J Sci Food Agric 1998, **76**, 411–420

Starch-Based Coatings: Effect on Refrigerated Strawberry (*Fragaria ananassa*) Quality

María A García,[1,2,3] Miriam N Martino[1,3,*] and Noemí E Zaritzky[1,3]

[1] Centro de Investigación y Desarrollo en Criotecnología de Alimentos (CIDCA), CONICET, Facultad de Ciencias Exactas, Universidad Nacional de La Plata, 47 y 116, La Plata (1900), Buenos Aires, Argentina
[2] Comisión de Investigaciones Científicas de la Provincia de Buenos Aires (CICPBA), Universidad Nacional de La Plata, 47 y, 116, La Plata (1900) Buenos Aires, Argentina
[3] Dpto de Ingeniería Química, Facultad de Ingeniería, Universidad Nacional de La Plata, 47 y 116, La Plata (1900), Buenos Aires, Argentina

(Received 26 July 1996; revised version received 15 May 1997; accepted 9 July 1997)

Abstract: Edible coatings can provide an alternative for extending post-harvest life of refrigerated fruit and vegetables. The influence of different starch-based coating formulations on quality attributes of strawberries stored at 0°C and a relative humidity of 84·8% was studied. Starch sources were classified according to the amylose content in starch, with medium amylose content (potato and corn) and high amylose content (amylomaize and amylose-rich product). Quality of fruits was evaluated by weight loss, firmness retention, microbial decay, surface colour development, titratable acidity and sugar content. The effects of starch amylose content and glycerol (plasticiser) concentration on coating properties were also analysed. The coatings reduced the number of infected fruits and extended storage life of strawberries by retarding senescence. The addition of glycerol improved coating performance, with 20 g litre^{-1} the most effective concentration. The starch source had a significant effect on surface colour development, weight loss and firmness retention. Coated strawberries produced the lowest ratios of chromaticity parameters (a/b, red/yellow) with regard to the control fruits, thus retarding senescence. High amylose content starches reduced weight loss, maintained firmness and reduced decay better than medium amylose content starches. © 1998 SCI.

J Sci Food Agric **76**, 411–420 (1998)

Key words: strawberries; starch; coating; plasticiser; amylose; quality

INTRODUCTION

Edible films or coatings have long been used empirically to protect food products. There are several reviews on the formulation technology and application of edible films (Guilbert 1986, 1988; Kester and Fennema 1986; Guilbert and Biquet 1989; Krochta 1991, 1992).

Compounds that can be used to formulate edible coatings include cellulose derivatives, starch and proteins. Edible films and coatings must have organoleptic properties as neutral as possible (colourless, odourless, tasteless, etc). Enhancement of the surface appearance (eg glossiness) and tactile characteristics (eg reduced stickiness) could be required. Organoleptic characteristics of hydrocolloid films are generally more neutral than those of the films formed from lipids or derivatives and waxes, which are often opaque, slippery and waxy tasting (Gontard and Guilbert 1992).

With regard to biodegradable packaging, starch is the most commonly used agricultural raw material, since it is a renewable source, inexpensive, widely available and relatively easy to handle (Gontard and Guilbert 1992; Lourdin *et al* 1995). However, few reports have dealt with starch-based coatings.

* To whom correspondence should be addressed.

 J Sci Food Agric 0022–5142/98/$17.50. Printed in Great Britain

Amylose is responsible for the film-forming capacity of starches. In addition, an important component of edible films is the plasticiser, which must be compatible with the polymer. According to Banker (1966) a plasticiser is defined as an essentially high boiling, non-separating substance, which when added to another material changes the physical and/or mechanical properties of that material. Water is a common plasticiser but is very difficult to control in biopolymers that are generally more or less hydrophilic (Gontard and Guilbert 1992). Plasticisation of biopolymeric films depends on the relative humidity (RH) of the package atmosphere and on the environment for unpacked products (Gontard and Guilbert 1992).

Edible coatings can provide an additional way for extending post-harvest life of fruits and vegetables. Traditionally, films and coatings have been used to reduce water loss, but new film materials and edible coatings formulated with a wider range of permeability characteristics facilitate achieving a 'modified atmosphere' effect in fresh fruits (Smith *et al* 1987). Several researchers have studied the application of coatings to vegetables such as tomato, cucumber and red peppers (El Gaouth *et al* 1991a, 1992) and fruits like bananas (Banks 1984), apples (Drake *et al* 1987) and mangoes (Dhalla and Hanson 1988). Coating fruits with semi-permeable films has shown to have influence on fruit physiology, to retard ripening and post-harvest metabolism, thus extending the fruit storage life (Trout *et al* 1952; Lowings and Cutts 1982; Olorunda and Aworth, 1984; Rolle and Chism, 1987).

Highly perishable fruits like berries and tropical fruits are the most appropriate products to protect with coatings, because of the additional cost expected with coating treatments. Strawberries as a typical soft fruit have a high physiological post-harvest activity. As a consequence, they have short ripening and senescence periods that makes commercialisation of high quality fruit a challenge. El Gaouth *et al* (1991b) reported the use of chitosan coating in controlling decay of strawberries during refrigerated storage. Chitosan, a high-molecular-weight cationic polysaccharide, has the capacity to inhibit growth of several fungi. These authors showed that a chitosan coating, with its ability to modify internal atmosphere in the tissue and its fungistatic properties, prolonged storage life and controlled decay of strawberries, with a beneficial effect on flesh firmness, titratable acidity and the synthesis of anthocyanins.

The objectives of the present work were to

1 study the ability of starch-based coatings to extend shelf life of refrigerated strawberries;
2 analyse the effect on the coating properties of the amylose content of different starches and glycerol as plasticiser; and
3 study the influence of different coating formulations on the quality attributes of strawberries, such as weight loss, firmness, surface colour development, titratable acidity and sugar content.

