Original article

Influence of ionizing treatment on the quality of stored strawberries

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Summary. The use of sustainable sanitization technique such as those of the ionization represent a good opportunity to the management of the post harvest of fresh and perishable fruits of short shelf life such as strawberry and more so if the application of these technologies does not influence significantly the evolution of the qualitative and nutraceutical aspects of the fruits. The aim of this work was to evaluate the effects of a ionizing treatment (T1) (Fruit Control Equipments, Italy) used for the environmental sanitization of the rooms storage (1±1°C) on fresh strawberries. Two everbearing cultivars of strawberry (cv. Portola and Murano) were considered about the evolution of the most rapresentative physical –chemical traits of fruits (weight losses (%), the skin colour, the total soluble solids content (SSC), the pulp firmness, the titratable acidity) and nutraceutical compounds (the total anthocyanin and phenolic contents and the antioxidant activity). The fruits were compared with untreated strawberries (control) stored in normal atmosphere (A.N.) and they were monitored after 3, 6, 9, 13 and 15 days (1±1°C and 95% RH). Both cultivars show their limit of marketability due the weight losses at 9 days. Fruits of cv. Murano show an high quality profile and the consumer acceptance seems to be related to treated samples with ions.

Key words: nutraceutical compounds, cultivar, shelf life, sustainability, ions

Introduction

The disinfestation, the decontamination, the shelf life extention and the quality improvement of products are some of the known applications in the use of the ionizing radiation technique in food processing (1, 2). This physical nonthermal technology has been widely applied in food storage, because it is more safety than other traditional chemical technology and over 30 countries in the world have approved more than 500 kinds of irradiated food for sale in the market (3). It shows positive effects in eliminating food-borne pathogens, reducing spoilage microorganisms, inhibing ethylene production/action, and retarding the ripening process (4). Different studies reported the advantage of the ionization technique for the limited effect on the loss in the nutrient stability, organoleptic changes (5-7) and the maintenance in the food appearance (3). Irradiation technique is no more destructive to vitamins than other food preservation methods (8). The dose (kGy) and the levels used are associated to different food matrix and they are in function of the differents requested applications (pasteurization for meat shellfish and spices, disinfestaction for dried fruits, flour and grain, inhibition of sprouting for patatoes, garlic and onions) (1). Fresh fruits and vegetables due their high perishability need to postharvest technology procedures to limit their quantitative and qualitative losses in the supply chain and the ionizing radiation is well reported to have some positive effects in the management of the products. Sanitization treatments with ions in fact have been successfully reported on different fresh cut products such as onions leaves (9), apple slices (9, 10), shredded carrots (11) while some tropical fruits (papaya, mango and banana) could decrease their ripening (1). In the fruits industry the ionizing technique is well known to be used in bulk shipments, after the packaging processing, in the treatment of fruits from areas harboring insects and in quarantine in the area where products are exported. The effectiviness of the technique is affected by different factors such as the commodity (cultivar, avaibility of water in the tissue, maturity at harvest, quality at harvest, postharvest handling procedures), the irradiation procedures (temperature of the irradiation, presence of oxygen in the environment, the dose of irradiation) and poststorage irradiation conditions (for example the rises in the levels of sucrose and reducing sugars in irradiated patatoes are higher if stored at 0-4°C than 25°C) (1). Rates of ionization up to 1kGy could be sufficient to eliminate most foodborn pathogens found on fruits (12) and they shouldn't reduce the caloric value and nutritional quality; against range of 1.00-3.00 kGy and levels major than 3.00 kGy could respectively accelerate the tissue softening and to promote the off –flavour emission due the increasing of the ripening of fruits. Strawberries are reported to tolerate high levels of irradiation (1.5-2 kGy) preserving the ascorbic acid content, the most important quality attributes and improving the shelf life for several additional days (1, 13). The ionizing can be also associated to other preserving technology such as the modified atmosphere packaging (MAP) (14) and the use of protein-based edible coatings, but on strawberry it was reported to be generally strongly affected by the cultivars used (15, 16). Among fresh and perishable fruits the strawberries such as other berries are regulary consumed without washing, so, more than others, they require efficient sanitization tools in the management of the supply chain (17, 18). The technical acceptance of a food treatment is today largely dependent also by environmental issue, and the use of sustainable sanitization technique such as the ionization of the storage environment or the improvement of standard procedures for sanitization could represent a good solution to ensure safety fresh products with high qualitative standard (19). In 2011 the European Food Safety Authority (20) assessed the safety of irradiated food and a survey carried out by the EU in 2011 (21) confirmed the 90% of 130 food matrix as regular and good for the marketability.

