Quality changes in fresh-cut celery as affected by heat treatment and storage

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Abstract: This work was intended to investigate the effect of thermal treatment (by immersion or heated air) on quality attributes of pre-cut celery stored at 0 °C for 21 days. The evolution of organoleptic characteristics, weight loss, surface color, chlorophyll content, texture and microbiological counts were determined. Quality of cut celery mostly maintained its initial level up to 14 days at 0 °C, regardless of the treatment applied. The control and heated-air-treated samples experienced a similar evolution of surface color, chlorophyll content, texture and microbial counts. There was a slight advantage of the heated air treatment compared to the control, as measured by sensory parameters. The immersion treatment allowed a better retention of the original color and the total chlorophyll content of pieces. However, after 14 days at 0 °C, a more noticeable tissue softening along with rapid microbial development was observed.

Keywords: ready-to-use vegetables; celery; heat shock; texture; chlorophyll; total aerobic population

INTRODUCTION

Thermal treatments have been utilized for more than a century to control pathogens in plant materials, their duration and temperature level being empirically determined in most cases.[1] The objectives of applying treatments are insect disinfestation, disease control, modification of tissue response to stress and product quality maintenance during storage.[1] Since some vegetables normally grow in contact with soil, which constitutes a considerable contamination source, control of microorganisms should be an important factor to take into account. In addition, minimally processed products with high pH (>4.6) and water activity (>0.85) are considered to be highly perishable if not subjected to preservative processes that delay undesirable biological and biochemical changes.[2]

One of the main objectives of any post-harvest technology is to retard senescence of organs and tissues. In green plants, lessening of chlorophyll degradation and consequent color loss are important requirements, and thermal treatments may provide an effective tool to complement refrigeration and modified atmosphere packaging. However, depending on temperature and exposure time, chlorophyll loss can be accelerated or retarded. Jacobi *et al*.[3] have applied thermal treatments to zucchinis, using high-humidity heated air, and observed significant skin yellowing in treated fruits compared with the controls. On the other hand, the use of temperatures above 25 °C decreased degreening rate in bananas,[1] while chlorophyll degradation in apples was accelerated with 35–40 °C treatment over 4 days.[4] In soy leaves, heating for 1 min at 53 °C did not cause tissue damage, whereas at 54 °C there was chlorosis, and above 55 °C necrosis.[1,5] Therefore, as allowable minimum and maximum treatment temperatures are very close, application of the method becomes problematical.

Celery presents low respiratory activity, very low ethylene production rate and moderate sensitivity to this hormone,[6] being suitable for minimal processing. Major changes that reduce quality of minimally processed celery are vascular browning at the ends of cut petioles, flaring of the cut surface and development of pithiness (i.e., the formation of aerenchyma in the pith).[7,8] Likewise, some slight variations of texture were reported during refrigerated storage which lead to variable increases in the maximum shear force of petioles.[9] Concerning wound-induced physiological changes leading to reduced quality (i.e., phenylalanine ammonia-lyase activity) of pre-cut celery, it must be pointed out that heat-shock treatment has been shown to diminish such changes.[7] The objective of this work was to analyze the effect of two types of thermal treatment on several quality attributes of pre-cut celery, after processing and during refrigerated storage.

EXPERIMENTAL

Plant material

Celery plants (*Apium graveolens* L.) cv. Golden Boy, greenhouse-grown in the La Plata horticultural belt (Buenos Aires, Argentina) were used. On reaching commercial size (after about 2 months of being

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transplanted), plants were harvested early in the morning, brought to the laboratory and processed immediately.

Processing

Stalks showing evidence of damage or disease symptoms were removed. Green leaves and basal segments of rosettes were discarded to obtain unbranched petioles, which were washed in tap water and subsequently cut into 4 cm-long sticks with a sharp stainless steel knife. Fresh-cut celery was disinfected by dipping in chlorinated water (100 ppm active chlorine, pH 6–6.5, 8 °C) for 3 min and then blotted dry.

