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ScienceDirect
Carbohydrate Polymers 68 (2007) 341–349
Carbohydrate Polymers
www.elsevier.com/locate/carbpol

Effect of pectin-based edible emulsion coating on changes in quality of avocado exposed to *Lasiodiplodia theobromae* infection

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Received 25 August 2006; accepted 30 November 2006
Available online 24 January 2007

Abstract

This study was carried out to evaluate the effect of pectin-based edible emulsion coating on activity and disease severity of *Lasiodiplodia theobromae* in avocados, and their subsequent influence on the fruit quality. In order to assess the influence of coating and disease, avocados were sorted and devided into four equal lots and all were incubated at 20 °C for up to 4 days. The first and second lots constituted samples which were stored as coated and uncoated, respectively, without fungal inoculation. The third and fourth lots were coated and un-coated fruits inoculated with the fungal disease. For coating, a previously standardized pectin-based emulsion was used. The incubated fruits were examined for the spread of disease, respiration rate and quality parameters, color and texture. As the incubation time increased, the volume of disease (VDS) increased, which in turn influenced the respiration rate (RR) in both coated and uncoated fruits. However, the coated fruits sustained a significantly slower rate of disease spread and RR. Similarly, the associated quality changes (texture and color) were much lower in coated fruits as compared with the control. Thus, the pectin based coating was effective in controlling the spread and severity of stem end rot in avocados. Changes in physical and physiological parameters of coated and uncoated fruits were well described by some form of semi-logarithmic models and were related to the VDS as well as case dependent incubation time.

Keywords: Avocado; Storage; Edible film; Pectin; Coating; *Lasiodiplodia theobromae*; Texture; Color; Respiration rate

1. Introduction

Post-harvest diseases of fruits and vegetables are a major problem in produce storage and significantly affect the cost of food production and produce trade. Ready to sell fresh or processed food carries a higher value than the same crop in the field because of the cumulative cost of production, harvesting, storage, distribution, and sales (Wilson & Pusey, 1985). Stem-end rot, caused by *Lasiodiplodia theobromae*, is one of the most common diseases of avocado in storage. This pathogen has a large host range and causes serious losses in warm and humid growing areas. It requires free moisture on the surface of fruits to penetrate. Natural openings such as lenticels or stomata and wounds are the primary infection courts for the fungi. Symptoms of stem-end rot include softening of the tissues, color changes of the infected tissue from green to brown and foul odor.

Post-harvest diseases of fruits are normally suppressed by low-temperature storage, by creating modified atmospheres (lower oxygen and elevated carbon dioxide levels), and/or some treatments that delay the tissue senescence. Use of edible coating has become a topic of great interest because of their potential value in increasing the shelf life of many food products. Edible coatings can create modified atmosphere, similar to that of modified atmosphere storage or package, their effectiveness being a function of coating permeability and fruit respiration. Fruit decay can be slowed by delaying ripening and moisture loss. Both

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0144-8617/$ - see front matter © 2007 Published by Elsevier Ltd.
doi:10.1016/j.carbpol.2006.11.020

these processes hasten the senescence, making the commodity more prone to pathogenic infection as a result of loss of cellular integrity and the tissue's natural defense mechanism. Besides these physiological effects, coatings can also form a physical barrier against pathogenic infection, reducing incidence of post-harvest disease (Amarante & Banks, 2001). Ben-Yehoshua (1966) observed delay and reduction in the incidence of decay with a polyethylene-wax-based coating in banana, particularly of the cut surfaces of fruit. However, in paraffin coated bananas, when the occurrence of anthracnose was high, an increase in decay rate was reported (Blake, 1966). It was shown that orange treated with a shellac-based coating had a lower decay than uncoated fruits, but methyl cellulose based coating did not show a beneficial effect on the fruits (Pojewijd, Nisperos-Carriedo, Burns, Parish, & Baldwin, 1995). McGuire and Hallman (1995) observed that cellulose and Carnauba wax coatings had no effect on incidence of post-harvest decay of guava fruits. A lower incidence of decay was reported in cucumbers coated with NatureSeal^{R}, with or without the addition of carnauba wax micro-emulsion than control (Baldwin, Nisperos-Carriedo, Hagenmaier, & Baker, 1997). Chitosan has been shown to be effective against decay by inhibiting fungal activity in strawberry (El Ghouth, Arul, Grenier, & Asselin, 1992a) and tomato (El Ghouth, Ponnampalam, Castaigne, & Arul, 1992b).

Respiration, one of the first functions to be affected when fruits are infected with pathogens, generally has been shown to increase with the severity of disease. The increased rate of respiration appears shortly after infection, certainly becomes obvious by the time of appearance of visible symptoms, and continues to rise during the multiplication and propagation of the pathogen (Nourian, Kushalappa, & Ramaswamy, 2002). Respiration rate has been used as a tool in predicting internal quality and storability of fruits. Color and textures are two physical quality parameters that affect consumer acceptability. Good quality avocados are firm, green and without any disease. Modeling of these parameters as affected by coating and incidence of disease enables the producer to take intelligent decisions to optimize the marketability and profitability of the product.