MATERIALS AND METHODS

The starches used for the coating formulations were classified according to their amylose content as follows:

1 Starches with medium amylose content (MAC starches): (1·1) commercial corn starch (Molinos Río de la Plata, Buenos Aires, Argentina) with 250 g amylose kg^{-1} of starch and (1·2) commercial potato starch (Fecofar, Buenos Aires, Argentina) with 230 g amylose kg^{-1} of starch.
2 Starches with high amylose content (HAC starches): (2·1) high amylose corn starch, Amylomaize VII (Amaizo, Hammond, IN, USA) with 650 g amylose kg^{-1} of starch and (2·2) amylose-rich corn product (ARP) obtained as described in a previous paper (García *et al* 1995) by corn starch fractionation with $MgSO_4$. ARP contains 500 g amylose kg^{-1} of starch.

In all cases, aqueous solutions of 20 g $litre^{-1}$ starch were cold-gelatinised with 10 g $litre^{-1}$ NaOH to obtain the coating (Young 1984; García *et al* 1995). These suspensions were then neutralised with 7 M H_3PO_4. Glycerol (0, 5, 10, 15 and 20 g $litre^{-1}$ of formulation) was added as plasticiser after neutralisation.

Rheological behaviour of these suspensions was analysed at 25°C using a rotational viscometer Haake Rotovisko RV2 (Dieselstr, Karisruhe, Germany) with a sensor system MVIP. Shear stress (σ) was measured as a function of shear rate ($\dot{\gamma}$) from 0 to 512 s^{-1}. Power law model ($\sigma = m\dot{\gamma}^n$) was applied to determine consistency index (m) and flow behaviour index (n). Apparent viscosity was measured at 512 s^{-1}.

Sample preparation

Strawberries (*Fragaria ananassa* cv Selva), at commercial ripening stage (75% red colour), grown in greenhouses of a local farm were harvested and immediately treated. Fruits of uniform size, free of physical damage and fungal infection were used. Strawberries were dipped in chlorinated water (0·25 g Cl_2 $litre^{-1}$), dried, dipped in the formulated suspensions at ambient temperature and dried again with air (1·2 m s^{-1}, 20°C and 85% RH). Control fruits were treated similarly, replacing immersion in starch suspensions by distilled water. Samples were stored in a cold chamber at O°C and 84·8% RH. Relative humidity of the storage chamber was measured using a General Eastern Hygrometer (Worburn, MA, USA) with a chilled mirror dew point sensor.

In each experiment, 120 fruits were used for the control sample and 120 fruits were used for each tested formulation containing 0, 5, 10, 15 and 20 g of glycerol as plasticiser per litre. All the coating formulations were tested at the same time. Ten fruits were used for each one of the following tests: weight loss, surface colour development and strawberries decay. As these tests were non-destructive, the same 10 fruits used for each test were analysed during the whole storage period. For destructive assays (firmness, titratable acidity and sugars content), five fruits were analysed at each storage time. Sampling times are described for each test. Overall, each experimental lot contained 720 fruits. The whole experiment with the corresponding determinations was repeated with two different lots of strawberries.

After 1 week, 10 strawberries (whole sample and cross-sections) were monitored under a Stereomicroscope Leitz (Leitz, Wetzlar, Germany) to analyse coating integrity. Micrographs of cross-sections were used to determine coating thickness. To visualize the coatings, samples were stained with iodine. The stock solution contained 2 g litre^{-1} I_2 and 20 g litre^{-1} KI (Lyne 1976).

Determination of the plasticiser concentration range

Experiments were performed using 0, 10, 20, 30, 40 and 50 g litre^{-1} glycerol in different starch formulations to determine the maximum amount of plasticiser compatible with the starch coatings. Adhesiveness of the formulations was analysed using four strawberries for each formulation. After the fruits were coated (including the drying stage) a piece of aluminum foil and a piece of filter paper (1 cm^2 square section) were placed on the surface of each strawberry. The fruits were stored at 0°C and 84·8% RH for 36 h. After this period, formulations that produced spots in the filter paper and also maintained aluminum foil attached to the surface of the fruits were rejected due to adhesiveness.

Determination of solubilised amylose content

The percentage of solubilised amylose was determined from the gelatinised suspensions with a DU650 Beckman spectrophotometer (Beckman, Fullerton, CA, USA). The method used is based on the formation of the characteristic amylose–I_2 complex (García *et al* 1995).

Strawberry decay

The fruits were inspected daily for decay and were considered infected when a visible lesion was observed. The results were expressed as percentage of the number of infected fruits. In addition, strawberries were rated daily for visual quality, fragrance and taste. These assays were performed to determine the maximum storage time for the other tests.

Weight loss

The same fruits were weighed at the beginning of the experiment and at 5, 12, 18, 26 and 29 days of storage. The results were expressed as percentage loss of initial weight.

Firmness

The compression force of strawberry flesh was measured with an Instron Testing Machine (Model 1141, Instron Corp, Canton, MA, USA) using a compression cell of 5 kg and an individual plate 1 cm in diameter, with a 10 cm min^{-1} crosshead speed. Determinations were performed at 0, 5, 12, 18, 22 and 26 days of storage for 0, 10 and 20 g glycerol litre^{-1} formulations. Strawberries of uniform size from which calyces were removed to obtain even surfaces were used to determine the break force (peak height).

Surface colour development

Colorimetric measurements were carried out with a Hunterlab colorimeter, equipped with an optical sensor, Model D-25-A3 (Hunter Associates Laboratory, Fairfax, VA, USA) calibrated with an appropriate device to reduce sampling area. Hunter scale was used: lightness (L) and chromaticity parameters a and b were registered at 1, 8, 15 and 22 days of storage.

The ratio of cromaticity parameters (a/b) was calculated. Also, colour differences were calculated as:

$$\Delta E = \sqrt{(\Delta L)^2 + (\Delta a)^2 + (\Delta b)^2}$$

where $\Delta a = a_i - a$, $\Delta L = L_i - L$ and $\Delta b = b_i - b$. Index i indicates the initial measurement.

