PECTIN-BASED EDIBLE COATING FOR SHELF-LIFE EXTENSION OF ATAULFO MANGO

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ABSTRACT

Mango is a commercial but highly perishable fruit, and therefore, a longer shelf life is necessary for its successful marketing and consumer satisfaction. This study aims at evaluating the effects of edible coating, based on pectin, on the quality and shelf-life extension of mangoes. The coating formulations included different combinations of pectin, beeswax, sorbitol and monoglyceride. The fruits were coated and stored at room temperature along with uncoated controls. Samples tested were evaluated periodically for quality parameters, which included visual observation, weight loss, respiration rate, color, firmness, pH, soluble solids (SS), titrable acidity and extent of decay. The coated-fruits reduced the rate of color development, texture softening, weight loss, CO₂ evolution and acid production (only pH and SS increased) compared with the control. The shelf life of control sample was less than a week, whereas the coated fruits remained good for over 2 weeks, thereby offering a significant advantage.

PRACTICAL APPLICATIONS

The study evaluates the use of pectin-based edible coating for extending the shelf life of mango. The formulation is a blend of hydrophilic and hydrophobic groups to provide controlled respiration and water vapor permeability. The properties of pectin films have been highlighted in a previous paper, and several applications based on the coating have been demonstrated. The present

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study demonstrates that modifications to the formulation were necessary in order to successfully apply it to mango. Mango is a popular commercial product with high heritability. Simple edible coatings that can help to improve the shelf life and marketability of the product will be of significant interest in the marketing of mango products.

INTRODUCTION

Mango (*Mangifera indica* L.) is the most economically important fruit in the Anacardiaceae family, with 70% of the mangoes in the world cultivated in India, whereas Mexico is the biggest exporter of fresh mango fruit (Snowdon 1990). Mango and mango products such as puree, nectar, pickles, canned slices and chutneys are popular worldwide and are becoming increasingly important in the western market (Schieber *et al.* 2003).

Mango is a climacteric fruit that exhibits a characteristic rise in ethylene production and respiration rate during fruit ripening, accompanied by changes in color, aroma volatiles and softness (Mitra 1997). International and domestic trade of mangoes have been limited because of its highly perishable nature and its susceptibility to low temperature injury, physical injury and post-harvest diseases (Mitra 1997). The fruit ripens in 3–9 days and must be consumed soon after harvest. Because of these reasons, its commercialization in distant markets is seriously limited (Litz 1997).

To extend the shelf life of fresh mango fruit, several techniques have been used. Low-temperature storage is the most common method to extend the storage life of fruits and vegetables; however, its full advantage cannot be realized for mango because of its chilling sensitivity. Lower temperatures prevent the normal metabolism of mango tissue, and the complex biochemical reactions associated with respiration continue in alternative pathways (Snowdon 1990). Different cultivars vary in susceptibility to chilling injury (Farooqui *et al.* 1985) but, generally, the green fruit may be stored at 10–15°C, while ripe fruits are able to tolerate lower temperatures (Medlicott *et al.* 1990). The optimum temperature for mango storage is between 12°C and 13°C (Kalra and Tandon 1983).

Controlled-atmosphere (CA) storage can also be used to extend the shelf life of mangoes (Mitra 1997). CA reduces respiration rate by lowering O₂ levels and elevating CO₂ in the storage chamber, and delays senescence. However, increased ethanol production and flavor problems because of anaerobic respiration have been reported (Lakshminarayana and Subramanyam 1970). Bender *et al.* (1994) reported that a 5% O₂ in combination with higher levels of CO₂ (10% and 25%) reduced ethylene production during 3 weeks of CA storage of mango at 12°C. For the long-term storage of mango, hypobaric
(low pressure) storage has also been studied. Storage of Irwin, Tommy Atkins and Kent mangoes at a pressure of 76–152 mm Hg at 13C with 98–100% relative humidity (RH) for up to 3 weeks resulted in a higher percentage of acceptable fruit, which took longer to complete their ripening after removal to normal pressure than those stored at 760 mm Hg. (Spalding and Reeder 1977). Post-harvest calcium treatment by vacuum infiltration has been shown to delay ripening in mango (Wills et al. 1988) by 12 and 8 days when pressure (115 kPa for 2 min) or vacuum infiltration (32 kPa) with CaCl₂ solution (2–8%) was applied. However, vacuum infiltration of Ca²⁺ caused peel injury in mango (Yuen et al. 1993).