Although there are several studies on the use of edible coatings on a variety of fruits and vegetables even in the context of the incidence and spread of disease, application of these to avocados is scarce. In our first study, methyl cellulose was shown to be effective as an edible film for avocados for extending the shelf-life by almost 30% margin (Maftoonazad & Ramaswamy, 2005). This study was later extended to pectin-based emulsion formulations which were systematically evaluated and optimized. The pectin-based emulsion was demonstrated to be far more effective than the methyl cellulose coating (Maftoonazad, 2006). This present study is an extension of the above work evaluating the effectiveness of the pectin-based emulsion coating in controlling the incidence and spread of stem-end rot disease in avocados. A subsequent objective is to model the quality changes associated with avocados as affected by coating and spread of disease.

2. Materials and methods

2.1. Fruit preparation

Avocado fruits (cv. Hass) were obtained from a local source. The fruits were carefully selected to be uniform in appearance (size and color) and feel firmness. Fruits were surface disinfected by immersion in 0.5% commercial bleach for 15 min, washed and dried under laminar flow hood.

2.2. Inoculum preparation

The fungal culture, *L. theobromae*, was obtained from the Agriculture and Agri – Food Canada, Summerland, British Columbia. They were grown on potato dextrose agar at 22 °C for 7 days and stored at 4 °C. Seven- to ten-day-old subcultures were flooded with 0.05% Tween 80 in distilled water and filtered through two layers of cheese-cloth. The concentration of spores in suspension was adjusted to 10^5 ml^{-1} conidia using a heamocytometer.

2.3. Fruit inoculation and incubation

In order to assess the influence of coating and disease, avocados were sorted and devided into four equal lots and all were incubated at 20 °C for up to 4 days. The first and second lots constituted samples which were stored as coated and uncoated, respectively, without fungal inoculation. The third and fourth lots were coated and uncoated fruits inoculated with the fungal disease. For inoculation, four wounds, each 4 mm diameter and 3 mm deep, were made on one side of the fruit using a sterile cork borer. Each wound was inoculated with 30 μl of spore suspension to induce disease. The same number of fruits were inoculated with sterile water to serve as control. The prepared fruits were incubated in two covered plastic trays, with 1 cm thick non-contacting layer of water at the bottom for keeping a high humidity. Some holes in the lid facilitated ventilation. Samples were removed at different time intervals (24, 48, 72 and 96 h) and evaluated for the disease severity and quality.

2.4. Coating emulsion and procedure

A 3% (w/w) pectin solution was prepared by rehydrating pectin (HM rapid set powder, TIC GUMS, Belcamp, Maryland, USA) in distilled water (12 h at 20 °C), and 45% (pectin dry basis) of sorbitol (Sigma, Oakville, ON,

Canada) was added and thoroughly mixed with magnetic stirring. Then, 40% (pectin dry basis) melted bees wax (Sigma, Oakville, Canada) was added and emulsified using a homogenizer (PowerGen 700, Fisher Scientific, Pittsburg, PA, USA) at 14000 rpm for 4 min. The quantities of sorbitol and beeswax were previously optimized based on their influence on mechanical and barrier properties of the formed film (Maftoonazad, 2006). Avocados were immersed in the coating solution for 1 min at 20 °C and then drained. The treated fruits were dried in a cold-air draft for 10 min to set a coat of the film on their surface. They were then stored along with control samples at 20 °C in trays.

2.5. Disease severity assessment

Following each incubation time, five avocados were removed and cut at the middle of each wound using a sharp knife. The diameter of the discolored tissue due to disease was measured as the average at three depths: top, middle and close to bottom, and the height was measured at the deepest point. The average volume of disease (cm^3) per inoculation site (VDS) was calculated (Nourian et al., 2002).

$$\mathrm{VDS} = \Sigma[(\pi d^2 h/4)_i]/n \quad (1)$$

where, d is the mean diameter and h is the depth of the inoculated site i, and n is the number of sites inoculated. The disease severity parameter VDS was related to texture and color quality parameters because these parameters were determined immediately beneath the diseased area. However, to relate the disease severity to fruit respiration, which was measured using five whole avocado fruit, the volume of disease per unit weight (cm^3/g) of fruit (VDW) was calculated:

$$\mathrm{VDW} = (\mathrm{VDS} \times n)/W \quad (2)$$

where VDS is the average volume of disease per unit site, n is the number of sites included in the sample, W is the total weight of the five fruits in g.

2.6. Respiration rate

A known quantity of avocados (about 1 kg) was placed in an airtight Plexi-glass chamber ($18 \times 12 \times 27$ cm). A CO_2 sensor (ACR Systems Inc; St-Laurent; PQ) connected to a data-logger (Smart Reader plus 7; Data Logger Analysis Software; Version 1.0 for Windows; ACR Systems Inc; St-Laurent, PQ) was installed in the chamber, to monitor CO_2 concentration. The data-logger was programmed to collect on-line data of CO_2 concentration at 1 min intervals over a 2 h period. Respiration rate was obtained from the regression slope of CO_2 concentration versus time data and evaluated as mL kg^{-1} h^{-1}.

