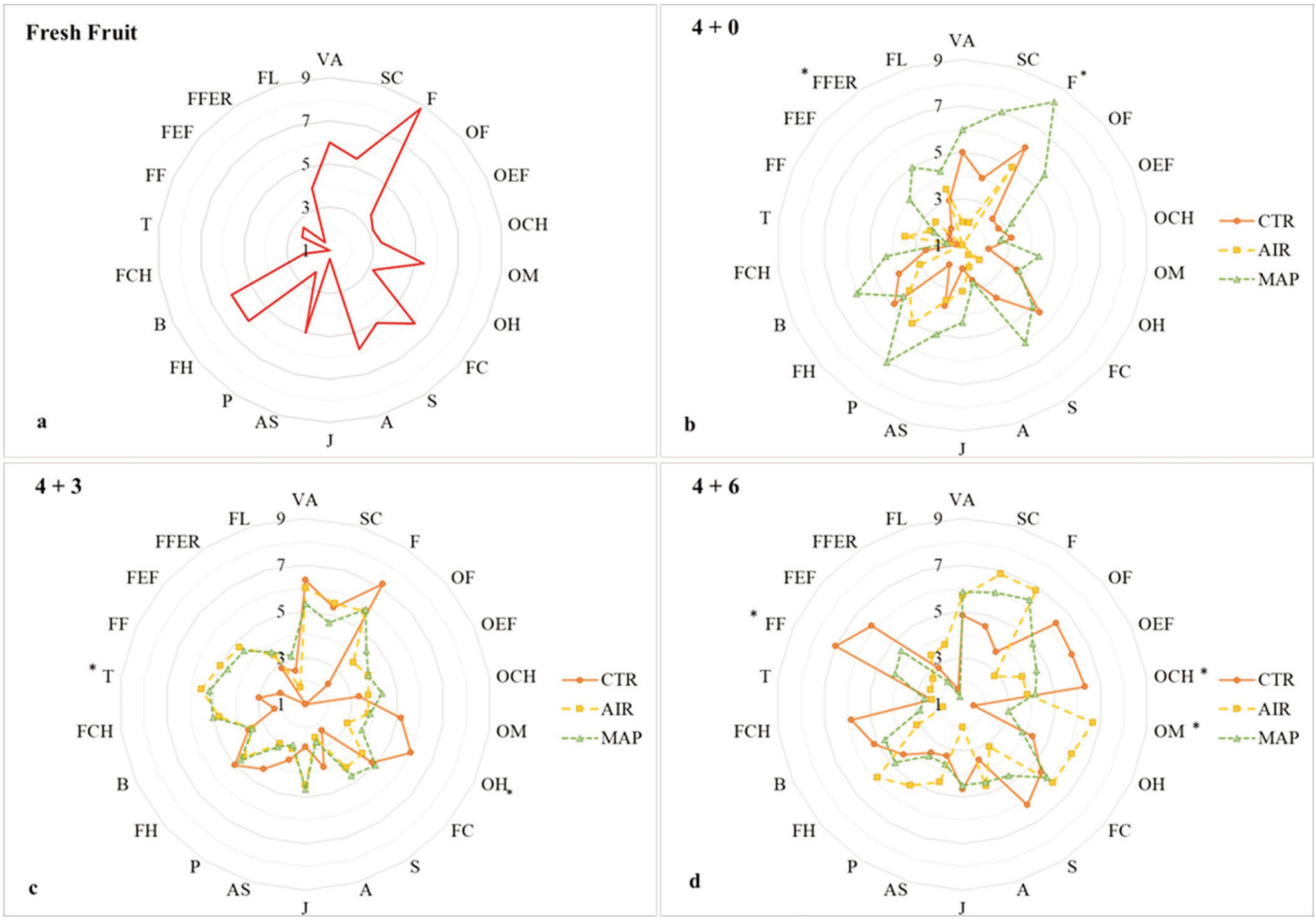

Figure 8. Sensory analysis performed by the panel on (a) the fresh fruit at harvest and on the samples of the control (CTR), passive-MAP (AIR) and active-MAP (MAP) treatments after (b) 4 days of controlled atmosphere storage, (c) 4 days of controlled atmosphere storage and 3 days of simulated shipping period, (d) 4 days of controlled atmosphere storage and 6 days of simulated shipping period. * indicates the presence of significant differences between treatments at the same analysis time. The descriptors were the following: visual appearance (VA); skin color (SC); firmness (F); fruit odor (OF); odor of exotic fruit (OEF); odor of cherimoya (OC); odor of medicine (OM); herbaceous odor (OH); flesh color (FC); sweetness (S); acid (A); juicy (J); astringent (AS); pungent/fermented (P); herbaceous flavor (FH); bitter (B); flavor of cherimoya (FC); texture (T); flavor of fruit (FF); flavor of exotic fruit (FEF); flavor of fermented fruit (FFER); floury (FL).

4. Conclusions

This study on Italian-grown cherimoya aimed to explore the feasibility of marketing this fruit on the European market. With this in mind, we evaluated the technology of Modified Atmosphere Packaging and assessed its effects on the post-harvest life of cherimoya fruits. With regard to extending the marketability of this product, the results are promising. In fact, the application of modified atmosphere, associated with cold storage, delayed the reaching of the physiological maturity phase by the fruit, allowing a longer management of the cherimoya supply chain, without affecting its quality, nutritional values, and safety for the consumer.

Physico-chemical changes, linked to the ripening of cherimoya fruits, were observed in MAP treated fruits after more than 7 days from harvest, while at the same time CTR fruits had already progressed to a degree of ripeness appropriate for consumption, and AIR fruits showed signs of physiological alterations, such as the interruption of accumulation of soluble solids. In addition, modified atmosphere packaging treatment seems to have contributed on maintaining fruit firmness, as CTR fruits had significant worse performance than both AIR and MAP treatments. This can also be considered a good result from the perspective of postharvest fruit management, as firmer fruits are less subject to handling damage.

