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Effects of polyvinylchloride films and edible starch coatings on quality aspects of refrigerated Brussels sprouts

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Abstract

To extend shelf life, the effects of polyvinylchloride film (PVC) and edible coatings on quality aspects of refrigerated Brussels sprouts were studied. Starch-based coatings were formulated using glycerol (G), sorbitol (S) or glycerol plus sunflower oil (O). Sprouts so treated as well as uncoated ones were placed on expanded polystyrene trays. Combinations of PVC and coatings (treatments named G-PVC, S-PVC and O-PVC) were also tested. Uncovered trays were maintained as controls. All packages were stored at 0 °C for 42 days and samples were removed every 14 days to determine commercial acceptability, weight loss, surface colour (of sprouts' heads and bases) and texture. Sprouts in all treatments maintained optimum quality conditions over the first 14 days. At the end of storage, browning of cut zones and losses in weight and firmness were minimised in PVC-packaged sprouts, particularly in G-PVC. Therefore, PVC and G-PVC treatments were selected to evaluate some nutritional quality components. Ascorbic acid and total flavonoid contents remained almost constant while radical scavenging activity increased after 42 days of storage. Thus, PVC and G-PVC treatments showed the best performance for long-term refrigerated storage of Brussels sprouts.

Keywords: Synthetic packaging film; Edible starch coatings; Brussels sprouts; Radical scavenging activity; Ascorbic acid; Total flavonoids content

1. Introduction

Quality of Brussels sprouts can be evaluated as functions of appearance, colour, compactness and odour. Post-harvest losses may occur very quickly and are mainly caused by yellowing, dehydration and action of pathogenic microorganisms. Pantastico, Subramanyam, Bhatti, Ali, and Akamine (1975) and Ryall and Lipton (1979) have observed that losses can be reduced by storing the produce at 0 °C and 90–95% relative humidity (RH). Likewise, Cantwell and Suslow (2005) have found that Brussels sprouts can be stored for 3–5 weeks at about 0 °C with RH >95%. Also, Ferreyra, Mugridge, and Chaves (1995) have covered trays with films made of polyvinyl chloride (PVC) or RD-106® (a multilayer low density linear polyethylene, co-extruded with ethyl vinyl acetate) and found this method effective for preserving the quality attributes of Brussels sprouts, despite the product being maintained at 0 °C with lower RH (85%).

The health promoting and cancer preventing action of some plant foods, specially green vegetables, is attributed not only to the abundant nutritional antioxidants they contain, such as vitamin C, but also to the high content of non-nutritional antioxidants, such as flavonoids and other polyphenolic compounds (Lin & Chang, 2005).

Packaging plays a fundamental role on food conservation, distribution and marketing. Some functions of packaging are to contain the food, to protect it from physical, chemical and microbiological action, to maintain food

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quality and healthfulness, to prevent adulteration and to prepare the product for commercial handling (Catalá, 1997). Numerous choices are available for packaging and conservation of vegetables. The combination of two or more systems with synergistic effects is generally recommended (Huxsoll & Bolin, 1989). Commercial post-harvest treatments and food preservation systems often combine various methods, an approach called hurdle technology (Hoover, 1997).

Synthetic films are particularly effective to protect products against mechanical damage. Among them, low-density polyethylene, polyvinyl chloride and polypropylene are often used for packaging fruits and vegetables (Kader & Watkins, 2000). However, once their usage cycle is over, the final disposal of these materials lead to ecological problems and additional recycling costs (Chaves, Fernández Lozano, Limongelli, & Mugridge, 1998).

The use of corn starch to produce biodegradable and/or edible films for food packaging is advantageous because it is a low-cost, renewable resource and is widely available in Argentina (Mollo, Eisenberg, Dominelli, & Galak, 1995). Suitably formulated edible films and coatings may maintain the quality of Brussels sprouts, by delaying senescence, reducing dehydration and diminishing microbial growth rate. Being composed of soft tissues, having an approximately spherical shape and a compact structure, Brussels sprouts may be appropriate for coating.

