Adv. Hort. Sci., 2015 29(2-3): 133-140

Effect of film packaging and storage temperature on physical and chemical changes in fresh-cut green asparagus

A. Palma (*), M. Schirra, S. D'Aquino
Istituto di Scienze delle Produzioni, CNR, Via De Mille, 48, 07100 Sassari, Italy.

Key words: antioxidants, modified atmosphere, quality attributes, toughness.

Abstract: The effect of two packaging materials, Film 1 (polyvinylchloride film, manually extensible, 12 µm thickness, O_2 permeability of 22,000 $cm^3/m^2/24$ h/atm) and film 2 (polyethylene film, 13 µm thickness, heat shrinkable, O_2 permeability of 8,500 $cm^3/m^2/24$ h/atm) on changes in oxygen, carbon dioxide and ethylene concentrations within film packaging, weight losses, chemical parameters and textural properties of fresh-cut green asparagus (*Asparagus officinalis* L.) were evaluated during three weeks of storage at 2 or 10°C. During the first two days of storage, in-package carbon dioxide and ethylene concentration increased progressively, while oxygen level decreased. An overall decrease in pH, sucrose and fructose content was observed while an increase in titratable acidity was observed in non-packaged asparagus. A significant increase in total phenols and total soluble solids was recorded, while in Film 2 at 10°C significant decreases were detected in total soluble solids. Antioxidant activity did not change in asparagus packaged at 2°C while in unpackaged and in Film 1 and 2 at 10°C there were significant decreases. Ascorbic acid contents declined rapidly after storage in all samples. Weight loss increased markedly in non-packaged asparagus; in asparagus packaged with Film 1 at 10°C significant differences were detected with respect to the other packaged treatments. Both packaging materials preserved rheological properties of spears whereas un-packaged asparagus lost crispness rapidly. The overall results showed that the best storage conditions to extend the shelf-life of fresh-cut green asparagus were achieved by combining packaging and storage at 2°C.

1. Introduction

Asparagus (*Asparagus officinalis* L.) is a highly perishable product with a very short shelf-life due to its high respiration rate, which leads to a rapid degradation of chemical compounds and toughening of the spears (Kader, 1992). During storage, physiological and compositional changes include loss of sugar, vitamins and water, toughening, degradation of pigments and bract opening that reduce spears quality (Villanueva *et al*., 2005). Among these, changes in texture, colour and brightness are the main factors which affect asparagus acceptance. Environmental humidity is also an important factor in determining asparagus freshness; weight loss of 3-6% makes the product unacceptable (Albanese *et al.,* 2007). Rapid cooling after harvest and low storage temperature notably reduce postharvest changes in quality characteristics. Modified atmosphere packaging (MAP), combined with low temperatures, has been used to extend the shelf-life of minimally processed vegetables by reducing respiration rate, retarding the maturation and senescence, reducing microbial proliferation and quality deterioration (King *et al.,* 1986; Zagory and Kader, 1988; Gontard *et al.,* 1996; Fonseca *et al.,* 2002).

These effects are related to the surrounding atmosphere of products: the depletion of oxygen and accumulation of carbon dioxide inside the packaging. All these factors are affected by metabolic activity, storage temperature and film gas diffusion characteristics.

The purpose of the present study was to evaluate the effect of two film-packaging materials on maintaining the quality of fresh cut green asparagus stored at 2°C (recommended storage and transport temperature) or 10°C (to simulate final display) (King *et al.,* 1993).

2. Materials and Methods

Plant material

Asparagus (*Asparagus officinalis* L. cv. Grande) spears were harvested from a commercial greenhouse located in Alghero (Sardinia). Commercially mature spears (25 cm long) were randomly harvested with some standing stalk in April and were immediately transported to the laboratory and refrigerated at 2°C and 10°C.

(*) Corresponding author: amedeo.palma@ispa.cnr.it

Received for publication 26 September 2014
Accepted for publication 16 June 2015

Preparation of samples and storage conditions

The asparagus samples were selected according to diameter and cut at a length of about 20 cm. Samples of about 300 g each were then un-packaged or packaged with Omni Film (a polyvinylchloride film manually extensible, 12 µm thickness, O_2 permeability of 22,000 $cm^3/m^2/24$ h/atm and water vapour transmission rate of 515 $g/m^2/24$ h/1 atm.) (Film 1) or with Bolphane BX polyethylene film (Bolloré Plastic Films Division, Dayville, France, 13 µm thickness, heat shrinkable, O_2 permeability of 8,500 $cm^3/m^2/24$ h/atm and water vapour transmission rate of 16 $g/m^2/24$ h/1 atm) (Film 2). Both films were applied tightly to each asparagus bunch and sealed by a hand-wrapping machine to stretch the film (SW-500 E, Sambo Tech Corporation Lovero, Gyeonggi-do, Korea) in the case of Film 1 and heat-shrunk by a Bellpack packaging machine (Tecnopack Packaging Equipment, Livorno, Italy) in the case of Film 2. In both packaged treatments, in-package gas atmosphere was achieved passively. All samples were stored for 21 days at 2°C (recommended storage and transport temperature) or 10°C to simulate retail outlet display.

Quality characteristics were determined at harvest and after 7, 15 or 21 days. These included weight loss, toughness, pH, titratable acidity, total soluble solid (TSS), sucrose, glucose, fructose, total phenols, antioxidant activity and ascorbic acid. Chemical analyses were determined on asparagus juice obtained using a domestic juicer and results were referred to 100 g of fresh weight (FW). Crude juice was centrifuged in an Eppendorf tube using a K3 System centrifuge (Centurion Scientific Ltd, West Sussex, England) at 12,000 rpm for 20 min; the clear supernatant was filtered through a 0.45 µm acetate cellulose filter (Sun *et al.,* 2005). Analyses were performed in triplicate. All reagents were of analytical or better grade.

