

# Alginate coatings for preservation of minimally processed ‘Gala’ apples

G.I. Olivas<sup>a</sup>, D.S. Mattinson<sup>b</sup>, G.V. Barbosa-Cánovas<sup>c,\*</sup>

<sup>a</sup> Centro de Investigación en Alimentación y Desarrollo, A.C., Av. Río Conchos S/N 31570, Cuauhtémoc, Chih., Mexico

<sup>b</sup> Washington State University, Horticulture and Landscape Arch., Johnson 50a, Pullman, WA 99164-6414, United States

<sup>c</sup> Washington State University, Biological Systems Engineering Department, LJ Smith 220, P.O. Box 646120, Pullman, WA 99164-6120, United States

Received 10 October 2005; accepted 27 November 2006

## Abstract

Edible coatings made from alginate were investigated for their capacity to preserve the quality of minimally processed ‘Gala’ apples. Apple wedges were immersed in a calcium chloride solution and subsequently coated with one of three different coating formulations: alginate, alginate-acetylated monoglyceride-linoleic acid, and alginate-butter-linoleic acid. Apple wedges were stored at 5 °C in 85% RH. Weight loss, color, texture, volatiles profile, microbial load, titratable acidity, and soluble solids were assessed over storage. Overall, it was found that alginate coatings prolonged the shelf-life of cut ‘Gala’ apples without causing anaerobic respiration. All coatings used minimized the weight loss during storage, and apples with coatings containing acetylated monoglyceride in particular remained the closest to original weight. Firmness of coated apples remained practically constant regardless of the type of coating, while control apples had a large decrease in firmness during storage. Browning of ‘Gala’ apple slices was retarded in all coated apples. A higher production of hexanol and trans-2-hexenal was observed in coated apples containing butter and acetylated monoglyceride.

© 2007 Elsevier B.V. All rights reserved.

**Keywords:** Edible coatings; Minimally processed fruit; Alginate; Apple; Quality; Gala; Fresh-cut

## 1. Introduction

Marketing of fresh-cut, packaged, and ready-to-eat products has increased rapidly due to increased consumer demand for fresh, convenient foods. People prefer healthy foods but have little time for food preparation. This trend also indicates a preference for “non-messy” fruit that is easy to prepare, convenient to eat at work and while traveling, and easy to share with family and friends (Harker et al., 2003). The development of fresh-cut, ready-to-eat fruit is difficult since cut fruit deteriorates faster than whole fruit (Watada and Qi, 1999). Minimally processed apples have a shorter shelf-life than their whole counterparts because of increased susceptibility to microbial spoilage, increased respiration rate, and ethylene production, which is stimulated by wounding of the tissue. Cell rupture from slicing of fruit is responsible for releasing intracellular products, such as enzymes, which can have a negative impact on the quality of cut apples, affecting the color, flavor, and tex-

ture (Ahvenainen, 1996). Color is a critical quality parameter of cut apples that can limit the shelf-life considerably (Rocha and Morais, 2003). Apples may also undergo faster weight loss when cut since surface area is increased and the fruit is no longer protected from the environment by the peel, which functions as a very efficient barrier to water loss.

Coatings of edible material applied as a thin layer to enhance the quality and extend the shelf-life of cut apple fruit can work as a barrier reducing both respiration and water loss (Kester and Fennema, 1986; Krochta, 1991, 1992; Guilbert and Biquet, 1996). Edible coatings are applied on cut apples to produce a modified atmosphere, which reduces decay, delays ripening and color changes, improves appearance, and functions as a carrier of anti-microbials, anti-browning agents, texture enhancers, nutraceuticals, flavors, and volatile precursors (Olivas and Barbosa-Cánovas, 2005). The success of an edible coating on apples depends on selecting coatings capable of maintaining a desirable internal gas composition appropriate for a specific product (Park, 1999). Alginate films are potentially a good option for cut apples, since these films become stronger when cross-linked with Ca, and at the same time, adhere to the cut apple surface through this cross-linking (alginate-Ca-pectin). Alginate is a salt of alginic acid, a polymer of D-mannuronic acid

\* Corresponding author. Tel.: +1 509 335 6188; fax: +1 509 335 2722.

E-mail addresses: [golivas@cascabel.ciad.mx](mailto:golivas@cascabel.ciad.mx) (G.I. Olivas), [barbosa@mail.wsu.edu](mailto:barbosa@mail.wsu.edu) (G.V. Barbosa-Cánovas).

(M) and L-guluronic acid (G), which is isolated from brown seaweed (Sime, 1990). Alginate films are poor moisture-barriers, as they are hydrophilic films, however, the incorporation of calcium reduces their water vapor permeability, making alginate films water insoluble. The capacity of hydrocolloid-based films as water vapor barriers increases as their solubility in water decreases (Kester and Fennema, 1986; Greener and Fennema, 1989).

Several types of edible coatings have been used for preserving apples. Lee et al. (2003) reported that apple slices coated with carrageenan, ascorbic acid, citric acid, and oxalic acid extended shelf-life by 2 weeks when packaged in trays at 3 °C. Sonti et al. (2003) coated apple cubes with whey protein concentrate and whey protein isolate, obtaining a delay in browning and texture decay. Whey protein concentrate coatings proved to be more effective in reducing weight loss than isolate coatings. Pérez-Gago et al. (2003) inhibited browning of apple slices by using a coating containing whey protein isolate and beeswax, but the coating did not prevent moisture loss from cut apples. Brancoli and Barbosa-Cánovas (2000) decreased ethylene production and surface discoloration of apple slices by coating slices with maltodextrin, methylcellulose ascorbic acid, and calcium chloride. Le Tien et al. (2001) delayed browning of apple slices by coating slices with calcium caseinate, carboxymethyl cellulose, and whey protein concentrate. Consistent with these previous studies, the objective of this research was to explore the potential use of alginate edible coatings on preserving the quality of sliced ‘Gala’ apples.

## 2. Materials and methods

‘Gala’ apples (*Malus domestica* Borkh.) were grown at the Washington State University Orchard and hand-picked on October 7th, 2004. The apples were stored at 4 °C in 85% RH for 5–9 days until used. Apples were washed and sanitized with chlorinated water (150 mg/L) and each apple was cut into eight wedges with a stainless-steel slicer. Two wedges were randomly selected and treated with each of four treatments so that the variation among apples could be blocked out. Fresh-cut apple wedges were immediately subjected to one of the following treatments: immersion in aqueous solution of 10% calcium chloride followed by application of alginate based coating (Alg-Ca); immersion in aqueous solution of 10% calcium chloride followed by application of alginate-acetylated monoglyceride-linoleic acid based coating (Alg-Ca-AMG); immersion in aqueous solution of 10% calcium chloride followed by application of alginate-butter-linoleic acid based coating (Alg-Ca-MF); control (no treatment).