Determination of reducing and total sugar content and titratable acidity

For each determination, five fruits were processed at different storage times. An Omni-Mixer 17106 (Sorval, Du Pont Instruments, Waterbury, CT, USA) was used to obtain homogenates for both titratable acidity and sugar content determinations.

Acidity was determined using 10 g aliquot of the homogenate made up to 100 ml solution with distilled water and was titrated with 0·1 M NaOH to an end point of pH 8·1 (AOAC 1980). Titratable acidity was expressed as meq of citric acid per 100 g fruit. Two samples were analysed for each storage time.

A qualitative analysis of the sugars present in the fruit was performed by thin layer chromatography. A silica gel on polyester plate (Sigma, St Louis, MA, USA)

with a particle size of 5–17 μm, layer thickness of 250 μm and mean pore diameter 60 Å was used. Standards of sucrose, xylose, glucose, fructose and their mixture (3 μl) were spotted; 2 and 4 μl of ethanol extract of strawberries were also spotted. The solvent was butanol : ethanol : water (2 : 1 : 1 v/v), and 7 mg *p*-aminobenzoic acid litre^{-1} in 2 ml H_2PO_4 litre^{-1} aqueous solution was the detection reagent.

The content of reducing sugars was determined spectrophotometrically using a modification of the Somogyi-Nelson method (Southgate 1976). Calibration curves of glucose were determined with 0·18 g litre^{-1} standard solution.

For total sugars determination, a preliminary hydrolysis of the samples was performed with 0·1 M HCl; once hydrolysed, samples were processed as described for reducing sugars. In both cases sample absorbance was measured at 520 nm.

Sugar content of strawberries was determined using 10 g aliquot of the homogenate and 25 ml ethanol. The mixture was homogenised again, then its volume was reduced by heating in a water-bath for 10 min. It was centrifuged at 2310 × *g* for 10 min and the supernatant was brought to 50 ml in a matrass. The extract was diluted 10 times, then a 50-μl aliquot was used to determine reducing sugars and another 50-μl aliquot for total sugars. Samples were treated as described for standards. Non-reducing sugars were calculated by the difference between total and reducing sugars. Sugars were expressed as grams of glucose per 100 g of fruit.

Statistical analysis

Systat-software (SYSTAT 1990) version 5·0 was used for all statistical analysis. Analysis of variance (ANOVA), Fisher LSD mean comparison test and regression analysis were applied. The significance levels used were 0·05 and 0·01. Standard error (SE) obtained from the ANOVA is reported for each determination in the legend of the corresponding figure.

RESULTS AND DISCUSSION

Visual coating characterisation

Surfaces of whole fruits were analysed; a micrograph of a cross-section obtained with the stereomicroscope is shown in Fig 1. Iodine-staining was a useful technique, since it specifically stained starch coatings without staining the fruit. The coatings containing plasticiser were homogeneous and covered the whole surface of the fruit including the achenes. Coatings without plasticiser were brittle and some cracks were observed on them. The iodine-staining method allowed the visualisation of these undesirable cracks.

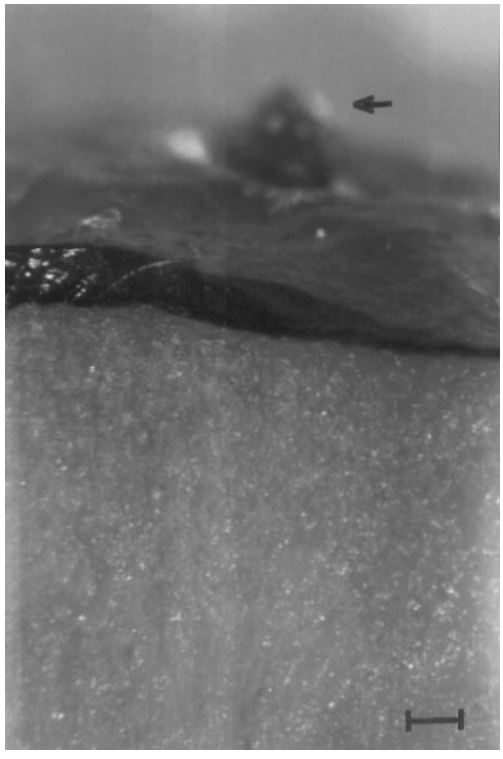

Fig 1. Micrograph of a strawberry (cross-section) coated with high amylose corn starch and 10 g glycerol litre^{-1} formulation. Coating was stained with iodine. The homogeneous area on the bottom is the inside of the strawberry and the thin dark horizontal area is the coating (which was measured). The spherical-looking object on the top of the micrograph (marked by an arrow) is one of the achenes of the fruit stained with iodine. Bar = 100 μm.

Coating thickness was determined from the micrographs, obtaining values between 40 and 50 μm.

Concentration of plasticiser and solubilised amylose

The maximum compatible concentration of glycerol in the coating formulations that did not produce adhesiveness was 20 g litre^{-1}. When the compatible limit within the polymer was exceeded, phase separation occured, leading to a physical exclusion of the plasticiser from the mixture (Donhowe and Fennema 1993). This phase separation corresponded to an extra adhesiveness of the coatings on the fruit surfaces and was evidenced as a spot in the filter paper. The rate of plasticiser migration depends on the functional groups, its polarity and the matrix structure. A consequence of plasticiser migration is the loss of coating flexibility (Park *et al* 1994).

Coatings were obtained after drying starch suspensions, basically an amylose matrix filled by starch granules. In the present study, amylose that was responsible for the formation of the coating network was released preferentially to the aqueous medium by the NaOH (García *et al* 1995). Amylopectin remained crystallised within the starch granules, reinforcing the amylose network (Ring and Stainsby 1982; Ring *et al* 1987;

Miles *et al* 1985). The amount of amylose solubilised from MAC and HAC starches was 18·75 g amylose per 100 g initial starch and 31·50 g amylose per 100 g initial starch, respectively.