Treatments and storage conditions

The treatments applied in this work were: (a) control sample (C), i.e., not exposed to thermal treatment; (b) water immersion (I) at 50 °C for 90 s; (c) exposure to heated air (HA) at 48 °C for 1 hour. These heating media and time–temperature combinations were selected according to results from previous experiments,[10] as they led to lower damage and good retention of the original color of celery petioles. In these preliminary studies, a total of four time–temperature combinations were evaluated for immersion in water treatments: 45 °C–120 s; 50 °C–90 s; 55 °C–60 s; and 55 °C–30 s. For hot air treatments, the following conditions were assayed: 48 °C–60 min and 50 °C–20 min. In these cases, treatment effects on fresh-cut celery quality were assessed by describing sensory characteristics of the product and determining weight loss of trays, surface color and texture changes (objective measurements).[10]

The immersion treatment was conducted in heated distilled water, using a thermostatic bath with permanent stirring. Celery cuts were placed in a plastic basket and dipped for 90 s. Samples were subsequently cooled and disinfected by immersion in chlorinated water with ice (100 ppm active chlorine, pH 6–6.5) for 3 min. After draining the excess water on absorbent paper, the product was packaged. With regard to the heated air treatment, it was carried out after disinfection of samples in chlorinated water as mentioned in the previous section. The product was then treated with heated air in an oven. Finally, samples were allowed to cool at room temperature before packaging.

In all tests, crystal polyethylene terephthalate (PET) trays ($17 \times 13 \times 5\,cm^3$) were used. They were covered with self-adhering polyvinyl chloride (PVC) film (thickness 10 μm; O_2 permeability 11 232 $cm^3\,m^{-2}\,atm^{-1}\,d^{-1}$; CO_2 permeability 48 552 $cm^3\,m^{-2}\,atm^{-1}\,d^{-1}$; water vapor permeability 40 g $m^{-2}\,d^{-1}$). Trays containing approximately 175 g of product were kept for 3 weeks at 0 °C. Samples were withdrawn for analysis at 0, 7, 14 and 21 days. Complete storage experiments were carried out in triplicate. As the evolution of the parameters analyzed was similar, results of one of the experiments are shown here.

Determinations

Evaluation of sensory characteristics

Product sensory quality was assessed by inspection of stored samples. Sensory quality attributes of fresh-cut celery included color (yellowing and/or onset of browning), texture (visible structural integrity, softening), aroma and general appearance (dehydration, pithiness development, formation of a translucent whitish appearance in cut sections and manifestation of diseases).[9,11] Samples were evaluated by a structured scale anchored in the following points: E (excellent, essentially free from defects); VG (very good, with very few minor defects); G (good, with an increasing but acceptable number of minor defects); F (fair, slight to objectionable moderate defects, lowest limit of sale appeal); and EP (extremely poor, not saleable). For each treatment and sampling point, 10 trays were evaluated.

Weight loss

Weight loss of trays was determined in a digital balance (±0.01 g) at the beginning and end of the storage period. Results were calculated as the relative weight loss with respect to the initial weight and expressed as a percentage.

Surface color

Measurements were carried out using a Minolta (Osaka, Japan) CR 300 colorimeter with an 8 mm diameter measuring area. The instrument was calibrated with a standard white plate ($Y = 93.2$; $x = 0.3133$; $y = 0.3192$). Readings were conducted by directly applying the colorimeter head to the convex surface of celery strips. Color was measured on 20 different pieces for each treatment and sampling point. The data recorded were the L^*, a^* and b^* coordinates of the CIE scale, from which color parameters as the hue angle [$h = \tan^{-1}(b^*/a^*)$] and chroma [$(C = (a^{*^2} + b^{*^2})^{1/2}$] were calculated.

Chlorophyll content

Chlorophyll was quantified as described in a previous work.[9] For each treatment and sampling point, the sticks coming three trays were combined and homogenized. Part of the pool was frozen in liquid N_2 and crushed in a laboratory mill (Janke & Kunkel Ika Labortechnik A10, Staufen, Germany). From this material, two 5 g subsamples were taken, and each was extracted three times with cold acetone. Successive extracts were centrifuged at 11 000 × *g* at 0 °C and the total chlorophyll content determined according to Bruinsma.[12] Absorbance was measured at 645, 652 and 663 nm and final results were expressed as μg chlorophyll g^{-1} fresh tissue.

Texture

Texture was determined according to a method mentioned in previous work.[9] The equipment used was a TA-XT2i texture analyzer (Stable Micro Systems Ltd, Godalming, UK), working with texture

analysis software (Texture Expert®) and operating in compression mode. When performing shear tests, the equipment was fitted with a Warner–Bratzler knife. A 25 kg transductor was employed, with a knife displacement rate of 0.5 mm s^{-1}. Petiole segments were cut transversally. For each treatment and sampling point, the maximum shear force (MSF) was measured on 20 different pieces. Results were expressed as MSF applied before breaking, in newtons (N).

