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Keeping Quality of Green Celery as Affected by Modified Atmosphere Packaging

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Summary

Shelf-life of celery is improved when stored under controlled atmosphere. However, as far as we know, there are very few reports about the effect of modified atmosphere packaging (MAP) on the quality and post-harvest life of green celery. Recommendations about plastic films that can be used are also scarce. The objective of this research was to study the effect of passive MAP on the post-harvest behaviour, chemical and sensorial quality changes and physiological disorders development of cold stored celery. Green celery stalks (cultivar 'Trinova') were packed in plastic bags made of either oriented polypropylene (OPP), low density polyethylene (LDPE) and macro perforated polypropylene as control (air) and stored at 4 ºC for 4 weeks. Under MAP conditions equilibrium atmospheres were reached after 10 days of storage at about 8–9 kPa O_2 + 7 kPa CO_2 and 8 kPa O_2 + 5 kPa CO_2 within OPP and LDPE bags respectively. Decay developed in control celery, affecting nearly 5 % of the stalks, and growth of internal leaves continued, lowering quality and reducing shelf life. However, both MAP inhibited these processes, decreased the development of pithiness and retained the sensory quality, reducing both the development of the butt end cut browning and chlorophyll degradation. OPP film resulted in a package atmosphere that differed most from air and celery stored in this material was rated to have an appearance most similar to that at harvest.

Zusammenfassung

Haltbarkeit von Selleriestängeln nach Verpackung in modifizierter Atmosphäre. Die Lagerfähigkeit von Sellerie kann durch Lagerung in kontrollierter Atmosphäre verbessert werden. Allerdings gibt es nach unseren Informationen nur sehr wenige Untersuchungen darüber, wie sich bei modifizierter Atmosphäre (MAP) die Art der Verpackung auf die Qualität und das Nachernteverhalten von Bleichsellerie auswirkt. Ebenso selten sind Empfehlungen für geeignete Plastikfolien. Gegenstand dieser Untersuchung war, die Wirkung von passiver MAP hinsichtlich des Nachernteverhalten, der Änderungen in den chemischen und sensorischen Eigenschaften und der unerwünschten physiologischen Prozesse bei kühlgelagerter Sellerie zu untersuchen. Grüne Selleriestängel der Sorte 'Trinova' wurden entweder in Polypropylen (OPP) oder leichtem Polyethylen (LDPE) und als Kontrolle in Polypropylen-Lochfolie verpackt und bei 4 ºC 4 Wochen gelagert. Unter MAP-Bedingungen wurde die Gleichgewichtsatmosphäre nach 10-tägiger Lagerung in OPP-Tüten mit etwa 8–9 kPa O_2 + 7 kPa CO_2 bzw. in LDPE-Tüten mit 8 kPa O_2 + 5 kPa CO_2 erreicht. Beim Kontrollsellerie waren annähernd 5 % der Stängel angefault, die inneren Blätter wuchsen weiter und verminderten so die Qualität und Haltbarkeit beim Endverbraucher. Beide MAP-Folien hemmten diese Prozesse, verminderten die Entwicklung von Markigkeit und konservierten die sensorische Qualität, in dem sie sowohl das Verbräunen der Schnittflächen als auch den Chlorophyllzerfall reduzierten. OPP-Folie führte zu einer Atmosphäre im Beutel, die sich am meisten von der Kontrolle in Polypropylen-Lochfolie unterschied. In dieser Folie verpackter Sellerie wurde hinsichtlich äußerer Merkmale annähernd wie frisch geernteter eingestuft.

Key words. *Apium graveolens* L. var. *dulce* (Mill.) Pers. – polymeric films – quality attributes – pithiness – leaves growth – *Erwinia* spp.

Introduction

It is generally accepted that modified atmosphere packaging (MAP) can reduce the loss of quality during the post-harvest life of a wide range of products (KADER et al. 1989). Quality attributes change as part of the senescence process, which involves degradation of proteins, chlorophylls, nucleic acids, membranes, and subsequent transport of some of the degradation products to other parts of the plant (BUCHANAN-WOLLASTON 1997). These changes are influenced by O_2 and/or CO_2 and, since MAP generally involves lowering O_2 and elevating CO_2 concentrations, it would affect these processes. Some changes are more influenced than

others because of the way they depend on atmospheric conditions (KANELLIS et al. 1993). Increases in CO_2 and decreases in O_2 concentrations exert largely independent effects on respiration and other metabolic reactions. Generally, the O_2 concentration must be reduced to less than 10 kPa before any retardation of respiration is achieved and only a few percent of CO_2 can have a marked effect on respiration and other processes. The responses to MAP depend on the product. For example, increases CO_2 helps in the retention of organic acids in tomato but accelerates the loss of acids in asparagus (WILLS et al. 1998).