Apple slices were then stored at 5 °C and 85% RH for subsequent analysis. The whole process was repeated independently on 3 separate days as replications.

### 2.1. Materials

The materials used for film formulation included alginate containing ~31% mannuronate salt and ~69% guluronate salt (Manugel<sup>TM</sup> supplied by ISP Alginates, San Diego, CA), fruc-

tose used as plasticizer (Aldrich Chemical Company Inc., Milwaukee, WI), and lipids: butter (~82% milk fat, ~16% water, ~1 milk solids), acetylated monoglyceride Myvacet 5-07K<sup>TM</sup> (Quest International, Hoffman Estates, IL), and linoleic acid. Glycerol alpha-monostearate (TCI America, Portland, OR) was used to increase the stability of the emulsions, calcium chloride to cross-link the alginate molecules (Aldrich Chemical Company Inc., Milwaukee, WI), and potassium sorbate to prevent microbial spoilage of the treated apple slices (Sigma Chemical Co., St. Louis, MO). Alginate with a high guluronate/mannuronate ratio was chosen based on its superior barrier properties (Olivas and Barbosa-Cánovas, 2004a). Fructose was chosen as a plasticizer since it was also found to produce films with lower water vapor permeability, compared to films containing glycerol, sorbitol, and polyethylene glycol (Olivas and Barbosa-Cánovas, 2004b). Previous studies (unpublished observations) showed that the water vapor permeability of alginate films containing acetylated monoglyceride (AMG) was lower than that of alginate films containing candelilla or beeswax. Also, studies on weight loss of apple slices coated with alginate films containing different lipids (AMG, beeswax, candelilla, butter, and linoleic acid) showed that films formulated with AMG work best as water vapor barriers. Hence, AMG was chosen for one of the treatments. Olivas et al. (2003) reported production of characteristic aroma volatiles in coated pear wedges, presumably due to  $\beta$ -oxidation of stearic acid contained in coating formulation. Therefore, linoleic acid was added to two coating formulations in this study to determine whether the apple slices could metabolize this lipid and produce characteristic aroma volatiles. Butter was added to one other studied film formulation with the same purpose, based on the variety of fatty acids found in butter.

### 2.2. Coating solution preparation

The Alg-Ca solution was prepared by mixing alginate and fructose in water in a proportion 1:0.4:71.5, respectively. Potassium sorbate was added (0.25 g per 100 g of water) to obtain a final concentration in the coated apple of around 0.05% (after evaporation of water). The solution was stirred until alginate was dissolved (20 min) and stored overnight under refrigeration. Afterwards, the solution was subjected to vacuum for 40 min to eliminate trapped air. For preparation of the Alg-Ca-AMG solution, an aqueous solution containing alginate, fructose, water, and potassium sorbate (same concentration as in Alg-Ca solution) was made. The solution was heated to 70 °C, and then AMG, glycerol alpha-monostearate, and linoleic acid were added. AMG comprised 35% of total alginate amount and glycerol alpha-monostearate and linoleic acid were 10 and 25% of total lipid amount, respectively. The solution was stirred for 2 min and then homogenized for 3 min at 25,000 rpm in a Benchtop Homogenizer PT 10/35 (Brinkmann Instruments, Westbury, NY). The solution was stored overnight under refrigeration and subjected to vacuum for 40 min to eliminate trapped air. The Alg-Ca-MF solution was prepared similarly to the Alg-Ca-AMG solution, but instead of acetylated monoglyceride, butter was added.

### 2.3. Coating application

Apple slices were first immersed in an aqueous solution of 10% CaCl<sub>2</sub> for 3 s, then immediately immersed in corresponding solutions (Alg-Ca, Alg-Ca-AMG, and Alg-Ca-MF) for 3 s. Apples were immersed in CaCl<sub>2</sub> prior to immersion in the coating solution, cross-linking the alginate with calcium in order to form a stronger insoluble film, and cross-linking the alginate with naturally occurring pectin on the fruit surface to obtain better adhesion to the fruit. The apple slices were dipped, then drained for 5 min and dried for 20 min in a food dehydrator at 38 °C (Excalibur 3924T, Sacramento, CA). Apple slices used as controls were not treated or subjected to drying. Apple slices were put on open plastic trays and stored in controlled temperature chambers at 5 °C and 85% (±2) RH for 9 days for subsequent analysis.

### 2.4. Water loss

To determine the effectiveness of alginate coatings as moisture-barriers, the weight of eight apple slices in each treatment was monitored during storage. It was assumed that weight loss corresponded entirely with water loss. The weight loss percent relative to initial weight was calculated by weighing the samples every 2 days in triplicate.

### 2.5. Texture

Change in the texture of apple slices was measured by compressing apple cylinders with a Universal Texture Analyzer TA.XT2 (Stable MicroSystems) at days 0, 2, 4, 6, and 8. The maximum force (Newtons) required to compress the sample by 30% was recorded as firmness of the apple cylinder. A 5 cm diameter flat plate with a 25 kg Newton load cell was used, and pre-test speed, test speed, and post-test speed were all set at 1 mm/s. Three cylinders measuring 10 mm diameter each were obtained from each slice by using a powered rotating cork borer (cylinder orientation perpendicular to core of apple). Three apple wedges per treatment were used, obtaining nine cylinders per repetition. The height of the specimen was adjusted at 15 mm using a parallel-blade trimming saw. Triplicates of each treatment were evaluated.

### 2.6. Microbial analysis

Quantification of aerobic mesophilic microorganisms, psychrotrophic microorganism, molds, and yeasts was conducted at days 0, 4, and 8. Two apple slices per treatment were removed from storage room and 25 g placed in a filter stomacher bag containing 225 mL of sterilized peptone water (0.1%). This was then blended for 90 s using a stomacher. Serial decimal dilutions of the filtrate in 0.1% peptone were pour-plated in duplicate on standard methods agar (SMA) (Becton Dickinson & Co., Sparks, MD) and incubated at 37 °C for 2 days, to count aerobic mesophilic microorganisms, and at 7 °C for 10 days, to count the aerobic psychrotrophs. The same decimal dilutions were spread-plated on dichloran-rose bengal-chloramphenicol (DRBC) agar

(Becton Dickinson & Co., Sparks, MD) and incubated for 5 days at 21 °C to count molds and yeasts.