Fruit coating is another method used to delay ripening and prolong the storage life of a produce (Ghaouth et al. 1991). Edible coating is a simple, environmentally friendly and relatively inexpensive technology that can delay ripening of climacteric fruits, delay color changes in nonclimacteric fruits, reduce water loss, reduce decay and improve appearance (Donhowe and Fennema 1994). Coatings can be formulated from different materials including lipids, resins, polysaccharides and proteins. In fact, most coatings are a composite of more than one film former, with the addition of low molecular weight molecules such as polyols that serve as plasticizers. Surfactants, anti-foaming agents and emulsifiers are also often used in coatings. Some coatings have been used on tropical fruits such as avocados and mangoes, with varying degrees of successes. Mathur and Srivastava (1955) and Bose and Basu (1954) reported that coating mango with paraffin wax emulsions (7%) resulted in increased shelf life, especially at reduced storage temperatures (12.8C). Coating with refined mineral oil, on the other hand, resulted in fruit injury. The oil coating resulted in an anaerobic condition severe enough to injure the fruit. Both coatings, however, decreased weight loss. Aqueous wax emulsions consisting of vegetable (sisal, sugar cane and carnauba) waxes and mineral petroleum with and without shellac and emulsifiers were reported to increase the storage life of mangoes (Dalal et al. 1971). A wax emulsion of 6% solids with 20 ppm 2,4-dichlorophenoxy acetic acid or 250 ppm maleic hydrazide delayed ripening of mango fruits compared with fruits treated with the same wax, with no growth regulators (Subramanyam et al. 1962). Polysaccharide-based coatings have also shown some benefits for extending the shelf life of mangoes. When coated with 0.75–1% TAL Prolong and stored at 25C, mango fruits showed retarded ripening and increased storage life (Dhalla and Hanson 1988). Baldwin (1994) also reported reduced weight loss in the coated fruit compared with uncoated controls and increased ethanol formation in fruit pulp after 13 days with 1% TAL Prolong. Nature Seal TAM, another cellulose-based coating, was also reported to delay ethylene production in coated mangoes stored at 21C (Mitra 1997). Diaz-Sobac et al. (1996) used a coating emulsion including maltodextrins, carboxymethyl cellulose, propylene glycol
and a mixture of sorbitan fatty acid esters on Manila mango. The emulsion was used to form films, which were employed to coat mangoes, to study their post-harvest life under different conditions (15 and 25°C and 80–85% RH) and to see the effects of the coatings on the respiration patterns and on the chemical composition of the fruits. Their results showed that this treatment can extend the post-harvest storage ability of Manila mangoes at least 20 days more than uncoated fruits, without the need of refrigerated storage. Baldwin et al. (1999) tested two types of coatings on Tommy Atkins mangoes. Their objectives were to study the effects of these coatings on internal and external fruit atmospheres, as well as quality factors, during simulated commercial storage at 10 or 15°C with 90–99% RH followed by simulated marketing conditions of 20°C with 56% RH. Both coatings created modified atmosphere, improved appearance and reduced decay, but only polysaccharide coating delayed ripening and increased concentration of flavor volatiles. The carnauba wax coating significantly reduced water loss compared with uncoated and polysaccharide coating treatments. Kittur et al. (2001) have investigated the effects of four different polysaccharide-based coatings on maintaining the quality and extension of shelf life of mango and banana at 27 ± 2°C, compared with waxol-coated and uncoated fruits. Their formulations consisted of modified starch, cellulose and chitosan, blended with a suitable lipid and a wetting agent. The data were also subjected to principal component analysis, to discriminate the characteristics of the five types of films. Their results revealed that chitosan-based coatings were superior in extending the shelf life and maintaining the quality of mango and banana.

Pectin is a class of complex water-soluble polysaccharides used to form coatings. It is a purified carbohydrate product obtained by aqueous extraction of some edible plant material, usually citrus fruits or apples. Under certain circumstances, pectin forms gels; this property has made them a very important additive in jellies, jams, marmalades and confectionaries, as well as edible coatings. Pectin is a high-volume and potentially important food ingredient available in high percentages in agricultural wastes. In addition, its nutritional benefits for human health and its pharmaceutical activities make it interesting to use in a variety of food products. Several studies have been performed on pectin films, dating mostly from the 1930s to 1950s (Henglein and Schneider 1936; Maclay and Owens 1947; Swenson et al. 1953). Generally, these studies involved derivatized pectins and the use of polyvalent cations such as calcium. Pectin coatings have been also studied for their ability to retard lipid migration and moisture loss, and to improve appearance and handling of foods. Zaleska et al. (2000) and Mariniello et al. (2003) used the complex of apple pectin with whey protein isolate and whole soy flour, respectively, as raw material for producing hydrocolloid edible films; pectinate coatings, however, are poor moisture barriers and can reduce water loss from the food by acting as a
sacrificing agent. Maftoonazad and Ramaswamy (2008) and Maftoonazad et al. (2007) used a pectin-based composite coating on avocados and evaluated the extent of quality changes under different storage temperatures, as well as some kinetic parameters (reaction rate constant and activation energy) for predicting the quality loss in stored avocados. Their results showed that pectin-based composite coatings significantly reduced the rate of physical, chemical and physiological changes in avocados during storage, extending the shelf life to over a month at 10°C.

To our knowledge, there are no published data about the use of pectin-based composite coating for maintaining the quality and extending the shelf life of Ataulfo mangoes. Consequently, the objective of this study was to evaluate the effect of edible coatings based on pectin and beeswax on the quality indices and shelf-life extension of Ataulfo mangoes.

MATERIALS AND METHODS

Fruits

The mango fruits (cv. Ataulfo) were obtained from a local market. Mature, green fruits, without any visible blemish, were brought to the lab, the pedicels were removed and the fruits were surface sterilized in 1% sodium hypochlorite solution for 15 min, then washed and air-dried. The fruits were then randomly divided into two lots. The first lot constituted the control and was stored without coating. The second lot was coated with pectin-based composite.

Preparation and Application of Coating

Principal Formulation (Part A). Pectin (15 g; high methoxy rapid set powder, TIC GUMS, Belcamp, MD) was rehydrated in distilled water (500 mL) for 18 h at 20°C. Sorbitol as plasticizer (6.75 g; Sigma, Oakville, ON, Canada) was then added to the pectin solution and thoroughly mixed with a magnetic stirrer. Melted beeswax (6 g) and monoglyceride (1.8 g; Sigma) were added as emulsifiers to this mixture and emulsified using a homogenizer (PowerGen 700, Fisher Scientific, Pittsburgh, PA) at 14,000 rpm for 4 min and cooled to 37 ± 2°C. Mangoes were then dipped in the coating emulsion for 1 min at 20°C and drained. To set a coat of film on the surface of mangoes, the treated fruits were dried in a cold air draft for 4 h. They were then stored along with control samples in trays without any cover to simulate a retail market. The trays were kept at room temperature, and samples from each treatment were taken out periodically for analysis.
**Refined Formulations (Part B).** Based on the results from the principal formulation, it was found necessary to refine the composition for improving the coating performance, especially to overcome the symptoms of anaerobic respiration. This was done in two steps: first, experiments were designed to screen different levels of pectin, sorbitol, beeswax and monoglycerides to identify the useful range of the above components in the formulation. In the subsequent step, three of the more potential formulations that showed normal ripening behavior of mangoes were selected and further studied to choose the best composition in terms of extending the shelf life of the mangoes without inducing anaerobiosis.