Loss of turgor incidence on textural behavior was also evaluated by compression tests. The same equipment was used for this purpose but in this case fitted with an aluminium compression plate (75 mm diameter). The pieces were placed on their side and then compressed by 20% of their width so as to increase the concavity of the adaxial side. Testing speed was again 0.5 mm s^{-1}. The compressive movement was reversed at the same rate. For each treatment and sampling point, measurements were made on 20 different pieces. Final results were expressed as maximum force in newtons (N).

Microbial analysis

For each treatment and sampling point, 50 g of product were taken from each tray and transferred to a previously sterilized Erlenmeyer flask with 150 mL 1% sterile peptone water. Maceration was maintained for 3 min in a Stomacher Seward Model 400 (London, UK). A peptone water solution (0.1%) was used to dilute (10^{-2} to 10^{-7}). Duplication of spreading and dilution was carried out to reduce sampling error. Viable bacteria were counted by spreading 0.1 mL of the previous dilutions onto Petri dishes containing suitable solid medium. Suspensions were disseminated using sterile glass pearls.

The total count of aerobe mesophiles was made on Plate Count Agar (PCA) incubated for 2 days at 30 °C. In turn, mold and yeast were counted in Yeast extract, Glucose, Chloramphenicol (YGC) after incubation for 5 days at 30 °C. Lactic bacteria were counted on Man–Rogosa–Sharp (MRS) agar, after incubating for 48 h at 37 °C. Microbial counts were expressed as colony-forming units (cfu g^{-1}). Also, a regression analysis was conducted to establish a relationship between counts and storage time. The following linear model was proposed to compare growth rates: log cfu g^{-1} = constant + growth rate (log cfu g^{-1} d^{-1}) × time (days).

Scanning electron microscopy

For each treatment and sampling point, 20 celery sticks were fixed in FAA (ethanol 96% w/w:distilled water:formaldehyde:glacial acetic acid; 50:35:10:5). Morphological and anatomical characteristics (cut sections, exposed vascular bundles and medulla parenchymatous tissue) were observed using a Philips ElectroScan 2010 environmental scanning electron microscope (ESEM) Wilmington, MA, USA, with a pressure range from 0 to 2.67×10^3 N m^{-2} and a temperature variation of ±50 °C from ambient temperature.

Statistical analysis

Results were subjected to analysis of variance (ANOVA). Sources of variation found were treatment (three levels) and storage time (four levels). Comparison of means was conducted using Fisher's least significant difference (LSD) test at a significance level $P = 0.05$.

RESULTS AND DISCUSSION

Evaluation of sensory characteristics

The evolution of attributes and degree of incidence of observed damage are summarized in Table 1. In overall terms, quality of cut celery in control and treated samples was judged between 'excellent' and 'very good' along the first 14 days of storage. Immersion-treated pieces better retained the original color. Yellowing was more evident in C and HA. On the 21st day of storage, differences of color between treatments were evident by visual inspection.

Further observations worth mentioning are the development of a white–translucent appearance in cut sections, though with low incidence. It was more noticeable in control and heated air-treated samples than in immersion-treated cuts. Browning was observed to occur in exposed sections but only at vascular strand level, and in the form of brown-orange dots. Even so, the two types of color alterations described above did not cause serious damage in any sample.

Medulla hollowing or disintegration was observed in the controls after day 14. Its incidence was 7% with respect to the total number of inspected pieces. In thermally treated samples, this damage was observed to appear only after day 21, affecting between 10% and 40% of inspected pieces in HA- and I-treated samples, respectively. Toward the end of storage, a slight deformation in cut sections along with a more evident protuberance of vascular strands were observed. This phenomenon mainly occurred in control and heated-air treated samples, and might be associated with some surface dehydration.

Toward day 21, off-odors previously described as 'similar to coumarin'[9] developed in immersion-treated samples simultaneously with the incidence of rot in the product thus treated.

In summary, immersion-treated samples exhibit good quality levels up to day 14 but, from this storage time on, damage development accelerated compared with C and HA-treated samples. Concerning quality levels in HA-treated samples, they were slightly superior to controls, with lower incidence of damage. Therefore, considering the evolution of sensory attributes over the complete storage period (21 days), higher quality levels were achieved by the HA treatment.