### 2.7. Color

The effect of alginate coatings on browning of apple slices was determined by measuring their surface color with a Minolta CM-2002 colorimeter (Minolta Camera, Co., Osaka, Japan) every 2 days for 8 days. Coatings were not removed from apples prior to testing. Readings were obtained in CIELAB scale ( $L^*$ ,  $a^*$ ,  $b^*$ ). Three wedges per treatment were taken and 6 color measurements made at 3 locations for each sample, totalling 18 measurements per treatment per replicated. Triplicates of each treatment were measured. The browning index (BI) was calculated and used as an indicator of intensity of brown color (Buera et al., 1985). The browning index was calculated as follows:

$$BI = \frac{100(x - 0.31)}{0.172}$$

where

$$x = \frac{a^* + 1.75L^*}{5.645L^* + a^* - 3.012b^*}$$

### 2.8. Titratable acidity and soluble solids content

Malic acid and soluble solids content were quantified every 3 days for 9 days in triplicate. Acid content in apple slices was determined by titration. Five slices were pureed with a commercial hand blender and apple juice obtained by pressing the puree through cheesecloth. Acids in the apple juice were titrated with 0.1N NaOH and expressed as mg of malic acid per 100 mL of apple juice. Soluble solids in the juice were determined with a refractometer ABBE 3 L (Milton Roy Company) using a sucrose scale calibrated at 20 °C. The amount of juice obtained decreased during storage as water loss in the apple slices increased. These higher concentrated juices were conducive to higher values of malic acid and soluble solids. Therefore, the amount of malic acid and soluble solids obtained was compensated for weight loss as follows:

$$V = \frac{X*(100 - \%WL_t)}{100}$$

where  $X$  is the value for soluble solids or malic acid obtained from apple juice before weight loss compensation,  $\%WL_t$  the percentage of weight loss at time  $t$ , and  $V$  is the corresponding true value for soluble solids or malic acid content after weight loss compensation.

### 2.9. Volatiles

Concentration of volatiles in apple slices was determined by gas chromatography–mass spectrometry using the solid phase microextraction (SPME) technique. The juice was obtained and compensated for weight loss as described above. Apple juice (2 mL) was placed in a 4.0 mL sample vial containing 0.65 g NaCl and stirred on a stirring plate. NaCl was used to enhance the activity coefficients of volatile components in the juice,

increasing their concentration in the headspace. A SPME device (Supelco, Co., Bellefonte, PA) with a fused silica, which was fiber coated with 65  $\mu\text{m}$  polydimethylsiloxane/divinylbenzene, was exposed to the headspace of the sample for approximately 1 h before GC injection. SPME injection was achieved through splitless injection for 2 min at 200 °C into a Hewlett-Packard 5890II/5970 GC/MSD equipped with a DB-1 60-m column. Chromatographic conditions were as described by Mattheis et al. (1991), however the transfer line temperature and ion source was held at 250 °C. This analysis was carried out at days 0, 3, 6, and 9 of storage. Samples at day 0 were taken 3 h after treatments were applied. As standard, a mixture of volatile compounds identified in 'Gala' apple was prepared by adding the same amount of pure standards GC grade. Known amounts of this mix were added to apple juice for standard mixture extraction and analysis.

### 2.10. Statistical analysis

The experiment was conducted as a split plot model. All determinations were conducted in triplicate. Treatments were considered as the whole plot factor and time as the sub-plot factor. Data analysis of variance using PROC GLM of the Statistical Analysis System (SAS Institute Inc., Cary, NC) was conducted. Specific differences were determined by preplanned orthogonal contrasts. All comparisons were made at a 5% level of significance.

## 3. Results and discussion

The alginate coating formulations formed strongly attached, continuous films on the surface of apple slices. Alg-Ca coatings were translucent and gave the fruit surface a bright appearance. Alg-Ca + AMG and Alg-Ca + MF were slightly white but also conferred a shiny appearance to the apple slice surface. All coatings demonstrated delay in loss of quality of apple slices defined as reduced weight loss, delayed firmness loss, and retarded onset of browning. Results of microbial analyses showed no differences among treatments during storage ( $p < 0.05$ ). The counts of mesophilic and psychrotrophic bacteria, as well as mold and yeast counts, remained at low levels from the beginning to the end of the study. Counts of mesophilic microorganisms were kept below  $1 \times 10^2$  CFU/g, while counts of psychrotrophic bacteria, and molds and yeasts, remained below  $1 \times 10^1$  CFU/g throughout the entire storage period. Such low microbial counts are consistent with the stringent hygienic practices employed in the study. However, in order to determine the ability of edible coatings to carry anti-microbials, thus decreasing the risk of food-borne illnesses with minimally processed fruit, an inoculation of the fruit and/or coating solution would be necessary.

### 3.1. Water loss

Slicing of apples exposes the skinless tissue to an environment with lower relative humidity, and causes substantial weight loss. A large increase in water loss occurred with uncoated control apples after slicing, as shown in Fig. 1. After 2 days of storage, control apples lost around 20% of their weight, while

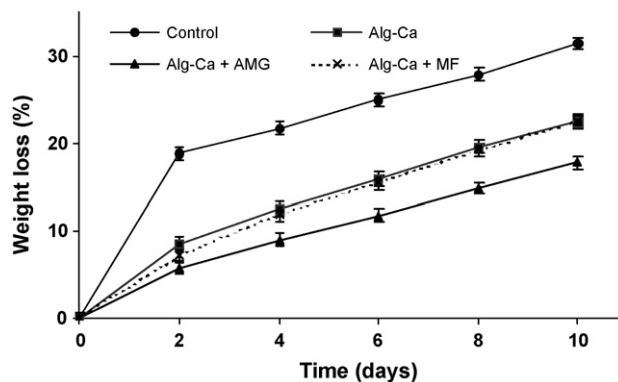


Fig. 1. Weight loss from apple slices stored 10 days at 5 °C and 85% RH. Alg-Ca: apple slices dipped in an alginate coating solution after immersion in a calcium chloride solution. Alg-Ca + AMG: apple slices dipped in an alginate and acetylated monoglyceride solution after immersion in a solution containing calcium chloride. Alg-Ca + MF: apple slices dipped in an alginate and a butter coating solution after immersion in a calcium chloride solution. Error bars show the standard error.

