

Full Length Research Paper

Quality of pears with permeability of Bio-Fresh™ edible coatings

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Bio-Fresh™ edible coatings in four concentrations (0.5, 0.8, 1.0 and 1.2%) were investigated on quality characteristics of conference pears (*Pyrus communis* L. cv. Conference) with regards to its permeability. The Bio-Fresh™ was applied on pears by dipping. It was found that the effect of Bio-Fresh™ on pears was significantly effective in maintaining the skin color of green and only coating 1.2% Bio-Fresh™ delayed the changes of firmness, soluble solid content and retardation of shriveling and weight loss. Coating of 1.2% Bio-Fresh™ showed low permeability to respiratory gases (O₂ and CO₂) and created modified atmosphere, reduced decay and improved the quality of pears. Increasing concentration of coating on the surface skin of pears blocked the pores and lenticels, providing a drop-down in O₂ partial pressure. As a consequence, coating of 1.2% showed low permeability with good quality of pears. The results of this study suggest that coating of 1.2% Bio-Fresh™ increased shelf life of pears after 30 days without significant losses in quality.

Key words: Edible coating, dipping, respiration, permeability, quality, gas exchange.

INTRODUCTION

Pears (*Pyrus communis* L. cv. Conference) are known as pome fruits and are very perishable and susceptible to deterioration accompanied by shriveling, softening and decay. Rapid postharvest physiological changes in conference pears are responsible for short ripening period, rapid senescence that results to short shelf life commodity and pose a challenge to their marketing (Lin et al., 2003), and also a serious constraint to efficient handling and transportation (Hassan and Nurhan, 2004). Controlled atmospheres (CA) and modified atmosphere packaging (MAP) like several storage techniques have

been developed over the years to extend the storage life of fruits. However, these techniques are not free from drawback. For instance, O₂ and CO₂ injury, increase ethanol production, flavour problem due to anaerobic respiration have been reported (Bender et al., 1994). Therefore, alternative practices are required for prolonging the shelf life of fresh pears.

The potential alternative storage methods for fresh agricultural produces could be edible coatings which could increase attention because of environmental consideration and the trends towards the use of

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convenience foods (Ozden and Bayindirli, 2002). Semi-permeable coating can create a modified atmosphere similar to CA (Nisperos-Carriedo and Shaw, 1990). The atmosphere created by coating can change in response to environmental conditions due to combined effect on fruits respiration and coating permeability. Coatings are also used to extend the shelf life of fruits and improve appearance (Baldwin et al., 1999). Surface coatings can also improve the postharvest quality of horticultural commodities by reducing water loss (Hagenmaier and Baker, 1993), improving the finish of the skin (Hagenmaier and Baker, 1995; Amarante, 1998) and reducing skin susceptibilities (Amarante et al., 2001).

The effects of coatings on shelf life extension of fruits have been studied by several researchers such as with apples (Rojas-Grau et al., 2008), mango (Srinivasa et al., 2002; Dang et al., 2008), kiwi (Xu et al., 2001). Coatings have been known to prevent fruits and vegetables from deterioration by inhibiting respiration, reducing dehydration, maintaining textural quality, retaining volatile flavor and decreasing microbial growth (Han et al., 2004).

However, in some cases, edible coatings were not successful and have degraded fruits quality (Hagenmaier, 2005). The occurrence of physiological disorders such as core flush, flesh breakdown was induced by improper coatings (Park, 1999). Modification of internal atmosphere by the use of edible coatings can increase disorders associated with high carbon dioxide or low oxygen concentration (Ben-Yehoshua, 1969).

The effect of edible coating on internal gas composition and their interactions on quality parameters must be determined for coated pears for effective application of Bio-Fresh™ edible coatings on pears to prolong the shelf life and avoid postharvest losses. The main objective of this study was to evaluate the quality of coated pears with the permeability of coatings.