Finally, given that control of microbial spoilage is the basis of an efficient supply chain, our results show that MAP with low oxygen concentrations slowed microbial growth, thus permitting a longer time to commercialization. In conclusion, short MAP treatments can be considered a useful, low-cost technique to prolong the shelf-life of cherimoyas and allow Mediterranean producers to expand into medium-distance markets, reducing product loss, increasing interest in this fruit and expanding the offer of tropical fruits from the Mediterranean.

Funding: No funding was received for conducting this study.

Acknowledgements: The authors would like to thank Orved S.p.a. and MedicAir Food S.p.a. for their contribution to the necessary instrumentation; Dr. Raimondo Gaglio for his supervision in the microbiological analyses.

References

Abufon J.C.A. (1985). *Efectos de aditivos, mondados y tiempo de almacenaje en la calidad de pulpa y rodelas congeladas de chirimoya (Annona cherimola Mill.) cv. Concha Lisa y Bronceada*. PhD Thesis. Universidad Catolica de Valparaiso.

Alique, R. (1995) 'Residual effects of short-term treatments with high CO_2 on the ripening of cherimoya (Annona cherimola Mill.) fruit', *Journal of Horticultural Science,* 70(4), pp. 609-15.

Alique, R. and Oliveira, G.S. (1994) 'Changes in Sugars and Organic Acids in Cherimoya (Annona cherimola Mill.) Fruit under Controlled Atmosphere Storage', *Journal of Agricultural and Food Chemistry,* 42(3), pp. 799-803. doi: 10.1021/jf00039a040

Alique, R. and Zamorano, J.P. (2000) 'Influence of harvest date within the season and cold storage on cherimoya fruit ripening', *Journal of agricultural and food chemistry,* 48(9), pp. 4209-4216.

Alique, R., Zamorano, J.P., Calvo, M.L., Merodio, C. and José L. (1994) 'Tolerance of cherimoya (Annona cherimola Mill.) to cold storage', *Journal of the American Society for Horticultural Science,* 119(3), pp. 524-8.

Asgary, S., Sahebkar, A., Afshani, M.R., Keshvar, M., Haghjooyjavanmard, S. and Rafieian-Kopaei, M. (2014) 'Clinical evaluation of blood pressure lowering, endothelial function improving, hypolipidemic and anti-inflammatory effects of pomegranate juice in hypertensive subjects', *Phytotherapy Research*, 28(2), pp. 193-9.