2.7. Texture firmness

Texture measurements were made using a computer controlled LRX Material Testing Machine (Lloyd Instrument Limited, Fareham, UK) equipped with a 50N load cell. Samples were subjected to a puncture test at a constant speed of 50 mm min^{-1}, using a 5 mm diameter round tipped puncture probe. Force-deformation curves were recorded and firmness [as represented by the slope (Nmm^{-1}) of the linear section of the force-deformation curve] was used as the indicator of textural property. At least 6 measurements were made on each fruit at different locations and 5 fruits were tested for each incubation time and the results were averaged.

3. Color

The color characteristics were assessed using a tristimulus Minolta Chroma Meter (Minolta Corp, Ramsey, NJ) to determine L value (lightness or brightness), a^* value (redness or greenness) and b^* value (yellowness or blueness) of avocado samples. The colorimeter was warmed up for 20 min and calibrated with a white standard. Measurements were taken for four samples and the average of L, a^* and b^* values were obtained. In addition to the L, a^* and b^* values, the total color difference was computed as the root mean square of the differences in individual L, a and b values as follow:

$$\Delta E = [(\Delta L^2 + \Delta a*^2 + \Delta b*^2)^{1/2}] \quad (3)$$

ΔL, Δa^* and Δb^* were obtained as differences in L, a^* and b^* values of test samples on any given day from those existed on the first day, thus representing the time related changes. Color of skin was determined on six different locations on the surface of the fruit. The instrument was calibrated with a white standard tile: $L = 95.87$, $a = -0.86$ and $b = 2.47$.

3.1. Statistical analysis

The experiment was designed as factorial, with four main factors of coating/inoculation (coated-inoculated, uncoated-inoculated, coated-control, uncoated-control) and five sub-factors of incubating times 0, 24, 48, 72 and 96 h. Each experimental unit consisted of one avocado and the entire experiment was conducted twice. The data output consisted of respiration rate, weight loss, color and firmness measurement. Data were analyzed by analysis of variance (ANOVA) using SAS software (SAS Institute, Cary, NC) and t-test was used to compare means in each incubation time. The significance levels used were $p < 0.05$ (*) and $p < 0.01$ (**).

4. Results and discussion

4.1. Effect of coating on disease severity of avocados

Disease developed in avocados with *L. theobromae*. The first visible symptoms of disease appeared after 24 h of incubation at room temperature, as dark discoloration

around the artificial wounds. At longer incubation times, the lesions enlarged in size in both coated and uncoated inoculated avocados. The disease severity measured as the volume of visually discolored tissue at the wound site, VDS (Eq. 1), increased significantly ($p < 0.01$) with an increase in incubation time (Fig. 1). Coated fruits showed lower VDS than that of uncoated fruits which confirmed the modification of internal atmosphere by use of coating and suppressing fungi growth and disease progress. Statistical analysis confirmed a highly significant effect of coating in decreasing VDS at each incubation time ($p < 0.01$). No disease was observed in the control coated samples incubated in the same tray of inoculated coated samples which shows the ability of coating to prevent disease incidence. A power model was used to describe the effect of incubation time (t) on VDS in coated and uncoated fruits (Eqs. 4 and 5):

$$\text{Uncoated avocados}: \text{VDS} = 1.0 \times 10^{-05} t^{4.68} (R^2 = 0.976) \quad (4)$$

$$\text{Coated avocados}: \text{VDS} = 6.0 \times 10^{-05} t^{4.44} (R^2 = 0.970) \quad (5)$$

From Fig. 1 and the above models, it is clear that the incidence of disease is not noticeable until about 24 h and then the spread of disease in uncoated avocado is more rapid by a factor of 5% on an exponential scale.

4.2. Effect of coating on respiration rate in inoculated and control fruits

The rate of respiration increased with an increase in disease severity (Fig. 2a). The respiration rate is expressed on a weight basis rather than site basis since it is measured based on a unit weight of the product (Nourian et al., 2002). The disease severity (VDW, Eq. 2) changed from a low 0.472 to 24.7, 154 and 277 $mm^3\ g^{-1}$ for coated samples and from 1.13 to 56.4, 288 and 488 $mm^3\ g^{-1}$ for uncoated fruits after 24, 48, 72 and 96 h incubation time, respectively. Increase in respiration rate of inoculated avocados can be explained by the increased metabolism, because the energy required for the metabolic activities are derived

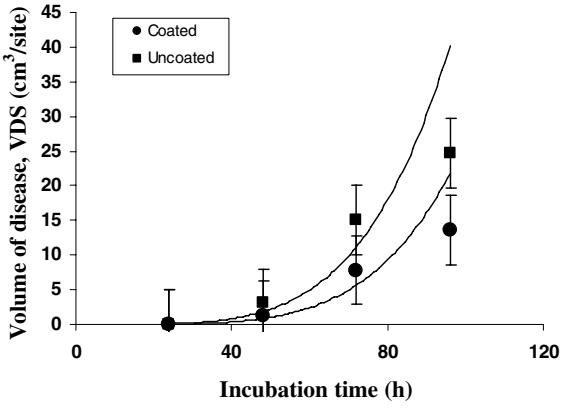

Fig. 1. Disease severity of coated and uncoated avocados as influenced by incubation time.