The rheological analysis of the starch suspensions (with and without glycerol as plasticiser) showed a pseudoplastic behaviour. The most viscous formulation (MAC starch-based with 20 g litre^{-1} of glycerol) showed an apparent viscosity at 512 s^{-1} of 22·64 mPa × s, the consistency index (m) was 0·027 mPa × s^{n} and the flow behaviour index (n) was 0·9107.

Microbial decay

Strawberry is a highly perishable fruit; the shelf life usually ends with a fungal infection due to *Botrytis cinerea* and *Rhizopus* sp. (Maas 1981).

The microbial attack of the fruit was visualised as brown spots and a softening of the injured zone. In the present study, the maximum storage life was defined as the time elapsed between the application of the coating and the visualisation of the fungal attack. The coatings reduced markedly the number of infected fruits and extended the storage life (Fig 2). Most of the coatings extended the storage life of the fruits by approximately 1 week beyond the control, except the fruits coated with the potato starch formulation without plasticiser. Plasticiser has a significant effect ($P < 0·05$) on storage life. Coatings with 10 and 20 g glycerol litre^{-1} showed the longest lives (Fig 3). The amount of amylose in the starches also has a significant effect (MAC and HAC starches differed significantly, $P < 0·05$). Specifically, HAC starch coatings with 20 g glycerol litre^{-1} were effective in extending fruit storage life 1·45 times with reference to control fruits and 1·16 times for fruits coated with MAC starches and 20 g glycerol litre^{-1}. This trend was similar for the other glycerol concentrations.

Weight loss

Weight loss of fruits increased with storage time for both control and coated fruits. Figure 4 shows lower weight losses of fruit coated with HAC starches than those coated with MAC starch formulations. Amylose source had a significant effect ($P < 0·05$) on weight loss: MAC and HAC starches differed statistically ($P < 0·05$) between each other and the control; the higher the amylose content the lower the weight loss. In particular, weight losses were reduced 44·5% by HAC starch coatings and 32·9% by MAC, both with 20 g glycerol litre^{-1}. The coating network becomes more compact with increasing amylose content, decreasing the water permeability of the coating.

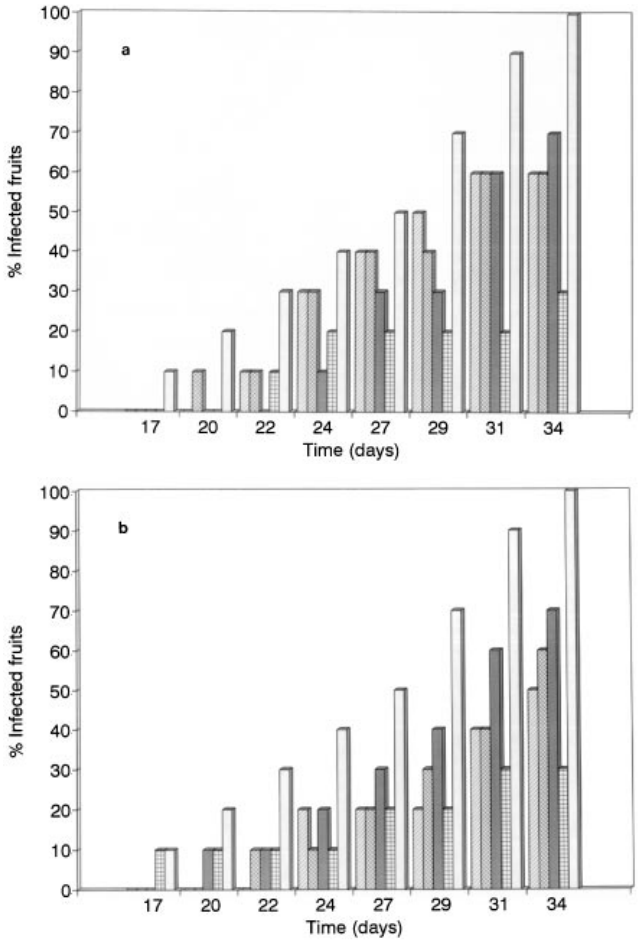

Fig 2. Microbial decay of strawberries expressed as percentage of infected fruits during storage time (SE = 6·760) for two plasticiser concentrations (a) 10 and (b) 20 g litre^{-1} glycerol: control fruits without coating (□); fruits with coatings containing starch of different origin: (▨) corn, (▨) potato, (■) high amylose corn and (▦) amylose-rich product.

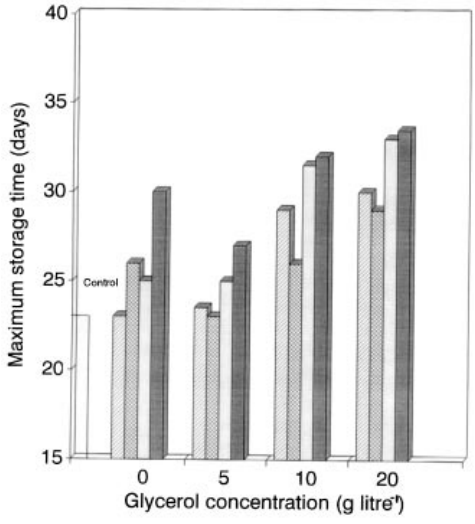

Fig 3. Concentration effect of glycerol as plasticiser of starch-based coatings on maximum storage time of strawberries refrigerated at 0°C. Maximum storage time was based on microbial decay (SE = 2·601). Control fruits without coating (□); fruits with coatings containing starch of different origin: (▨) corn, (▨) potato, (▨) high amylose corn and (■) amylose-rich product.