Benassi, G., Correa, G.A.S.F., Kluge, R.A. and Jacomino, A.P. (2003) 'Shelf life of custard apple treat-

ed with 1-methylciclopropene: an antagonist to the ethylene action', *Brazilian Archives of Biology and Technology,* 46(1), pp. 115-20.

Berger, H. and Galleti, L. (2004) 'Color as a harvest index for cherimoya', *V International Postharvest Symposium 682.* Verona, Italy, 30 June 2005, pp. 1471-1474.

Biale, J. and Barcus, D. (1970) 'Respiratory patterns in tropical fruits of the Amazon Basin', *Tropical Science,* 12, pp. 93-104.

Boakye, A.A. (2013) 'Assessment of Some Health Beneficial Constituents of Edible Portions of Four Underutilised Fruits'. PhD Thesis. University of Ghana.

Bruinsma, J. and Paull, R.E. (1984) 'Respiration during Postharvest Development of Soursop Fruit, Annona muricata L.', *Plant Physiology,* 76(1), pp. 131-8. doi: 10.1104/pp.76.1.131

Bueno-Solano, C., López-Cervantes, J., Campas-Baypoli, O., Cortez-Rocha, M., Casillas-Hernández, R., Milan-Carrillo, J. and Sánchez-Machado D. (2009) 'Quantitative HPLC analysis of riboflavin and aromatic amino acids in three forms of shrimp hydrolysates', *Journal of Liquid Chromatography & Related Technologies*®, 32(20), pp. 3009-24.

Calabrese, F. (1978) *Tropical and subtropical fruit growing*. Italy: Cooperativa Libraria Universitaria Editrice.

Cautín, R. and Agustí, M. (2005) 'Phenological growth stages of the cherimoya tree (Annona cherimola Mill.)', *Scientia Horticulturae,* 105(4), pp. 491-7. doi: 10.1016/j.scienta.2005.01.035

CBI. The European market potential for exotic tropical fruit. Available at: https://www.cbi.eu/market-information/fresh-fruit-vegetables/exotic-tropical-fruit/market-potential (Accessed 03/03/2022)

Cordeiro, N., Sousa, L., Freitas, N. and Gouveia, M. (2013) 'Changes in the mesocarp of Annona cherimola Mill. Madeira during postharvest ripening', *Postharvest biology and technology,* 85, pp. 179-84.

Cortellino, G., Gobbi, S., Bianchi, G. and Rizzolo, A. (2015) 'Modified atmosphere packaging for shelf life extension of fresh-cut apples', *Trends in Food Science & Technology,* 46(2), pp. 320-30.

Cura, B.D., Escribano, M.I., Zamorano, J.P. and Merodio, C. (1996) 'High Carbon dioxide Delays Postharvest Changes in RuBPCase and Polygalacturonase-related Protein in Cherimoya Peel', *Journal of the American Society for Horticultural Science,* 121(4), pp. 735-9. doi: 10.21273/JASHS.121.4.735

D'Aquino, S., Piga, A., Molinu, M.G., Agabbio, M. and Papoff, C.M. (1998) 'Maintaining quality attributes of «craxiou de porcu» fresh fig fruit in simulated marketing conditions by modified atmosphere', *Acta Horticulturae,* 480, pp. 289-94. doi: 10.17660/ActaHortic.1998.480.48

Dattola, A., Sortino, G., Vonella, V., Zappia, R. and Gullo, G. (2019) 'Effect of fruit-set time on the quality performance of Anona cherimola Mill. fruit in south Italy', *Scientia Horticulturae,* 246, pp. 272-8.

De la Plaza, J. L., and Muñoz-Delgado, L. (1980) 'Controlled atmosphere storage of cherimoya'. *Proceedings of 15th international congress of refrigeration.* Venetia, Italy, September 23-29, pp. 701-712.

Djarot, P. and Badar, M. (2017) 'Formulation and production of granule from annona muricata fruit juice as antihypertensive instant drink', *Int J Pharm Pharm Sci,* 9, pp. 18-22.