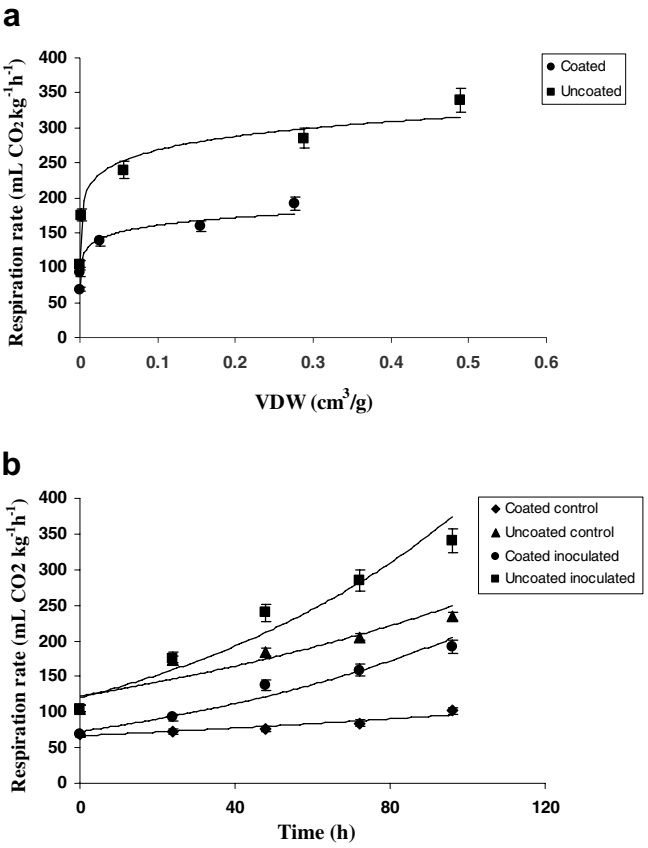

Fig. 2. Effect of pectin-based coating on respiration rate of avocado fruits (a) as influenced by disease severity and (b) during incubation time.

from respiratory pathways. This means that the disease affected tissues respire more rapidly and use up their reserved supplements faster than healthy tissue. The rate of respiration increases shortly after infection and continues to rise during reproduction of the pathogen (Agrios, 1997). As shown in Fig. 2a coating had a highly significant effect on respiration rate of the inoculated fruits. It can be attributed to the reduced oxygen uptake by the coated fruits and thereby lowering the respiration rate of the commodity. Again a power model well described the effect of disease severity (VDW) on respiration rate (RR) of coated and uncoated fruits:

$$\text{Uncoated avocados}: \text{RR} = 339\text{VDW}^{0.101} (R^2 = 0.986) \quad (6)$$

$$\text{Coated avocados}: \text{RR} = 200\text{VDW}^{0.0951} (R^2 = 0.983) \quad (7)$$

In these two equations, the power coefficient for the two cases were nearly the same (showing somewhat parellel curves, Fig. 2), but the intercept for the coated sample was less than 40% for the uncoated fruits.

Fig. 2b shows the effect of pectin-based edible coating on time based respiration rate of inoculated and control fruits. Again a highly significant difference was observed between coated and uncoated fruits with or without infection ($p < 0.01$). Since the uncoated control avocados show the normal respiration pattern, any increase in respiration

of inoculated avocados is related to the spread of the disease, and any decrease in the respiration rate is the effect of coating. The effect of coating on the lowering of respiration rate is clearly obvious from the figure. Eqs. (8)–(11) describe the respiration rate (RR) in avocados as affected by incubation time (t) for both coated and uncoated fruits with or without disease:

$$\text{Coated inoculated} : \text{RR} = 72.8e^{0.0107t} (R^2 = 0.967) \quad (8)$$

$$\text{Coated control} : \text{RR} = 66.0e^{0.00400t} (R^2 = 0.911) \quad (9)$$

$$\text{Uncoated inoculated} : \text{RR} = 120e^{0.0118t} (R^2 = 0.941) \quad (10)$$

$$\text{Uncoated control} : \text{RR} = 122e^{0.00740t} (R^2 = 0.840) \quad (11)$$

The pattern is very clear: the exponential rate of respiration increase in coated control (0.00040/h) is the least with coated control increasing to 0.0074/h without coating, 0.00107/h with coated inoculated to 0.0118/h with uncoated inoculated sample which is most susceptible for the spread of the disease. Reduction of the respiration rate as a result of coating with edible films has also been reported for banana (Banks, 1984), pear (Meheriuk & Lau, 1988) and tomato (Nisperos & Baldwin, 1988). Although the rates of increase of respiration rate in coated and uncoated inoculated fruits were the same, the uncoated samples were much higher in respiration rate in each incubation time.