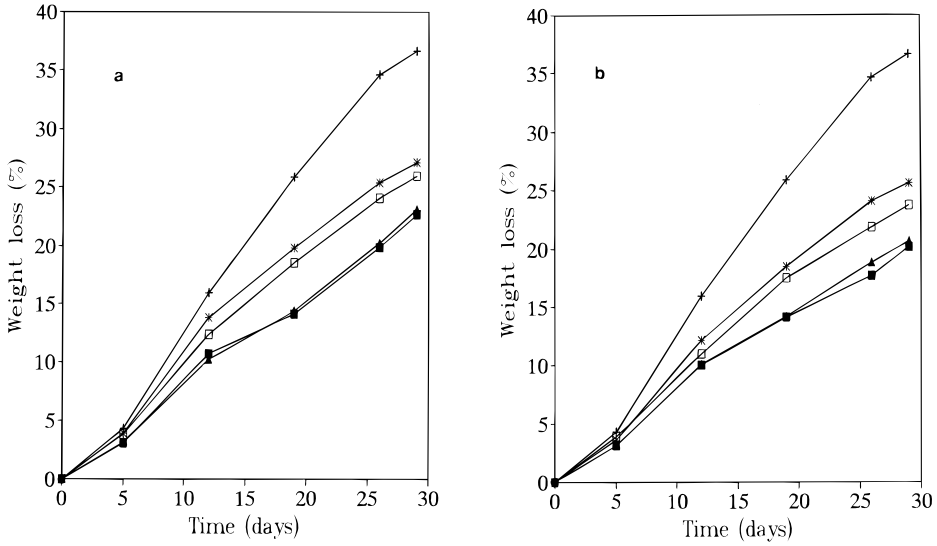

Fig 4. Effect of starch based coatings on weight loss of strawberries stored at 0°C (SE = 2·115) for two plasticiser concentrations (a) 10 and (b) 20 g glycerol litre^{-1}: control fruits without coating (+); fruits with coatings containing starch of different origin: (∗) corn, (□) potato, (▲) high amylose corn and (■) amylose-rich product.

Plasticiser addition also had a significant effect ($P < 0{\cdot}05$) on weight loss. Fruits with coatings without plasticiser showed higher weight losses than fruits with 10 and 20 g glycerol litre^{-1} coatings. Non-uniform coverage (evidenced by cracks) of strawberries by coatings without glycerol may have caused this result. Only 10 and 20 g glycerol litre^{-1} formulations showed significant differences between each other, 20 g litre^{-1} being the most effective one.

When glycerol is present in the amylose network, direct interactions between amylose chains are reduced and the distance between amylose chains is increased. Besides, plasticisers and polymers may interact through the development of secondary intermolecular forces giving a complex or a molecular aggregate. Differences in permeability of the plasticised films can be attributed to several factors such as physical state and molecular weight of the plasticiser, alterations in film structure and chemical interaction between the plasticiser and the permeant. Alcohols such as glycerol are compatible with amylose and improve mechanical properties of the films, because they may decrease intermolecular attraction and interfere with the amylose packing. Amylose molecules without plasticiser should form extremely crystalline and fragile films (Donhowe and Fennema 1993).

In general, plasticisation improves flexibility and extensibility while decreasing the barrier properties of films (Lieberman and Gilbert 1973). However, in some films like those of methylcellulose, permeability is only slightly modified by glycerol addition. Since glycerol is a small molecule, it may fill the vacancies within the polymer matrix (Porter 1980). On the other hand, Herald *et al* (1996) and Gennadios and Weller (1990) reported that the incorporation of selected additives into corn zein films did not produce significant differences in water vapour permeability. These facts could explain the particular influence of glycerol in starch-based coatings.

Firmness

Break force decreased as a function of storage time for both control and coated fruits, as is shown in Fig 5 for 10 and 20 g glycerol litre^{-1} formulations. All coatings showed a beneficial effect on firmness retention, obtaining the best results with HAC starch formulations. The firmness retention was calculated as $(F_t/F_0) \times 100$, with F_t the break force at time t and F_0 the break force at 0. At final storage time, control fruits showed firmness retention values of 49·2% while coated fruits with HAC starch formulations with 10 and 20 g glycerol litre^{-1} had values of 64·9 and 68·9%, respectively.

Texture modifications in fruits and vegetables are related to the composition of cell wall, enzyme activity, metabolic changes and water content. The rate and extension of firmness loss during ripening of soft fruits like strawberries is the main factor to determine fruit quality and post-harvest shelf life. According to Manning (1993), fruit softening is attributed to the degradation of cell wall components due to specific enzyme activity.

As observed with weight loss of fruits, the amylose source in the coating had a significant effect ($P < 0{\cdot}05$) on fruit firmness. Starch coatings with HAC needed statistically ($P < 0{\cdot}05$) higher forces to rupture fruits than MAC starch coatings.

The presence of glycerol in the formulations significantly ($P < 0{\cdot}05$) improved fruit firmness, 20 g litre^{-1} being the most effective concentration.