Eum, H.L., Hong, S.C., Chun, C., Shin, I.S., Lee, B.Y., Kim, H.K. and Hong, S.J. (2013) 'Influence of temperature during transport on shelf-life quality of highbush blueberries (Vaccinium corymbosum L. cvs. Bluetta, Duke)', *Horticulture, Environment, and Biotechnology,* 54(2), pp. 128-33. doi: 10.1007/s13580-013-0114-y

Farina, V., D'Asaro, A., Mazzaglia, A., Gianguzzi, G. and Palazzolo, E. (2017a) 'Chemical-physical and nutritional characteristics of mature-green and mature-ripe 'Kensington Pride' mango fruit cultivated in Mediterranean area during cold storage', *Fruits,* 72(4), pp. 221-9. doi: 10.17660/th2017/72.4.4

Farina, V., Gianguzzi, G., D'Asaro, A., Mazzaglia, A. and Palazzolo, E. (2017b) 'Fruit production and

quality evaluation of four litchi cultivars (Litchi chinensis Sonn.) grown in Mediterranean climate', *Fruits,* 72(4), pp. 203-11. doi: 10.17660/th2017/72.4.2

Filtenborg, O., Frisvad, J.C. and Thrane, U., (1996) 'Moulds in food spoilage', *International journal of food microbiology,* 33(1), pp. 85-102.

Ganesan, A.R., Subramani, K., Shanmugam, M., Seedevi, P., Park, S., Alfarhan, A.H., Rajagopal, R. and Balasubramanian, B. (2020) 'A comparison of nutritional value of underexploited edible seaweeds with recommended dietary allowances', *Journal of King Saud University-Science,* 32(1), pp. 1206-11.

Gentile, C., Di Gregorio, E., Di Stefano, V., Mannino, G., Perrone, A., Avellone, G., Sortino, G., Inglese, P. and Farina, V. (2019) 'Food quality and nutraceutical value of nine cultivars of mango (Mangifera indica L.) fruits grown in Mediterranean subtropical environment', *Food chemistry,* 277, pp. 471-9. doi: 10.1016/j.foodchem.2018.10.109

Gentile, C., Mannino, G., Palazzolo, E., Gianguzz,i G., Perrone, A., Serio, G. and Farina, V. (2021) 'Pomological, Sensorial, Nutritional and Nutraceutical Profile of Seven Cultivars of Cherimoya (Annona cherimola Mill)', *Foods,* 10(1), pp. 35. doi: 10.3390/foods10010035

Gianguzzi, G., Mazzaglia, A., Sortino, G. and Farina, V. (2017) 'Instrumental and sensory evaluation of seven apple (Malus domestica Borkh.) cultivars under organic cultivation in Sicily', *Agronomy Research*, vol. 15(5), pp. 1878-1889. doi: 10.15159/ar.17.048

Gullo, G., Dattola, A. and Zappia, R. (2019) 'Comparative study of some fruit quality characteristics of two of Annona cherimola Mill. grown in southern Italy', *AIMS Agriculture and Food,* 4(3), pp. 658-71.

Gupta-Elera, G., Garrett, A.R., Martinez, A., Robison, R.A. and O'Neill K.L. (2011) 'The antioxidant properties of the cherimoya (Annona cherimola) fruit', *Food Research International, Exotic Fruits: their Composition, Nutraceutical and Agroindustrial Potential*. 44(7), pp. 2205-9. doi: 10.1016/j.foodres.2010.10.038

Harker, F.R., Elgar, H.J., Watkins, C.B., Jackson, P.J. and Hallett, I.C. (2000) 'Physical and mechanical changes in strawberry fruit after high carbon dioxide treatments', *Postharvest Biology and Technology,* 19(2), pp. 139-46.

Jamkhande, P.G., Ajgunde, B.R. and Jadge, D.R. (2017) 'Annona cherimola Mill. (Custard apple): a review on its plant profile, nutritional values, traditional claims and ethnomedicinal properties', *Oriental Pharmacy and Experimental Medicine,* 17(3), pp. 189-201. doi: 10.1007/s13596-017-0263-0

Jayas, D.S. and Jeyamkondan, S. (2002) 'PH-Postharvest Technology: Modified Atmosphere Storage of Grains Meats Fruits and Vegetables', *Biosystems Engineering,* 82(3), pp. 235-51. doi 10.1006/bioe.2002.0080

Jung, S., Rickert, D., Deak N., Aldin E., Recknor J., Johnson L. and Murphy P. 2003. 'Comparison of Kjeldahl and Dumas methods for determining protein contents of soybean products', *Journal of the American Oil Chemists' Society,* 80(12), pp. 1169-1173.