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Table 1. Sensory characteristics of immersion- (I) and heated-air-treated (HA) cut celery stored for 21 days at 0 °C

Days at 0 °C	Type of damage	C	I	HA
7	Yellowing	–	–	–
	White–translucent appearance (incipient)	45% ± 3%	13% ± 1%	32% ± 2%
	Browning (very incipient)	10% ± 1%	13% ± 1%	26% ± 2%
	Hollowing	–	–	–
	Off-odor, 'similar to coumarin'	–	–	–
	Rots	–	–	–
	Evaluation	VG	E	E
14	Yellowing	–	–	–
	White–translucent appearance	43% ± 3%	30% ± 2%	50% ± 4%
	Browning (incipient)	20% ± 2%	12% ± 1%	20% ± 2%
	Hollowing	7% ± 1%	–	–
	Off-odor, 'similar to coumarin'	–	–	–
	Rots	–	–	–
	Evaluation	VG	E	E
21	Yellowing	+	–	+
	White–translucent appearance	43% ± 3%	10% ± 1%	27% ± 2%
	Browning	20% ± 2%	10% ± 1%	17% ± 1%
	Hollowing	11% ± 1%	40% ± 3%	10% ± 1%
	Off-odor, 'similar to coumarin'	–	+	–
	Rots	20% ± 2%	47% ± 4%	–
	Evaluation	F	EP	G

C, Control; I, Immersion in water (50 °C, 90 s); HA, heated air (48 °C, 1 h); –, not affected product; +, slightly affected product; ++, very affected product. E, excellent; VG, very good; G, good; F, fair; EP, extremely poor. Note: percent values were calculated referring the number of damaged pieces to the total number of inspected pieces, at each sampling point.

Weight loss

Weight loss in trays significantly increased ($P < 0.05$) over storage time at 0 °C, in control, I- and HA-treated samples (Table 2). For all samples studied, the regressional data analysis showed a linear relationship of weight loss and time during storage (Table 2). The greatest weight loss rate occurred in heated-air treated samples. Although water is the dominant component of plant tissue, small changes in its content may have a substantial impact on quality.[13] The crispy characteristic of fresh products is related to turgor pressure, whose decrease may contribute, along with other factors, to softening. Therefore, moisture loss appears as one of the primary parameters affecting celery quality. Weight losses of 2.5–5% in cut celery were found to lead to flaccidity, wrinkling, shrinkage and hollowing by Avena-Bustillos *et al*.[14] In our tests, this limit was not reached even after 21 days of storage.

Table 2. Weight loss of trays containing pre-cut celery for various treatments and storage periods. Results are expressed as percentage (%) with respect to the initial weight

	Treatment		
Time (days)	Control	Immersion	Heated air
0	0.00	0.00	0.00
7	0.47	0.41	0.49
14	0.84	0.79	0.91
21	1.23	1.27	1.33
$LSD_{0.05}$	0.06		
Regression equation	Weight loss (%) = 0.0602 × Time (days)	Weight loss (%) = 0.0588 × Time (days)	Weight loss (%) = 0.0646 × Time (days)
r	0.994	0.992	0.995
p	≪0.01	≪0.01	≪0.01

Surface color

Surface color evolution in cut celery was characterized by means of the color angle (h), whose initial value was 118.6° (Fig. 1). Taking the CIE scale as reference, a 90° angle represents a yellow colour,[15] while $h = 180°$ corresponds to a green tint. Thus the value for h in our material denotes a yellow-greenish coloration.

Both in C and HA-treated samples, h decreased slightly by 5% over the 21-day period. There were no significant differences between the control and HA-treated samples ($P > 0.05$) at all sampling points. Concerning the immersion-treated samples, the color angle h remained substantially constant close to the initial value ($P > 0.05$) over the whole period considered. With regard to the chroma value (color saturation), it was 30.4 at the beginning of storage (day 0) and did not experience any significant variation along the storage time, either in the control or in the thermally treated samples (data not shown). The variation of L^* (lightness) is shown in Table 3, where a slight increase is observed both for control and heated-air-treated pieces. Conversely, no variation in this parameter was detected during the refrigerated storage of immersion-treated samples. As indicated in previous work,[9] the increase of L^* would indicate a slight product yellowing.