4.3. Effect of coating on firmness of in inoculated and control fruits

Avocado texture decreased with increase in incubation time after inoculation, along with increase in disease severity (Figs. 3a and b). However; the pectin-based coating reduced fruit softening in both inoculated and control fruits significantly ($p < 0.01$) and had a beneficial effect on firmness retention. Retention of firmness can be explained by retarded degradation of insoluble proto-pectins to the more soluble pectic acid and pectin. During fruit ripening, depolymerization or shortening of chain length of pectin substances occurs with and increase in pectin-estrase and polygalactronase activities. Low oxygen and high carbon dioxide concentrations created by coating reduce the activities of these enzymes and allows retention of the firmness of fruits and vegetables during storage (Salunkhe, Boun, & Reddy, 1991). Eqs. 12 and 13 show the effect of disease severity on firmness (F) of avocado in coated and uncoated avocados:

$$\text{Coated} : F = 5.74\text{VDS}^{-0.137} (R^2 = 0.901) \quad (12)$$

$$\text{Uncoated} : F = 3.87\text{VDS}^{-0.195} (R^2 = 0.913) \quad (13)$$

The firmness of uncoated fruits decreased at a rate 40% faster than the coated samples.

Eqs. (14)–(17) describe loss of firmness during incubation time in inoculated and control avocados with or without coating:

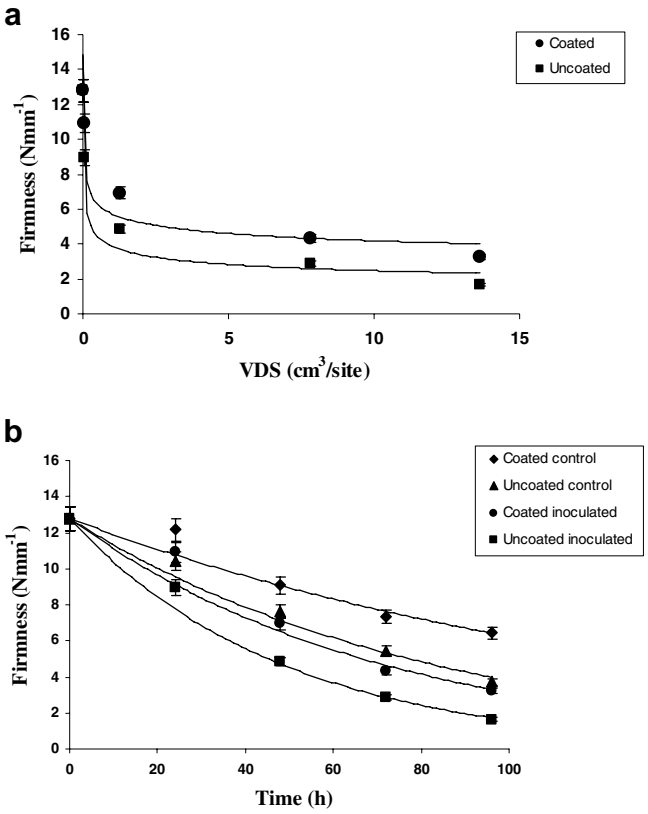

Fig. 3. Effect of pectin-based coating on firmness of avocado fruits (a) as influenced by disease severity and (b) during incubation time.

$$\text{Coated inoculated} : F = 12.8e^{-0.0141t} (R^2 = 0.969) \quad (14)$$

$$\text{Coated control} : F = 12.8e^{-0.00720t} (R^2 = 0.955) \quad (15)$$

$$\text{Uncoated inoculated} : F = 12.8e^{-0.0208t} (R^2 = 0.991) \quad (16)$$

$$\text{Uncoated control} : F = 12.8e^{-0.0121t} (R^2 = 0.989) \quad (17)$$

The loss in firmness trends were similar to those observed with respiration rate except that the firmness decreased while the respiration rate increased with the disease and without the help of coating. The exponential firmness loss rate in uncoated inoculated sample was almost three times that in coated control samples.

4.4. Effect of coating on color in inoculated and control fruits

At different levels of disease, produced by different intervals of incubation time, the color, quantified as L, a^*, b^* and ΔE, varied in different ways. These changes were manifested by a decrease in L and b^* values and an increase in a^* value and total color difference values. As shown in Figs. 4a and b, the rate of L value reduction in samples without coating was higher than in coated samples for both inoculated and control avocados. Statistical analysis showed highly significant effect for coating on L values ($p < 0.01$). This color shift towards lower L value is indicative of lower brightness of samples with the progression of incubation time. The following equations represent the relationship

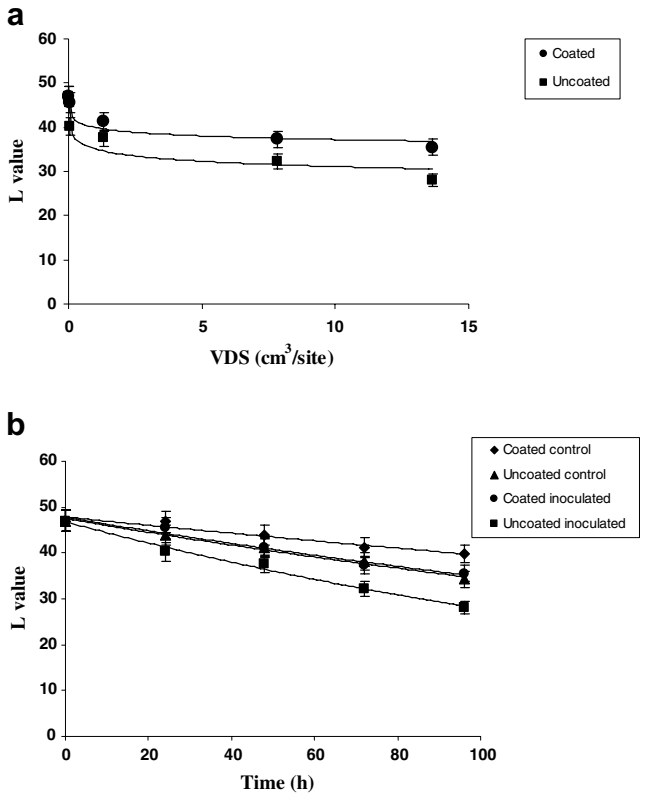

Fig. 4. Effect of pectin-based coating on L value of avocado fruits (a) as influenced by disease severity and (b) during incubation time.