coated apples lost ~7% of their weight ( $p < 0.05$ ). Alginate coatings on apple slices proved to work effectively as water vapor barriers during the entire storage period (Fig. 1). The three alginate coatings, Alg-Ca, Alg-Ca-AMG, and Alg-Ca-MF, prevented water loss by producing high relative humidity at the surface of sliced apples, thus reducing the gradient to the exterior. The best coating to prevent water loss was Alg-Ca-AMG ( $p < 0.05$ ), which allowed a 17.8% loss compared to 31.4% for control apples at day 10 ( $p < 0.05$ ). No performance differences were found between the Alg-Ca and Alg-Ca-MF coatings, which allowed about 28% less weight loss than the control apple slices ( $p < 0.05$ ) at day 10. Wong et al. (1994) found that coatings containing emulsions of mixed components seem to perform best as vapor barriers. Alg-Ca coatings, which contain no lipids in their formulations, also retarded weight loss, although it is well known that hydrocolloids do not perform very well as water vapor barriers in high water activity foods due to their high hygroscopic nature. However, in this case, Alg-Ca coatings performed relatively well in limiting water loss. This is probably due to the ability of calcium to cross-link alginate, making the coating insoluble, bearing in mind that the capacity of hydrocolloid-based films to function as water vapor barriers increases as their solubility in water decreases (Kester and Fennema, 1986; Greener and Fennema, 1989). AMG has been used in casein-alginate and casein coatings by Pavlath et al. (1993) and Krochta (1990), who reported a reduction in moisture loss for coated apple slices. Krochta (1990) reported 50–70% reduction in moisture loss. AMG is an acetylated monoglyceride derived from fully hydrogenated cottonseed oil (primarily glycerides of fatty acids: linoleic, oleic, and palmitic). Butter, on the other hand, is composed principally of triglycerides (~68% unsaturated). As Fig. 1 shows, Alg-Ca + AMG performed better as water vapor barriers than Alg-Ca + MF coatings. According to Kamper and Fennema (1984), lipids containing saturated long-chain fatty acids (e.g. AMG) form coatings with better water vapor barrier properties than unsaturated short-chain fatty acids (e.g. butter). The former produces a more densely packed struc-

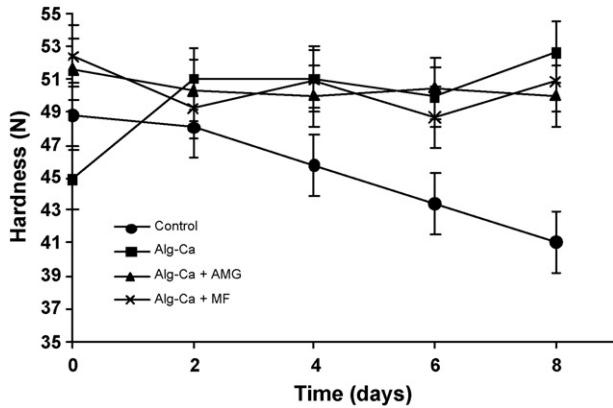


Fig. 2. Firmness from apple slices stored 10 days at 5 °C and 85% RH. Alg-Ca: apple slices dipped in an alginate coating solution after immersion in a calcium chloride solution. Alg-Ca + AMG: apple slices dipped in an alginate and acetylated monoglyceride solution after immersion in a solution containing calcium chloride. Alg-Ca + MF: apple slices dipped in an alginate and a butter coating solution after immersion in a calcium chloride solution. Error bars show the standard error.

ture and has less mobility than unsaturated short-chain fatty acids.

### 3.2. Texture

Texture is a major factor defining the quality of fruit and strongly influences acceptability by consumers (Harker et al., 1997). Texture of fruit is determined by cell wall composition, cell turgor, cellular anatomy, and water content (Mohsenin, 1986). It has been found that the rate of softening in apples depends on the calcium status of the flesh (Poovaiah et al., 1988). It also depends on water loss (Glenn and Poovaiah, 1985). Alginate coatings preserved the texture of apple slices (Fig. 2). Analysis of firmness of apple slices at time 0 was conducted 2 h after treatment and no significant difference was observed ( $p < 0.05$ ). Firmness of coated apple slices remained practically constant, with no significant difference among coated apples observed ( $p < 0.05$ ), whereas that of control apples decreased considerably throughout storage ( $p < 0.05$ ). The reasons for alginate coatings preserving the texture of apple slices could be explained by their capacity to work as barriers to water vapor, preventing loss of turgor in apples, and due to calcium contained in their formulation. The effect of calcium in keeping the texture of apple slices is probably higher than the effect of alginate coatings in avoiding water loss, since according to Diehl and Hamann (1979), softening of apples is attributed more to cell wall degradation than to a reduction in turgor pressure. Cell wall degradation occurs with the solubilization and depolymerization of pectic substances. Calcium can delay degradation of cell wall polymers (Sams and Conway, 1984) by cross-linking the pectins, important components of the cell wall and middle lamella, to form insoluble salts that form ionic linkages between pectin molecules (Lamikanra, 2002). Calcium infiltration dramatically retards the loss of texture. Previous studies by Poovaiah et al. (1988) have shown that apple cylinders containing calcium subjected to tensile stress tend

to fracture through cells, while control ones separate between cells.

Another factor that could enhance the preservation of texture in coated apple slices is heat (38 °C for 20 min to dry coating), which has been demonstrated as beneficial to the preservation of apple texture (Kim et al., 1993). The increase in firmness with heat treatment is associated with a decrease in pectin solubility and esterification (Lidster et al., 1979). To determine if heat treatment applied in this study had any relevant effect on the apple slices, an untreated apple slice was heated in the same way as for coated slices (38 °C for 20 min), and firmness of apple slices before and after heat treatment recorded. An increase of 7% in the firmness of heated apples compared to those not heated was observed, demonstrating that thermal treatment indeed played a significant role in enhancing the texture of coated apples.