Modified atmosphere packaging

The atmosphere composition (O_2, CO_2 and C_2H_4) inside the packages was determined after 1, 3, 7, 14 and 21 days of storage. Gas samples (1 mL) were withdrawn from each package with a gas-tight syringe. Ethylene was determined using a Varian 3300 GC (Varian Analytical Instruments, Walnut Creek, CA, USA) equipped with a flame ionisation detector (FID), Carbowax 20 M 80/120 mesh Carbograph 1 AW 30 column (Alltech, Milan, Italy), column temperature of 60°C, injector 110°C, and detector 180°C. Oxygen and CO_2 concentrations were determined with a Agilent 6890 GC system equipped with a thermal conductivity detector (TCD), CTR I column 6'X1/4' outer & 6'X1/8' inner (Alltech, Milan, Italy); column temperature was 60°C, injector 120°C, and detector 160°C. Helium was used as carrier gas.

Assessment of physical parameters

The weight loss of each lot was determined by a precision scale (Sartorius CP 22025-OCE, Gottingen, Germany). Textural properties were measured using two different methods based on a cutting test at 7.5 and 15 cm from the tip using a 1.2-mm thickness blade (speed 3 mm s^{-1}) and a puncture test at 15 cm from the tip using a 2-mm needle (speed 1 mm s^{-1}, depth 3 mm) (Rodrıguez *et al*., 2002 a). Both test were accomplished using a texturometer interfaced with a computerized system with specific software (DO-FB0.5TS, Zwick Roell, Ulm, Germany).

Chemical analysis

Titratable acidity was determined by titrating 5 mL of juice using a potentiometric titrator (Titrino 720 SM, Metrohm, Herisau, Switzerland) with 0.1 N NaOH till pH 8.1. The pH was measured by a pH meter (Orion 720A). Total soluble solids (TSS) were determined using a digital refractometer (PR-101, Atago, Tokyo, Japan) and expressed as °Brix; ascorbic acid by extraction with metaphosphoric acid and determined volumetrically by titration with 2,6-dichlorophenolindophenol (AOAC Method 967.21). Total phenolic content was analyzed according to the Folin-Ciocalteau colorimetric method (Singleton and Rossi, 1965). Total phenols were expressed as gallic acid equivalent. Antioxidant activity was assessed using the free radical 2,2'-diphenyl-1-picrylhydrazyl (DPPH) (Bonded *et al.,* 1997). The mixture, containing 3 mL of a methanol solution of 0.16 mM DPPH and 0.025 mL of asparagus extract, was allowed to react in a cuvette and the absorbance of the DPPH solution was determined at 515 nm after 15 min of reaction. Trolox (6-hydroxy-2,5,7,8-tetramethylchroman-2-carboxylic acid) was used as a reference to compare the antioxidant activity. The activity was expressed as mM Trolox equivalent antioxidant activity (TEAC) related to 100 g of fresh weight. Analysis of carbohydrate was performed by coupling a liquid chromatograph system consisting of a D-7000 manager, L-7100 pump, L7200 auto-sampler (LaChrom, Merck-Hitachi Ltd., Tokyo, Japan) with an evaporative light scattering detector (ELSD Sedex 60Lt, Alfortville, France). A Bio-Rad aminex fast carbohydrate column (100 mm x 7.8 mm, 9 µm, lead form, Bio-rad, Milan, Italy) with a guard column (Bio-rad micro-guard Carbo-P aminex cation exchange resin, lead form) thermostated at 80°C, was employed. The isocratic mobile phase was H_2O ultra-pure and a flow rate of 0.8 mL/min was employed. The ELSD detector was set as follows: drift tube temperature 45°C; nebulizer gas (air) pressure, 2.5 bar; and photomultiplier 8. Stock standard solutions of each carbohydrate were prepared in ultra-pure water and their quantification in asparagus juice was calculated according to the linear calibration curves of standard compounds. The analyses were conducted in triplicate for all parameters.

Visual assessment

The external appearance of spears (turgidity, formation of longitudinal striation, colour changes and presence of off-flavour) was assessed by a panel of six untrained technicians. Spear quality was evaluated using a 1 to 5 subjective scale (1= unacceptable; 2= acceptable; 3= good; 4= very good; 5= excellent, freshly harvested appearance).