between disease severity and L value in coated and uncoated fruits:

$$\text{Coated}: L = -1.19\ln(\text{VDS}) + 39.9 (R^2 = 0.930) \quad (18)$$

$$\text{Uncoated}: L = -1.72\ln(\text{VDS}) + 35.1 (R^2 = 0.922) \quad (19)$$

The differences between the two were clear, significant but small.

Also, time related change in L values for coated and uncoated samples with or without infection can be explained by Eqs. (20)–(23):

$$\text{Coated inoculated}: L = 47.0e^{-0.00320t} (R^2 = 0.976) \quad (20)$$

$$\text{Coated control}: L = 47.0e^{-0.00190t} (R^2 = 0.954) \quad (21)$$

$$\text{Uncoated inoculated}: L = 46.0e^{-0.00520t} (R^2 = 0.990) \quad (22)$$

$$\text{Uncoated control}: L = 47.0e^{-0.00320t} (R^2 = 0.988) \quad (23)$$

The time based change in L showed strong trends again the uncoated inoculated samples demonstrating changes at a rate almost three times that of coated control with the other two showing intermediate rate.

Changes in a^* value of skin color of avocado are shown in Figs. 5a and b. a^* value was more negative in coated samples showing a more predominant greenness of avocado skin. Again, the changes in the greenness occurred at a slower rate in coated samples. The time related color shift towards positive a^* value indicates more redness in color

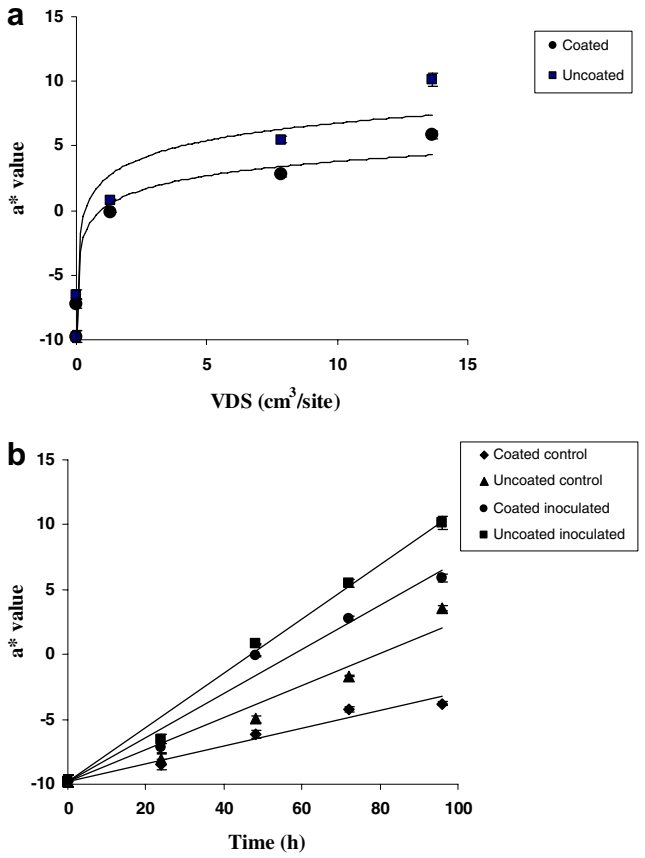

Fig. 5. Effect of pectin-based coating on a^* value of avocado fruits (a) as influenced by disease severity and (b) during incubation time.

that is the result of ripening. Inoculated fruits showed browning around inoculation sites. Eqs. 24 and 25 show the effect of disease severity on a^* value of avocado in coated and uncoated avocados:

$$\text{Coated}: a* = 1.60\ln(\text{VDS}) + 0.12 (R^2 = 0.962) \quad (24)$$

$$\text{Uncoated}: a* = 1.96\ln(\text{VDS}) + 2.25 (R^2 = 0.939) \quad (25)$$

Eqs (26)–(29) describe the degreening behavior of skin during incubation time in inoculated and control avocados with or without coating:

$$\text{Coated inoculated}: a* = 0.169t - 9.76 (R^2 = 0.971) \quad (26)$$

$$\text{Coated control}: a* = 0.0682t - 9.76 (R^2 = 0.964) \quad (27)$$

$$\text{Uncoated inoculated}: a* = 0.208t - 9.76 (R^2 = 0.987) \quad (28)$$

$$\text{Uncoated control}: a* = 0.123t - 9.76 (R^2 = 0.949) \quad (29)$$

Figs. 6a and b show the effect of coating on b^* value of avocado skin as affected by disease progress. The rate of decrease in b^* value is faster in uncoated fruits. This decrease in b^* value indicates reduction in yellowness of samples and an increase toward darker chroma. The following equations represent the relationship between disease severity and b* value in coated and uncoated fruits:

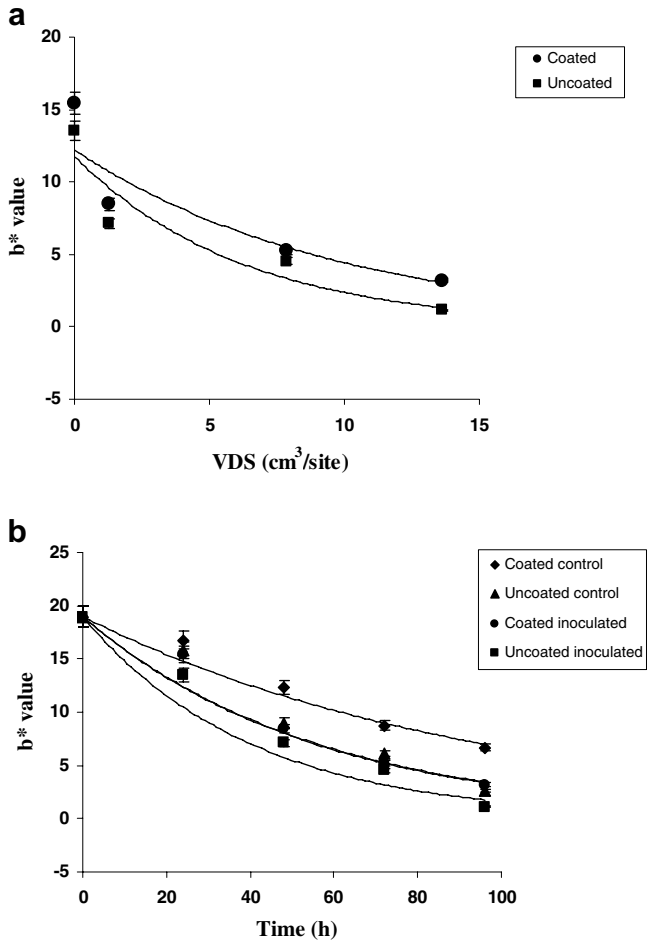

Fig. 6. Effect of pectin-based coating on b^* value of avocado fruits (a) as influenced by disease severity and (b) during incubation time.

$$\text{Coated} : b* = -1.87\ln(\text{VDS}) + 8.66 (R^2 = 0.993) \quad (30)$$

$$\text{Uncoated} : b* = -1.80\ln(\text{VDS}) + 7.13 (R^2 = 0.961) \quad (31)$$

The time related changes in b^* values for coated and uncoated samples with or without infection can be explained by Eqs. (32)–(35):

$$\text{Coated inoculated} : b* = 19.0e^{-0.0178t} (R^2 = 0.975) \quad (32)$$

$$\text{Coated control} : b* = 19.0e^{-0.0104t} (R^2 = 0.970) \quad (33)$$

$$\text{Uncoated inoculated} : b* = 19.0e^{-0.0248t} (R^2 = 0.913) \quad (34)$$

$$\text{Uncoated control} : b* = 19.0e^{-0.0181t} (R^2 = 0.955) \quad (35)$$

The total color difference (ΔE), which is a combination of parameters L, a^*, and b^* values, is a colorimetric parameter extensively used to characterize the variation in color perception. An increase in ΔE was observed with progress of disease and storage time (Figs. 7a and b). The total color difference in coated samples changed at a lower rate than in uncoated samples, and thus it can be recognized that coating has a beneficial effect on the reduction of color changes in avocado. Eqs. 36 and 37 show the effect of disease severity on ΔE value of avocado in coated and uncoated avocados:

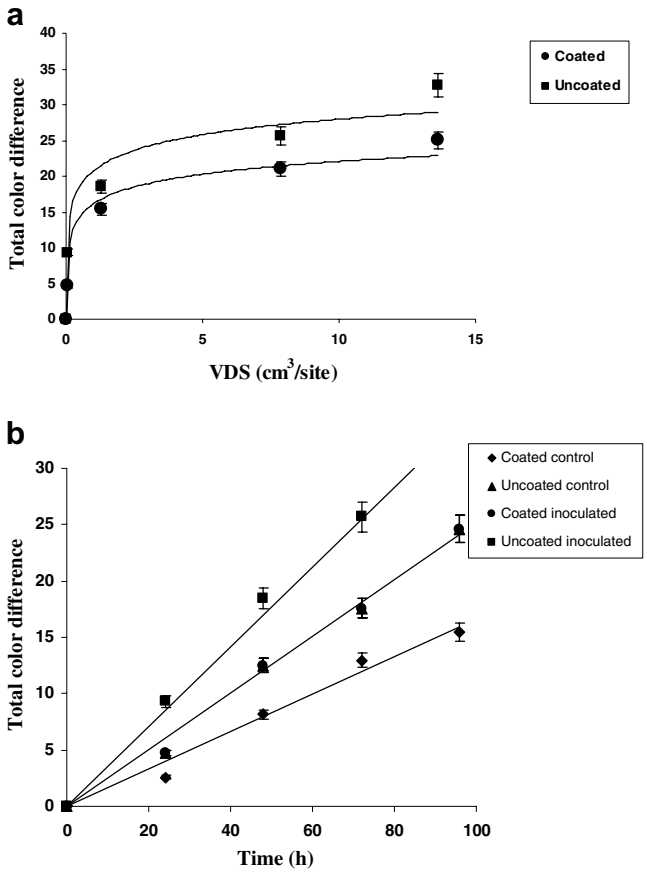

Fig. 7. Effect of pectin-based coating on total color difference of avocado fruits (a) as influenced by disease severity and (b) during incubation time.