MAP implies the use of polymeric films of different permeabilities to O_2, CO_2, ethylene and water vapour. Atmospheric composition within the package changes as a result of the respiration rate of the plant tissue and the gas diffusion characteristics of the film (KADER et al. 1989). If commodity and film permeability characteristics are properly matched, an appropriate atmosphere can passively evolve within a sealed package through consumption of O_2 and production of CO_2 by the process of respiration (RAKOTONIRAINY et al. 2001).

Although much research has been done to define optimum MAP conditions for many fresh vegetables, very little work has been published on the effect of MAP on quality changes in celery stalks. Most of the research refers to the use of controlled atmospheres. Celery can benefit from 2 to 5 kPa O_2 and 5 to 10 kPa CO_2 atmospheres at low temperatures (GARIÈPY et al. 1986; SUSLOW and CANTWELL 2000; CSIRO 2001, GOMEZ and ARTES 2003). However, a low O_2 concentration (0.5–1 kPa) or CO_2 concentrations higher than 15 kPa, sometimes as a consequence of temperature fluctuations, may result in physiological damage and the production of off-odours, thus reducing the shelf-life (GOMEZ and ARTES 2003). As a consequence MAP of celery must be designed to maintain both O_2 and CO_2 at the appropriated concentrations. Celery is commonly offered to consumers packaged in non-sealed polymeric bags or in macro-perforated plastic bags, and a beneficial modified atmosphere is not generated. This results in a poor quality, shrivelling, loss of green color and development of pithiness and others physiological disorders.

The objective of this research was to characterise how MAP affects celery quality in terms of single attributes such as colour, chemical properties (soluble solids content, titratable acidity, pH), development of rots and pithiness and sensory quality.

Materials and Methods

Plant material and packaging

'Trinova' celery stalks (*Apium graveolens* L. var. *dulce* Mill.) were obtained from a greenhouse located in the Mediterranean Region of Murcia, Spain. Plants were harvested early February, carefully selected to ensure freedom from defects and immersed for 1 min into a 100 mg L^{-1} NaOCl solution (pH 7.5) at 5 ºC. After blotted dry, sound stalks were cut to a length of 25 cm (average mass 372 ± 52 g) and then packed in plastic bags (30 cm length x 20 width) of either oriented polypropylene (OPP, 35 μ thickness), low density polyethylene (LDPE, 25 μ thickness) and macro perforated polypropylene (2 holes of 6 mm ∅ by dm^2) as control. Six bags for each treatment were prepared. All bags were stored at 4 ºC for 28 days.

Gas analysis

Changes in gas composition within bags were periodically monitored by taking samples with a 1 mL plastic syringe through a rubber seal placed on the film. Samples were then analysed with a gas chromatograph (Thermo Finnigan. Trace GC. Thermo Finigan Inc., Rodano, Italy. $T_{injector}$= 150ºC, T_{TCD}= 150 ºC, T_{oven}= 40 ºC during 5 min and 80 ºC during 1 min, ramp of 20 ºC min^{-1}) equipped with a Porapack column (30 m length, 0.32 mm ∅) and using He as carrier gas (20 ml min^{-1}). Commercially prepared gas standards (Air Liquid, Madrid, Spain) were used for calibrating the GC.

Stalks quality

Quality attributes of stalks were measured at harvest and at the end of storage. Titratable acidity (TA) was quantified by titrating 10 mL of celery juice (obtained by a juice extractor, Moulinex, Barcelona, Spain) with NaOH solution (0.1 mol L^{-1}) to an endpoint of pH 8.1 and expressed as g of citric acid per 100 ml of juice (AOAC 1984). Soluble solids content (SSC) was measured with a digital refractometer (Atago, Tokyo, Japan) and expressed as ºBrix at 20 ºC. The pH was measured with a pH meter (Crison micro pH 2002, Barcelona, Spain).

Surface colour was determined in each stalk on 3 spots along 4 randomly chosen petioles and on 3 points on the butt end cut. A compact tristimulus chromameter (Minolta CR-300, Ramsey, NJ, US) with a 8 mm diameter viewing aperture was used (reference tile of Y= 94.3; x= 0.3142; y= 0.3211, illuminant C, 2 º observer). Readings were expressed as L*, a* and b* parameters and Hue angle was calculated.