**Weight Loss**

Initial weight of the fruits was taken with a balance (Shimadzu Corp., Kyoto, Japan), and periodical observation on the loss in weight of the stored fruits was recorded. The physiological loss in weight was calculated and expressed as percentage loss in weight based on original mass.

**Instrumental Analysis**

The instrumental analysis in this work was adopted from the procedures used by Maftoonazad and Ramaswamy (2005).

1. **Respiration rate:** Respiration rate was measured using a CO₂ sensor (ACR Systems Inc., St-Laurent, QC, Canada) connected to a data-logger (Smart Reader plus 7; Data logger Analysis Software, version 1.0 for windows, ACR Systems Inc.). The respiration rate was obtained from the regression slope of CO₂ concentration versus time data and evaluated as mL CO₂/kg/h.

2. **Color:** The color characteristics were assessed using a tristimulus Minolta Chroma Meter (Minolta Corp, Ramsey, NJ). The color of the mango was expressed as $L^*$ value (lightness), $a^*$ value (redness or greenness) and $b^*$ value (yellowness or blueness).

3. **Firmness:** Texture measurement was evaluated using a computer-controlled LRX Material Testing Machine (Lloyd Instrument Ltd., Fareham, UK) equipped with a 50-N-load cell. Samples were subjected to a puncture test at a constant speed of 50 mm/min using a 5-mm-diameter, round-tipped puncture probe. Force–deformation curves were recorded, and firmness (as represented by the slope of the linear section of the force–deformation curve) was used as the indicator of textural property. Several measurements were made on each fruit at different locations, and three to four fruits were used for each treatment.
Chemical Analysis

Total soluble solid (TSS) content of the fruit was determined using a hand refractometer (Atago, Tokyo, Japan). The pH was measured with a standard-calibrated pH meter (Brinkman Co., Mississauga, Ontario, Canada). Titrable acidity was determined by the titrimetric method of the AOAC (1990).

Experimental Design and Data Analysis

A factorial design of experiments was used with two main factors: storage time and treatment. With storage time at six levels, and treatments at two or four levels, it was a $3 \times 2$ factorial design for Part A and a $3 \times 4$ design for the subsequent refinement study (Part B). Each experimental unit consisted of one mango fruit per randomly removed per treatment time, and the entire experiment was conducted twice. Weight loss, respiration rate, color, firmness, pH, TSS and titrable acidity of coated and control samples were evaluated until the overall acceptability became unsatisfactory for each lot of samples. Generated data were then subjected to analysis of variance using the GLM (PROC GLM) and Mixed (PROC Mixed) procedure of the SAS statistical package (version 8.02, SAS Institute Inc., Cary, NC). Scheffe’s multiple comparison procedure was employed to evaluate the main differences when the main effects or interaction means were statistically significant ($P \leq 0.05$). All multiple comparisons were conducted at the 0.05 or 0.01 level of significance.

RESULTS AND DISCUSSION

Part A

The principal coating formulation used in this phase of study was the one developed successfully in our laboratory for extending the shelf life of avocados after a detailed study on film-making properties and coating performance (Maftoonazad 2006). It was initially assumed that the same formulation would work well for mangoes as well, and hence, a detailed storage study was carried out with coated mangoes.

Weight Loss. One of the beneficial effects of coating is the reduction in weight loss. The control and coated mangoes lost weight at different rates when stored at ambient temperature (Fig. 1). In general, loss of weight gradually increased with the storage time and was linear for both coated and control fruits. Statistical analysis showed that the weight loss in coated mangoes was significantly lower than in control mangoes held at the same temperature ($P \leq 0.05$). After 6 days of storage, control mangoes lost 6.3% of their original
weight, whereas coated mangoes lost only 4.4%. Although rapid ripening of the fruits and the incidence of disease did not permit the storage trial to go beyond 6 days for control fruits, coated fruits could be stored up to 11 days without visual signs of spoilage, with a final weight loss of 8.5%. Thus, the coating restricted the water loss and extended the shelf life of mango. Kittur et al. (2001) also used different polysaccharide composite coatings (cellulose, starch and chitosan) on mango and noticed that coated mangoes showed the least weight loss. In their study, polysaccharide coatings alone had no significant influence on the fruit weight loss. Addition of a lipid component such as beeswax (as shown in the current study), glycerol monostearate or palmitic acid significantly enhanced effectiveness of these coatings, indicating their regulation of the hydrophilic–hydrophobic balance, which would in turn, restrict the water loss.
Different commodities lose water in different ways, but for most fruits and vegetables, water is mainly lost because of cuticular transpiration, while for some, water loss occurs through stomates and lenticels (Woods 1990). The purpose of edible films is to intensify or simulate the fruit’s natural barrier, if already present, or to replace it in cases where handling and washing would partially remove or alter the natural coating. Slower rate of weight loss in coated mangoes can be attributed to the added barrier properties (Schreiner et al. 2003).