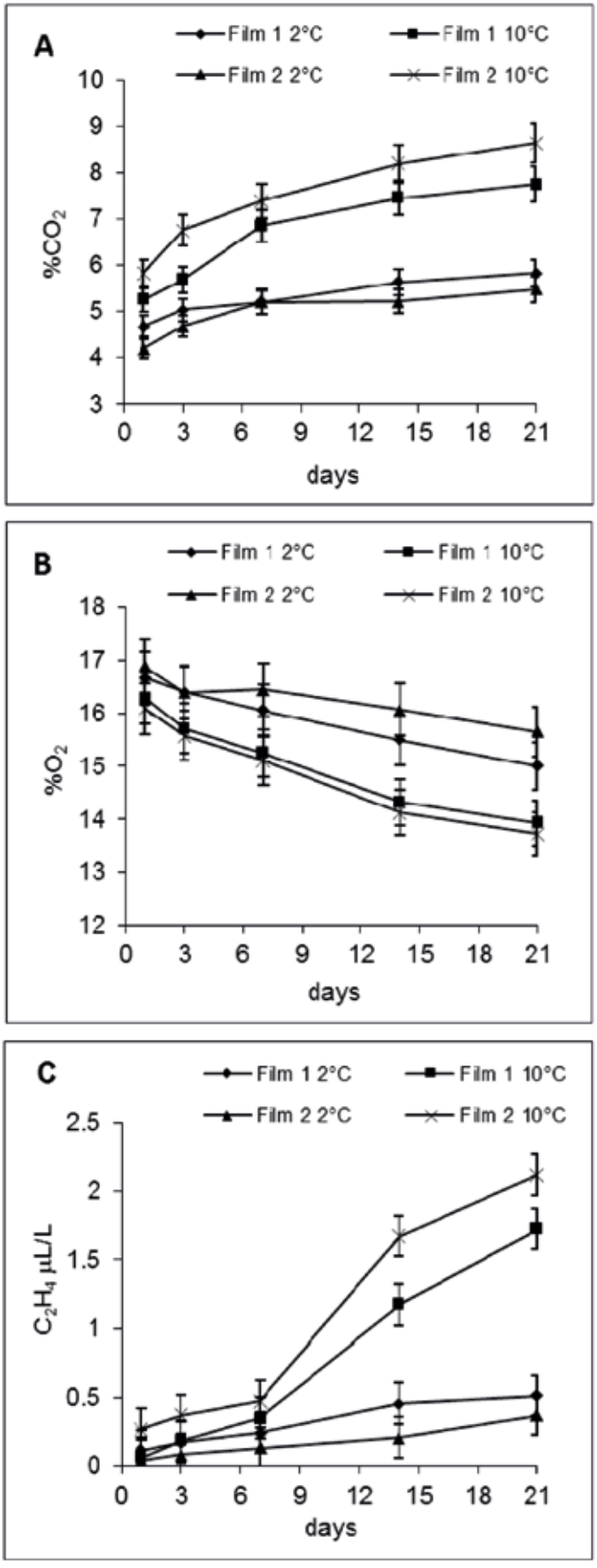

Fig. 1 - Influence of film packaging (Film 1, Omnifilm PVC film; Film 2, Bolphane BX polyolefinic film) and storage conditions on in-package CO_2 (A), O_2 (B) and ethylene levels (C). Vertical bars represent the standard deviation. LSD are given at the 5% level.

Statistical analysis

Statistical analysis was carried out using Statgraphics software (Timberlake, version 5 professional, 2000). Separation of means was performed by the LSD test, $P \leq 0.05$.

3. Results

Modified atmosphere packaging

The levels of in-package CO_2 and O_2 were significantly affected by storage temperature (Fig. 1). At 2°C, CO_2 partial pressure was always lower than at 10°C (Fig. 1A), while O_2 levels were higher (Fig. 1B). In-package CO_2 increased steadily in all treatments during the first 3-7 days, thereafter it increased at a lower rate in packages stored at 10°C, while it was quite stable or increased slightly in those stored at 2°C. In contrast, in-package O_2 partial pressure decreased gradually in all packages with final values in the range of 13.8-16.5 kPa.

Irrespective of the type of film, when asparagus spears were stored at 10°C, ethylene rates were slightly higher than samples stored at 2°C during the first 7 days, thereafter a dramatic increase occurred in both films, especially in samples sealed with Film 2 which always displayed levels significantly higher than those sealed with Film 1 (Fig. 1C).

Weight losses

Weight losses increased markedly in non-packaged asparagus, slightly in samples sealed with Film 1 and stored at 10°C but with values always significantly higher than in the other packages, and were negligible in samples sealed with Film 2 at both storage temperature and in those sealed with Film 1 stored at 2°C. In particular, at the end of storage weight losses averaged 1% and 4% in asparagus spears packaged with Film 1, 0.3% and 0.8% in those packaged with Film 2 and 12 and 30 % in un-packaged spears stored at 2°C or 10°C, respectively (Fig. 2).

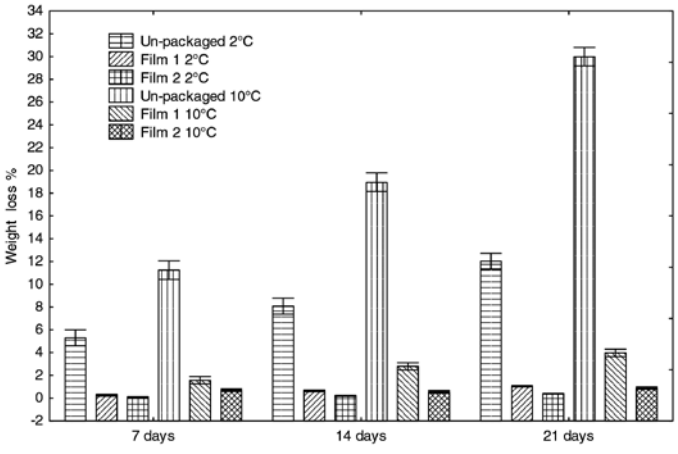

Fig. 2 - Influence of film packaging and storage conditions on weight loss in green asparagus. Vertical bars represent LSD, $P \leq 0.05$.