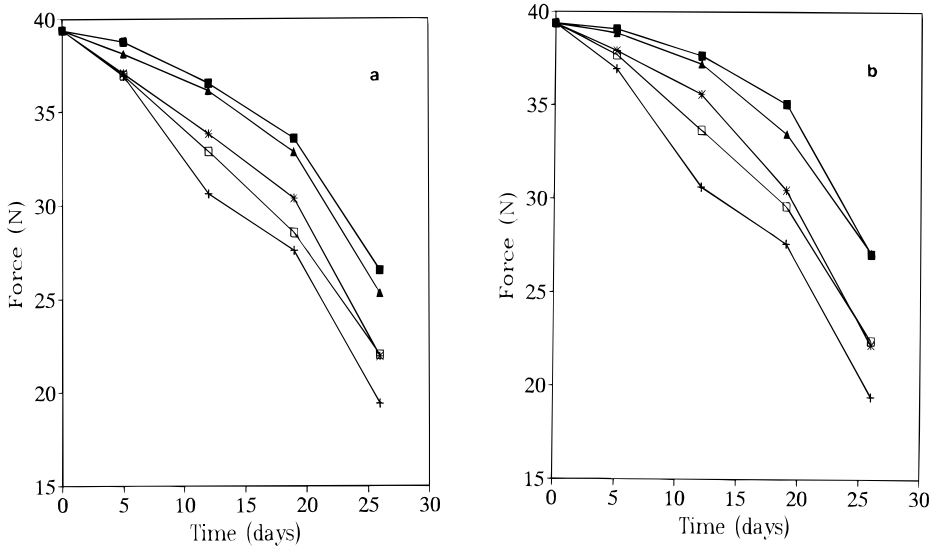

Fig 5. Effect of coatings on firmness (Newton) of strawberries stored at 0°C (SE = 2·993). Control fruits without coating (+); fruits with coatings containing starch of different origin: (∗) corn, (□) potato, (▲) high amylose corn and (■) amylose-rich product. Coatings contained (a) 10 and (b) 20 g glycerol litre^{-1} as plasticiser.

Surface colour development

Colour changes during post-harvest ripening were evidenced by a decrease in lightness (*L*), an increase in redness (*a*) and a decrease in yellowness (*b*). Changes were evaluated by colour differences (ΔE) and *a*/*b* ratio.

ΔE increased with storage time. In this case, lightness differences (ΔL) accounted for more than 70% of the ΔE values. Control fruits showed significantly higher ΔE values ($P < 0{\cdot}05$) as compared to coated fruits. ANOVA gave a significant effect ($P < 0{\cdot}05$) of plasticiser concentration and storage time of fruits at 0°C.

With reference to plasticiser concentration, 20 g glycerol litre^{-1} formulations were significantly more effective in colour retention than any other glycerol concentration. There was also a significant difference ($P < 0{\cdot}05$) between control fruits and fruits treated with 15 g glycerol litre^{-1}.

Differences in ΔE values found between formulations with similar amylose content were not significant; however, significant differences ($P < 0{\cdot}05$) were observed between HAC and MAC starch groups.

As is shown in Fig. 6, *a*/*b* ratios remained almost constant during the first 8-days storage period and then increased with storage time (while the parameter *a* increased, *b* decreased). Control fruits with the highest *a*/*b* values showed significant differences ($P < 0{\cdot}05$) with regard to the coated fruits. Thus, the senescence delay, evidenced by the decrease in colour changes, demonstrates the effectiveness of coating treatment.

Fruits treated with 20 g glycerol litre^{-1} formulations gave the lowest *a*/*b* ratios compared to the other glycerol concentrations. Differences in *a*/*b* ratio detected between HAC and MAC starch formulations were not significant.

Titratable acidity

Starch-based coatings had a marked effect on titratable acidity of strawberries stored at 0°C.

ANOVA showed significant effects ($P < 0{\cdot}05$) of the presence of plasticiser and storage time on titratable acidity of strawberries. Non-significant differences were found between coatings with different amylose contents. Figure 7 only shows the effect of plasticiser and storage time on titratable acidity. Coated fruits showed higher values of titratable acidity as a function of storage time compared to the control. A decline in acidity demonstrates maturation development, thus coating delayed

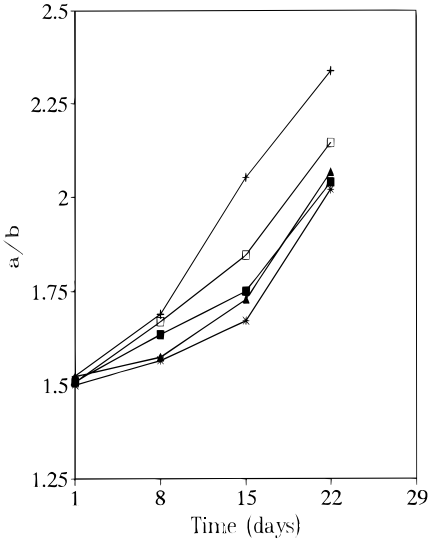

Fig 6. Surface colour of strawberries stored at 0°C: *a*/*b* = the ratio of chromaticity parameters (SE = 0·089); (∗) corn, (□) potato, (▲) high amylose corn and (■) amylose-rich product starch coatings with 20 g glycerol litre^{-1} and (+) control.

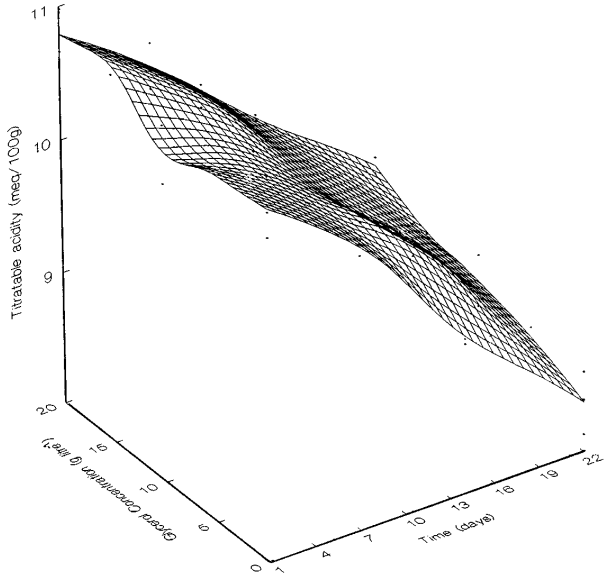

Fig 7. Effect of glycerol concentration and storage time on titratable acidity of strawberries stored at 0°C (SE = 0·734).

fruit maturation. These results agreed with those reported by El Gaouth *et al* (1991b) who analysed the effects of chitosan and a commercial coating on strawberries.

Coatings with 15 and 20 g glycerol litre^{-1} did not differ significantly ($P < 0{\cdot}05$), showing the highest values of titratable acidity. This group differed significantly from the other samples (Fig 7).