**Respiration Rate.** From the CO₂ production rates (Fig. 2), it is clear that coated mangoes show characteristic climacteric peaks on the fourth day, while the climacteric trend is relatively suppressed in coated fruits. In the case of the control mangoes, the CO₂ production rate increased rapidly from an initial value of 390 mL CO₂/kg/h to a peak value of 470 mL CO₂/kg/h on day 4, and then decreased to 360 on day 6. For the coated fruits, the CO₂ production rate started at 270 mL CO₂/kg/h and increased gradually to 300 mL CO₂/kg/h on day 3, and then decreased to 180 mL CO₂/kg/h on day 11. Thus, the coating was effective in not only retarding the occurrence of the respiratory climacteric peak but also in suppressing the climacteric trend, both helping to extend the shelf life and improve the storage quality of the mangoes. Coating fruits with a semi-permeable film has generally been shown to delay ripening by modifying the levels of endogenous CO₂, O₂ and ethylene (Banks 1984, 1985). Reduction of the respiration rate as the result of polysaccharide-based coating has also been reported for mango cultivars (cvs. Alphonso and Manila; Diaz-Sobac et al. 1996; Kittur et al. 2001). The edible coatings could have a dual effect of allowing lower amount of oxygen for the respiratory activity as well as restricting the diffusion of CO₂ out of the tissue, both causing beneficial...
secondary physiological changes during the ripening process. The processes affected by elevated CO₂ in fruits and vegetables have been listed by Kader (1986). High CO₂ concentration in the internal atmosphere of the fruit reduces respiration rate as the result of coating and prevents or delays responses to ethylene. Such an inhibition was proposed to explain the 20–30% differences observed in the initial and the final rate of respiration in green peppers and tomatoes having the pedicel sealed with linolin (Burg and Burg 1965). Although the mode of the action of elevated CO₂ concentration in the internal atmosphere of the fruit is not known, the effect has been generally attributed to the inhibitory action on the various enzyme systems involved in the mitochondrial activity. Yang (1985) reported that accumulated CO₂ may function as a natural ethylene antagonist and delay many responses of fruit tissue to ethylene. Although CO₂ has been shown to act as a competitive inhibitor of ethylene, causing a delay in ripening, the direct effect of elevated CO₂ on the ethylene production is uncertain (Burg and Burg 1967). Thus, it is observed from our results that proper coating reduced the rate of aerobic respiration of Ataulfo mangoes and, therefore, appreciably increased the storage life of the fruit. However, such lowering of aerobic respiration in a few cases stimulated anaerobic respiration and lowered the organoleptic qualities and appearance of the fruits; this effect has also been reported by others. Baldwin et al. (1999) reported that polysaccharide-coated mangoes (cv. Tommy Atkins) showed 66-fold higher ethanol and 7-fold higher acetaldehyde content compared with uncoated fruit. Our result and Baldwin’s result confirmed what has been reported in the literature – that polysaccharide-based coatings are less permeable to respiratory gases such as O₂ and CO₂ and more permeable to water vapor compared to waxes.

**Firmness.** Ripening of the mango fruit is represented by softening of the flesh, and edible coating has beneficial effects on firmness retention and delaying flesh softening. Textural changes in stored mango fruit are shown in Fig. 3. In control fruits, firmness decreased rapidly from 7.3 to 2.2 N/mm on day 4 and then decreased gradually to 1.9 N/mm on day 6. The firmness values for the coated fruits decreased from 7.7 to 3.8 N/mm at the end of the experiment (day 11). The statistical analysis showed that the effects of the main factors, treatment and day, were significant (P ≤ 0.05), and that the pectin and beeswax coating had a strong effect on the retention of firmness. However, statistical analysis did not show significant effects for coating up to day 2 (P ≤ 0.05).

Srinivasa et al. (2002) studied the effect of chitosan and low-density polyethylene film on the texture of mangoes packed in carton boxes. They found that a 50% loss of compression force can be seen in the control fruits on day 3. A similar trend, but at a lower rate, was observed in packaged fruits.
During the entire storage period, the coated fruits showed better rupture force than control fruits. Baldwin et al. (1999) coated mangoes (cv. Tommy Atkins) with a polysaccharide-based (NS) or a carnauba wax (TFC) coating and stored them at 10°C and 90–95% RH for 17 days followed by 20°C and 56% RH for 3 days in boxes. Their results revealed that at the end of storage, NS-coated fruits showed the maximum firmness, requiring 7.0 N to compress 2 mm, followed by TFC (5.3 N) and uncoated controls (2.8 N). Thus, all of the above results indicated that edible coating significantly maintains firmness. Firmness retention could be due to two reasons: one is the reduction (restriction) of moisture loss because of water vapor transmission rate (WVTR) of the film and hence the maintenance of turgidity of the fruit, whereas the second is the delayed degradation of the components responsible for the structural rigidity of the fruit, primarily the insoluble pectin and protopectin.

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fruit is characterized by an increase in the solubility of cell wall pectins (Roe and Bruemmer 1981). In mangoes, the ripening is believed to be initiated in the inner mesocarp tissue close to the seed and then progress outward (Lazan and Ali 1993). Mitcham and McDonald (1992) studied the cell wall modification of mango fruit during ripening. They observed that the activity of polygalacturonase (PG), the enzyme responsible for degrading the (1→4)-linked galacturonic acid residues and pectin esterase (PE), which catalyzes the deesterification of methyl groups from acidic pectins, increases with ripening. They also indicated that the molecular mass of the cell wall hemicellulose decreased with ripening. Various post-harvest treatments such as modified-atmosphere packaging and modified atmosphere coating, as well as storage at low temperatures, slowed the softening and resulted in corresponding retardation of both PG and PE activity (Lazan et al. 1990; Lazan and Ali 1993).

From Figs. 2 and 3, it can be recognized that there exists a negative correlation between weight loss and reduction in firmness. During the storage, weight loss increases and firmness decreases. Some loss in firmness could have been contributed by the simultaneous weight loss in these samples, although it is not possible to separate these two effects.