MATERIALS AND METHODS

Pears (*P. communis* L. cv. Conference) were harvested and stored at ultra low oxygen (ULO) condition at temperature of -1°C and 90% relative humidity in the cold storage. Bio-Fresh™ is an edible coating solution which is composed of sucrose fatty acid ester and carboxymethyl cellulose (CMC) in a concentrated liquid form (distributed by De Leye, Agrotrade, Netherlands).

Preparation of Bio-Fresh™ and coating of fruits for experiment

Bio-Fresh™ was diluted in water with a temperature of 37 - 38°C to obtain the desired concentration: 0.5, 0.8, 1.0 and 1.2% (0.83, 1.328, 1.66 and 1.992 L Bio-fresh™ per 100 L water). The diluted solutions were mixed for a few minutes and then the pears were dipped in the dilution for a few seconds so that the pears can be thoroughly wetted on all sides. After that, the pears were dried by air blowing. The coated pears are used for studying ripening and gas exchange characteristics. Each batch contained four groups of treatments with 30 single fruit replicates for each treatment. The pears were evaluated for quality parameters color, firmness, soluble solid contents, weight loss and incidence of disorders and for coating

permeability. The experiments were conducted immediately after coating called Shelf-0 and after 30 days of storage of coated pears called shelf-1.

Firmness measurement

The firmness of pears was measured by using a universal texture analyzer ((LRX, Lloyd Instruments, Hampshire, UK) by measuring the maximum penetration force required for a 11 mm diameter self cutting plunger to penetrate 1 cm into the pear at a rate of 8 mm/s. The values were taken at two points on the equator of each pear.

Soluble solid content measurement

Soluble solid content was measured from the pressed juice of the pear by means of a refractometer (HANNA, UK) and the results were expressed as °Brix.

Color measurement

The surface color of pears was directly measured with a spectrophotometer (CM-2500d, Minolta, Japan). The equipment was set up for illuminant D65 and 10° observer angle and calibrated using a standard black reflector plate for zero and white reflector plate for one. The color changes were quantified in the L*, a*, b color space (defined by CIE in 1976). The hue value was also calculated in order to compare color change among different treatments. On each pear, five readings in five different areas were taken. The numerical values of a* parameter was employed to calculate hue angle.

Incidence of disorders

Pears were cut longitudinally for measuring the internal browning and internal cavities using 30 pears. The flexibility of neck was measured by observing the shrinkage in neck by pressing. The visual evaluation was done for external flexible necks, and internal browning and cavities for pears by hedonic scale. The samples were evaluated using the following hedonic scale: 0 = excellent, 1 = very good, 2 = good and 3 = fair good 4 = bad for flexible necks. A value of 2 is considered as the commercial acceptability threshold.

Weight loss measurement

The samples were weighted using 30 pears individually with a laboratory balance. The results were expressed as the percentage loss of the initial weight. Weight loss was calculated from the initial weight using the formula:

$$\text{Weight loss (\%)} = \frac{(W_i - W_s)}{W_i} \times 100$$

Where, W_i is the initial weight and W_s is the weight in the sampling period.

Gas exchange measurement

Pears were weighed by a laboratory balance and placed in the jar. Each jar of 1.7 ml contains pear fruits resulting in approximately 250 g pear L⁻¹ jar. The jar were stored in a temperature controlled room and connected to a flow through system. Two conditional airs were applied at 20 kPa O₂, 0 kPa CO₂ and 0 kPa O₂, 0 kPa CO₂ by

gas mixtures. The gas mixtures were made from pure gases using an in house built mixing panel equipped with mass flow controllers (Brooks Instrument, The Netherlands). The compositions of the mixtures were measured by using gas analyser (Checkmate II, PBI Dansensor, Denmark). The gas analyser has an accuracy of $\pm 0.1\%$ absolute of O_2 reading and $\pm 0.5\%$ absolute of CO_2 reading, respectively and calibrated against calibrated mixtures (Air products N.V., USA). For each condition, five jars were connected in series and flushed with conditional air with a flow rate of 10 L per hour for at least one day. The air stream through the jar was stopped after equilibrium of gas mixtures and the jars were closed. The partial pressure of O_2 and CO_2 changes in the jars with time were measured twice in the day with checkmate II and the exact time of measurement was recorded.