The use of new storage technique or the new applications can achieve new market scenario and improve the processing of some fresh foods. The most common and important fruits consumed in the Mediterranean diet is strawberry, and it assumes an important role in the prevention of such chronic pathologies for its high content of essential nutrients and beneficial phytochemicals. In particular the polyphenol composition, the anthocyanin profile, and the total antioxidant capacity of strawberries vary from cultivar to cultivar and depend on storage practices. Considering the importance of the ionizing as storage technique and the limited studies about the effect of this practice in the post harvest storage of strawberries, the goal of the present work was to evaluate the effects of the ionization treatment, applied as environmental sanitation tool, on the quality traits and the nutraceutical compounds of two different everbearing strawberries cultivars (cv Portola and cv Murano) up to 15 days of storage.

Materials and methods

Sample preparation and storage conditions

The tests were performed on two everbearing varieties of strawberry (*Fragaria* x *ananassa* Duch.) cv Portola (P) and cv Murano (M) obtained at the red ripe stage of maturity from a commercial orchard of the Agrifrutta Soc. Coop. SRL (Piedmont, Italy), where the experiment was carried out. Selected on the basis of uniform size, colour, and freedom from evident defects or diseases, the fruits were randomly distributed in 250 g polyethylene terephthalate (PET) trays, with five replicates per treatment and analysis day. Strawberry fruits, exposed into the cold room (730 m^3 of volume) to a flushing of ionization treatment (Fruit Control Equipments, Italy) (T1 P and T1 M) were compared with control (Control P and Control M) maintained under normal atmosphere (A.N.) up to the end of storage. The samples were stored at 1±1°C in a cold room held at 90-95% RH for 3, 6, 9,13 and 15 days.

Qualitative fruits assessment

Weight loss

The weight (water) loss of each strawberry tray was measured using an electronic balance (SE622, WVR, USA) with an accuracy of 0.01 g. The weight of each tray was recorded at harvest and at the end of each storage period. The weight losses are reported as a percentage of the initial fruit weight of each package. The results are expressed as an average of five replicates.

The pulp firmness, the soluble solids content (SSC) and titratable acidity (TA)

The pulp firmness was measured using a hand-held penetrometer (Effegi, Turoni, Italy) with a calibration scale in grams and a 5 mm diameter plunger, in accordance with standard industry practice. The head was pushed into the strawberry flesh to the depth of the head (5 mm) (22).

Two measurements each for 30 fruits were made on opposite sides of the central zone and then averaged to give a mean value for the fruit. The measurements are reported in Kg/cm^2. SSC analysis was conducted using squeezed strawberries at 20°C. The SSC concentration was determined through the homogenisation of five individual fruits from each lot with an Atago Pal-1 pocket refractometer (Atago Co. Ltd., Japan) and is expressed in units of Brix at 20°C (23). The TA was measured using an automatic titrator (Titritino 702, Metrohm, Swiss) and was determined potentiometrically using 0.1 N NaOH to an end point of pH 8.1 in 5 mL of juice diluted in 50 mL of distilled water.

Colour

Colour was measured on the first 15, non-mouldy fruits from each basket (three baskets were randomly chosen for each package). The mean of the 30 fruit measurements was used for data analysis. Colour was measured on the side of a slightly flattened whole fruit using a tristimulus colour analyser (Chroma Meter, Model CR-400, Minolta, Germany) equipped with a measuring head with an 8-mm-diameter measuring area. The analyser was calibrated to a standard white reflective plate and used Commission Internationale d l'Eclairage (CIE) Illuminant C.