Results evidence a positive effect of water immersion heating (50 °C 90 s) on color retention in minimally

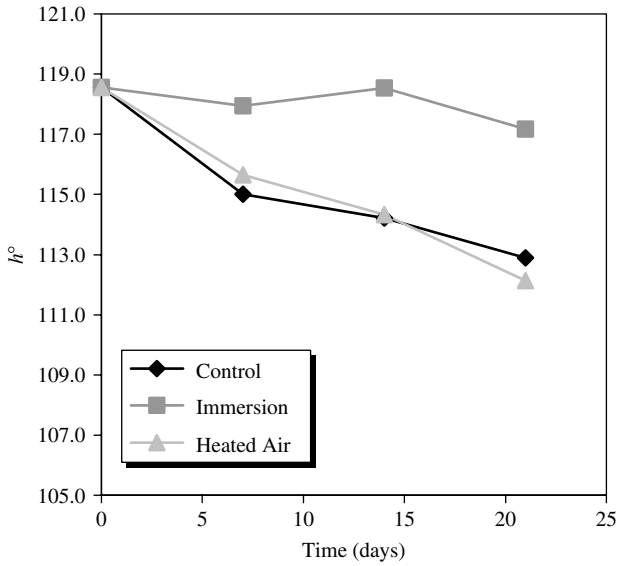

Figure 1. Surface color (hue angle, *h*) of cut celery, thermally treated by immersion or heated air and stored for 21 days at 0 °C. $LSD_{0.05}$ = 1.8.

Table 3. L^* value (lightness) of the CIE scale in thermally treated, minimally processed celery stored at 0 °C for up to 21 days ($LSD_{0.05}$ = 3.36)

	Treatment		
Time (days)	Control	Immersion	Heated air
0	62.61	62.61	62.61
7	65.98	60.78	65.81
14	65.88	58.74	65.66
21	66.88	60.35	68.03

processed celery. Immersion thermal treatments (up to 10 min in water at 43–55 °C) were also effective in retarding yellowing in broccoli.[16–19]

Chlorophyll content

The initial chlorophyll content (34.5 μg g^{-1} fresh tissue) decreased ($P < 0.05$) in the control after 14 days at 0 °C (Fig. 2). At the end of storage, concentration decreased to 42% of the initial value. In oven-treated samples, a similar evolution was observed and there were no significant differences with the control in all sampling points. Immersion-heated pieces did not experience significant losses in chlorophyll content ($P > 0.05$) after 21 days at 0 °C, in agreement with surface color determinations.

In bananas, inhibition of degreening as a consequence of various thermal treatments was attributed to a lower activity of the enzymes acting on chlorophyll degradation, so leading to retention of this pigment.[19]

Texture

The crispness of celery is one of its main quality attributes and depends on many factors, such as dehydration, proportion of fibrous tissue, degree of lignification and extent of alteration of pectic

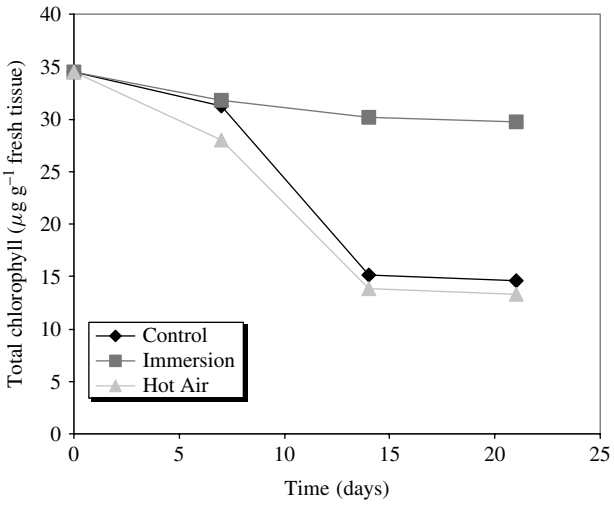

Figure 2. Total chlorophyll content of cut celery, thermally treated by immersion or heated air and stored for 21 days at 0 °C. $LSD_{0.05}$ = 7.5.

substances.[9] Petiole cross-sections are 'crescent-shaped' with prominent ribs on the abaxial side. A great collenchyma band is present beneath the epidermis in each rib and two collenchyma bands appear on the adaxial side.[20] When using Warner–Bratzler knife to characterize texture of celery pieces in the shear test, the main purpose was to evaluate the force necessary to transversally cut the vascular strands, the fibers and the collenchyma.