Kader, A.A. (1986) 'Biochemical and physiological basis for effects of controlled and modified atmospheres on fruits and vegetables', *Food technology*, 5, pp. 99-100.

Kader, A.A. (2002) *Postharvest Technology of Horticultural Crops*. University of California. Agriculture and Natural Resources.

Kader, A.A., Zagory, D., Kerbel, E.L. and Wang, C.Y. (1989) 'Modified atmosphere packaging of fruits and vegetables', *Critical Reviews in Food Science & Nutrition,* 28(1), pp. 1-30.

Kosiyachinda, S. and Young, R.E. (1975) 'Ethylene production in relation to the initiation of respiratory climacteric in fruit', *Plant and Cell Physiology,* 16(4), pp. 595-602. doi: 10.1093/oxfordjournals.pcp.a075180

Lahoz, J., Gutiérrez, M., Martínez-Cayuela, M., Pascual, L. and Vargas, A. (1990) 'Efecto de la refrigeración sobre la maduración del fruto del chirimoyo', *Ars Pharmaceutica,* 31, pp. 321-9.

Lakshminarayana, S., Subhadra, N. and Subramanyam, H. (1970) 'Some aspects of developmental physiology of the mango fruit', *Journal of Horticultural Science,* 45(2), pp. 133-42.

Lee, H.J., Kim, K.C., Piao, Y.L. and Hwang, Y.S. (2002) 'A Potential of Postharvest CO_2 Treatment on the Market Quality of Strawberries during Simulated Export', *Korean Journal of Agricultural Science,* 29(1), pp. 24-31.

Lee, S.K. and Kader, A.A. (2000) 'Preharvest and postharvest factors influencing vitamin C content of horticultural crops', *Postharvest Biology and Technology,* 20(3), pp. 207-20.

Lee, T.C., Hsieh, C.H., and Chang, P.T. (2016) 'Packaging affects the postharvest quality of atemoya fruits (Annona cherimola M.× Annona squamosal L.)', *Net Journal of Agricultural Science*, *4*(4), pp. 58-62.

Li, C., Shen, W., Lu W., Jiang, Y., Xie, J. and Chen, J. (2009) '1-MCP delayed softening and affected expression of XET and EXP genes in harvested cherimoya fruit', *Postharvest biology and technology,* 52(3), pp. 254-9.

Liu, K., Liu, J., Li H., Yuan, C., Zhong, J. and Chen, Y. (2016) 'Influence of postharvest citric acid and chitosan coating treatment on ripening attributes and expression of cell wall related genes in cherimoya (Annona cherimola Mill.) fruit', *Scientia Horticulturae,* 198, pp. 1-11. doi: 10.1016/j.scienta.2015.11.008

Loizzo, M.R., Tundis, R., Bonesi, M., Menichini, F., V., Avallone, L. and Menichini, F. (2012) 'Radical scavenging, antioxidant and metal chelating activities of Annona cherimola Mill. (cherimoya) peel and pulp in relation to their total phenolic and total flavonoid contents', *Journal of Food Composition and Analysis,* 25(2), pp. 179-84. doi: 10.1016/j.jfca.2011.09.002

Ludders, P. (2002) 'Cherimoya (Annona cherimola Mill.) - Botany, cultivation, storage and uses of a tropical-subtropical fruit', *Erwerbsobstbau,* 44(4), pp. 122-6.

Manríquez, D.A., Muñoz-Robredo, P., Gudenschwager, O., Robledo and P., Defilippi, B.G. (2014) 'Development of flavor-related metabolites in cherimoya (Annona cherimola Mill.) fruit and their relationship with ripening physiology', *Postharvest Biology and Technology,* 94, pp. 58-65. doi: 10.1016/j.postharvbio.2014.03.004

Martínez-Ferrer, M., Harper, C., Pérez-Muntoz, F. and Chaparro, M. (2002) 'Modified atmosphere packaging of minimally processed mango and pineapple fruits', *Journal of Food Science,* 67(9), pp. 3365-3371.