$$\text{Coated} : \Delta E = 2.58\ln(\text{VDS}) + 16.1 (R^2 = 0.970) \quad (36)$$

$$\text{Uncoated} : \Delta E = 3.13\ln(\text{VDS}) + 20.8 (R^2 = 0.960) \quad (37)$$

Eqs. (38)–(41) describe the change in total color difference during incubation time in inoculated and control avocados with or without coating:

$$\text{Coated inoculated} : \Delta E = 0.251t (R^2 = 0.993) \quad (38)$$

$$\text{Coated control} : \Delta E = 0.166t (R^2 = 0.981) \quad (39)$$

$$\text{Uncoated inoculated} : \Delta E = 0.353t (R^2 = 0.993) \quad (40)$$

$$\text{Uncoated control} : \Delta E = 0.251t (R^2 = 0.993) \quad (41)$$

Although change of color parameters in coated fruits decreased and it was obvious to the naked eye, statistical analysis showed no significant difference ($p > 0.05$) in a^* value, b^* value and ΔE of coated and uncoated inoculated fruits. This is most likely due to the overlapping in most cases of the coated inoculated with uncoated control samples (example Eq. 38 vs. 41; 32 vs. 35; 20 vs. 23) creating confounding error when coated and uncoated were compared for overall difference. The lower color changes in coated fruit may be related to the effect of coating in creating modified atmospheres within the fruit. The presence of CO_2 in the storage atmosphere is an important factor in preventing chlorophyll degradation.

Table 1
Simple correlation matrix among different quality parameters of avocado, following inoculation with *Lasiodiplodia theobromae* and incubation for different duration, to produce different disease severity

Coated-inoculated						
Parameters	Respiration rate	Firmness	L value	a^* value	b^* value	ΔE
Respiration rate	1					
Firmness	−0.995	1				
L value	−0.965	0.995	1			
a^* value	0.975	−0.993	−0.986	1		
b^* value	−0.958	0.997	0.987	−0.997	1	
ΔE	0.969	−0.998	−0.992	0.999	−0.999	1
Uncoated-inoculated						
Respiration rate	1					
Firmness	−0.974	1				
L value	−0.983	0.932	1			
a^* value	0.997	−0.988	−0.973	1		
b^* value	−0.995	0.970	0.965	−0.992	1	
ΔE	0.999	−0.977	−0.981	0.998	−0.996	1

Table 2
Simple correlation matrix among different quality parameters of avocado, without inoculation

Coated						
Parameters	Respiration rate	Firmness	L value	a^* value	b^* value	ΔE
Respiration rate	1					
Firmness	−0.838	1				
L value	−0.895	0.990	1			
a^* value	0.828	−0.996	−0.991	1		
b^* value	−0.888	0.993	0.999	−0.993	1	
ΔE	0.882	−0.994	−0.999	0.994	−0.999	1
Uncoated						
Respiration rate	1					
Firmness	−0.953	1				
L value	−0.990	0.984	1			
a^* value	0.994	−0.974	−0.999	1		
b^* value	−0.923	0.993	0.967	−0.956	1	
ΔE	0.968	−0.995	−0.993	0.988	−0.990	1

4.5. Sensitivity of quality parameters to disease severity and coating

There was high multi-colinearity among quality parameters, as indicated by the correlation matrixes (Tables 1 and 2). In all treatments, respiration rate was negatively correlated with firmness, L and b^* values, while it was positively correlated with a^* value and ΔE. Firmness and L value were negatively correlated with a^* value and ΔE. The correlation matrix indicated that all of the quality parameters are related to coating and disease severity and thus these parameters could successfully used to predict fruit quality from disease in coated and uncoated avocados.

5. Conclusions

Progress of disease in avocado fruit induced by *L. theobromae*, was affected by use of pectin-based edible coating. Physical and physiological changes associated with progress of disease were decreased by coating of fruits. Increase in incubation time resulted in increase of VDS in inoculated samples, but in a slower rate in coated fruits. The power and logarithmic models were found to adequately describe the relationship between quality changes and disease severity in coated and uncoated fruits. All quality parameters were responsive to coating and disease severity. It can be concluded that there is potential to develop practically usable models to predict loss of avocado fruit quality due to the increase of disease and increasing shelf-life using coating. However, such models should be based on many replications and should be validated under commercial conditions before recommendation.

Acknowledgments

The authors acknowledge the financial support from the Natural Sciences and Engineering Research Council of Canada. Financial support from ''Agricultural Research, Education and Extension Organization'' in Iran to the first author is highly appreciated.

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