CIELAB or L*a*b* space was used to describe the colour. This colour space is device-independent and able to create consistent colours regardless of the device used to acquire the image. L* is the luminance or lightness component, which ranges from 0 to 100, while a* (green to red) and b* (blue to yellow) are two chromatic components, with values varying from −120 to +120 (24). These values were used to calculate chroma, which indicates the intensity or colour saturation, using the following equation:

$$C^* = [a^{*2} + b^{*2}]^{1/2}$$

The total anthocyanin and phenolic contents and the antioxidant activity

To determine the total anthocyanin content, the total phenolic content, and the total antioxidant capacity, an extract of samples was obtained using 10 g of fruit added to 25 ml of extraction buffer (500 ml methanol, 23.8 ml deionised water and 1.4 ml hydrochloric acid 37%). After 1 h in the dark at room temperature, the samples were thoroughly homogenised for a few minutes with an ultra turrax (IKA, Staufen, Germany) and centrifuged for 15 min at 3000 rpm.

The supernatant obtained by centrifugation was collected and transferred into glass test tubes and stored at −20°C until analysis.

The total anthocyanin content was quantified according to the pH differential method (25). Anthocyanins were estimated by the difference of absorbance at 510 and 700 nm in a buffer at pH 1.0 and pH 4.5, where $A_{tot} = (A_{515} - A_{700})$ pH 1.0 − $(A_{515} - A_{700})$ pH 4.5. The results are expressed as milligrams of cyanidin-3-glucoside (C3G) equivalents per 100 g of fresh weight (fw). The total phenolic content was measured using Folin-Ciocalteu reagent with gallic acid as a standard at 765 nm following the method of Slinkard and Singleton (26). The results are expressed as milligrams of gallic acid equivalents (GAE) per 100 g of fresh weight (F.W.). Antioxidant activity was determined using the ferric reducing antioxidant power (FRAP) assay (27).

The antioxidant capacity of the dilute fruits extract was determined by its ability to reduce ferric iron to ferrous iron in a solution of 2,4,6-Tripyridyl-s-triazine (TPTZ) prepared in sodium acetate at pH 3.6. The reduction of iron in the TPTZ-ferric chloride solution (FRAP reagent) results in the formation of a blue-coloured product (ferrous tripyridyltriazine complex), the absorbance of which was read spectrophotometrically at 595 nm 4 min after the addition of appropriately diluted fruits extracts or antioxidant standards to the FRAP reagent. The results are expressed as mmol Fe^{2+} per 1 kg of fresh fruits. All of these analyses were performed using the UV-Vis spectrophotometer 1600 PC VWR International.

Sensory evaluations (consumer assesment)

In order to have additional parameters for evaluating the acceptability of the fruits stored fifteen panelists previously trained with commercial samples were invited to perform a sensory evaluation of the strawberries. The panellists (60% female and 40% male, between 20 and 30 years of age) were recruited from among students in the DISAFA, University of Turin.

For that, 10 fruits selected at random from each tray were presented to each panellist. The sensory descriptors used were appearance, aroma, texture, flavour and overall acceptability. During each session, the samples were presented in randomized order to the panelists, who judged the descriptors using a 9 point hedonic scale at room temperature (20±1°C), where 9= "like extremely," 7 = "like moderately," 5 = "neither like nor dislike," 3 = "dislike moderately," and 1 = "dislike extremely." The scores below 3 indicated unacceptable samples.

Statistical analysis

All statistics were performed using IBM-SPSS.22 for Windows (2015). The data obtained were treated with two-way analysis of variance (ANOVA) and the means were separated using the Tukey's ($P \leq 0.05$).

Results and Discussion

Weight loss

The strong susceptibility to weight losses of strawberries is due to their skin and the high content in water; the control of this parameter is essential not only for the marketability of the fruits (limit of losses to 6%) but also for the maintenance of the nutrient profile (28). The strawberries weight loss gradually increased over time and it was affected by the cultivar (Fig. 1). Softening of the fruits due the thinning of cell walls and the liquidification of cell contents occurred particularly at 13 days of the storage for both the cultivars.