Texture

Figure 3 illustrates results with regard to changes in maximum shear stress to cut and displacement of F max of asparagus spears. Over the storage period, the profile of the curves and F max following cutting at 7.5 (Fig. 3A) and 15 cm (Fig. 3B) from the tip were very similar. The maximum shear force required for cutting (Figs. 3A, 3B) and force displacement (deformation L (mm) at F max) (Figs. 3C, 3D) was affected by packaging, storage time and temperature. Changes at harvest time (time 0) were notably higher in un-packaged asparagus, especially in samples cut at 15 cm of both storage temperatures and in those cut at 7.5 cm and stored at 10°C. The smallest changes occurred in packages stored at 2°C, where the breaking force and displacement at F max were significantly lower than all other treatments, perhaps due to the lower weight loss. For both parameters, differences between the two films were negligible. Overall results of puncture test revealed minor changes both in F max (Fig. 4A) and deformation (Fig. 4B) in packaged samples, especially in those stored at 2°C; in contrast, both parameters increased in unpackaged asparagus, especially in those stored at 10°C.

Chemical analysis

In Table 1 the influence of film packaging and storage condition on pH, TSS, TA, sucrose and fructose is reported. With respect to harvest time, pH decreased at both storage temperatures. Titratable acidity increased significantly in unpackaged asparagus stored at 10°C; changes were obvious after 14 days of storage when the asparagus spears were in advanced decay, while in the other treatments values were fairly stable. A slight increase in TSS

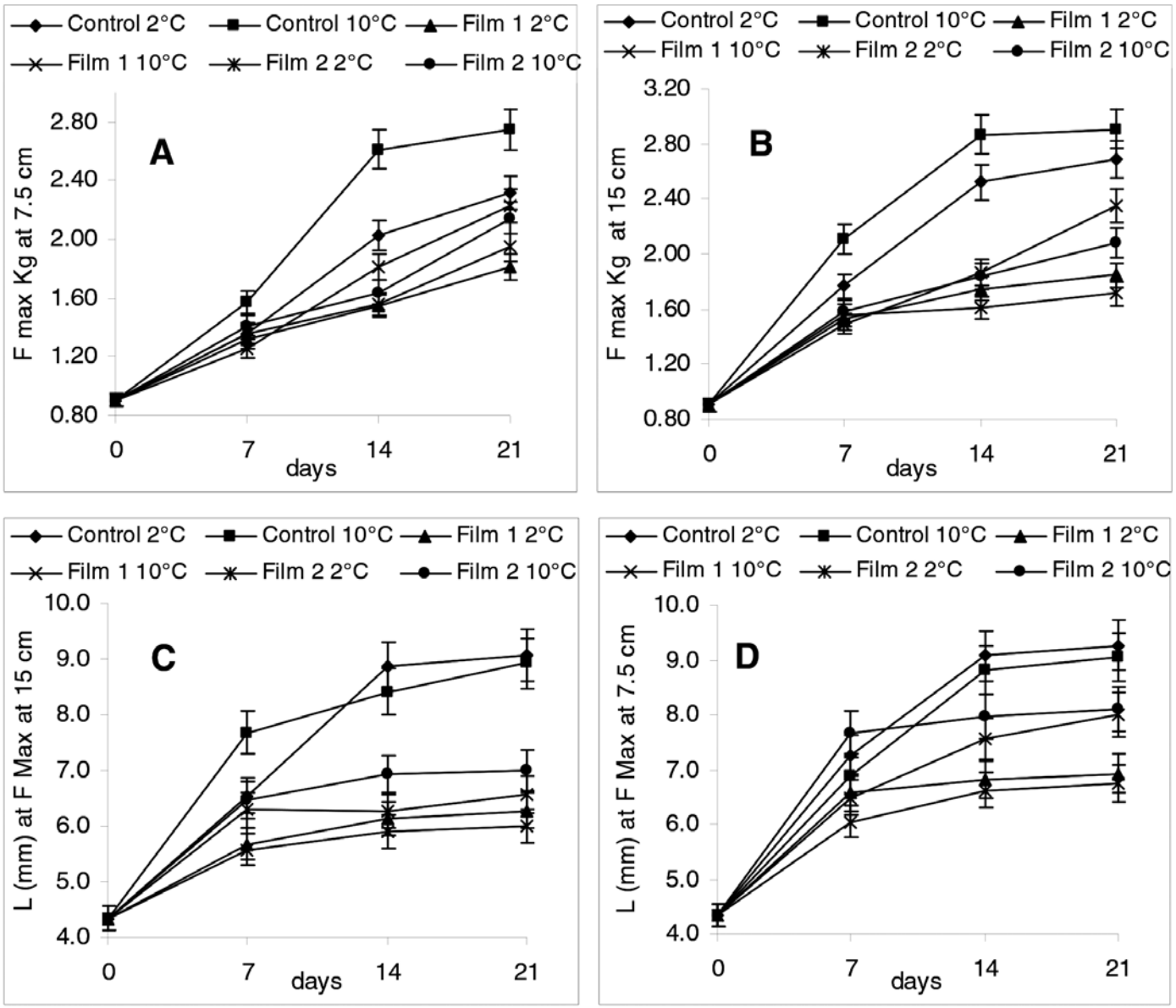

Fig. 3 - Effect of film packaging (Control, un-packaged; Film 1, Omnifilm PVC film; Film 2, Bolphane BX polyolefinic film) and storage conditions (2°C and 10°C) on cutting force (F max) and force displacement (L at F max) in green asparagus during 21 days of storage at 7.5 cm (A and C) and 15 cm (B and D) of the tip. Vertical bars represent the standard deviation. LSD are given at the 5% level.