Composite coatings are mainly blends of polysaccharides, proteins and lipids. The goal of composite coating formulations is to combine the desirable properties of the materials mentioned above to improve barrier properties, integrity, adhesivity, flexibility and general performance (Baldwin, Nisperos-Carriedo, Hagenmaier, & Baker, 1997; García, Martino, & Zaritzky, 2000; Guilbert, 1986; Krochta & De Mulder-Johnston, 1997; Nísperos-Carriedo, 1994). Coatings based on proteins or polysaccharides are claimed to have low permeability to CO_2 and O_2 which delay senescence and extend storage life of treated vegetables (Avena-Bustillos, Cisneros-Zeballos, Krochta, & Saltveit, 1993; Avena-Bustillos, Krochta, Saltveit, Rojas-Villegas, & Sauceda-Pérez, 1994; Baldwin, 1994; Drake, Cavalieri, & Kupferman, 1991; García, Martino, & Zaritzky, 1998a, García, Martino, & Zaritzky, 1998b). Owing to the hydrophilic nature of these coatings, the addition of lipids would be desirable to improve their water vapour barrier properties.

The aims of the present work were:

(a) To evaluate the effect of the packaging system (combined use of PVC film with starch-based coatings) on Brussels sprouts, analysing commercial acceptability, weight loss, surface colour and texture during refrigerated storage.
(b) To evaluate nutritional quality attributes (radical scavenging activity, ascorbic acid and total flavonoids) of Brussels sprouts at the end of their storage period.

2. Materials and methods

2.1. Plant material

Brussels sprouts (*Brassica oleracea* L. *gemmifera* DC) cultivar Oliver, field-grown in the La Plata horticultural region (Province of Buenos Aires, Argentina), were used. The vegetables were harvested early in the morning and immediately carried to the laboratory. Sprouts of uniform size, free from physical damage and disease symptoms were selected and external leaves were removed. The sprouts (about 200 g) were then placed on expanded polystyrene trays (15.5 cm × 15.5 cm × 2 cm), 10 sprouts per tray. A total of 128 trays were used (four trays for each sampling point and treatment) i.e., 1280 Brussels sprouts.

2.2. Coating formulation and application

Starch-based coatings were formulated using 20 g/l commercial corn starch (Molinos Río de la Plata, Argentina) suspensions. These were cold gelatinised with 10 g/l sodium hydroxide solution (García et al., 1998a, 1998b). Suspensions were then neutralised with 7 M phosphoric acid. As plasticizers, glycerol (G coating formulation) or sorbitol (S coating formulation) (Merck & Co, NJ) were added at a concentration of 20 g/l. In addition, polyoxyethylene-sorbitan monostearate (Tween 40, Sigma-Aldrich, St Louis, MO) was added at a concentration of 2 ml/l to improve coating adhesion to the product. The oil coating formulation (O) was obtained by adding 2 g/l of sunflower oil (Aceitera General Deheza S.A., Córdoba, Argentina) to the formulation plasticized with glycerol. The lipid phase was dispersed in the aqueous phase, and the mixture homogenised using an (Ultra-Turrax Janke & Kunkel IKA Staufen, Germany) with a dispersing device (S 25 N-10 G) at 7800 rpm for 5 min, and then degassed under vacuum. Concentrations of starch (20 g/l), plasticizer (20 g/l) and oil (2 g/l) were selected from previous works (García et al., 1998a, 1998b, 2000).

Coating was carried out at room temperature by dipping sprouts for 10 s in the formulated suspensions and then drying under air flow (1.2 m/s at 20 °C) for about 2 h (García, Martino, & Zaritzky, 2001).

2.3. Coating characterisation

The surface tension of each suspension was measured by the Ring Method using a CSC-DUNOUY 70535 (Fairfax, VA) instrument. The rheological characterisation was conducted at constant controlled temperature (20 °C) in a Haake RV2 (Haake, Germany) rotational viscometer, as described in a previous work (García, Pinotti, Martino, & Zaritzky, 2004). An MVIP type sensor system of coaxial cylinders was used.

2.4. Sample treatments

Eight treatments were applied, corresponding to the following packaging systems: (a) Trays containing untreated Brussels sprouts, which were used as controls (C); (b) Trays containing Brussels sprouts coated with different starch-based formulations (G, S and O); (c) Uncoated Brussels sprouts placed on trays, covered with polyvinyl chloride film (PVC), provided by Casco Argentina S.A., Buenos Aires; Table 1 lists PVC film and coating characteristics; (d) Combined treatments: sprouts coated with various formulations, placed on PVC-covered trays (G-PVC, S-PVC and O-PVC).

2.5. Storage conditions

Trays were placed in cold stores at 0 °C and 84.8% RH for 42 days. At 0, 14, 28 and 42 days of storage, four trays from each treatment and the controls were removed for analysis.