According to the the limit of marketability, the cv. Portola is widely marketable up to 9 days, while the cultivar Murano is already at the limit of marketability to 9 days. At this time point negligible values of +0.4% and +0.6% were observed respectively for the cv. Portola and cv. Murano treated samples (T1P and T1M) against the control samples.

Pulp firmness, soluble solids content (SSC) and titratable acidity (TA)

In the Table 1 the qualitative parametres of stored strawberries are reported. The maintaining of pulp firmness is mainly due to the maintenance of high relative humidity, close to saturation, which prevents dehydration of the fruits. The two cultivars were significantly different in terms of pulp hardness already at the harvest time (0 days) showing a measured difference of 0.13 kg/cm^2. The highest values were observed for all the storage time for the cv. Murano. Up to 3 days of storage the hardness profile of the two cultivar is well defined and no statistically differences were observed among control and treated samples within each varieties. It is possible to observe, for both cultivars, an increasing pulp hardness along the storage time probably due the gelification of the pectin in the tissues under cold storage conditions (29-31). The phenomena observed then, could be attributed also to increasese of the weight loss, since water losses could affect the hardness measure, as suggested by other authors (32). The genotype of cv. Murano and Portola affects strongly also the total soluble solid content and the evolution of measured values is similar to those of pulp hardness. Strawberries of cv. Murano are more sweet and higher values were maintained along all the storage time. Generally high sugar content is required for good strawberry flavor. At 9 days of storage, limit of marketability according to weigt loss, the highest SSS value (11.0 °Brix) is reported for strawberries treated with ions (T1M). The increase of SSC values in strawberries aren't caused to the metabolic activity of the fruits during the ripening because they are non climateric fruits, but the weight losses, although minimal, greatly affects the concentration of the total sugars. As aspected the lowest TA values were observed from

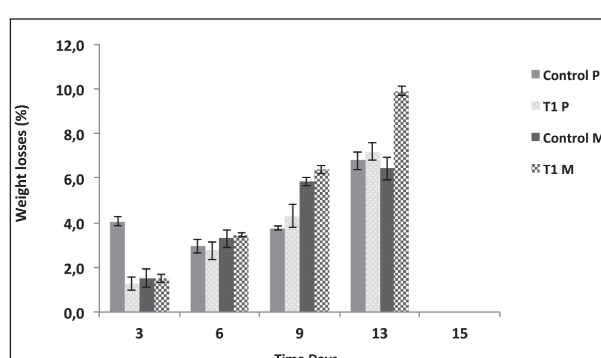

Figure 1. Weight losses of strawberries cv. Portola and cv. Murano in the storage time

Table 1. The pulp firmness, the soluble solids content (SSC) and titratable acidity (TA) of cv. Murano and cv. Portola.