A panel of five trained person evaluated visual appearance, aroma, flavour and colour; scoring on a nine-point scale (9: excellent, 7: good, 5: acceptable, limit of marketability, 3: poor and 1: extremely poor) based on KADER et al. (1973). Decay was estimated by calculating the percentage of affected plants. According to SALTVEIT and MANGRICH (1996) pithiness was estimated from the extent of the whitish discoloration.

Leaf growth (in mm) was measured with an electronic digital caliper (Vernier, Mitutoyo, Japan) considering the growth of leaves over the 25 cm initial stalk length to the upper leaflet.

Statistical analysis

A completely randomized design with 6 replications per treatment where each bag represented a replicate was run. Statistical evaluation was performed using an analysis of variance (ANOVA), the sources of variance being packaging material and storage time (95 % of confidence level) followed by LSD multiple range test for means comparison. Mean values were considered significantly different at P= 0.05.

Results and Discussion

Atmosphere analyses

As expected, both polymeric bags achieved a steady state atmosphere within approximately 10 days of storage. At that stage, the CO_2 concentration generated within bags differed significantly between packaging materials (Figs. 1A and 1B). In contrast, differences between O_2 concentrations were not significant. O_2 concentration was always above the critical threshold (0.5–1 %) for off-odours development (SALTVEIT 1997) and CO_2 was below the concentration potentially inducing of physiological damage (GOMEZ and ARTES 2003). At the same time, the equilibrium atmospheres were close to the recommended concentrations for CA storage of celery (GARIÈPY et al. 1986; SUSLOW and CANTWELL 2000; CSIRO 2001, GOMEZ and ARTES 2003).

Chemical attributes

Under both MAP, the TA of celery stalks did not decline during storage (Table 1). In contrast, TA decreased in stalks stored in air. The same trends were observed for SSC. Both MAP lowered the respiratory activity and, as a consequence, SSC did not decline. No differences between both modified atmospheres were detected for that parameter. However, it could be hypothesized that when stored in air soluble solids were faster consumed to maintain a higher metabolic activity. Compared to value at harvest, MAP and air stored stalks underwent a slow increase in pH with no differences among treatments (MAP versus air). For air treatment it could be related to the decrease in TA. For MAP it has been reported that when CO_2 is introduced into a package, it is partly dissolved in the water-phase and the fat-phase of the food. This results in a concentration of dissolved CO_2 that would affect the final pH (DEVLIEGHERE et al. 1998). Variation in CO_2 levels could be important in perturbing intracellular pH (BOWN 1985).

Colour

Decrement in the Hue angle values of petioles was lower in MAP if compared to control, where Hue decreased the most indicating a pronounced loss of chlorophyll (Fig. 2A). Yellowing of the leaves due to chlorophyll degradation is the most obvious visible symptom of leafy vegetables senescence (BUCHANAN-WOLLASTON 1998). It has been previously reported that high CO_2 concentrations can improve chlorophyll retention in broccoli. MAP resulted in no differences in green colour retention of florets evaluated by Hue, compared to the values at harvest (BARTH and ZHUANG 1996). For