2.6. Analysis of general quality attributes

2.6.1. Sensory evaluation

Sensory quality of products was evaluated by ten untrained panelists. Samples were evaluated using the following hedonic scale: 1 = bad, 2 = fairly good, 3 = good, 4 = very good and 5 = excellent. A value of 3 was considered as the commercial acceptability threshold.

2.6.2. Weight losses

Water losses were determined by the difference between the initial weight of each tray and the weight at various times during storage. A digital precision balance (±0.1 g) was used for this purpose. Results were expressed as percentage weight loss, compared to the initial sample weight. Control and treated samples were tested at the same time.

2.6.3. Surface colour

Colorimetric measurements were taken at three positions on sprouts' heads as well as in the cut zones (basis), using a Minolta colorimeter CR 300 Series (Osaka, Japan) calibrated with a standard white plate ($Y = 93.2$, $x = 0.3133$, $y = 0.3192$). The CIELab scale was used to determine lightness (L^*) and chromaticity parameters a^* (red–green) and b^* (yellow–blue). With them, the total colour difference ($\Delta E = [(\Delta a^*)^2 + (\Delta b^*)^2 + (\Delta L^*)^2]^{1/2}$) was calculated. The reference values (a_0^*, b_0^* and L_0^*) were those of the initial condition of the untreated sprouts.

2.6.4. Texture

Firmness of sprouts was measured with a texturometer TA-XT2i (Stable Micro Systems Ltd, Godalming, Surrey, UK) operating in the compression mode with a 25 kg cell. The equipment was fitted with an aluminum compression plate (75 mm diameter) and samples were laterally compressed 3 mm at a constant rate of 1 mm s^{-1}. The force (N) was automatically plotted as a function of deformation (mm) by the Texture Expert® Exceed software, to provide the maximum forces. Each of these values was the average of at least eleven determinations.

2.7. Nutritional quality

The radical-scavenging activity and the contents of ascorbic acid and total flavonoids were determined on control samples at the beginning of storage (day 0) and on samples which kept the highest quality level after 42 days of storage at 0 °C (PVC and G-PVC). Brussels sprouts obtained from four trays (combined material) were homogenised and frozen with liquid N_2. Part of the pool of samples was crushed in a laboratory mill (Janke & Kunkel Ika Labortechnik A10).

2.7.1. Radical scavenging activity (RSA)

Samples of frozen material (1 g) were extracted with 5 mL ethanol 96° at room temperature, with constant stirring for 20 min. After centrifugation at 11,000*g*, the antiradical activity was determined on the extracts, by spectrophotometry at 515 nm, based on the reaction with the stable radical 2,2-diphenyl-1-picrylhydrazyl (DPPH·) (Brand-Williams, Cuvelier, & Berset, 1995). The effective mean concentration (EC_{50}), which is the antioxidant content required to reduce DPPH· initial concentration by 50%, was calculated. The EC_{50} value was employed to calculate the amount of DPPH· that can be neutralised by the

Table 1
Thickness and permeabilities of PVC film and edible starch-based coatings

Packaging treatment	Water vapour permeability × 10^{10} (g m^{-1} s^{-1} Pa^{-1}) $LSD_{0.05} = 0.31$	Thickness (μm) $LSD_{0.05} = 8.36$	CO_2 permeability × 10^9 (cm^3 m^{-1} s^{-1}) $LSD_{0.05} = 1.63$	O_2 permeability × 10^{10} (cm^3 m^{-1} s^{-1}) $LSD_{0.05} = 1.03$	
Coating	Starch	3.68 ± 2.24[a]	50	29.2 ± 13.89	15.9 ± 2.99
	Starch + glycerol	2.57 ± 1.04	50	5.69 ± 0.97	4.61 ± 0.51
	Starch + sorbitol	1.75 ± 0.14	50	4.19 ± 0.81	2.48 ± 0.32
	Starch + glycerol + oil	1.92 ± 0.47	50	5.87 ± 0.58	3.83 ± 0.76
	PVC film	0.00914 [b]	15	0.0832[c]	0.1924[c]

Glycerol and sorbitol concentration = 20 g/L; O = sunflower oil (2 g/L).
[a] Value ± standard deviation.
[b] Provided by the supplier, measured at 38 °C and 100% RH.
[c] Provided by the supplier, measured at 23 °C and 0% RH.

antioxidants present in the ethanolic extract, prepared from 100 g of fresh Brussels sprouts. Final results were expressed as μmol $DPPH^{\cdot}$/100 g fresh tissue. Determinations were carried out, at least, in duplicate.