Results from texture determinations are presented in Fig. 3. No immediate effects (day 0) were observed on celery pieces after applying the thermal treatments. Maximum shear force (MSF) (Fig. 3(a)) decreased significantly ($P < 0.05$) in immersion-treated samples, after 21 days in cold store. Their final MSF was 78% of the initial value. In asparagus, Lau *et al.*,[21] working with thermal treatments between 70 and 98 °C and times from 5 to 120 min, have found longer heating to higher temperatures to cause decreasing shear stress. Although treatments applied by these authors were more severe, they ascribed the shear stress drop to losses in mechanical resistance and cell adhesion.

Results found in compression tests are shown in Fig. 3(b). Again, the maximum force decreased after 21 days of storage at 0 °C. In control samples, the reduction was not significant ($P > 0.05$), while in immersion-treated ones the sharpest decrease was observed with a final maximum force reaching only 55% of the initial value. Conversely, in pieces exposed to heated dry air treatment, the force measured after 3 weeks of storage at 0 °C diminished moderately, to 73% of the initial value. This agrees with texture determinations conducted by shear tests, though the effects indirectly evaluated from the two test types (shear or compression) would be different. Rather than turgor losses, the results would indicate softening of celery petioles since, after a prolonged period in storage (21 days) cell wall degradation processes would be more pronounced.

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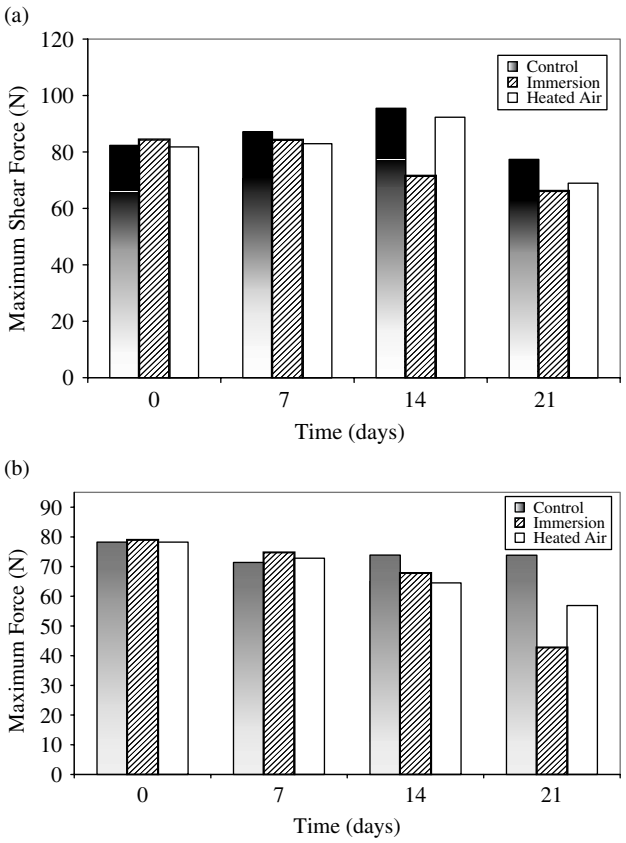

Figure 3. (a) Maximum shear force (MSF), in newtons, of cut celery thermally treated by immersion or heated air and stored for 21 days at 0 °C. $LSD_{0.05} = 12.97$. (b) Maximum compression force, in newtons, of cut celery thermally treated by immersion or heated air and stored for 21 days at 0 °C. $LSD_{0.05} = 18.22$.

As plant tissues are subjected to stress, collapse may occur by cell separation or rupture. Release of cell contents, and so juiciness, would depend on cell rupture. Provided the forces that keep cells together are high, collapse would occur at cell wall level. This would normally occur in fresh, raw vegetables. In such tissues, a high turgor level is observed, being evaluated as fragile and crispy products.[22] Conversely, if adhesion between cells is weak, they would separate. This is a consequence of dissolution of middle lamella and cell wall polymers.[22] Towards the end of storage in pre-cut celery, the latter situation could have occurred. An indication of this is reflected by the dissimilar condition exhibited by the medullar parenchymal tissue in samples taken at the beginning (Fig. 4(a)) and end of storage, both for heat-treated samples (Fig. 4(b)) and controls (Fig. 4(c)).