	Storage Time (days)					
Samples	**0**	**3**	**6**	**9**	**13**	**15**
			Hardness (kg/cm²)			
Control P	0.77 ± 0,17 *b*	0.87 ± 0.21 *b*	0.87 ± 0.17 *bc*	0.92 ± 0.18 *ab*	0.81 ± 0.24 *c*	/ ± /
T1 P	0.77 ± 0,17 *b*	0.83 ± 0.26 *b*	0.81 ± 0.18 *c*	0.83 ± 0.14 *b*	0.79 ± 0.22 *c*	/ ± /
Control M	0.90 ± 0,19 *a*	1.03 ± 0.23 *a*	0.97 ± 0.17 *ab*	0.93 ± 0.18 *ab*	1.26 ± 0.14 *a*	/ ± /
T1 M	0.90 ± 0,19 *a*	1.13 ± 0.27 *a*	1.08 ± 0.18 *a*	0.98 ± 0.14 *a*	1.05 ± 0.21 *b*	/ ± /
			SSC (°Brix)			
Control P	7.5 ± 1.0 *b*	8.1 ± 0.6 *b*	8.5 ± 0.2 *c*	6.8 ± 0.1 *d*	8.1 ± 0.1 *c*	/ ± /
T1 P	7.5 ± 1.0 *b*	7.9 ± 0.9 *b*	7.5 ± 0.1 *d*	6.2 ± 0.1 *c*	6.0 ± 0.0 *d*	/ ± /
Control M	10.4 ± 1.5 *a*	11.0 ± 0.2 *a*	10.4 ± 0.2 *b*	10.7 ± 0.1 *b*	12.3 ± 0.2 *a*	/ ± /
T1 M	10.4 ± 1.5 *a*	11.6 ± 0.4 *a*	10.8 ± 0.1 *a*	11.0 ± 0.2 *a*	11.4 ± 0.5 *b*	/ ± /
			TA (meq/L)			
Control P	7.12 ± 0.22 *a*	7.62 ± 0.12 *a*	6.48 ± 0.38 *a*	6.06 ± 0.39 *ns*	5.91 ± 0,72 *ns*	/ ± /
T1 P	7.12 ± 0.22 *a*	6.31 ± 0.79 *ab*	6.74 ± 0.31 *a*	6.13 ± 0.86 *ns*	5.16 ± 0.41 *ns*	/ ± /
Control M	5.10 ± 0.63 *b*	5.48 ± 0.11 *b*	4.55 ± 0.26 *b*	4.84 ± 0.37 *ns*	6.01 ± 0.54 *ns*	/ ± /
T1 M	5.10 ± 0.63 *b*	5.82 ± 0.11 *b*	5.32 ± 0.43 *b*	5.85 ± 0.76 *ns*	5.56 ± 0.24 *ns*	/ ± /

Data are means ± SD. Values with the same letter at the column level are not statistically different with the Tukey's test (0.05)

the harvest time for the cv. Murano (5.10 meq/L). For each control time the different storage tretaments did not affect the total TA evolution within each cultivar.

Colour

The maintenance of red colour is crucial for the consumer especially considering that this aspect is essential for all the fruits that as strawberries need to the packaging for their marketability and for this they cannot be evaluated through the flavour profiles. The brilliance of the skin and the green colour of the leafs are good indicators of freshness. At the harvest point (0 days) both cultivars show a similar brightness value parameter (L) and no statistically significantly differences were observed between fruits (41.17 and 42.54 respectively for the cv. Portola and cv. Murano) (Fig. 2). The L values of skin tended to decrease during the storage time and the lowest values were observed for each time point for the cv. Murano and cv. Portola control samples. According to literature (33, 34) the L values trend reflects the darkening of strawberries, probably due the accumulation of anthocyanins, during the ripening process. Strawberries cv. Portola showed lower brightness if compared with cv. Murano but this result can be ascribed to a genetical component and, no to the storage treatments. The ionization treatment didn't affect significantly the changes in the brightness of the strawberries fruits. Similary to the L also the C values changed during the storage time decreasing from the harvest time (respectively 54.36 for Portola and 55.29 for Murano). The lower value of chroma means that fruits become less vivid, and this is due the oxidative browning reactions that occur more effectively with the progress of the storage time and for untreated fruits (control samples). For each qualitative analysis comparable chroma values were found in all treatments during the storage time. The ionization treatments didn't affect the chroma value and no statistically differences were observed for each storage time between all samples of cultivars.

The total anthocyanin, phenolic contents and the antioxidant activity

The anthocyanins pigments are the main contributor of the color in strawberries fruits and their content in the fresh fruits is variable into a range of 150-800 mg/Kg (35,36,37). Strawberries cv. Portola show an higher total anthocyanin content at harvest (38.21 mg/100 g C3G) (Figure 3) if compared to cv. Murano (5.57 mg/100 g C3G) but in the storage time