Changes in the concentration of reducing and non-reducing sugars

Thin layer chromatography showed that the predominant sugars in the ethanol extract were glucose and fructose, followed by sucrose; no significant levels of xylose were detected.

Glucose absorptivity was calculated from the calibration curve, being its value $393{\cdot}767 \pm 5{\cdot}772$ litre g^{-1} cm^{-1}; the linear correlation coefficient was $r^2 = 0{\cdot}999\,14$.

Storage time had a significant effect on reducing sugars. Figure 8a shows the increase of reducing sugars during storage time. Plasticiser content and starch source did not show significant effects.

At the same time, the content of non-reducing sugars decreased with storage time (Fig 8b). In this case, ANOVA showed a significant effect ($P < 0{\cdot}05$) of storage time and plasticiser concentration. As in titratable acidity, 15 and 20 g glycerol litre^{-1} concentrations were the most effective in maintaining the values of non-reducing sugars.

During 27 days of storage at 0°C, reducing sugar content increased from 1·85 to 4·95 g of glucose per 100 g fruit and the non-reducing sugar content decreased from 1·50 to 0·50 g of glucose per 100 g fruit for control fruit. Sugar metabolism due to post-harvest

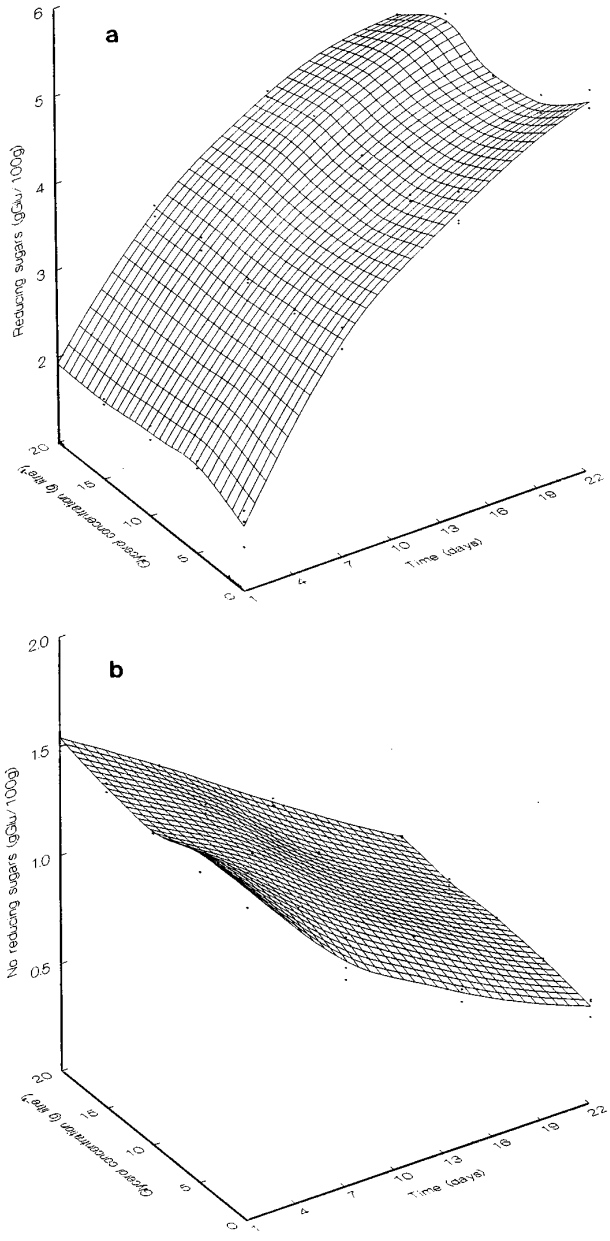

Fig 8. Effect of glycerol concentration and storage time on sugar content of strawberries stored at 0°C: (a) reducing sugars (SE = 0·574), (b) non-reducing sugars (SE = 0·071).

ripening is responsible of these differences in sugar content.

Qualitative aroma and flavour observations

Qualitative aroma and flavour observations were performed in this study as complementary analyses to the previously reported results. The application of coatings improved the overall organoleptic characteristics of the strawberries. Fruit flavour was not altered by the coatings when eaten. Fruits coated with HAC starch formulations maintained its aroma for longer times than those coated with MAC.

CONCLUSIONS

Starch-based coatings extended the storage life of strawberries and retarded the senescence process.

The addition of glycerol as plasticiser improved coating performance and was necessary to obtain coating integrity. Coatings with glycerol gained elasticity, with 20 g litre^{-1} the optimum concentration. Glycerol addition showed its beneficial effect on flesh firmness and reducing weight loss of strawberries.

Starch source had a significant effect on surface colour development, weight loss and firmness retention. Two groups of starches with different maximum amylose content were used: HAC (650 g amylose kg^{-1} of starch) and MAC (250 g amylose kg^{-1} of starch). HAC starch coatings reduced strawberries decay and weight loss, maintaining flesh firmness better than MAC. Coated strawberries produced the lowest *a*/*b* ratios with regard to the control fruits, thus retarding senescence.

The overall organoleptic conditions of the fruits were improved, since coated strawberries maintained their firmness, turgency and surface colour for longer times. These facts may help industry efforts in decreasing economic losses during commercialisation.

ACKNOWLEDGEMENTS

The financial support provided by CONICET (Consejo Nacional de Investigaciones Científicas y Técnicas), CICPBA (Comisión de Investigaciones Científicas de la Provincia de Buenos Aires) and University of La Plata is gratefully acknowledged.

REFERENCES

AOAC 1980 *Official Methods of Analysis* (13th edn). Association of Official Analytical Chemists, Washington, DC, USA.

Banker G S 1966 Film coating. Theory and practice. *J Pharm Sci* **55** (1) 81–89.

Banks N H 1984 Some effects of TAL Pro-Long coatings on ripening bananas. *J Exper Bot* **35** 127–137.