2.7.2. Ascorbic acid content (AA)

Samples were taken from the homogenised frozen crushed material, weighed accurately to 1 g each, extracted in 5 ml aqueous solution of citric acid (3% w/v) for 10 min and then centrifuged. From the supernatant of each extract, 1 ml aliquots were centrifuged again for 2 min at 10,000*g* in an Eppendorf 5415C centrifuge. Ascorbic acid concentration was quantified by HPLC using a Waters Model 6000A (Milford, MA) chromatograph, fitted with a UV/Vis detector, following the technique of Wimalasiri and Wills (1983). A C18 column (Beckman) was used, with 4.6 mm internal diameter and 25 cm in length, packed with particles 5 μm in diameter. A mixture of acetonitrile:water (70:30), which contained 0.01 M $(NH_4)H_2PO_4$ at a flow rate of 2 ml min^{-1} was used as eluent, the pH being adjusted to 4.3 with orthophosphoric acid. Detection was carried out at 254 nm, and a standard ascorbic acid solution was used for identification and quantification purposes. Final results were expressed as mg ascorbic acid/100 g fresh tissue. Determinations were carried out, at least, in duplicate.

2.7.3. Total flavonoids

These were determined by a modified version of the technique proposed by Kim, Jeong, and Lee (2003). Ten grams of frozen and crushed tissue were extracted with 25 ml of ethanol 96°. After centrifugation, 20 ml of the resulting extracts were concentrated in a rotary evaporator R-124 (Büchi Labortechnik AG, Flawil, Switzerland) at 30 mmHg and 40 °C, until dryness. The residues were resuspended in 2 ml of doubly distilled water. In order to prepare the reaction mixtures 1500 μl of double distilled water plus 500 μl of the concentrated samples were added to a test tube. Various solutions were added sequentially to complete the system, the times being counted from the start of reaction: 150 μl of $NaNO_2$ (5%) at time 0; 150 μl of $AlCl_3$ (10%) after 5 min, and finally, 500 μl of NaOH (1 M) after 11 min.

All solutions were mixed by stirring in a vortex, and their absorbance was measured at 510 nm. A standard curve was constructed using various catechin concentrations, in the range of 7–37 μg ml^{-1}. Total flavonoids levels in the samples were expressed as mg catechin/100 g fresh tissue. Determinations were carried out, at least, in duplicate.

2.8. Statistical analysis

A factorial analysis was employed, where the sources of variation were storage time (four levels) and treatment (eight levels). Means were compared by the Fisher's least significant difference (LSD) test, at a significance level $p \leqslant 0.05$.

3. Results and discussion

3.1. Coating characterisation

The surface tension of a coating suspension is an essential factor for determining coating success. The peel or surface of many vegetables has low surface tension for protection purposes; however, this natural advantage is a shortcoming for aqueous coatings (García et al., 2001).

Table 2 shows that the addition of plasticizer and lipids decreased surface tension, facilitating coating adhesion to foodstuffs. Best results were obtained with formulations including Tween 40, a well-known surfactant. Coating integrity is a critical factor related to adhesion and flexibility, and these characteristics are incompatible with the irregular shapes of most vegetables. Integrity is mainly determined by the rheological characteristics of filmogenic suspensions. García et al. (2001) have observed a pseudoplastic behaviour in all of them. Addition of plasticizer and lipid to corn starch suspensions lead to a decrease in the apparent viscosity (Table 2), improving coating flexibility by reducing polymer chain interactions.

Table 1 shows that O_2 permeability was much lower than that for CO_2, suggesting different gas solubility in the films with a selective action on gas permeability. Unplasticized coatings gave significantly ($p < 0.05$) higher barrier properties (water vapour and gas permeability) than plasticized formulations (Table 1). The presence of lipids caused a significant decrease ($p < 0.05$) in the water vapour permeability of emulsified starch-based coatings (Table 1), without modifying gas selectivity. In agreement

Table 2
Characterisation of starch-based coating formulations

Coating formulation	Surface tension (dyn cm^{-1})	Apparent viscosity, η_{ap} (mPa s)
Starch	60.7 ± 0.120[a]	12.9 ± 0.063
Starch + glycerol	59.6 ± 0.764	12.0 ± 0.182
Starch + glycerol + sunflower oil	59.1 ± 0.679	11.3 ± 0.092
Starch + glycerol + sunflower oil + Tween 40	46.1 ± 0.91	nd[b]
Starch + sorbitol	51.4 ± 0.082	12.6 ± 0.176
Starch + sorbitol + sunflower oil	54.0 ± 0.266	9.64 ± 0.182
Starch + sorbitol + sunflower oil + Tween 40	47.4 ± 0.84	nd

[a] Value ± standard deviation.
[b] nd: not determined.

with Krochta and De Mulder-Johnston (1997), every component of a composite coating contributes to the overall performance of the formulation. In our experiments, the starch formed a supporting matrix, the plasticizer imparted film integrity, the lipids contributed with their hydrophobicity and the surfactant provided good coating adhesion.