Mastrocola, D., Manzocco, L. and Poiana, M. (1998) 'Prevention of Enzymatic Browning During Freezing, Storage and Thawning of Cherimoya (Cherimoya cherimola, Mill) Derivatives', *Italian journal of food science,* 10, pp. 207-216.

Mathooko, F.M., Sotokawa, T., Kubo, Y., Inaba, A. and Nakamura, R. (1993) 'Retention of freshness in fig fruit by CO_2-enriched atmosphere treatment or modified atmosphere packaging under ambient temperature', *Journal of the Japanese Society for Horticultural Science,* 62(3), pp. 661-7.

Mazzaglia, A., Lanza, C. M., Farina, V., and Barone, F. (2010) 'Evaluation of Fruit Quality in Loquat Using Both Chemical and Sensory Analyses', *Acta horticulturae, 887*, pp. 345-349. 10.17660/ActaHortic.2011.887.59

Mbogo, G.P., Mubofu, E.B. and Othman, C.C. (2010) 'Post harvest changes in physico-chemical properties and levels of some inorganic elements in off vine ripened orange (Citrus sinensis) fruits cv (Navel and Valencia) of Tanzania', *African Journal of Biotechnology,* 9(12).

Migliore, G., Farina, V., Tinervia, S., Matranga, G. and Schifani, G. (2017) 'Consumer interest towards tropical fruit: factors affecting avocado fruit consumption in Italy', *Agricultural and Food Economics,* 5(1), pp. 1-12. doi: 10.1186/s40100-017-0095-8

Minor tropical fruits. Food Outlook. FAO. Available at http://www.fao.org/fileadmin/templates/est/COMM_MARKETS_MONITORING/Tropical_Fruits/Documents/Minor_Tropical_Fruits_FoodOutlook_1_2018. pdf. 67–75 (Accessed 03/03/2022)

Montero, L.M., Escribano, M.I., De La Plaza, J.L. and Merodio, C. (1995) 'Chilling temperature storage