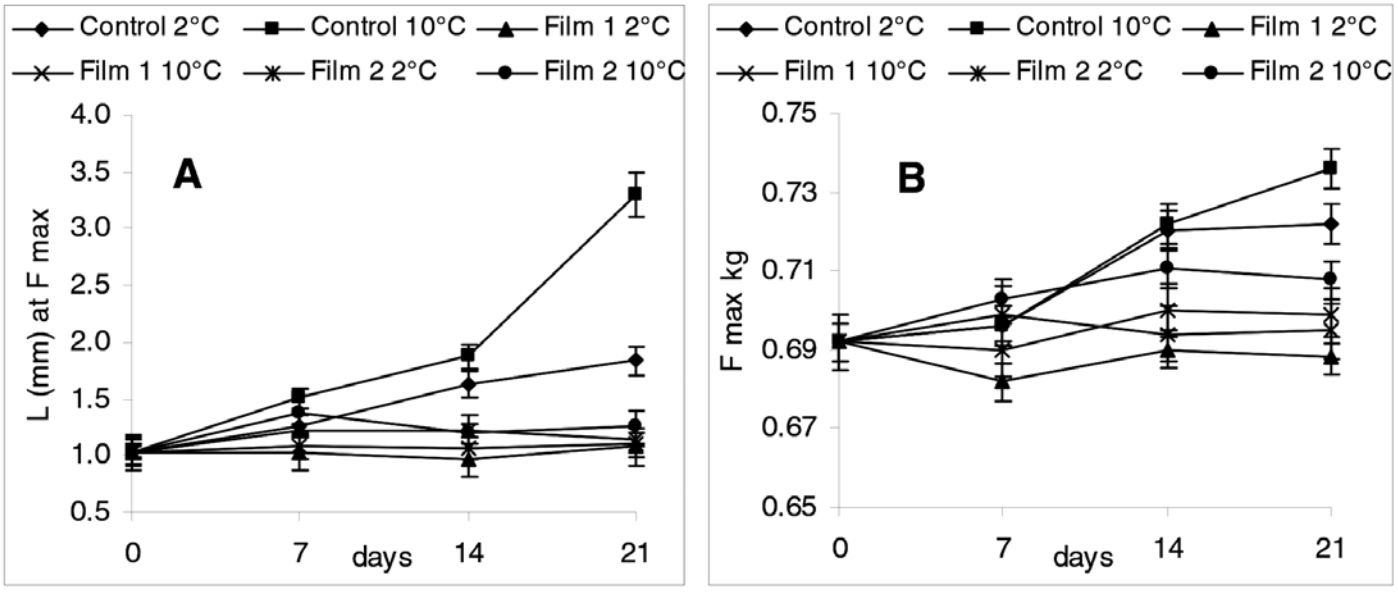

Fig. 4 - Influence of film packaging (Control, un-packaged; Film 1, Omnifilm PVC film; Film 2, Bolphane BX polyolefinic film) and storage conditions (2°C and 10°C) on force puncture test (F max) (A) and displacement of force (L at F max) (B) in green asparagus during storage. Vertical bars represent the standard deviation. LSD are given at the 5% level.

Table 1 - Influence of film packaging (Film 1, Omnifilm PVC film; Film 2, Bolphane BX polyolefinic film) and storage conditions on pH, total soluble solids (TSS), titratable acidity (TA), sucrose and fructose in asparagus spears

Storage period	pH	SST (°Brix)	TA (g/100g as citric acid)	Glucose (g/100g)	Fructose (g/100g)
7 days storage					
Harvest	6.15 a	5.20 bc	0.11 abc	1.29 a	1.51 a
Un-packaged 2°C	5.93 c	5.23 bc	0.12 ab	1.19 b	1.40 abc
Film 1 2°C	6.04 b	5.86 a	0.09 c	1.19 b	1.42 ab
Film 2 2°C	6.18 a	5.16 c	0.11 abc	1.03 c	1.30 cd
Un-packaged 10°C	5.84 d	5.33 bc	0.13 a	1.04 c	1.31 bcd
Film 1 10°C	6.04 b	5.40 b	0.10 bc	0.93 d	1.35 bcd
Film 2 10°C	6.07 b	5.30 bc	0.11 abc	0.96 cd	1.27 d
14 days storage					
Harvest	6.15 a	5.20 bc	0.11 b	1.29 a	1.51 a
Un-packaged 2°C	5.88 d	5.53 ab	0.12 b	1.19 b	1.31 b
Film 1 2°C	6.07 b	5.80 a	0.11 b	1.21 b	1.24 b
Film 2 2°C	5.95 c	5.30 bc	0.09 c	1.04 c	1.28 b
Un-packaged 10°C	5.90 cd	5.10 c	0.15 a	1.02 c	0.98 c
Film 1 10°C	6.06 b	5.23 bc	0.11 b	0.84 d	1.04 c
Film 2 10°C	6.07 b	4.80 d	0.11 b	0.75 e	1.02 c
21 days storage					
Harvest	6.15 a	5.20 b	0.11 b	1.29 a	1.51 a
Un-packaged 2°C	5.70 e	5.73 a	0.12 b	1.01 c	1.28 b
Film 1 2°C	5.93 c	5.73 a	0.11 b	1.18 b	1.07 c
Film 2 2°C	5.86 d	5.13 b	0.10 b	1.00 c	1.05 c
Un-packaged 10°C	5.88 cd	5.67 a	0.23 a	0.88 d	0.85 d
Film 1 10°C	6.03 b	5.03 bc	0.12 b	0.84 d	0.98 d
Film 2 10°C	6.07 b	4.70 c	0.12 b	0.81 d	0.75 e