The barrier properties to water vapour and gases of PVC film are significantly ($p < 0.05$) higher than those of edible coatings. However, the average PVC film selectivity, evaluated as the ratio of CO_2 to O_2 permeability (4.32), was lower than in starch-based coatings (13), and this is a desirable property for vegetable packaging, to facilitate the generation of a passively modified microatmosphere.

3.2. Analysis of general quality attributes

3.2.1. Sensory attributes

Up to 14 days of refrigerated storage, sprouts maintained "excellent" quality levels, regardless of the treatment considered (Fig. 1). After day 28, quality reduction was observed; this could be attributed (in order of importance) to dehydration, browning in cut zones (bases), growth of pathogens and yellowing. At this time, quality decreased below the commercial acceptability threshold (value of 3 in the hedonic scale) in treatments G, S and O (Fig. 1). Another detrimental factor observed in these treatments was coating detachment, possibly caused by the effect of dehydration.

At 28 days of storage at 0 °C, the PVC treatment allowed quality attributes to remain similar to the initial values. In the combined treatments, G-PVC, S-PVC and O-PVC, the quality levels, though slightly below those for PVC, were "very good" and positioned above the commercial limit (Fig. 1).

After 42 days of storage at 0 °C, samples corresponding to the treatments G, S and O exhibited browning in the cut zones and yellowing in the heads, thus leading to quality levels considerably below the acceptability threshold. In contrast, in the PVC treatment, commercial quality slightly decreased after 42 days at 0 °C. Sprouts thus packaged revealed incipient browning in cut zones. After the same storage period at 0 °C, G-PVC, S-PVC and O-PVC combined treatments were evaluated as "good", which coincided with the pre-established commercial threshold.

3.2.2. Weight loss

Weight losses of controls increased significantly ($p < 0.05$) during storage (Fig. 2), exceeding 8% at day 14. This percentage was considered by Robinson, Browne, and Burton (1975) as the maximum acceptable for Brussels sprouts. A similar trend was observed in coated sprouts, regardless of the formulation. Nevertheless, until day 14, untrained panelists judged all samples as "excellent", indicating that dehydration was not perceived as a defect.

At the end of storage (day 42), weight losses of samples corresponding to C, G, S and O treatments varied between 22% and 33%. Sorbitol and oil-coated sprouts showed considerably higher weight losses than glycerol-coated samples (1.44 and 1.21 times as high, respectively).

Plastic film packaging substantially reduced weight losses below the maximum admissible in coated or uncoated

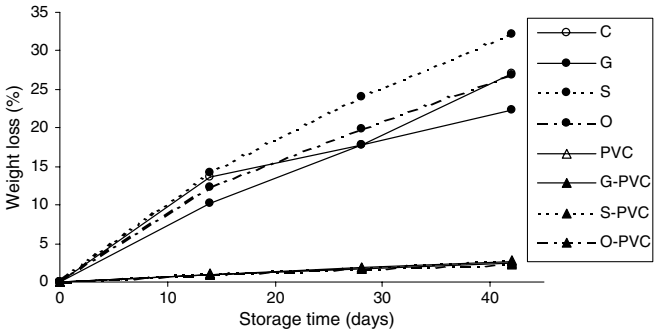

Fig. 2. Effect of various packaging systems on weight loss (%) of Brussels sprouts during storage at 0 °C for 42 days ($LSD_{0.05} = 1.75$).