induces changes in protein patterns and protease activity in cherimoya fruit', *Postharvest Biology and Technology,* 5(3), pp. 251-60.
Moreno, J. and De La Plaza, J., (1982) 'The respiratory intensity of cherimoya during refrigerated storage: a special case of climacteric fruit?', *Acta Horticolturae,* 138, pp. 179-186.
Ollilainen, V., Vahteristo, L., Uusi-Rauva, A., Varo, P., Koivistoinen P. and Huttunen, J. (1993) 'The HPLC determination of total thiamin (vitamin B1) in foods', *Journal of Food Composition and Analysis,* 6(2), pp. 152-65.
Othman, O.C., Fabian, C. and Lugwisha, E. (2014) 'Post Harvest Physicochemical Properties of Soursop (Annona Muricata L.) Fruits of Coast Region, Tanzania', *Journal of Food and Nutrition Sciences,* 2(5), pp. 220. doi: 10.11648/j.jfns.20140205.13
Palma, T., Aguilera, J.M. and Stanley, D.W. (1993) 'A review of postharvest events in cherimoya', *Postharvest Biology and Technology,* 2(3), pp. 187-208. doi: 10.1016/0925-5214(93)90047-7
Palma, T., Stanley, D.W., Aguilera, J.M. and Zoffoli J.P. (1993) 'Respiratory behavior of cherimoya (Annona cherimola Mill.) under controlled atmospheres', *HortScience,* 28(6), pp. 647-649.
Pareek, S., Yahia, E.M., Pareek, O.P. and Kaushik, R.A. (2011) 'Postharvest physiology and technology of Annona fruits', *Food Research International, Exotic Fruits: their Composition, Nutraceutical and Agroindustrial Potential,* 44(7), pp. 1741-51. doi: 10.1016/j.foodres.2011.02.016
Paull, R. E. (1982) 'Postharvest variation in composition of soursop (Annona muricata L.) fruit in relation to respiration and ethylene production [Indigenous to tropical America, Hawaii]', *Journal American Society for Horticultural Science*.
Pesis, E., Dvir, O., Feygenberg, O., Arie, R.B., Ackerman, M. and Lichter, A. (2002) 'Production of acetaldehyde and ethanol during maturation and modified atmosphere storage of litchi fruit', *Postharvest Biology and Technology,* 26(2), pp. 157-65. doi: 10.1016/S0925-5214(02)00024-8
Pinillos, V., Peinado and S., González, M. (2008) 'Fruit development and maturation phenology of'Fino de Jete'cherimoya', *Proc. 4th International Symposium on Tropical and Subtropical Fruits*, 975, pp. 335-42.
Pinto, A. de Q., Cordeiro, M.C.R., De Andrade, S., Ferreira, F.R., Filgueiras, H. de C., Alves and R., Kinpara, D.I. (2005). *Annona species*. Embrapa Cerrados-Livro científico (ALICE).
Prieto, H., Utz D., Castro, Á., Aguirre, C., González-Agüero, M., Valdés, H., Cifuentes, N., Defilippi, B.G., Zamora, P., Zúñiga, G. and Campos-Vargas, R. (2007) 'Browning in Annona cherimola Fruit: Role of Polyphenol Oxidase and Characterization of a Coding Sequence of the Enzyme', *Journal of Agricultural and Food Chemistry,* 55(22), pp. 9208-18. doi: 10.1021/jf070586
Puccio, S., Perrone, A., Sortino, G., Gianguzzi, G., Gentile, C. and Farina, V. (2019) 'Yield, pomological characteristics, bioactive compounds and antioxidant activity of Annona cherimola Mill. grown in mediterranean climate', *AIMS Agriculture and Food,* 4(3), pp. 592-603. doi: 10.3934/agrfood.2019.3.592
Rico-Munoz, E., Samson, R.A. and Houbraken, J. (2019) 'Mould spoilage of foods and beverages: Using the right methodology', *Food Microbiology,* 81, pp. 51-62.
Rodov, V., Copel, A., Aharoni, N., Aharoni, Y., Wiseblum, A., Horev, B. and Vinokur, Y. (2000) 'Nested modified-atmosphere packages maintain quality of trimmed sweet corn during cold storage and the shelf life period', *Postharvest Biology and Technology,* 18(3), pp. 259-66.
Ross, A.C. (2010). Vitamin A. Humana Press, Totowa, NJ: pp. 335-56. doi 10.1007/978-1-60761-627-6_16
Sabbe, S., Verbeke, W. and Damme, P.V. (2009) 'Perceived Motives, Barriers and Role of Labeling Information on Tropical Fruit Consumption: Exploratory Findings', *Journal of Food Products Marketing,* 15(2), pp. 119-38. doi: 10.1080/10454440802316750
Scheldeman, X. (2002) *Distribution and potential of cherimoya (Annona cherimola Mill.) and highland papayas (Vasconcellea spp.) in Ecuador*. PhD Thesis. University of Gent, Belgium.
Schroeder, C.A. (1956) 'Cherimoyas, sapotes, and guavas in California', *Yearbook of the California*