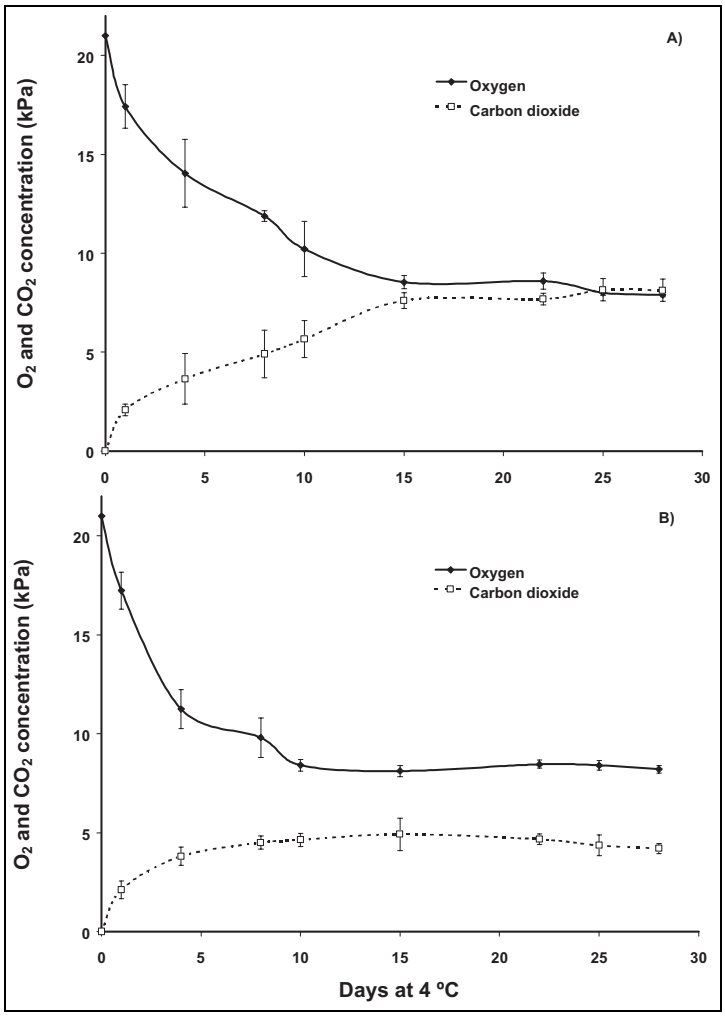


Fig. 1. Changes in O_2 and CO_2 concentrations within A) oriented polypropylene (OPP) and B) low density polyethylene (LDPE) bags for green celery stalks stored at 4 ºC for 28 days.

Table 1. Titratable acidity (TA), pH, and total soluble solids content (SSC) of green celery stalks stored in either oriented polypropylene (OPP), low density polyethylene (LDPE) and perforated (air) bags at 4 ºC for 28 days.

Treatments	pH	TA (g citric acid 100 ml^{-1})	SSC (ºBrix)
Initial	5.87b^{z} ± 0.04	0.065 a ± 0.01	3.63 a ± 0.23
After 28 d at 4 ºC			
Air	6.13 a ± 0.02	0.054 b ± 0.003	2.63 b ± 0.35
OPP	6.32 a ± 0.15	0.063 a ± 0.007	3.47 a ± 0.47
LDPE	6.28 a ± 0.07	0.062 a ± 0.001	3.03 ab ± 0.32

^{z} Mean ± standard deviation (n= 6). Values followed by the same letter within the same column are not significantly different (LSD 5 %).

celery, the amount of chlorophyll could be directly related to how green the stalks are, since chlorophyll is the only pigment present in significant amounts. For leafy vegetables a linear relationship between pigment and colour has been reported (LANCASTER et al. 1997).

Browning of the butt end cut developed for all treatments, indicated by a decrease in Hue angle (Fig. 2B). Use of MAP partially inhibited this process because browning is closely related to the O_2 and CO_2 concentrations within the packages. Even when for both LDPE and OPP bags nearly the same O_2 concentration was reached, a trend for a better efficiency for delaying this disorder was observed when the highest the CO_2 concentration. Efficacy of MAP could be improved by decreasing the O_2 concentration to an acceptable minimum as soon as possible. Consequently, the use of active MAP should be considered.

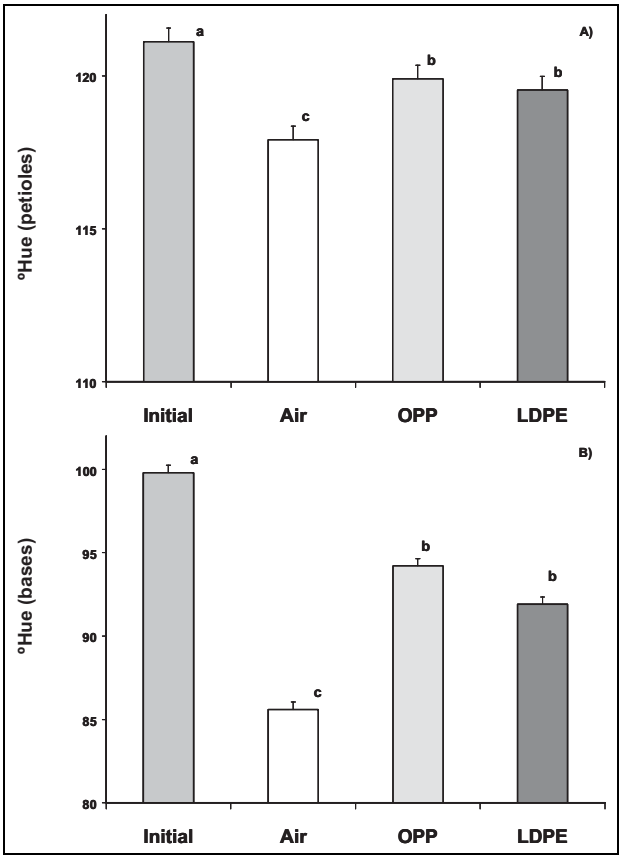


Fig. 2. Changes in Hue values of A) petioles and B) butt end cut of green celery stalks stored in either oriented polypropylene (OPP), low density polyethylene (LDPE) and perforated (air) bags at 4 ºC for 28 days.