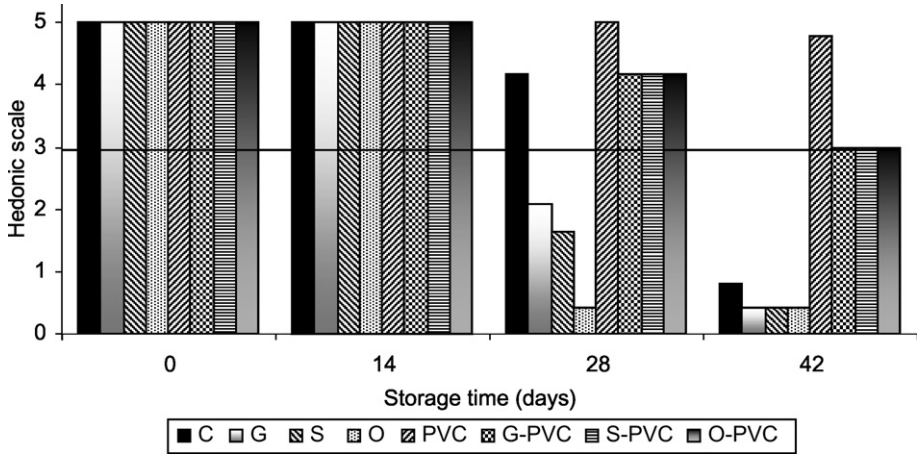

Fig. 1. Effect of the different packaging systems on sensory evaluation of Brussels sprouts during storage at 0 °C for 42 days. The line corresponds to the commercial acceptability threshold (value 3 in the hedonic scale).

sprouts (Fig. 2). A significant weight loss increase was observed only from day 14 on ($p < 0.05$).

3.2.3. Surface colour

Surface colour of bases. When evaluating sensory characteristics, one of the main negative attributes detected was browning in the cut zones. Fig. 3 shows the variation of the colour parameters L^* and ΔE during storage. The decrease of L^* determined the increase in ΔE as a function of time. At the end of storage, the combined treatments, especially G-PVC, resulted in lower ΔE increases, compared with the control samples and with the corresponding treatment where plastic film was not used (Fig. 3).

PVC packaging was the most effective choice to minimise browning in the cut zones (Fig. 3), the results achieved being in agreement with those obtained in the evaluation of organoleptic characteristics.

Surface colour of heads. Table 3 shows the values L^* (lightness), chroma (colour saturation), hue (basic tint) and ΔE at the beginning and end of the storage period. At the beginning of the experiments sprouts' hue was 124°. Except for the control, hue variations, as an effect of treatments and time of storage at 0 °C, were not significant ($p > 0.05$).

A significant increase in chroma was observed at day 0 ($p < 0.05$), due to the effect of coatings. After 42 days of storage, chroma values decreased in samples treated with G, S and O ($p < 0.05$), by 18.2%, 20.2% and 16.5%, respectively, which indicated reduced saturation, with an increase in the gray component of colour.

In PVC packaged sprouts, no significant chroma changes were observed ($p > 0.05$) during the storage period. With regard to the combined treatments, the trend was similar to that observed for "coated-only", although the decrease in chroma observed after 42 days was smaller ($p < 0.05$), due to the effect of the plastic film.

The L^* parameter showed a slight increase in the initial value after coating application, also resulted in ΔE variations. Beyond the initial changes attributed to the treat-

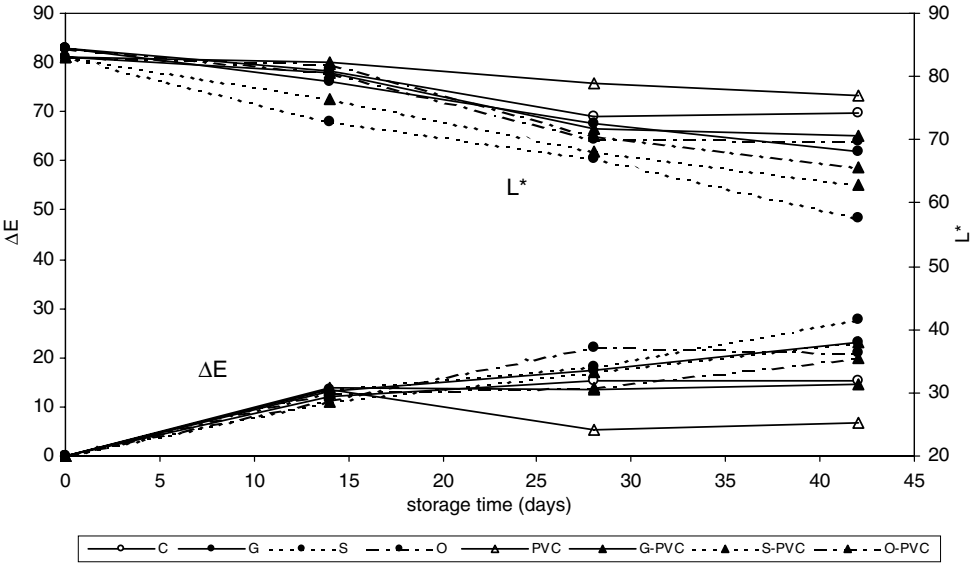

Fig. 3. Surface colour of Brussels sprouts bases. Total colour difference ΔE ($LSD_{0.05} = 4.67$) and lightness L^* ($LSD_{0.05} = 4.73$) for various packaging systems and storage times at 0 °C.