### 3.3. Color

When apples are cut, the tissue cells are broken and enzymes, such as polyphenol oxidases (PPOs) are liberated and brought into contact with their substrates, causing browning (Garcia and Barret, 2002). Browning development in apple slices was delayed after applying alginate coatings ( $p < 0.05$ ). This preservative effect may be explained by the presence of calcium chloride, which has been identified as an anti-browning agent in some circumstances, and by the ability of coatings to work as barriers to oxygen, necessary for browning reactions to occur. Calcium chloride, which is present in the coated apples, is an anti-browning agent known to inhibit PPO by interaction of the chloride ion with copper at the PPO active site (Garcia and Barret, 2002). Fig. 3 illustrates how coated apples undergo less browning during storage compared to control apples. During the first 6 days of storage, no significant difference was found among the studied coatings ( $p < 0.05$ ). However, after day 8, Alg-Ca and Alg-Ca + MF treatments resulted in 20% less browning than the control apples. Although Alg-Ca + AMG coated apples experienced more browning than Alg-Ca and Alg-Ca + MF coated

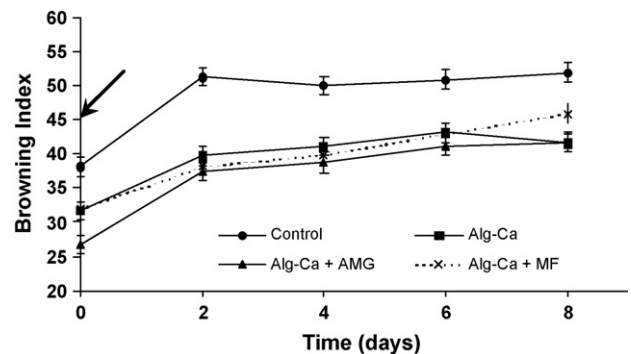


Fig. 3. Browning index from apple slices stored 10 days at 5 °C and 85% RH. Alg-Ca: apple slices dipped in an alginate coating solution after immersion in a calcium chloride solution. Alg-Ca + AMG: apple slices dipped in an alginate and acetylated monoglyceride solution after immersion in a solution containing calcium chloride. Alg-Ca + MF: apple slices dipped in an alginate and a butter coating solution after immersion in a calcium chloride solution. Error bars show the standard error. Arrow shows the value of browning index for apple slices with no coating heated 20 min at 38 °C.

apples, their browning index was still significantly lower than that of control apples after day 8 of storage ( $p < 0.05$ ).

As mentioned in the methodology section, control apples were not subjected to any thermal treatment, however treated apples were. To determine the effect of treating apple slices at 38 °C for 20 min on the development of browning, uncoated apple slices were subjected to the described drying process. A browning index of 45 was obtained for uncoated apples (18% higher than control apples at time 0), showing that treatment at 38 °C for 20 min produced apple slices with a higher browning index than those without heat treatment. According to Sataque and Wosiacki (1987), the optimum temperature for PPO is 30–40 °C. Nevertheless, although coated apple slices underwent a drying treatment at 38 °C for 20 min, the browning index was significantly lower than for control apple slices without heat treatment. Such an observation demonstrates the high capacity of these coatings to inhibit browning of cut apples. It has been previously found that coating apple slices with films, based on carrageenan and whey protein, carrying anti-browning agents and calcium chloride, successfully preserves the color and texture of apple slices (Lee et al., 2003). Whey protein isolate and concentrate, calcium caseinate, and carboxymethyl cellulose based films have also proven useful in delaying browning of apple slices (Nisperos-Carriedo and Baldwin, 1994; Le Tien et al., 2001; Sonti et al., 2003; Pérez-Gago et al., 2003). It is important to add that some of the described coatings included anti-browning agents, such as ascorbic acid and calcium chloride as color preservers.

### 3.4. Titratable acidity and soluble solids content

According to Sadler and Murphy (1998), acids in fruit tend to decrease with fruit maturity as sugar contents increase. Also, a decrease in titratable acidity occurs in apples heated at 38 °C (Lidster et al., 1979). Table 1 shows the titratable acidity (malic acid content) and soluble solids contents of apple slices during storage. Malic acid concentration decreased in all treatments during storage ( $p < 0.05$ ). No significant difference was found between control and treated apples ( $p < 0.05$ ). No significant difference in the concentration of soluble solids among all studied treatments and the control was found ( $p < 0.05$ ; Table 1). According to Lidster et al. (1979) and Porritt and Lidster (1978), there is a decrease in titratable acidity on apples heated at 38 °C for 4–6 days. Bett et al. (2001) on the other hand stored cut ‘Gala’ apples at 1 °C for 14 days and did not find changes in soluble solids. Boylston et al. (1994) found that the length of storage or condi-

tions of storage did not affect the soluble solids concentrations and titratable acidity of ‘Gala’ apples.

### 3.5. Volatiles

Extremely impermeable coatings may alter the respiration rate of apple slices, creating an atmospheric condition of low O<sub>2</sub> and high CO<sub>2</sub>, which may be conducive to anaerobic respiration resulting in ethanol production and, subsequently, the formation of off-flavors and cellular death (Kays, 1991); however, during this work, no ethanol production was observed in any of the treatments. Low O<sub>2</sub> and high CO<sub>2</sub> contents in apple also can affect the flavor and aroma of fruit by significantly reducing the synthesis of characteristic fruit aroma compounds, such as acetate esters (Mattheis et al., 1991; Fellman et al., 1993; Ke et al., 1994). Addition of volatile precursors into coating formulations can help sustain the volatile production rate of coated fruit during storage, since fruit can take up these precursors and use them to produce aroma compounds. The major volatiles found in ‘Gala’ apples are butanol, butyl acetate, 2-methylbutyl acetate, hexyl acetate, 2-methylbutanol, and hexanal, of which the major contributors to sensory attributes are 2-methylbutyl acetate, butanol, and hexyl acetate (Young et al., 1996; Fan et al., 2001). In this study, changes in the content of ethanol, 1-butanol, butyl acetate, 2-methyl butyl acetate, hexanal, trans-2-hexenal, 1-hexanol, and hexyl acetate were monitored during storage of apple slices (Table 2).

At the beginning of the experiment, around 25 different volatile compounds were found in the apple slices. At the end, the number of volatiles in the control apples remained almost the same (28), while the number of volatiles in the coated apples increased to 38 for Alg-Ca-AMG and Alg-Ca-MF, and 43 for Alg-Ca (data not shown). This higher number of volatile compounds most likely indicates that the coatings affected the metabolism in volatile production and/or acted as good barriers, reducing loss of volatiles.