Robbs *et al*.[23] have found changes in appearance and texture of celery, which can begin within 10 days of storage, to progress like bacterial decay. Likewise, these phenomena could be associated with soft rot and discoloration caused by certain strains of *Pseudomonas fluorescens* and *Ps. marginalis*.[24]

Our texture determination results coincided with those from sensory evaluation, since immersion-treated samples exhibited, after 21 days of storage, a high incidence of hollowing and rot (Table 1) – factors that would cause product softening.

Microbial analysis

Microbial counts carried out in this work are exhibited in Fig. 5. Initial levels of the aerobe mesophile flora were of 2.5 log cfu g^{-1}, both for control and thermally treated samples. After 21 days, total mesophile counts in control samples were observed to increase significantly by 2.75 log cfu g^{-1} above the initial value ($P < 0.05$). In heated-air treated samples counts remained stable around initial levels over the first week at 0 °C, increasing significantly from then on ($P < 0.05$) until the end of storage and to reach values similar to the control samples (Fig. 5). In immersion-treated celery, the significant increase of counts ($P < 0.05$) occurred after the third day in cold store, and kept rising up to the end of storage, to reach final values of 7.5 log cfu g^{-1}. In all treatments, fungi and yeast counts reached 3 logarithmic cycles after 21 days in storage. Such a value coincided with the maximum allowable limit.[25] With regard to lactic bacteria levels, they reached 3.2 and 3.3 logarithmic cycles, which coincided with results found by Robbs *et al*.[23,24]

The bacterial population levels present in control and heated-air-treated samples of cut celery were lower than the microbiological limits, even after 21 days of storage. The limits considered were set by the *Guide de Bonnes Practiques Hygieniques Concernant les Produits Végétaux prêts à l'emploi dits de la IV gamme*.[26] Parameters listed in that guide are $m = 5 \times 10^5$ cfu g^{-1} for the final product and 5×10^6 cfu g^{-1} at the expiration date, and $M = 5 \times 10^7$ cfu g^{-1} in the minimally processed product at the expiration date of the product (Fig. 5). Conversely, in immersion-treated samples the value of m was exceeded after the 14th day of refrigerated storage.

By regressional analysis, the growth rate of aerobe mesophile in untreated cut celery (control) was 0.12 log cfu d^{-1} ($r = 0.985$). For heated-air-treated pieces, the rate was 0.16 log cfu d^{-1} ($r = 0.978$), whereas the highest growth rate was exhibited by immersion-treated samples, with 0.24 log cfu d^{-1} ($r = 0.954$). Therefore, after 21 days at 0 °C, levels reached by these samples increased by 5 cycles with reference to the initial count, so exceeding the value of m, which means that product quality was marginally acceptable. Likewise, total counts of immersion-treated samples after 21 days were close to the value of M (Fig. 5), so such treatment would not be suitable to preserve celery cuts for storage periods longer than 7–14 days.

CONCLUSIONS

The quality of cut celery in control and thermally treated product was maintained around initial levels during 14 days in storage at 0 °C. Control and heated-air-treated samples experienced comparable evolution of quality parameters such as surface color,