Table 3
Surface colour (L^*, chroma, hue angle and ΔE) of Brussels sprouts' heads stored at 0 °C for 42 days

Treatment	L^*		Chroma		Hue (°)		ΔE	
	Day 0	Day 42	Day 0	Day 42	Day 0	Day 42	Day 0	Day 42
Control (C)	55.8	59.6	35.1	34.9	124.0	122.5	0.00	6.76
G	60.6	58.1	40.7	33.3	121.8	121.0	8.52	5.46
S	58.4	57.2	38.9	31.1	122.6	121.5	6.09	6.32
O	58.8	60.2	39.6	33.1	122.4	121.2	7.09	7.80
PVC	55.8	60.1	35.1	35.8	124.0	123.5	0.00	5.84
G-PVC	60.6	56.8	40.7	34.7	121.8	122.4	8.52	5.97
S-PVC	58.4	57.1	38.9	34.4	122.6	123.0	6.09	5.25
O-PVC	58.8	54.2	39.6	34.6	122.4	122.1	7.09	7.23
$LSD_{0.05}$	3.70		2.36		1. 37		2.63	

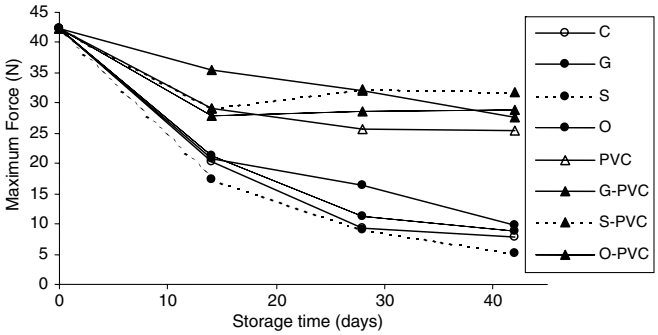

Fig. 4. Effect of the different packaging systems on texture (maximum force, N) of Brussels sprouts during storage at 0 °C for 42 days ($LSD_{0.05} = 7.34$).

ment, no further variations were observed in L^* or ΔE, during storage.

3.2.4. Texture

Results from texture determinations are shown in Fig. 4. The maximum force at the beginning was 42.4 N, and decreased as a function of time during storage at 0 °C. This decrease was faster and to a greater extent in control and coated samples ($p < 0.05$) than in those treatments where PVC film was used. After 42 days at 0 °C, the average decrease of the maximum force in treatments C, G, S and O represented 81.4% of the initial value.

Average firmness decreased by 32.8% of the initial force after 42 days of refrigerated storage for treatments PVC, G-PVC, S-PVC and O-PVC.

Dehydration has a major impact on vegetable texture. The decrease in Brussels sprouts firmness showed an inverse correlation ($r = 0.894$; $p < 0.01$) with the increase in weight loss; thus, the higher the weight loss, the less firm the product.

When analysing objective properties of samples, such as weight loss, surface colour and firmness, the PVC treatment showed the best performance and, among the combined methods, the G-PVC treatment showed the best results. The latter led to reduced browning of the bases, and less loss of firmness especially after 14 days of storage.

For this reason, samples from PVC and G-PVC treatments, were analysed, to determine the radical-scavenging activity, ascorbic acid content and concentration of total flavonoids at the end of refrigerated storage. The reference values for these determinations corresponded to the control sprouts at the start of the storage period (day 0).

3.3. Nutritional quality

3.3.1. Radical-scavenging activity

At the beginning of storage (day 0), the radical-scavenging activity (RSA) was 391 μmol DPPH·/100 g fresh tissue and, at the end of refrigerated storage (day 42), the radical scavenging activity had increased by 56% in PVC and by 31% in G-PVC.

This type of behaviour has already been observed in another species of Cruciferae, the botanical family to which Brussels sprouts belong to; Starzynska, Leja, and Mareczek (2003) found a rapid increase of RSA in broccoli flower buds stored for 3 days at 20 °C, reaching the maximum value (54%) of DPPH· scavenging. The researchers have pointed out that the simultaneous accumulation of phenylpropanoids and flavonoids was induced by the storage of inflorescences.