**Color.** Depending on the cultivar, the peel color of mango fruits changes on ripening from dark green to olive-green, with sometimes reddish, orange-yellow or yellowish hues. One of the beneficial effects of the coating is delaying in the coloring of mangoes. Color evaluation of mango skin is influenced by coating and storage times (Fig. 4). They were evaluated based on the lightness ($L^*$ value), $+a^*$ value (red direction), $-a^*$ value (green direction), $+b^*$ value (yellow direction) and $-b^*$ value (blue direction). The $L^*$ value increased with storage time, and because it is a measure of the color in the light–dark axis, this increase demonstrated that the skin color was turning more bright (tissue taking a lighter shade). Lightness values of the coated fruits were lower than those of control samples and changed at much slower rates. The results of statistical analysis showed a significant difference in $L^*$ values ($P \leq 0.05$) between control and coated mangoes after day 2. The $a^*$ value of coated and uncoated fruits is shown in Fig. 4b. In control fruits, $a^*$ value increased sharply from 0.09 on day 1 to 10 on day 2 and then gradually to 17 on day 6. For coated fruits, the $a^*$ value increased gradually from $-2.3$ to 6.0 on day 11. Clearly, the changes in the greenness occurred at a much slower rate in coated samples, and did not reach the day 6 $a^*$ value of uncoated samples even after 11 days of storage. Statistical analysis showed highly significant differences between the $a^*$ values of the coated and control samples ($P \leq 0.05$). The time-related color shift toward positive $a^*$ values indicated more redness in color because of ripening. Figure 4c shows the increase in $b^*$ value measured on mango skin. In control fruits, the $b^*$ value increased slowly
FIG. 4. CHANGES IN SKIN COLOR PARAMETERS OF MANGOES DURING AMBIENT TEMPERATURE STORAGE
A, B and C are for principal formulation (coated and control); D, E and F are for refined formulations P1, P3 and P4, respectively.
from 49 on day 1 to 54 on day 6. For coated fruits, the $b^*$ value gradually increased from 40 on day 1 to 45 on day 11. After 2 days of storage, the time-related changes in the $b^*$ value for the coated samples started to show significant differences ($P \leq 0.05$) from the control. This increase in $b^*$ value indicated more yellowness in sample color and an increase toward lighter chroma.

The results of the different color changes in mango flesh are seen in Fig. 5. These changes are characterized by a decrease in $L^*$ value and an increase in $a^*$ and $b^*$ values. In control fruits, the $L^*$ value decreased sharply to 73 on day 2 and then decreased gradually to 70 on day 6, whereas in coated fruits, $L^*$ value decreased gradually from day 1 to day 11 without any sharp decrease. This color shift toward a lower $L^*$ value is indicative of the lightness of samples reducing with the passing of time. Although statistical analysis showed highly significant effects for coating on $L^*$ values ($P \leq 0.05$), multiple comparison tests did not show a significant difference in $L^*$ values between control and coated fruits up to 3 days. Figure 5b,c show changes in $a^*$ and $b^*$ values of the flesh color of mangoes in relation to storage time. The $a^*$ value in control fruits increased quite sharply from 3 to 12 on day 2 and then increased slowly until day 6. On the other hand, the $a^*$ value increased of coated fruits gradually to 11 on day 11. The $a^*$ value was less positive in coated samples indicating the flesh to be greener; and statistical analysis showed significant differences in $a^*$ values between the test samples during storage ($P \leq 0.05$). The time-related color shift towards positive $a^*$ values indicated more redness in color, the result of ripening. A similar trend, but at slower rates could be observed for $b^*$ values, indicating an increase in yellowness of samples and toward lighter chroma. The results showed that the color changes (skin and flesh) of the Ataulfo mango sharply changed from green to yellow in the very early days of storage and then gradually changed from light yellow to darker yellow and yellow-orange. Thus, the pectin-based coating was effective in preserving green color and delaying mesocarp discoloration. Diaz-Sobac et al. (1996) reported that at a fully mature stage, control mangoes (cv. Manila) showed a sharp change in color from green to yellow between 7 and 9 days of storage, whereas mangoes coated with the emulsion based on maltodextrins and carboxymethyl cellulose showed only a minor yellowing. This sharp change in color was also seen in our study. Kolekar et al. (1992) also reported a delay in the coloring of mango fruits coated with sucrose esters. In a different study of Alphonso mango, the results of Kittur et al. (2001) showed significant differences in color between fruits coated with chitosan-based coating and control mangoes. Maftoonazad and Ramaswamy (2005) studied the effect of methyl cellulose-based coating on the color of avocados stored at room temperatures. Their results revealed that coated fruits had more green color than control; this confirmed the effect of coating on the
FIG. 5. CHANGES IN FLESH COLOR PARAMETERS OF COATED AND CONTROL MANGOES DURING AMBIENT TEMPERATURE STORAGE
green color in the present study. During the course of ripening, chloroplasts in the peel are transformed into chromoplasts containing red and yellow pigments (Lizada 1993). Well-arranged grana and osmophilic globules were observed in the chloroplasts of the cells in the peel of unripe mangoes (Parikh et al. 1990). During ripening, these membranes lose integrity and osmophilic globules appear, showing the transformation of the chloroplast to a chromoplast containing red or yellow carotenoid pigments. The precursors of the synthesis of carotenoids in mangoes are mevalonic acid and geraniol (Mattoo et al. 1968) via the isoprenoid pathway. These two compounds accumulate before the climacteric increase, but decrease in concentration during the climacteric period. Because a related increase in phosphatase activity was also detected, Mattoo et al. (1968) concluded that phosphatase activity was an important regulatory factor in mango carotenogenesis. This last process seems to be accompanied both in the peel and the pulp by changes in the ultrastructure of plastids (Parikh and Modi 1990). During the process of fruit ripening, the composition of carotenoids of mango fruit may change, with β-carotene being the most abundant carotene in unripe fruit and phytofluene in ripe fruit; γ-carotene, on the other hand, is the predominant form present in all stages of ripening (Lakshminarayana 1980). Edible coating can create or modify atmosphere within the fruit. Retardation of chlorophyll degradation in such fruits may be attributed to high CO₂ and low O₂ levels in the headspace. The retention of chlorophyll by our edible film indicated the effect of pectin and beeswax film in retarding the ripening process and thus allowing the extension of shelf life.