After weighing, intact coated fruits were put into the five jars, sealed and placed at two different gas conditions: 20 kPa O_2 , 0 kPa CO_2 for oxidative respiration and 0 kPa O_2 , 0 kPa CO_2 for fermentation at temperature of $10^\circ C$. The O_2 and CO_2 gas concentration profiles in the sealed jar due to respiration and fermentation of the fruits were measured as a function of time using gas analyzer checkmate II. The gas percentages were converted to partial pressure by multiplying with the measured total pressure. The gas permeability of coating was estimated from a difference in the gas profiles between the measured gas concentration profiles of coated and uncoated fruits.

The modified Michaelis-Menten kinetics model has been applied to describe the respiration characteristics of intact pears (Peppelenbos et al., 1996; Peppelenbos and van't Leuven, 1996). A non-competitive inhibition model was used to describe the respiration of the pears as follows:

$$R_{O_2} = - \frac{V_{m,O_2} \cdot P_{O_2}}{(K_{m,O_2} + P_{O_2}) \left(1 + \frac{P_{CO_2}}{K_{mn,CO_2}}\right)} \quad (1)$$

$$R_{CO_2} = -r_{q,ox} \cdot R_{O_2} + \frac{V_{mf,CO_2}}{\left(1 + \frac{P_{O_2}}{K_{mf,O_2}}\right)} \quad (2)$$

Where, V_{m,O_2} (mol/m³s), the maximum O_2 consumption rate; V_{mf,CO_2} (mol/m³s), the maximum CO_2 production; K_{m,O_2} (kPa) and K_{mf,O_2} (kPa), the Michaelis-Menten constant for O_2 consumption and CO_2 production, respectively; P_{O_2} (kPa), the O_2 partial pressure; P_{CO_2} (kPa), the CO_2 partial pressure; K_{mn,CO_2} (kPa), the Michaelis-Menten constant for non-competitive CO_2 inhibition, $r_{q,ox}$ the respiration quotient at high O_2 partial pressure, and R_{O_2} (mol/m³s) and R_{CO_2} (mol/m³s), the O_2 consumption rate and CO_2 production rate of the sample, respectively.

Changing of the gas concentrations inside the jar due to respiration of fruit was described as follows:

$$(V_{jar} - V_{pear}) \frac{\partial C_{O_2}}{\partial t} = V_{pear} \cdot R_{O_2} \quad (3)$$

$$(V_{jar} - V_{pear}) \frac{\partial C_{CO_2}}{\partial t} = V_{pear} \cdot R_{CO_2} \quad (4)$$

Where, C_{O_2} (mol/m³s) and C_{CO_2} (mol/m³s) are the O_2 and CO_2 concentration, t (s) is the time; V_{jar} (m³) and V_{pear} (m³) are the volume of jar and pears.

Difference in gas concentration between the coated membranes can be expressed base on the Fick's first law of diffusion as follows:

$$V_{pear} R_{O_2} = S_{pear} h_{O_2} (C_{O_2,o} - C_{O_2,i}) \quad (5)$$

$$V_{pear} R_{CO_2} = -S_{pear} h_{CO_2} (C_{CO_2,o} - C_{CO_2,i}) \quad (6)$$

Where, h_{O_2} (m/s) and h_{CO_2} (m/s) are the permeability for O_2 and

CO_2 , S_{pear} is the surface area of the pear (m²), C is the mean O_2 and CO_2 concentration (mol/m³). Subscript i and o indicate inside and outside the coated membrane.