The method used in the present work is known to only partially characterise the total ability of non-enzymatic components of plant tissues to defend themselves against oxidative stress (Starzynska et al., 2003). The estimation of the total antioxidant activity in flower buds of broccoli stored at 5 °C showed an increase in the inhibition of linoleic acid peroxidation (Leja, Mareczek, Starzynska, & Rozek, 2001). In addition, Leja, Mareczek, and Ben (2003) found that the high radical-scavenging activity observed after harvesting in the peel of two apple cultivars considerably increased during storage at 1 °C, both in cold store and in controlled atmosphere storage.

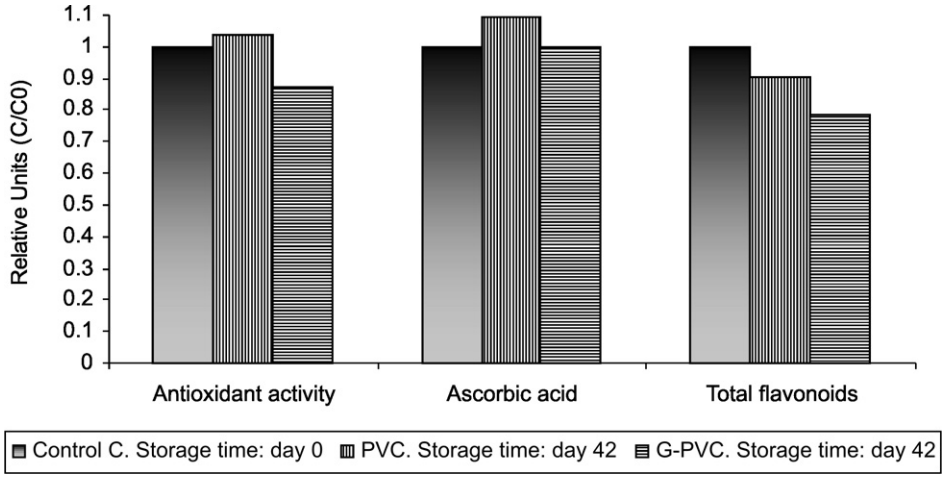

Fig. 5. Relative values (C/C_0) of radical scavenging activity ($LSD_{0.05} = 2.98$), ascorbic acid content ($LSD_{0.05} = 4.64$) and total flavonoids content ($LSD_{0.05} = 4.24$) in Brussels sprouts after 42 days of storage at 0 °C. C_0 corresponded to control samples at initial time (reference value) and C corresponded to uncoated samples packaged in PVC (PVC) or samples coated with starch formulation with glycerol and packaged in PVC (G-PVC).

3.3.2. Ascorbic acid

In our experiments, the initial ascorbic acid content of fresh Brussels sprouts was 77 mg/100 g fresh tissue. The ascorbic acid content did not vary significantly in any of the treatments investigated (Fig. 5). Lee and Kader (2000) have reported minimal losses of ascorbic acid during storage of cruciferous vegetables, unlike in other products where large losses were observed. Vegetables with high ascorbic acid retention were those having high contents of total sulfur and glutathione. In crucifers, glutathione may be involved in the mechanism responsible for dehydroascorbic acid reduction to ascorbic acid (Albrecht, Schafer, & Zottola, 1990). Lee and Kader (2000) have classified Brussels sprouts as "of high retention" of ascorbic acid (greater than 95%).

3.3.3. Total flavanoids

The initial content of total flavonoids was 8.2 mg catechin/100 g fresh tissue. No significant variations were observed ($p > 0.05$) in the total flavonoids concentration after 42 days of refrigerated storage, for the treatments analysed in this section (PVC and G-PVC) (Fig. 5). However, Starzynska et al. (2003) did find that storage of broccoli inflorescences induced accumulation of flavonoids at 5 °C and 20 °C.

4. Conclusions

Brussels sprouts packaged in PVC film and samples coated with a starch-based formulation with added glycerol and also packaged in PVC film were the two treatments leading to best quality attributes, based on parameters such as commercial acceptability, weight losses, firmness and surface colour, determined at the end of a storage period of 42 days at 0 °C. Samples preserved by these treatments were able to maintain the contents of ascorbic acid and total flavonoids, while increasing the radical-scavenging activity. The results of these parameters would suggest no reduction in nutritional quality.

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