The concentration of butyl acetate and 2-methyl-1-butyl acetate decreased during the first 6 days in all samples. After day 6, however, an increase of both acetates was observed in all treatments. No significant statistical difference was found ( $p < 0.05$ ) among all treatments. In the same way, no significant difference was found in the concentration of 2-methyl-1-butyl acetate among treatments at the end of the study. Fellman et al. (1993) found lower amounts of butyl acetate and higher amounts of 2-methyl-1-butyl acetate on refrigerated apples stored under low O<sub>2</sub> and high CO<sub>2</sub>, compared to apples stored under refriger-

Table 1  
Acidity and soluble solids of apple slices stored at 5 °C at 85% RH

Treatment	Acidity (mg of malic acid/100 mL of apple juice)				Soluble solids (°Brix)			
	Day 0	Day 3	Day 6	Day 9	Day 0	Day 3	Day 6	Day 9
Control	336.4	312.6	277.7	265.7	14.6	12.9	11.6	14.1
Alg-Ca	335.8	332.9	311.1	291.3	14.6	13.2	12.0	12.8
Alg-Ca-AMG	335.5	320.0	308.4	308.9	13.9	13.2	13.1	13.7
Alg-Ca-MF	333.1	317.5	307.9	293.1	13.5	13.7	12.9	12.9

No statistical difference was found between treatments.

Table 2  
Changes in volatiles from apple slices during storage at 5 °C and 85% RH

	Volatile concentrations (µg/mL)			
	Day			
	0	3	6	9
<b>1-Butanol</b>				
Control	0.616 <sup>a</sup>	0.228 <sup>a</sup>	0.180 <sup>a</sup>	0.338 <sup>a</sup>
Alg-Ca	0.634 <sup>a</sup>	0.451 <sup>b</sup>	0.405 <sup>b</sup>	1.510 <sup>b</sup>
Alg-Ca + AMG	0.562 <sup>a</sup>	0.486 <sup>b</sup>	0.465 <sup>b</sup>	2.114 <sup>c</sup>
Alg-Ca + MF	0.534 <sup>a</sup>	0.456 <sup>b</sup>	0.381 <sup>b</sup>	2.491 <sup>c</sup>
<b>Butyl acetate</b>				
Control	0.392 <sup>a</sup>	0.179 <sup>a</sup>	0.154 <sup>a</sup>	0.330 <sup>a</sup>
Alg-Ca	0.479 <sup>a</sup>	0.163 <sup>a</sup>	0.145 <sup>a</sup>	0.566 <sup>a</sup>
Alg-Ca + AMG	0.375 <sup>a</sup>	0.170 <sup>a</sup>	0.130 <sup>a</sup>	0.642 <sup>a</sup>
Alg-Ca + MF	0.405 <sup>a</sup>	0.158 <sup>a</sup>	0.121 <sup>a</sup>	0.573 <sup>a</sup>
<b>2-Methyl butyl acetate</b>				
Control	0.133 <sup>a</sup>	0.053 <sup>a</sup>	0.036 <sup>a</sup>	0.063 <sup>a</sup>
Alg-Ca	0.125 <sup>a</sup>	0.025 <sup>b</sup>	0.018 <sup>b</sup>	0.075 <sup>a</sup>
Alg-Ca + AMG	0.111 <sup>a</sup>	0.026 <sup>b</sup>	0.015 <sup>b</sup>	0.058 <sup>a</sup>
Alg-Ca + MF	0.109 <sup>a</sup>	0.022 <sup>b</sup>	0.012 <sup>b</sup>	0.052 <sup>a</sup>
<b>Hexanal</b>				
Control	0.658 <sup>a</sup>	0.642 <sup>ab</sup>	0.675 <sup>a</sup>	0.720 <sup>a</sup>
Alg-Ca	0.578 <sup>a</sup>	0.462 <sup>b</sup>	0.636 <sup>a</sup>	0.814 <sup>a</sup>
Alg-Ca + AMG	0.802 <sup>a</sup>	0.893 <sup>a</sup>	0.910 <sup>a</sup>	1.164 <sup>b</sup>
Alg-Ca + MF	0.549 <sup>a</sup>	0.643 <sup>ab</sup>	0.812 <sup>a</sup>	0.876 <sup>b</sup>
<b>Trans-2-hexenal</b>				
Control	0.222 <sup>a</sup>	0.279 <sup>a</sup>	0.262 <sup>a</sup>	0.566 <sup>a</sup>
Alg-Ca	0.183 <sup>ab</sup>	0.146 <sup>b</sup>	0.117 <sup>b</sup>	0.614 <sup>a</sup>
Alg-Ca + AMG	0.210 <sup>ab</sup>	0.187 <sup>b</sup>	0.165 <sup>b</sup>	0.892 <sup>b</sup>
Alg-Ca + MF	0.174 <sup>b</sup>	0.165 <sup>b</sup>	0.165 <sup>b</sup>	0.999 <sup>b</sup>
<b>1-Hexanol</b>				
Control	0.086 <sup>a</sup>	0.033 <sup>a</sup>	0.036 <sup>a</sup>	0.083 <sup>a</sup>
Alg-Ca	0.094 <sup>a</sup>	0.046 <sup>a</sup>	0.037 <sup>b</sup>	0.147 <sup>ab</sup>
Alg-Ca + AMG	0.073 <sup>a</sup>	0.047 <sup>a</sup>	0.040 <sup>b</sup>	0.180 <sup>b</sup>
Alg-Ca + MF	0.089 <sup>a</sup>	0.047 <sup>a</sup>	0.031 <sup>b</sup>	0.184 <sup>b</sup>
<b>Hexyl acetate</b>				
Control	0.029 <sup>a</sup>	0.007 <sup>a</sup>	0.012 <sup>a</sup>	0.027 <sup>a</sup>
Alg-Ca	0.033 <sup>a</sup>	0.004 <sup>a</sup>	0.003 <sup>b</sup>	0.012 <sup>b</sup>
Alg-Ca + AMG	0.019 <sup>a</sup>	0.005 <sup>a</sup>	0.003 <sup>b</sup>	0.011 <sup>b</sup>
Alg-Ca + MF	0.027 <sup>a</sup>	0.004 <sup>a</sup>	0.002 <sup>b</sup>	0.007 <sup>b</sup>

Alg-Ca: apple slices dipped in an alginate coating solution after immersion in a calcium chloride solution. Alg-Ca + AMG: apple slices dipped in an alginate and acetylated monoglyceride solution after immersion in a solution containing calcium chloride. Alg-Ca + MF: apple slices dipped in an alginate and butter coating solution after immersion in a calcium chloride solution. Values in the same column for each volatile with the same letter are not different at the 5% level.