**TSS.** TSS (°Brix) is an important maturity index for fruits, and edible coatings are effective in lowering TSS, or, in other words, lowering ripening rates. The changes in soluble solids of coated and control fruits with storage times are shown in Fig. 6a. The TSS increased during storage time for coated and non-coated samples. TSS sharply increased from 10% on day 1 to 17% on day 2 and then gradually to 20% on day 6 for control fruits. In coated fruits, it slowly increased from 11% on day 1 to 15% on day 11. Again, the changes in the percentage of soluble solids occurred at a much slower rate in coated samples and did not reach the day 6 TSS value of uncoated samples even after 11 days of storage (Fig. 6). Statistical results showed a significant difference \( P \leq 0.05 \) in TSS values between control and coated fruits from day 2. The results of our experiments revealed that coated mangoes showed a smaller reduction in TSS values than controls. Lower TSS values for coated mangoes have also been reported by other researchers (Diaz-Sobac et al. 1996; Srinivasa et al. 2002). On one hand, the high percentage of soluble solids in the control fruits is attributed partly to water loss and drying of mango fruits; on the other hand, the increase in SS is a direct consequence of the breakdown of
complex carbohydrates into water-soluble sugars during normal ripening, a consequence that is also observed as pulp softening. Edible coatings delayed ripening as indicated by changes in TSS observed in our experiments, as well as those reported by other researchers. During ripening, starch is degraded rapidly by the combined action of amylases, starch phosphorylase and 1,6-glucosidase and sucrose synthase, to sugars such as sucrose, glucose and fructose along with traces of maltose. At the start of the ripening, sucrose is the predominant sugar in the pulp, and its formation precedes accumulation of glucose and fructose (Kittur et al. 2001). Based on our experiments, the TSS values of pectin-based coated fruits were lower than those of the control, suggesting that the former synthesized sugars at a slower rate than the latter.

FIG. 6. CHANGES IN SOLUBLE SOLIDS IN THE FRUITS DURING STORAGE
(A) Principal formulation and (B) refined formulations P1, P3 and P4.
**pH and Titrable Acidity.** As the mango fruit ripens, organic acid content decreases and the sugar content increases, thus making the mango fruit taste sweeter. Coating is known to delay the decline in acidity. The variation in pH and acidity in control and coated mangoes are shown in Figs. 7 and 8. With storage time, pH increased for both coated and control samples (Fig. 7). The increase was more pronounced in control than in coated fruits. Initially, the pH of the fruits was 2.9, but as the fruit ripened, the pH of control fruits increased quite sharply to 4.2 on day 6, compared with 3.3 in coated fruits on the same day. Statistical analysis did not show significant effects for coating up to 5 days of storage. The pH for coated fruits shows different rates of increase and never reached the day 6 control fruits. The acidity (related and expressed also as titrable acidity) for coated and non-coated fruits is shown in Fig. 8. The titrable acidity values decreased sharply starting from 0.35, decreasing to 0.05
on day 6. As expected, this reduction was much less for coated fruits. Statistical analysis showed a highly significant difference \((P \leq 0.05)\) between control and coated samples after day 3 of the storage. The results of our experiment agree with the results of other researchers who have reported similar pH and acidity changes in mango fruits as the result of coating. Diaz-Sobac et al. (1996) reported higher increases of pH and decreases of acidity in control samples compared with the pH and acidity in mangoes coated with maltodextrin and carboxymethyl cellulose. In a different study, Maftoonazad and Ramaswamy (2005) studied the effect of methyl cellulose and sodium alginate on the pH and acidity changes in peaches. They reported that acids in peaches decreased at a slightly higher rate in control samples compared with coated fruits.

During aerobic respiration in plant cells, as evidenced by tri-carboxylic acid pathway of glucose oxidation, organic acids are actively involved in many enzyme-catalyzed reactions; a reduction in the acidity may be expected as a result of such activity during the ripening process. Citric acid is the predominant acid followed by varying amounts of glycolic, malic, tartaric and oxalic acids (Medlicott and Thompson 1985). In general, levels of citrate and succinate gradually decrease during ripening, whereas malate shows different changes with different cultivars. With the onset of ripening, the levels of malic and succinic dehydrogenase increased, whereas the level of citrate synthase increased several fold on maturation but decreased markedly at ripening (Boqui et al. 1974). Generally, the activity of most of organic acids increases during ripening, reaching its maximum a little ahead of the climacteric peak and then declines (Dubery et al. 1984). A decline in acidity demonstrates advancement of maturation and ripening; thus, edible coating contributes to delaying the fruit maturation and ripening through reduction of respiration rate.
and lower utilization of organic acids stored in the vacuoles as respiratory substrate (Medlicott et al. 1987).

**Visual Appearance and Disease Progress.** Beneficial effects of fruit coatings include improvement of appearance and reduction of post-harvest decay. Control fruits started to turn yellow on day 2, and shrinkage and shriveling of skin was noticed on day 6. The fruits turned unattractive because of the formation of wrinkles on the surface, which was associated with the loss of water from the fruits. Therefore, evaluation of control fruits at ambient temperature was discontinued after day 6. On the other hand, coating imparted an attractive smooth sheen to the fruits, and coated fruits maintained wholesome appearance even after 11 days of storage at ambient temperature. However, in some cases, brown spots were observed at the end of storage on the surface of the fruits, which perhaps indicated anaerobic respiration. It was also noticed that this discoloration was limited only to the skin of the fruit, and that the area of the flesh beneath this discoloration was not affected. Baldwin et al. (1999) reported that polysaccharide coatings were less permeable to respiratory gases, such as O₂, than waxes. Their results also showed that coating can improve the appearance of mangoes by imparting a subtle shine.