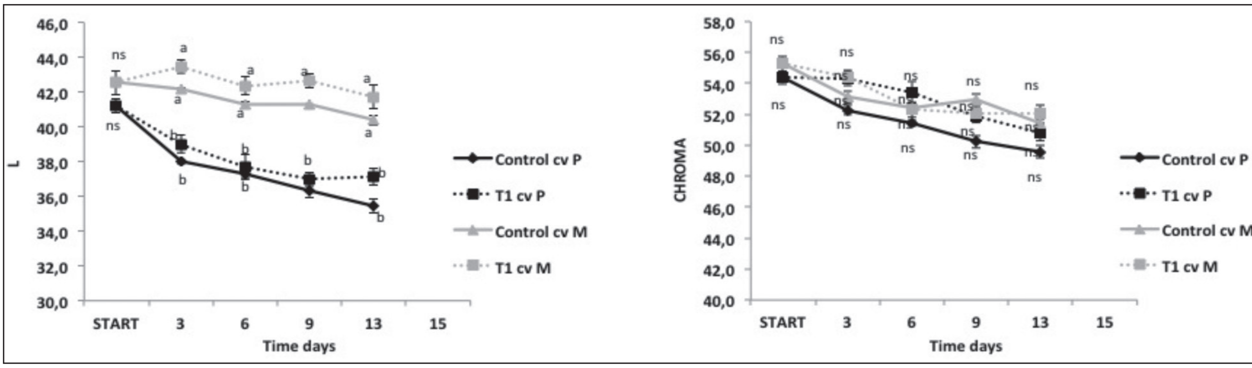

Figure 2. Evolution of L and chroma colour parameter of strawberries cv. Portola and cv. Murano in the storage time

the evolution of this nutraceutical compounds presents a different behaviour. Comparing to the harvest time, a small increase was observed for samples of cv. Murano while a decrease was observed for cv. Portola, although no statistically differences were reported among control and treated fruits relatively to each cultivar. At 9 days of storage (limit of marketability) the total anthocyanin content are in a range of 8.35 to 15.57 (mg/100 g C3G).

The evolution of total phenolic contents in our study (Figure 4) is not linear and these results are according with previous studies (38) which reported how the concentration of total phenolics in strawberry fruit can be maintained or changed during the storage time. Strawberries of cv. Murano have been confirmed for their high nutraceutical properties showing at harvest a total phenolicvalues superior against fruits belonging to cv. Portola (respectively 201.23 and 155.23 mg/100g of gallic acid).

The antioxidant capacity of the fruit is the key parameter for the description of their nutritional quality and it is the indicator of the presence of bioactive substances, responsible for the potential health benefit, within the food matrix. In particular, the strawberries have a much higher antioxidant capacity (from 2 to 11 times) than apples, peaches, pears, grapes, tomatoes, oranges or kiwi. In our study no changes in content took place in stored strawberries as a results of oxidation reactions normally occurring in fruits. No statistically differences were observed among samples for each quality control (Fig. 5). At 9 days of storage the antioxidant content of fruits of cv. Murano are into a range of 20.85 and 22.12 mmol Fe^{2+}/kg while Strawberries of cv. Portola are into a range of 20.29 and 21.90 mmol Fe^{2+}/kg.

Sensory evaluations (consumer assesment)

The sensory evaluation was performed at 9 days of storage corresponding to the limit of fruits marketability due the weight losses. The preference test results showed that the cv. Murano was more preferred than the cv. Portola showing an higher score for each descriptor considered in this study. The panel preferences for strawberries cv. Murano was consistent and could be related with the greatest contents of soluble solid content and the best brightness of the fruits as observed in previous analysis. Sensory evaluation results reveal the ionizing effect on sensory characteristics for the strawberries cv. Portola and cv. Murano. In relation to the descriptors list the test have shown

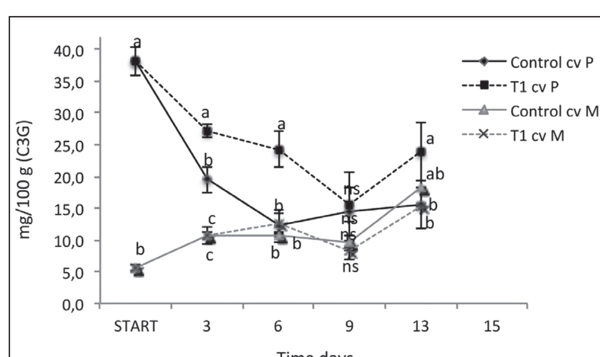

Figure 3. Evolution of total anthocyanins content of strawberries cv. Murano and cv. Portola in the storage. (Results were expressed as means ± standard error. For each days, values signed with different letters are significantly P<0.05 different according to Tuckey's test)