Values in columns followed by unlike letters of each storage period and harvesting time are significantly different according to the Duncan's test of the least significant difference at $P \leq 0.05$.

after storage occurred in unpackaged asparagus or in samples packaged with Film 1 at 2°C, while in Film 1 at 10°C a significant decrease was detected; few changes occurred in the other samples. Glucose and fructose were the predominant sugars, with slightly higher levels of fructose with respect to glucose (Table 1), while sucrose was detected in traces with concentrations lower than 0.3 g/100 g FW (data not shown). At harvest the concentrations of glucose and fructose were 1.29 and 1.51 g/100 g, respectively. During storage their content gradually declined, especially in samples stored at 10°C, which always showed higher losses. The effect of film wrapping was not so evident. Significant differences detected at some sampling dates were not confirmed in others, denoting an inconsistent and overall not significant effect of the films. With regard to ascorbic acid, differences were observed among all samples (Table 2). The obtained data show that ascorbic acid content was higher at harvest and then decreased quickly during storage. The kinetics of degradation of ascorbic acid content during storage fit an exponential function of the following kind: $y = a\, e^{-bx}$, where the coefficient "a" represents the initial concentration and coefficient "b" refers to the rate of ascorbic acid degradation of stored asparagus (Fig. 5). The percentages of ascorbic acid retention after 14 days of storage at 2°C were 63.5, 57.7 and 45.8% while at 10°C they were 34.9, 29.7 and 20.5% in normal atmosphere, packaged with Film 1 and Film 2 respectively. Total phenolic compounds at harvest were determined to be 69.16 mg/100 g FW (Table 2). Over the storage period, significant increases were detected in packaged and unpackage asparagus spears stored at 2°C and a similar trend was observed in asparagus packaged and stored at 10°C, although the increase was less than at 2°C, while in unpackaged spears stored at 10°C total phenols remained similar to those at harvest. Antioxidant activity was fairly stable in asparagus stored at the lower temperature, while in asparagus stored at 10 °C it decreased more than samples stored at 2°C; most of the decline occurred during the first week of storage and with the highest losses detected in unwrapped spears stored at 10°C. (Table 2).

Table 2 - Influence of film packaging (Film 1, Omnifilm PVC film; Film 2, Bolphane BX polyolefinic film) and storage conditions on ascorbic acid, total phenols and antioxidant activity in asparagus spears

Storage period	Ascorbic acid (mg/100g)	Total phenols (mg/100g)	Antioxidant activity (mM TEAC)
7 days storage			
Harvest	22.70 a	69.16 cd	1.71 ab
Un-packaged 2°C	18.23 b	69.98 bcd	1.61 b
Film 1 2°C	17.20 b	74.19 a	1.77 a
Film 2 2°C	13.57 c	72.93 abc	1.79 a
Un-packaged 10°C	11.20 d	68.44 d	1.41 c
Film 1 10°C	11.00 d	74.48 a	1.47 c
Film 2 10°C	8.30 e	73.72 ab	1.46 c
14 days storage			
Harvest	22.70 a	69.16 c	1.71 ab
Un-packaged 2°C	14.43 b	80.35 a	1.63 bc
Film 1 2°C	13.10 b	78.79 a	1.73 ab
Film 2 2°C	10.47 c	82.21 a	1.79 a
Un-packaged 10°C	7.93 d	70.60 bc	1.35 d
Film 1 10°C	6.77 d	74.05 b	1.44 c
Film 2 10°C	4.67 e	73.84 b	1.45 c
21 days storage			
Harvest	22.70 a	69.16 c	1.71 a
Un-packaged 2°C	11.30 b	84.14 a	1.63 b
Film 1 2°C	9.68 c	83.27 a	1.73 a
Film 2 2°C	9.43 c	85.97 a	1.76 a
Un-packaged 10°C	7.63 d	69.52 c	1.35 d
Film 1 10°C	5.17 e	76.91 b	1.49 c
Film 2 10°C	4.63 e	75.10 b	1.48 c

Values in columns followed by unlike letters of each storage period and harvesting time are significantly different according to the Duncan's test of the least significant difference at $P \leq 0.05$.

Visual assessment

After 7 days of storage at the test temperatures, packaged spears were judged as excellent, unpackaged ones scored 3 at 2°C and 2 at 10°C (data not shown). The main alterations detected in unpackaged samples were longitudinal striations due to excessive water loss, especially toward the base. These phenomena increased during storage and were more evident in spears stored at 10°C. As a result, after 14 days unpackaged asparagus stored at 10°C were unmarketable (score 1) (Villanueva *et al.,* 2005). After 21 days, spears stored at 2°C and packaged with Film 2 and Film 1 were scored 3 and 2, respectively, with the main defect being a loss of green color, which also occurred in unpackaged samples. After 21 days of storage even unpackaged samples stored at 2°C were unmarketable, while packaged spears, with only slight discoloration, were still marketable.

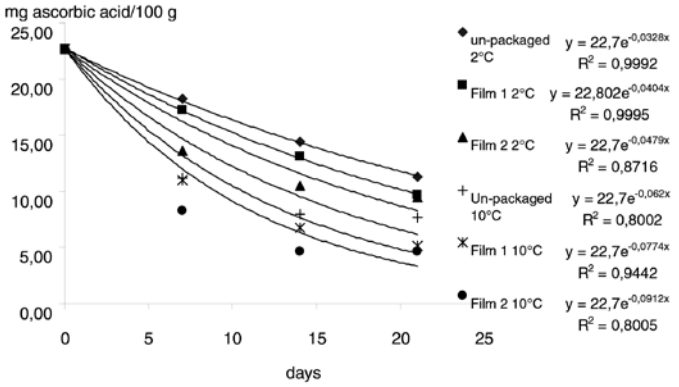

Fig. 5 - Kinetic model of ascorbic acid degradation during storage.