ated air. Golias (1984) found a decrease in production of hexanal and 1-butanol on apples under anaerobic conditions, attributed to retardation of biochemical oxidative processes. In this work, an increase in production of hexanal and 1-butanol was found on coated apples, compared to control apples ( $p < 0.05$ ). Apple slices coated with Alg-Ca + AMG and Alg-Ca + MF had higher hexanal and 1-butanol values compared with control apples. However, no significant difference between Alg-Ca + AMG and Alg-Ca + MF coatings was found ( $p < 0.05$ ). Such findings may indicate that the modified atmosphere produced inside the coated apples by coatings was not too extreme, and/or that coated apples produced hexanal and 1-butanol using the linoleic acid from the

Alg-Ca + AMG and Alg-Ca + MF coatings as substrate. The high amount of hexanal and 1-butanol in Alg-Ca (no linoleic acid) coating could indicate that apple slices were able to metabolize sorbic acid (2,4-hexadienoic acid) for production of these volatiles. According to Paillard (1979), butanol and hexanal, as well as hexanal and trans-2-hexenal, are produced in apple tissue through lipid oxidation of polyunsaturated fatty acids, and that fatty acids can be supplied externally. Presence of hexanal as well as trans-2-hexenal in apples is associated with a “green note” in the apple flavor, giving the impression of unripeness (Paillard, 1985). In this work, an increase in production of trans-2-hexenal and hexanal was observed after day 6; it was significantly higher on those apples coated with Alg-Ca + AMG and Alg-Ca + MF. Concentration of hexyl acetate decreased during the first days of storage and increased after day 6. Control apples had a higher concentration of hexyl acetate compared to coated ones ( $p < 0.05$ ) and no significant difference was found among coated apples. It has also been demonstrated that pear wedges coated with films composed of methylcellulose and stearic acid show higher production of hexyl acetate and butyl acetate during refrigerated storage than uncoated controls (Olivas et al., 2003).

#### 4. Conclusions

Alginate coatings can preserve the quality of apple slices without causing any anaerobic respiration in the fruit. These coatings form a good film on the surface of the apple slice, giving the fruit a bright, translucent, fresh-like appearance. Alginate coatings work as barriers to water vapor by decreasing the water loss of apple slices. They also prevent a loss in texture and decrease the browning deterioration of apple slices. An increase in the amount and number of volatiles found in coated apples was observed during storage. The higher concentration of flavor characteristic volatiles on coated apples may be attributed to the metabolization of fatty acids contained in the coatings. The use of alginate coatings for the preservation of minimally processed fruit is a promising technology that can improve the quality of fresh products and increase their shelf life and stability. Further research needs to be conducted in order to determine whether volatiles produced in coated apples may impart undesirable flavors.

#### References

- Ahvenainen, R., 1996. New approaches in improving the shelf life of minimally processed fruit and vegetables. *Trends Food Sci. Technol.* 7, 179–187.
- Bett, K.L., Ingram, D.A., Grimm, C.C., Lloyd, S.W., Spanier, A.M., Miller, J.M., Gross, K.C., Baldwin, E.A., Vinyard, B.T., 2001. Flavor of fresh-cut Gala apples in barrier film packaging as affected by storage time. *J. Food Quality* 24, 141–156.
- Boylston, T.D., Kupferman, E.M., Foss, J.D., Buering, C., 1994. Sensory quality of Gala apples as influenced by controlled and regular atmosphere storage. *J. Food Quality* 17, 477–494.
- Brancoli, N., Barbosa-Cánovas, G.V., 2000. Effect of polysaccharide film on ethylene production and enzymatic browning of apple slices. In: Barbosa-Cánovas, G.V., Gould, G.W. (Eds.), *Innovations in Food Processing*. Technomic, Publishing Co., Lancaster, Pennsylvania, pp. 233–242.
- Buera, M.P., Lozano, R.D., Petriella, C., 1985. Definition of colour in the non-enzymatic browning process. *Die Farbe*. 32–33, 318–322.