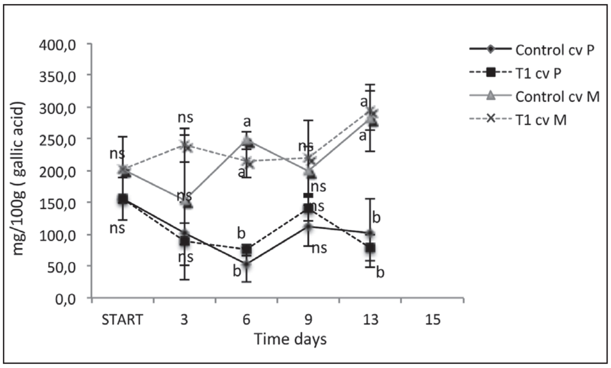

Figure 4. Evolution of polyphenols content of strawberries cv. Murano and cv. Portola in the storage. (Results were expressed as means ± standard error. For each days, values signed with different letters are significantly P<0.05 different according to Tuckey's test)

for each tested cultivar the superiority of strawberries stored under ionizing technology (treated samples). The T1 cv Murano samples showed a good balance among all the descriptors considered achieving a score of 8 for the appearance and 7 score for the other judments, while a score of 5 was observed to describe the profile of T1 cv Portola.

Conclusions

The consumer perception of quality and freshness of perishable fruits such as strawberries can be strongly influenced by the postharvest technology. Compared with the traditional storage technology, physical preservation technique such as the ionization of the storage environment can retain strawberry nutrients and the main qualitative traits. The ionization doesn't alter the colour of the strawberries whose change is mainly due to the storage time; observing the L colour parameter the ionization treatments seem to maintain fruits of each cultivar, more brights. In conclusion the adoption of this technique could represent a positive value for the environmental dimension of the companies which adopt it and it can guarantee the reinforcement of the supply chain management of the picking house by a sustainability point of view.

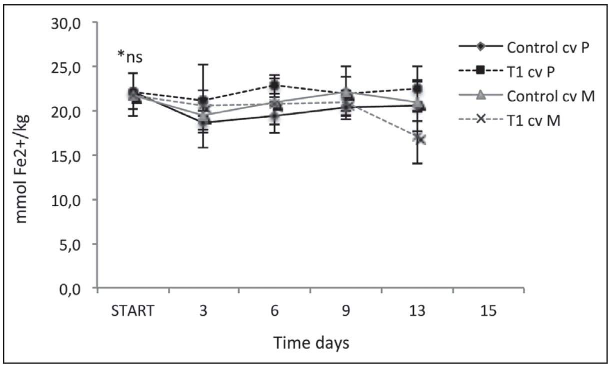

Figure 5. Evolution of the antioxidant activity of strawberries cv. Murano and cv. Portola in the storage. (Results were expressed as means ± standard error. *ns = no statistically differences, for each days among values P<0.05 according to Tuckey's test)

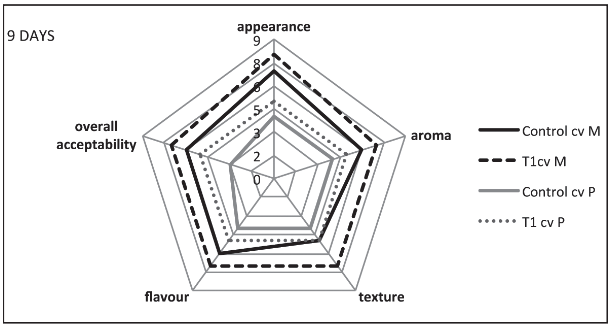

Figure 6. Sensory evaluation of strawberries cv. Murano and cv. Portola after 9 days of storage.

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