4. Discussion and Conclusions

This study confirms a delay of the processes of physical and chemical deterioration in asparagus spears in response to storage temperature and modified atmosphere resulting from two different packaging solutions. The response was evident in visual appearance, weight loss, and some chemical parameters.

Modified atmospheres are known to reduce the metabolic activity of harvested products. In the present experiment the modified atmosphere was passively created by the accumulation of CO_2 released by respiration and its composition was affected by storage temperature and film permeability to gases. The final partial pressures of CO_2 and O_2 were within the tolerance limits for this commodity, which are above 10k Pa for O_2 and below 15 kPa for CO_2 (Berrang *et al.,* 1990). Ethylene concentration was generally higher at 10°C than at 2°C, especially, after 7 days. Moreover, when asparagus were stored at 10°C, differences in ethylene concentrations were also affected by the type of film. Nevertheless, the in-package gas composition was remarkably effective in all conditions at delaying chemical and physical compositional changes, regardless of storage temperature. It is likely that the potential negative effect of ethylene, especially in packages stored at 10°C, was counteracted by CO_2, which notoriously can mitigate the negative effect of ethylene by interacting with its receptors (Burg, 2004).

The rate of weight loss was dependent on storage temperature, packaging, and type of film used. Prevention of weight loss due to the maintenance of high relative humidity is a major advantage of packaging, and the beneficial effect of this practice was particularly evident in this study. However, the different permeability to water vapor of the two films led to significant differences in weight loss between Film 1 and Film 2, especially at 10°C. As a result, overall appearance of asparagus stored at 2°C and sealed with Film 2 (the less permeable) declined at a slower rate and allowed better maintenance of market quality.

Asparagus toughening has generally been associated with the lignification process (Siomos *et al*., 2000). Postharvest texture changes are influenced by numerous biochemical modifications of plant tissues, such as compositional modifications of cell walls, lignification of the pericyclic fibers, increases in phenolic compounds such as ferulic acid and *p*-coumaric acid, deposition of polysaccharides, mainly xylan, and storage conditions (Rodriguez *et al.,* 2002 b; 2004; 2005). The results of the present study are in agreement with previous findings (Waldron and Selvendran, 1990; Rodriguez *et al.,* 1999 a, b). Moreover, textural properties were influenced by water loss; toughness increases as a consequence of turgor reduction.

The increased titrable acidity detected in unpackaged asparagus stored at 10°C might be induced by the advanced decaying process, which did not occur in packaged samples. A slight increase in TSS after storage occurred in unpackaged or packaged asparagus with Film 1 at 2°C, while in Film 1 at 10°C a significant decrease was recorded; few changes occurred in the other samples. Packaged and unpackaged spears showed significant reductions in glucose and fructose content during storage, particularly in those stored at 10°C. Changes in TSS, glucose and fructose generally denoted marked differences between unpackaged and packaged samples and, above all, between the two storage temperatures. The few differences in chemical composition between packaged and non-packaged asparagus, in contrast with the marked differences detected in weight loss and textural properties, may indicate that the overall beneficial effect of packaging is a consequence of the reduced transpiration occurring in packaged asparagus rather than the physiological effect due to the increased levels of CO_2 and reduced availability of O_2. As for ascorbic acid content, the results reflect a significant decrease with storage which is more accentuated in unpackaged samples and in those stored at 10°C (Esteve *et al.*, 1995). The kinetics of degradation confirmed this trend, in fact the highest rate of degradation was approximately 0.4 mg ascorbic acid/100 g/day and 0.8 mg ascorbic acid/100 g/day for packaged asparagus and 0.3 mg ascorbic acid/100 g/day and 0.6 mg ascorbic acid/100 g/day for unpackaged samples, refrigerated at 2°C and 10°C, respectively. Total phenolic content increased during storage: changes were clear after 14 days in packaged spears and stored at 2°C. This trend can be ascribed to an increase of phenols in asparagus cell walls (Rodriguez *et al*., 2002 b). However, in unpackaged spears stored at 10°C no change occurred in phenols content when they were in advanced decay, most likely because decaying cells are no longer able to synthesize phenolic compounds. Antioxidant capacity was fairly stable during storage in asparagus spears packaged with Film 1 and Film 2 stored at 2°C. In contrast, antioxidant capacity of packaged and unpackaged spears stored at 10°C declined during both periods with values significantly lower than at harvest. The antioxidant activity in foods depends on the content of components such as phenolic compounds, carotenoids and ascorbic acid and their fate during processing or storage. In this study the antioxidant capacity might have been balanced by the decreasing trend of ascorbic acid and the increasing tendency of total phenols. As a result, higher levels of antioxidant activity was detected in packaged asparagus stored at 2°C, which contained more total polyphenols and lost vitamin C at a slower rate than all other treatments.

However, considerations about changes in chemical parameters should take account the effect of transpiration, as a loss of water inevitably leads to an increase of solute concentration, and this effect might be particularly marked in unpackaged samples where weight loss over the storage period ranged between about 6 and 32 %.

The overall results of this study show the positive effect on quality retention of cold-stored asparagus, both from a market point of view and from the chemical and nutraceutical perspective. In particular, the best results were achieved with the less permeable film (Film 2) and storage at 2°C.