Avocado Society for the year 1956, pp. 49-56.
Sevillano, L., Sola M.M. and Vargas, A.M. (2010) 'Induction of small heat-shock proteins in mesocarp of Cherimoya fruit (Annona cherimola Mill.) produces chilling tolerance', *Journal of Food Biochemistry,* 34(3), pp.625-38. doi: 10.1111/j.1745-4514.2009.00304
Shen, W.B., Li C.R., Chen, J.Y., Xie J.H. and Lu W.J. (2009) 'Expansin gene expression in cherimoya fruit is correlated with flesh firmness during fruit ripening and softening', *The Journal of Horticultural Science and Biotechnology,* 84(3), pp. 333-9.
Siddiq, M., Ahmed, J., Lobo and M.G., Ozadali, F. (2012) *Tropical and Subtropical Fruits: Postharvest Physiology, Processing and Packaging*. John Wiley & Sons.
Soltani, M., Alimardani, R., Mobli, H. and Mohtasebi, S.S. (2015) 'Modified atmosphere packaging: a progressive technology for shelf-life extension of fruits and vegetables', *Journal of Applied Packaging Research,* 7(3), pp.2.
Sortino, G., Saletta, F., Puccio, S., Scuderi, D., Allegra, A., Inglese, P. and Farina, V. (2020) 'Extending the Shelf Life of White Peach Fruit with 1-Methylcyclopropene and Aloe arborescens Edible Coating', *Agriculture,* 10(5), pp. 1-18. doi: 10.3390/agriculture10050151
Spínola, V., Mendes, B., Câmara, J.S. and Castilho, P.C. (2013) 'Effect of time and temperature on vitamin C stability in horticultural extracts. UHPLC-PDA vs iodometric titration as analytical methods', *LWT - Food Science and Technology,* 50(2), pp. 489-95. doi: 10.1016/j.lwt.2012.08.020
Testa, R., Migliore, G., Schifani, G., Tinebra, I. and Farina, V. (2020) 'Chemical–Physical, Sensory Analyses and Consumers' Quality Perception of Local vs. Imported Loquat Fruits: A Sustainable Development Perspective', *Agronomy,* 10(6), pp.870. doi: 10.3390/agronomy10060870
Tinebra, I., Scuderi, D., Sortino, G., Inglese, P. and Farina, V. (2021) 'Effects of Argon-Based and Nitrogen-Based Modified Atmosphere Packaging Technology on the Quality of Pomegranate (Punica granatum L. cv. Wonderful) Arils', *Foods,* 10(2), pp.370. doi: 10.3390/foods10020370
Toivonen, P.M. and Brummell, D.A. (2008) 'Biochemical bases of appearance and texture changes in fresh-cut fruit and vegetables', *Postharvest biology and technology,* 48(1), pp. 1-14.
Tugwell, B. and Chvyl, W. (1996) 'Modified atmosphere packaging for citrus', *Proceedings of International Symposium Citrus,* 2, 1150-1152.
Van Passel, S. (2013) 'Food miles to assess sustainability: a revision', *Sustainable Development,* 21(1), pp. 1-17.
Vanhove, W. and Van Damme, P. (2013) 'Value Chains of Cherimoya (Annona Cherimola Mill.) in a Centre of Diversity and its on-Farm Conservation Implications', *Tropical Conservation Science,* 6(2), pp. 158-80. doi: 10.1177/194008291300600201
Varoquaux, P. and Wiley, R.C. (1994) 'Biological and biochemical changes in minimally processed refrigerated fruits and vegetables', *Minimally Processed Refrigerated Fruits & Vegetables,* pp. 226-68.
Vigliante, I., Mannino, G. and Maffei, M.E. (2019) 'Chemical Characterization and DNA Fingerprinting of Griffonia simplicifolia Baill', *Molecules,* 24(6), pp. 1032.
Wang, C.Y., (1990) 'Physiological and biochemical effects of controlled atmosphere on fruits and vegetables', *Food Preservation by Modified Atmospheres,* 197-223.
Wang, Y.S., Tian, S.P. and Xu, Y., (2005) 'Effects of high oxygen concentration on pro- and anti-oxidant enzymes in peach fruits during postharvest periods', *Food Chemistry,* 91(1), pp. 99-104. doi: 10.1016/j.foodchem.2004.05.053
Watkins, C.B., Manzano-Mendez, J.E., Nock, J.F., Zhang, J. and Maloney, K.E. (1999) 'Cultivar variation in response of strawberry fruit to high carbon dioxide treatments', *Journal of the Science of Food and Agriculture,* 79(6), pp. 886-90.
Williams, S., (1984). *Official methods of analysis*. Association of Official Analytical Chemists.
Yemm, E. and Willis, A., (1954) 'The estimation of carbohydrates in plant extracts by anthrone', *Biochemical Journal,* 57(3), pp. 508-14.

Yonemoto, Y., Higuchi, H. and Kitano, Y. (2002) 'Effects of storage temperature and wax coating on ethylene production, respiration and shelf-life in cherimoya fruit', *Journal of the Japanese Society for Horticultural Science,* 71(5), pp. 643-50.

Zhang, Z., Huber, D.J., Qu, H., Yun, Z., Wang, H., Huang, Z., Huang, H. and Jiang, Y. (2015) 'Enzymatic browning and antioxidant activities in harvested litchi fruit as influenced by apple polyphenols', *Food Chemistry,* 171, pp. 191-9.

Zhao, P., Zhang, B., Wang, L. and Li, G. (2009) 'Determination of phosphorus content in foods by vanadium molybdate yellow colorimetric method', *Shandong Agricultural Sciences,* 2.