Decay in the mango fruits were identified as anthracnose, caused by *Colletotrichum gloeosporioides* and stem-end rot (SER), caused by a number of fungi including *Lasiodiplodia theobromae*. Anthracnose symptoms typically appear as the fruit ripens. The lesions are observed at first on the surface of the fruit but later penetrate into the flesh; eventually the flesh beneath the lesions undergoes a soft decay (Snowdon 1990). SER brings heavy losses to mango during transit and storage. The darkening of the skin around the base of pedicel is an early symptom of the disease development on the mature fruit. The lesions extend quickly within a few days and form circular brownish-black areas of water-soaked tissue, which can progress over the whole fruit. On the control fruits, the first symptoms of decay were observed after 5 days at ambient temperature. At this time, 5% of the fruits had anthracnose symptoms represented as small regions on their surfaces. At the end of the experiment, 9% of the control fruits showed symptoms of anthracnose and less than 1% had SER (total = 10%). In comparison, 3% of the coated fruits exhibited anthracnose at the end of experiment (11 days). Thus, the results suggested that pectin-based coating would help to reduce post-harvest diseases of mango. Maftoonazad et al. (2006) studied the effect of pectin-based coating on the physical and physiological changes in avocados as influenced by SER. Their results showed that pectin-based coating can reduce the rate of disease progress. Many post-harvest diseases of mangoes show the phenomenon of quiescence, in which until the ripening of the produce symptoms do not progress (Jeffries and Dodd 1990). Edible coating can delay ripening and also
the progress of the disease. It is also possible that coating can form a physical barrier against new pathogenic infections, reducing the incidence of post-harvest disease (Amarante and Banks 2001).

**Part B: Refinement**

As mentioned in the previous section, some coated mangoes exhibited symptoms of anaerobic respiration. Anaerobic respiration obviously results from reduced availability of oxygen, which in turn results from reduced oxygen transmission through the coating. Based on this, it was decided to address the issue by slightly modifying the composition of coating materials. This was explored in two steps: in the first step, experiments were designed to screen different levels of pectin, sorbitol, beeswax and monoglycerides. Table 1 shows the different compositions used in this study. In general, it was observed that only the coating formulations with less than 2% pectin were suitable for this cultivar of mango (cv. Ataulfo) without adversely affecting its quality. Mangoes treated with more than 2% pectin developed off-flavor because of anaerobiosis even when the surface color looked fairly normal, suggesting that these coatings have lower oxygen permeability. Kittur et al. (2001) used different formulations based on different levels of chitosan, starch and cellulose on mango. Their results showed that the formulations with a total solid level of 1.5–2.5% were effective, whereas higher concentration resulted in anaerobiosis. They concluded that coatings would have an optimum percentage of solid levels, according to the type of fruit or vegetable cultivar.

In the second phase, the three best compositions showing normal ripening behavior of mangoes were selected and further studied. These were identified as P1, P3 and P4 (Table 1). These formulations were then studied further with

<table>
<thead>
<tr>
<th>Code</th>
<th>Pectin (g pectin/100 g distilled water)</th>
<th>Sorbitol (% based on pectin dry weight)</th>
<th>Beeswax (% based on pectin dry weight)</th>
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<tbody>
<tr>
<td>P1</td>
<td>1.3</td>
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<td>1.3</td>
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<td>P4</td>
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<tr>
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</tr>
<tr>
<td>P9</td>
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respect to shelf-life extension as well as their influence on quality factors (weight loss, firmness, color, pH, TSS, appearance and decay), and the results are summarized below:

**Weight Loss.** Figure 1b shows the influence of pectin-based coatings on the weight loss of mangoes stored up to 13 days. Generally, the loss of weight gradually increased for both coated and control samples. Treatment P3 and P4 resulted in the lower weight loss. After 7 days of storage, control fruits lost about 7.9% of their weight, whereas fruits subjected to treatments P1, P3 and P4 lost 7.7%, 6.4%, and 5.8% of their weights, respectively, at the end of 7 days. They continued to lose weight to 12.8%, 12.2% and 11.2%, respectively, at day 13. Expectedly, all these also had slightly higher weight loss than observed in the first study (Fig. 1) because of the lower level of pectin concentration (thereby increasing the water vapor permeability). Although Fig. 1b shows that control and coated mangoes lost weight at different rates, statistical analysis did not indicate this difference to be significant; this, however, did show that the mean values are statistically different on different days. The mean values for weight loss on each day were also significantly different from those on the following days; for example, day 1 was significantly different from that on days 3, 5 and 7. The difference in the ability of these coatings to reduce weight loss could be attributed to differences in the permeability characteristics, which in turn could be attributed to differences in the relative concentrations of the main ingredients in each composition (Table 1). Overall, P3 and P4 were found to be more effective than P1 and control for reduction of weight loss of Ataulfo mangoes.