Acknowledgements

We thank Domenico Mura (CTRE CNR ISPA) for his contribution with chemical and physical analyses.

The work reported in this paper was presented at the "POSTHARVEST2014 Reducing Postharvest Losses to Feed the World Congress" held in Barletta, Italy, on 22-23 May 2014.

References

ALBANESE D., RUSSO L., CINQUANTA L., BRASIELLO A., DI MATTEO M., 2007 - *Physical and chemical changes in minimally processed green asparagus during cold-storage.* - Food Chem., 101: 274-280.

AOAC, 2007 - *Official methods of analysis, 18th ed.* - Association of official analytical chemists International, Gaithersburg, MD, USA.

BERRANG M.E., BRACKETT R.E., BEUCHAT L.R., 1990 - *Microbial, colour and textural qualities of fresh asparagus, broccoli and coliflower stored under controlled atmosphere.* - Food Prot., 53(5): 391-395.

BONDED V., BRAND-WILLIAMS W., BERSET C., 1997 - *Kinetics and mechanism of antioxidant activity using the DPPH free radical method.* - Leb.-Wiss. Tech., 30: 609-615.

BURG S.P., 2004 - *Ethylene*, pp. 132–239. - In: BURG S.P. (ed.) *Postharvest physiology and hypobaric storage of fresh produce*. CABI Publishing, Wallingford, UK.

ESTEVE M.J., FARRÈ R., FRIGOLA A., 1995 - *Changes in ascorbic acid content of green asparagus during the harvesting period and storage*. - J. Agr. Food Chem., 43: 2058-2061.

FONSECA S.C., OLIVEIRA F.A.R., BRECHT J.K., 2002 - *Modelling respiration rate of fresh fruits and vegetables for modified atmosphere packages: a review.* - J. Food Eng., 52: 99-119.

GONTARD N., THIBAULT R., CUQ B., GUILBERT S., 1996 - *Influence of relative humidity and film composition on oxygen and carbon dioxide permeabilities of edible films*. - J. Agr. Food Chem., 44: 1064-1069.

KADER A.A., 1992 - *Postharvest biology and technology: An overview.* - Postharvest technology of horticultural crops, University of California, Vol. 3311.

KING G.A., HENDERSON K.G., LILL R.E., 1986 - *Asparagus: effect of controlled atmosphere storage on shelf-life of four cultivars.* - New Zealand J. Experimental Agr., 14: 421-424.

KING G.A., HURST P.L., IRVING D.E., LILL R.E., 1993 - *Recent advances in the postharvest physiology storage and handling of green asparagus*. - Postharvest News Inf., 4(31): 85-89.

RODRIGUEZ R., JARAMILLO S., HEREDIA A., GUILLEN R., JIMENEZ A., FERNANDEZ-BOLANOS J., 2004 - *Mechanical properties of white and green asparagus: changes related to modifications of cell wall components.* - J. Sci. Food Agr., 84: 1478-1486.

RODRIGUEZ R., JARAMILLO S., HEREDIA A., GUILLEN R., JIMENEZ A., FERNANDEZ-BOLANOS J., 2005 - *Cell wall phenolics of white and green asparagus*. - J. Sci. Food Agric., 85(6): 971-978.

RODRIGUEZ R., JIMENEZ A., GUILLEN R., HEREDIA A., FERNANDEZ-BOLANOS J., 1999 a - *Turnover of white asparagus cell wall polysaccharides during postharvest storage.* - J. Sci. Food Agric., 47: 4525-4531.

RODRIGUEZ R., JIMENEZ A., GUILLEN R., HEREDIA A., FERNANDEZ-BOLANOS J., 1999 b - *Postharvest changes in white asparagus cell wall during refrigerated storage.* - J. Agric. Food Chem., 47: 3551-3557.

RODRIGUEZ R.C., SMITH A.C., WALDRON K.W., 2002 a - *Mechanical properties of green asparagus*. - J. Sci. Food Agric., 82: 293-300.

RODRIGUEZ R.C., SMITH A.C., WALDRON R.R., 2002 b - *Effect of storage on wall-bound phenolics in green asparagus*. - J. Agric. Food Chem., 50: 3197-3203.

SINGLETON V.L., ROSSI J.A., 1965 - *Colorimetry of total phenolics with phosphomolybdic-phosphotungstic acid reagents*. - Amer. J. Enol. and Vitic., 16: 144-158.

SIOMOS A., SFAKIOTAKIS E.M., DOGRAS C.C., 2000 - *Modified atmosphere packaging of white asparagus spears: composition, color and textural quality responses to temperature and light.* - Scientia Hort., 84: 1-13.

SUN T., TANG J., POWERS J.R., 2005 - *Effect of pectolytic enzyme preparations on the phenolic composition and antioxidant activity of asparagus juice.* - J. Agric. Food Chem., 53: 42-48.

VILLANUEVA M.J., TENORIO M.D., SAGARDOY M., RENONDO A., SACO, M.D., 2005 - *Physical, chemical, histological and microbiological changes in fresh green asparagus (*Asparagus officinalis*, L.) stored in modified atmosphere packaging.* - Food Chem., 91: 609-619.

WALDRON K.W., SELVENDRAN R., 1990 - *Composition of the cell walls of different asparagus (*Asparagus officinalis*) tissues.* - Physiol. Plantarum, 80: 568-575.

ZAGORY D., KADER A.A., 1988 - *Modified atmosphere packaging of fresh produce*. - Food Technology, 9: 70-77.