- Diehl, K.C., Hamann, D.D., 1979. Structural failure in selected raw fruits and vegetables. *J. Texture Stud.* 10, 371–400.
- Fan, X., Argenta, L., Mattheis, J., 2001. Impacts of ionizing radiation of volatile production by ripening gala apple fruit. *J. Agric. Food Chem.* 49, 254–262.
- Fellman, J.K., Mattison, D.S., Bostick, B.C., Mattheis, J.P., Patterson, M.E., 1993. Ester biosynthesis in 'Rome' apples subjected to low-oxygen atmospheres. *Postharvest Biol. Technol.* 3, 201–214.
- García, E., Barret, D.M., 2002. Preservative treatments for fresh cut fruits and vegetables. In: Lamikanra, O. (Ed.), *Fresh-Cut Fruits and Vegetables*. CRC Press, Florida, pp. 267–304.
- Glenn, G.M., Poovaiah, B.W., 1985. Cuticular permeability to calcium compounds in Golden Delicious' apple fruit. *J. Am. Soc. Hort. Sci.* 110, 192–195.
- Golias, J., 1984. Biogenesis of volatile flavor compounds in apples in a low-oxygen atmosphere. *Acta Univ. Agric. Fac. Agron.* 32, 95–100.
- Greener, I.K., Fennema, O., 1989. Barrier properties and surface characteristics of edible, bilayer films. *J. Food Sci.* 54, 1393–1399.
- Guilbert, S., Biquet, B., 1996. Edible films and coatings. In: *Food Packaging Technology*. VCH Publishers, Inc., New York.
- Harker, F.R., Stec, M.G.H., Hallettand, I.C., Bennett, C.L., 1997. Texture of parenchymatous plant tissue: a comparison between tensile and other instrumental and sensory measurements of tissue strength and juiciness. *Postharvest Biol. Technol.* 11, 63–72.
- Harker, F.R., Gunson, F.A., Jaeger, S.R., 2003. The case for fruit quality: an interpretive review of consumer attitudes, and preferences for apples. *Postharvest Biol. Technol.* 28, 333–347.
- Kamper, S.L., Fennema, O., 1984. Water vapor permeability of an edible, fatty acid, bilayer film. *J. Food Sci.* 49, 1482–1485.
- Kays, S.J., 1991. Metabolic processes in harvested products. In: *Postharvest Physiology of Perishable Plant Products*. Van Nostrand Reinhold, New York, pp. 75–142.
- Ke, D.E., Yahia, M., Mateos, Kader, A.A., 1994. Ethanol fermentation of Bartlett pears as influenced by ripening stage and atmospheric composition. *J. Am. Soc. Hort. Sci.* 119, 976–982.
- Kester, J.J., Fennema, O.R., 1986. Edible films and coatings: a review. *Food Technol.* 40, 47–59.
- Kim, D.M., Smith, N.L., Lee, C.Y., 1993. Apple cultivar variations in response to heat treatment and minimal processing. *J. Food Sci.* 58, 1111–1114, 1124.
- Krochta, J.M., 1990. Casein-acetylated monoglyceride coatings for sliced apple products. In: Presented at the Annual Meeting of the Institute of Food Technologists, Anaheim, CA, June 16–20.
- Krochta, J.M., 1991. Coatings for substrates including high moisture edible substrates. U.S. Patent 5,019,403.
- Krochta, J.M., 1992. Control of mass transfer in foods with edible coatings and films. In: Sing, R.P., Wirakartakusumah, M.A. (Eds.), *Advances in Food Engineering*. CRC Press, Boca Raton, FL, pp. 517–538.
- Lamikanra, O., 2002. Enzymatic effects of flavor and texture of fresh-cut fruits and vegetables. In: Lamikanra, O. (Ed.), *Fresh-Cut Fruits and Vegetables*. CRC Press, Florida, pp. 126–185.
- Le Tien, C., Vachon, C., Mateescu, M.A., Lacroix, M., 2001. Milk protein coatings prevent oxidative browning of apples and potatoes. *J. Food Sci.* 66, 512–516.
- Lee, J.Y., Park, H.J., Lee, C.Y., Choi, W.Y., 2003. Extending shelf-life of minimally processed apples with edible coatings and antibrowning agents. *Lebensm-Wiss Technol.* 36, 323–329.
- Lidster, P.D., Tung, M.A., Garland, M.R., Porritt, S.W., 1979. Texture modification of processed apple slices by a postharvest heat treatment. *J. Food Sci.* 44, 998–1000, 1007.
- Mattheis, J.P., Fellman, J.K., Chen, P.M., Patterson, M.E., 1991. Changes in headspace volatiles during physiological development of Bisbee Delicious apple fruit. *J. Agric. Food Chem.* 39, 1902–1906.
- Mohsenin, N.N., 1986. *Physical Properties of Plant and Animal Materials*, second ed. Gordon and Reach Science Publishers, NY.
- Nisperos-Carriedo, M.O., Baldwin, E.A., 1994. Method of increasing the stability of fruits, vegetables or fungi and composition thereof. U.S. Patent 5,376,391.
- Olivas, G.I., Rodriguez, J.J., Barbosa-Cánovas, G.V., 2003. Edible coatings composed of methylcellulose stearic acid, and additives to preserve quality of pear wedges. *J. Food Process. Pres.* 27, 299–320.
- Olivas, G.I., Barbosa-Cánovas, G.V., 2005. Edible coatings for fresh-cut fruits. *CRC Crit. Rev. Food Sci.* 45, 657–670.
- Olivas, G.I., Barbosa-Cánovas, G.V., 2004a. Water vapor permeability of alginate films as affected by calcium treatment. In: IFT Annual Meeting Technical Program Abstracts 83C-10.
- Olivas, G.I., Barbosa-Cánovas, G.V., 2004b. Alginate-calcium films: water vapor permeability and mechanical properties as affected by plasticizer and relative humidity. In: IFT Annual Meeting Technical Program Abstracts 83C-1.
- Paillard, N.M., 1979. Biosynthesis des produits volatils de la pomme: formation des alcools et des esters a partir des acides gras. *Phytochemistry* 18, 1165–1171.
- Paillard, N.M., 1985. Evolution of the capacity of aldehyde production by crushed apple tissues during an extended storage of fruits. In: Charalambous, G. (Ed.), *The Shelf Life of Foods and Beverages*. Elsevier Science Co., New York, pp. 369–378.
- Park, H.J., 1999. Development of advanced edible coatings for fruits. *Trends Food Sci. Technol.* 10, 254–260.
- Pavlath, A.E., Wong, D.S.W., Kumosinski, T.F., 1993. New coatings for cut fruits and vegetables. *Chem. Technol.*, 36–40.
- Pérez-Gago, M.B., Serra, M., Alonso, M., Mateos, M., DelRío, M.A., 2003. Effect of solid content and lipid content of whey protein isolate-beeswax edible coatings on color change of fresh-cut apples. *J. Food Sci.* 68, 2186–2191.
- Poovaiah, B.W., Glenn, G.M., Reddy, A.S.N., 1988. Calcium and fruit softening. *Physiol. Biochem. Hort. Rev.*, 107–154.
- Porritt, S.W., Lidster, P.D., 1978. The effect of prestorage heating on ripening and senescence of apples during cold storage. *J. Am. Soc. Hort. Sci.* 103, 584–587.
- Rocha, A.M.C.N., Morais, A.M.M.B., 2003. Shelf life of minimally processed apple (cv. Jonagored) determined by colour changes. *Food Control* 14, 13–20.
- Sadler, G.D., Murphy, P.A., 1998. pH and titratable acidity. In: Suzanne Nielsen, S. (Ed.), *Food Analysis*. Aspen Publishers, Inc., Gaithersburg, Maryland, pp. 101–116.
- Sams, C.E., Conway, W.S., 1984. Effect of calcium infiltration on ethylene production, respiration rate, soluble polyuronide content, and quality of 'Golden Delicious' apple fruit. *J. Am. Soc. Hort. Sci.* 109, 53–57.
- Sataque, E.Y., Wosiacki, G., 1987. Characterization of apple (*Malus domestica*, var. Gala) polyphenol oxidase. *Arq. Biol. Tecnol.* 30, 287–299.
- Sime, W.J., 1990. Alginates. In: Harris, P. (Ed.), *Food Gels*. Elsevier Applied Science, London, pp. 53–58.
- Sonti, S., Prinyawiwatkul, W., Gillespie, J.M., McWatters, K.H., Bhale, S.D., 2003. Probit analysis of consumer perception of fresh-cut fruits and vegetables and edible coating. In: IFT Annual Meeting Technical Program Abstracts, 104D-26.
- Watada, A.E., Qi, L., 1999. Quality of fresh-cut produce. *Postharvest Biol. Technol.* 15, 201–205.
- Wong, D.W.S., Tillin, S.J., Hudson, J.S., Pavlath, A.E., 1994. Gas exchange in cut apples with bilayer coatings. *J. Agric. Food Chem.* 42, 2278–2285.
- Young, H., Gilbert, J.M., Murray, S.H., Ball, R.D., 1996. Causal effects of aroma compounds of Royal Gala apple flavours. *J. Sci. Food Agric.* 71, 329–336.