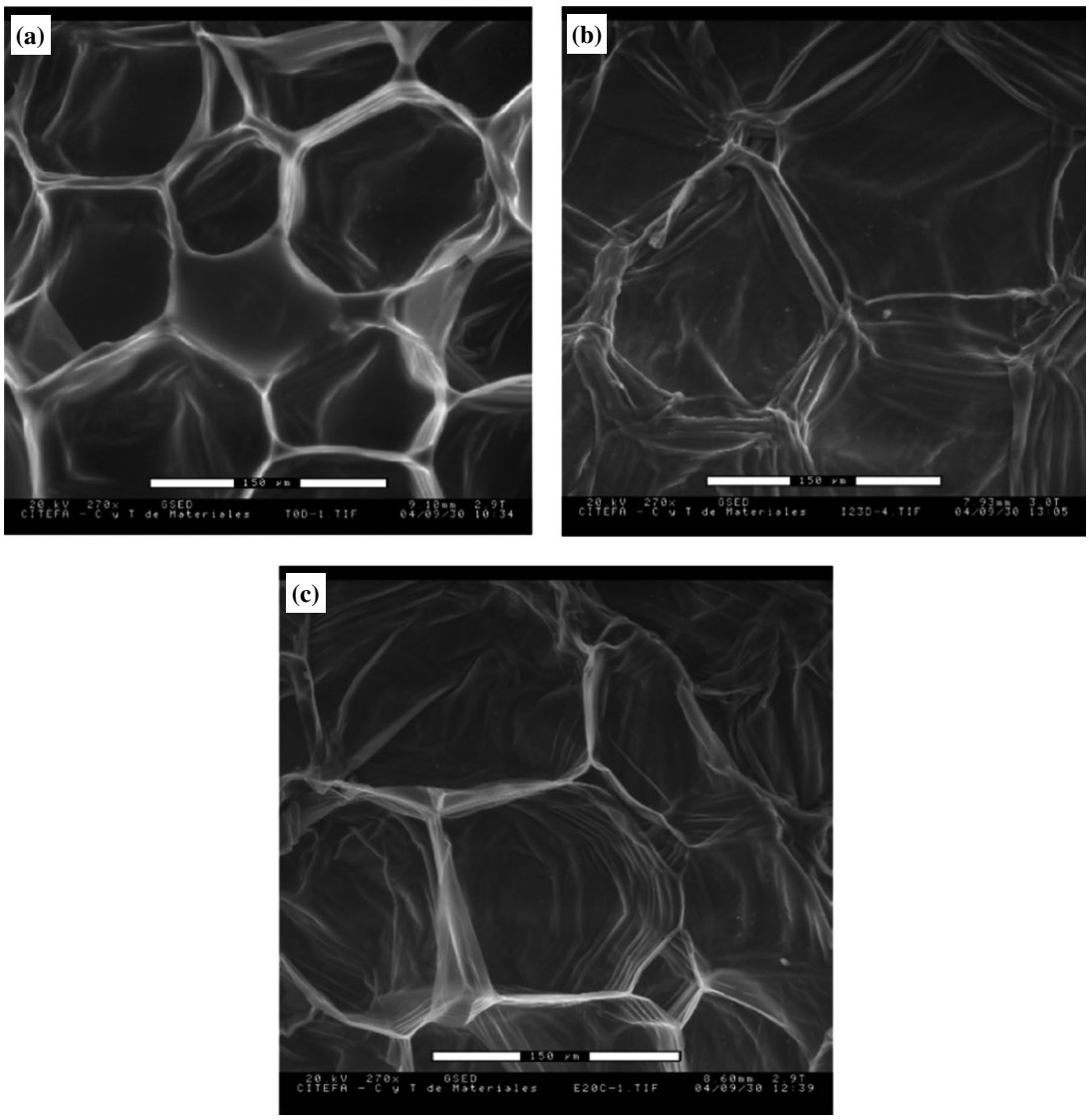

Figure 4. Environmental scanning electron micrographs of medullar parenchyma (a) in untreated (controls) cut celery petioles, at the beginning of storage, (b) in immersion-treated cut celery petioles, after 21 days' storage at 0 °C, and (c) in untreated (controls) cut celery petioles, after 21 days' storage at 0 °C. Scale bar = 150 μm.

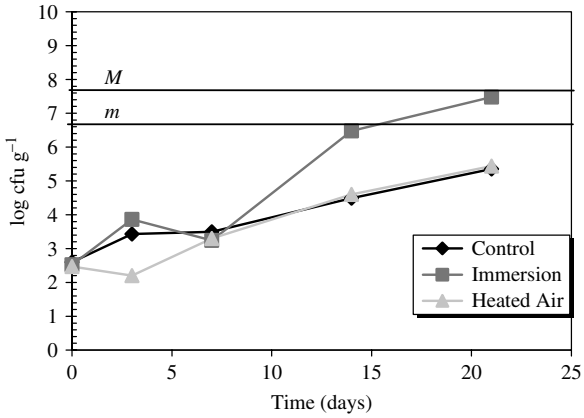

Figure 5. Counts of mesophile aerobe flora (log cfu g^{-1}) of cut celery thermally treated by immersion or heated air and stored for 21 days at 0 °C. $LSD_{0.05} = 0.95$.

chlorophyll content, texture and microbial counts. A slight advantage in the sensory characteristics evolution of heated-air treated samples was observed compared with the controls. Immersion-treated pieces showed a better retention of the original color and total chlorophyll content, but after 14 days of storage at 0 °C tissue softening was more noticeable, being accompanied by rapid microbial development.

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