Sensory quality

After storage, sensory quality declined compared to that at harvest (Fig. 3). The visual appearance significantly decreased, probably due to the loss of greenness (Fig. 2A) and to the development of browning at the butt end cut (Fig. 2B). In control plants an undesirable colour of petioles and butt was observed. The aroma and flavour were also lost and, in addition, pithiness developed. Nevertheless, the lysis of parenchymatous cells was not very pronounced. In neither treatment off-odours or off-flavours were detected.

MAP contributed to avoid microbial spoilage probably by the inhibitory effect of CO_2 on microorganism growth. It has been reported that increasing CO_2 concentration significantly reduced the development of bacteria on chicory leaves at 2 and 6 ºC (CARLIN and NGUYEN-THE 1994). Soft rots developed in 5 % of the celery stalks stored in perforated bags. Strains of *Erwinia* spp. were isolated from deteriorated tissue.

Internal leaves continued to grow during storage although MAP partially inhibited that growth. Leaves growth was 40.3 ± 3.9 mm, 20.4 ± 1.1 mm and 14.2 ± 3.9 mm under control, LDPE and OPP respectively, being differences among treatments statistically significant (LSD 5 %, n= 6). Increasing CO_2 and decreasing O_2 had an additive effect because OPP, with the highest CO_2 and the lowest O_2 concentrations, presented stalks with a minimal internal petioles elongation. In order to keep eating and commercial quality, that growth must be avoided.

Considering all the sensory parameters together, data indicated that a higher CO_2 and a lower O_2 concentration compared to air retained a better quality of green celery stalks. Results presented here showed advantages of using MAP technique for the storage of green celery. While green celery stored in OPP bags was perceived to have the highest scores for sensory evaluation and the lowest development of decay, browning, and pithiness, the stalks stored in perforated bags had the poorest quality.

Taking all different quality factors together, the MAP composition that had the most significant effect on keeping quality of 'Trinova' celery stored at 4ºC for 28 days was about 8–9 kPa O_2 and 7 kPa CO_2. Under

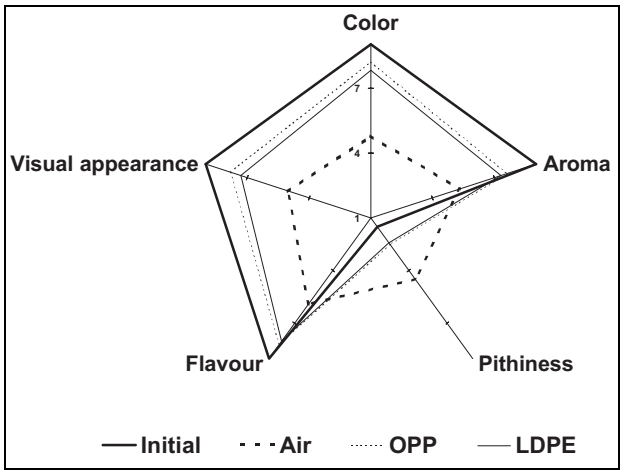


Fig. 3. Changes in sensory quality attributes of green celery stalks stored in either oriented polypropylene (OPP), low density polyethylene (LDPE) and perforated (air) bags at 4 ºC for 28 days.

this atmosphere no CO_2 injury occurred, the change in Hue value was minimal for both petioles and butt end cut, internal leaf growth was reduced, and decay was almost completely inhibited. At such O_2 concentration an additional benefit was found from raising the levels of CO_2 since OPP packages, with a higher CO_2 concentration than the LDPE bags provided the best product. However, it would premature to recommend these conditions as the optimal storage atmosphere in MAP for celery stalks. This work was done for the temperature most frequently used by processors, so temperature dependency of all the involved processes has not been characterised, and results should not be extrapolated. Even though it could be assumed that the underlying principles are the same for other cultivars, interpretation should be careful.

From a practical point of view, the use of MAP is neither expensive, nor a complex technique and could be easily incorporated by the fresh processing celery industry.

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