Dhalla R, Hanson S W 1988 Effect of permeability coatings on the storage life of fruits. II. Pro-long treatments of mangoes (*Mangifera indica* L cv Julie). *Int J Food Sci Technol* **23** 107–112.

Donhowe I G, Fennema O R 1993 The effects of plasticizers on crystalinity, permeability, and mechanical properties of methylcellulose films. *J Food Process Preserv* **17** 247–257.

Drake S R, Fellman J K, Nelson J W 1987 Post-harvest use of sucrose polyesters for extending the shelf-life of stored Golden Delicious apples. *J Food Sci* **52** 1283–1285.

El Gaouth A, Arul J, Ponnampalam R, Boulet M 1991a Use of chitosan coating to reduce water loss and maintain quality of cucumber and bell pepper fruits. *J Food Process Preserv* **15** 359–368.

El Gaouth A, Arul J, Ponnampalam R, Boulet M 1991b Chitosan coating effect on storability and quality of fresh strawberry. *J Food Sci* **56** 1618–1620.

El Gaouth A, Ponnampalam R, Castaigne R, Arul J 1992 Chitosan coating to extend the storage-life of tomatoes. *HortScience* **27** 1016–1018.

García M A, Martino M N, Zaritzky N E 1995 Comparison of amylose enrichment procedures for food applications. *Cereal Chem* **72** 552–558.

Gennadios A, Weller C L 1990 Edible films and coatings from wheat and corn proteins. *Food Technol* **44** (10) 63–69.

Gontard N, Guilbert S 1992 Bio-packaging: technology and properties of edible and/or biodegradable material of agricultural origin. In *Food Packaging and Preservation*, ed Mathlouthi M. Chapman & Hall, London, UK, pp 159–180.

Guilbert S 1986 Technology and application of edible protective films. In *Food Packaging and Preservation: Theory and Practice*, ed Mathlouthi M. Chapman & Hall, London, UK, pp 371–394.

Guilbert S 1988 Use of superficial edible layer to protect intermediate moisture foods. Application of tropical fruits dehydrated by osmosis. In *Food Preservation by Moisture Control*, ed Seow G. Elsevier Applied Science, New York, USA, pp 199–219.

Guilbert S, Biquet B 1989 Les films et enrobages comestibles. In *L'Emballage des Denrées Alimentaires de Grande Consomation*, eds Bureau G & Multon J L. Technique et Documentation, Lavoisier, Apria, Paris, France.

Herald T J, Hachmeister K A, Huang S, Bowers J R 1996 Corn zein packaging materials for cooked turkey. *J Food Sci* **61** 415–417.

Kester J J, Fennema O R 1986 Edible films and coatings: a review. *Food Technol* **12** 47–59.

Krochta J M 1991 Innovation for tomorrow's foods. *USA Today* **91** (1) 78–79.

Krochta J M 1992 Control of mass transfer in foods with edible coatings and films. In *Advances in Food Engineering*, eds Singh R P & Wirakartakusumah M A. CRC Press, New York, USA, pp 517–538.

Lieberman E R, Gilbert S G 1973 Gas permeation of collagen films as affected by cross-linkage, moisture and plasticizer content. *J Polym Sci* **41** 33–43.

Lourdin D, Della Valle G, Colonna P 1995 Influence of amylose content on starch films and foams. *Carbohydr Polym* **27** 261–270.

Lowings P H, Cutts D F 1982 The preservation of fresh fruits and vegetables. *IFST Proc* **15** 52–54.

Lyne F A 1976 Chemical analysis of raw and modified starches. In *Examination and Analysis of Starch and Starch Products*, ed Radley J A. Applied Science, London, UK, pp 133–165.

Maas J L 1981 Postharvest diseases of strawberry. In *The Strawberry—cultivars to marketing*, ed Childers N F. Horticultural Publications, Gainesville, FL, USA, pp 329–353.

Manning K 1993 Soft fruits. In *Biochemistry of Fruit ripening*, eds Seymour G B, Taylor J E & Tucker G A. Chapman & Hall, London, UK, pp 347–373.

Miles M J, Morris V J, Orford P D, Ring S G 1985 The roles of amylose and amylopectin in the gelation and retrogradation of starch. *Carbohydr Res* **135** 271–281.

Olorunda A O, Aworth O C 1984 Effects of Pro-long, a surface coating agent, on the shelf-life and quality attributes of plantain. *J Sci Food Agric* **35** 573–578.

Park H J, Bunn J M, Weller C L, Vergano P J, Testin R F 1994 Water vapour permeability and mechanical properties of grain protein-based films as affected by mixtures of polyethylene glycol and glycerin plasticizers. *Trans ASAE* **37** 1281–1285.

Porter S 1980 The effect of additives on the properties of an aqueous film coating. *Pharm Technol* **3** 67–75.

Ring S G, Stainsby G 1982 Filler reinforcement of gels. *Prog Food Nutr Sci* **6** 323–329.

Ring S G, Colonna P, I'Anson K J, Kalichevsky M T, Miles M J, Morris V J, Orford P D 1987 The gelation and crystallisation of amylopectin. *Carbohydr Res* **162** 277–293.

Rolle R, Chism G W 1987 Physiological consequences of minimally processed fruits and vegetables. *J Food Qual* **10** 157–165.

Smith S M, Geeson J, Stow J 1987 Production of modified atmospheres in deciduous fruits by the use of films and coatings. *HortScience* **22** 772–776.

Southgate D A T 1976 *Determination of Food Carbohydrates.* Applied Science, London, UK, pp 105–106.

Trout S A, Hall E G, Skyes S M 1952 Effects of skin coatings on the behavior of apples in storage. *Aust J Agric Res* **4** 57–81.

Young A H 1984 Fractionation of starch. In *Starch, Chemistry and Technology* (2nd edn), ed Whistler R L, BeMiller J N & Paschall E F. Academic Press, Orlando, FL, USA, pp 249–283.