**Firmness.** Figure 3 also shows changes in firmness of mango test samples during storage at ambient temperature. The firmness decreased with time both for control and coated fruits; however, the pectin-based composite coating maintained firmness better than the control. As before, the control fruits softened rapidly and were fully ripe within 7 days of storage. Their firmness index decreased sharply from 4 N/mm on day 1 to 2 N/mm on day 3, and then decreased gradually to 1.5 N/mm on day 7. This fast textural softening is attributed to the rapid ripening behavior. Statistical analysis showed not only a significant difference ($P \leq 0.05$) between coated and control samples, but also among the different coating treatments P1, P3 and P4. Treatments P1 and P3 were more effective than P4 and better controlled the firmness retention, with P3 being the most effective. These results suggested that the treatment formulation P3 was more desirable and provided a better combination of oxygen and WVTRs than other treatments or control, which led to a desired inhibition of pectolytic enzyme activity, responsible for cell wall degradation.
Skin Color. The results of different color changes in mango skin as influenced by storage time, as well as different coating formulas, are also shown in Fig. 4d–f. The changes demonstrated an increase in $L^*$, $a^*$ and $b^*$ values. The rate of increase in control samples was higher than in coated samples (Fig. 4d). Statistical analysis showed highly significant effects for coating on $L^*$ values ($P \leq 0.05$). No significant difference was observed between P1 versus P3 and P4 coated fruits ($P \leq 0.05$; Table 1). In addition, P3 was better than other treatments in delaying lightness changes in this cultivar of mango.

Changes in $a^*$ and $b^*$ values of the skin color of mango are shown in Fig. 4b,c. The $a^*$ value was less positive in coated samples compared with control, indicating the mango skin to be greener; statistical analysis further showed highly significant differences in $a^*$ values between control and coated fruits ($P \leq 0.05$). The time-related color shift toward more positive $a^*$ values in the control compared with coated indicates more redness, as the result of ripening. Statistical analysis of data showed that there are not only significant differences between treatments P1 and P4 but also between P3 and P4. In addition, fruits with P4 treatment exhibited the most, and those treated with P3 showed the least, change in $a^*$ values based on statistical analysis (Table 1).

Figure 4c shows the increase in $b^*$ values measured in mango skin, with highly significant differences between control and coated samples ($P \leq 0.05$) and a significant difference among coated samples. This increase in $b^*$ value indicates an increase in yellowness of the samples and an increase toward lighter chroma. This response was slower in coated samples. Fruits coated with P3 exhibited the least, and those coated with P4 showed the most, change in $b^*$ value. The lower color changes in coated fruits may be attributed to the effect of coating in creating modified atmosphere within the fruit (i.e., higher concentration of CO$_2$ in the internal atmosphere); this is known to be an important factor in preventing chlorophyll degradation. P3 was more effective than others in lowering color changes, which may be related to lower permeability of this composition to O$_2$ and CO$_2$ compared with other formulations treated here.

TSS and pH. Changes in TSS and pH parameters are included in Figs. 6 and 7, respectively. In general, TSS values were lower in coated fruits compared with control (lower TSS means a lower ripening rate). TSS in control fruits increased to 20.8% on day 7 compared with fruits subjected to P1 (17.1%), P3 (19.2%) and P4 (20%) treatments. The TSS on day 13 for coated fruits reached the value of that on day 7 for control fruits, which meant that P1, P3 and P4 did not disturb the normal ripening behavior compared with the earlier experiments (Fig. 6a). Statistical analysis did not show any significant difference among P1, P3 and P4 coated fruits ($P > 0.05$). As mentioned before,
the formation of TSS results from the breakdown of complex carbohydrates into water-soluble sugars.

In general pH increased with the storage period, and coated fruits showed a lower value throughout compared with control fruits (Fig. 7b). Although statistical analysis showed highly significant differences between control and coated fruits, it did not show significant differences among coated fruits in spite of the significant differences between least square means ($P \leq 0.01$; Table 1). The least square mean for P3 was $(3.39 \pm 0.05)$, which was lower than others, which could mean that P3 coated fruits utilized less organic acid as respiratory substrates during the respiratory process.

Appearance and Decay. As expected, the control fruits started to turn yellow on day 2 and appeared yellow-orange on day 7. The loss of water from the control fruits was associated with the shrinkage of skin. Visual impairment started to manifest on day 5, and the fruits became unattractive after day 7. Anthracnose started to develop on the surface of the fruits on day 5 and progressed to day 7, after which the storage test for control fruits was terminated. On the other hand, the P1, P3 and P4 coated fruits showed gradual color changes and loss of greenness, which is attributed to the beneficial effect of coating. Coating treatments imparted an attractive natural-looking gloss and smooth skin to the fruit. P1 and P4 coated mangoes showed slight skin wrinkling accompanied by some symptoms of anthracnose on the surface. P3 coated fruits stayed smooth and firm throughout the study with no signs of wrinkling and decay until day 13. For the three of the coating compositions tested (P1, P3 and P4), no signs of surface browning discoloration and off-flavor were detected. Overall, the results of refining of formulations showed that treatment P3 was the most effective in shelf-life extension and maintaining the quality of mango Ataulfo stored at ambient temperature.

CONCLUSIONS

Application of the pectin-based coating on Ataulfo mangoes was effective in reducing the associated physiological changes and extending the storage life. This coating limited the transpiration and consequently diminished weight reduction by water evaporation, also reduced respiration rate and prevented or delayed responses to ethylene. For post-harvest fruit handling, these are considered to be key factors. This coating favorably affected several physiological and chemical properties of the fruit during storage. The coating also imparted sheen and enhanced the visual appeal of the fruits, reduced decay, reduced the color changes in both skin and flesh, and lowered the softening of the tissue.
It delayed ripening as indicated by changes in TSS, pH and titrable acidity. The control fruits could only be stored for 7 days before becoming unacceptable, whereas the coated fruits remained good up to 13 days of storage at room temperature, thereby providing twofold shelf-life extension at room temperature. However, coating can sometimes result in anaerobic respiration and off-flavor development. To prevent this and to get the best results, the formulation need to be optimized to strike a balance between gas and water vapor transmission, which would depend on the fruit and/or vegetable cultivar (especially the respiration rate). P3 was found to be the best formulation combination for the mango under the conditions tested.

REFERENCES