Changing of the gas concentrations inside the jar as function of time was described as follows:

$$(V_{jar} - V_{pear}) \frac{\partial C_{O_2,o}}{\partial t} = -S_{pear} h_{O_2} (C_{O_2,o} - C_{O_2,i}) \quad (7)$$

$$(V_{jar} - V_{pear}) \frac{\partial C_{CO_2,o}}{\partial t} = -S_{pear} h_{CO_2} (C_{CO_2,o} - C_{CO_2,i}) \quad (8)$$

The Michaelis-Menten kinetics was used to describe the respiration characteristics of pears. The Michaelis-Menten constant K_m values for O_2 and CO_2 was assumed to be constant in each batch of experiment. The maximum O_2 consumption rate V_{m,O_2} and maximum CO_2 fermentative production rate V_{mf,CO_2} vary from batch to batch depending on the maturity of pears. So, the respiration was carried out to determine the V_{m,O_2} and V_{mf,CO_2} in a close jar.

Statistical analysis and model parameter estimation

Analysis of variance (ANOVA) was applied to the data obtained from each treatment to detect significance of differences at 5% level of significance ($P < 0.05$) to analyze color, firmness and soluble solid contents and also Turkey mean comparison ($P < 0.05$) was used to show the comparison of each treatment mean. Statistical software, the S-PLUS 8.0 version was used.

An iterative least square estimation procedure written in MATLAB (The Mathworks, Inc., Natick, USA) was used to determine respiration parameters and gas permeability of coating by fitting the model solutions to measure O_2 and CO_2 concentration change profiles.

RESULTS AND DISCUSSION

Firmness

The effect of Bio-FreshTM coating on the firmness of pears was measured. The statistical analysis showed that all coating concentrations were effective for maintaining firmness. The mean comparison test confirmed that only coating of 1.2% Bio-FreshTM had significant ($p < 0.05$) firmness values than control sample during shelf life study (Figure 1).

Color

The color changes have been quantified in the L^* , a^* , b^* color space. The a^* -values were correlated best with visual observance of green color: more negative a^* -values indicated more green color. Therefore, color data were expressed as a^* -values. The statistical analysis revealed that Bio-FreshTM was significantly ($p < 0.05$) effective for retaining the green color of pears (Figure 2). All coating concentrations had significantly more negative a^* -values than control sample among different shelf life conditions, and coating of 1.2% Bio-FreshTM had higher negative values than others concentration.

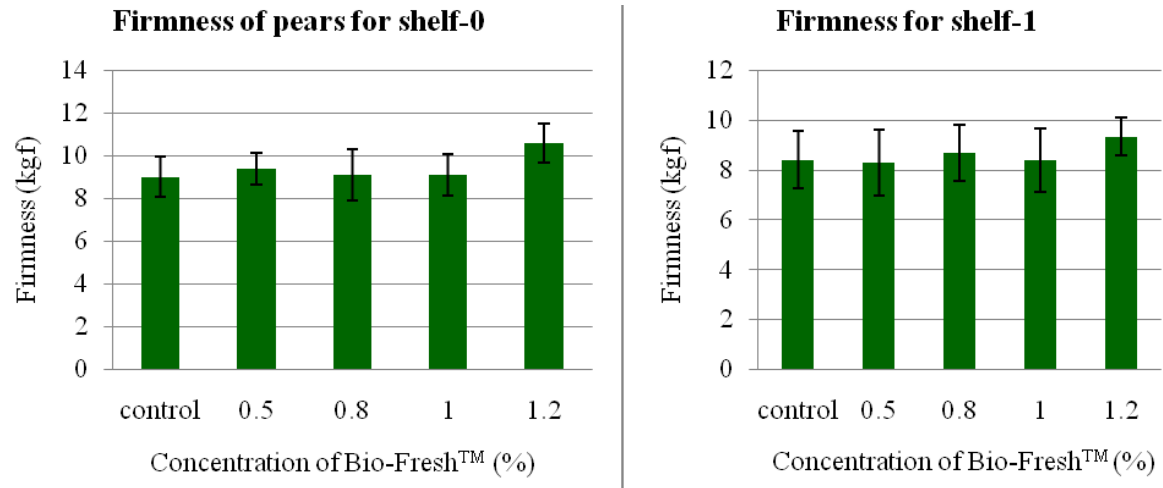


Figure 1. Changes of firmness among different concentration of Bio-Fresh™ during shelf life study.

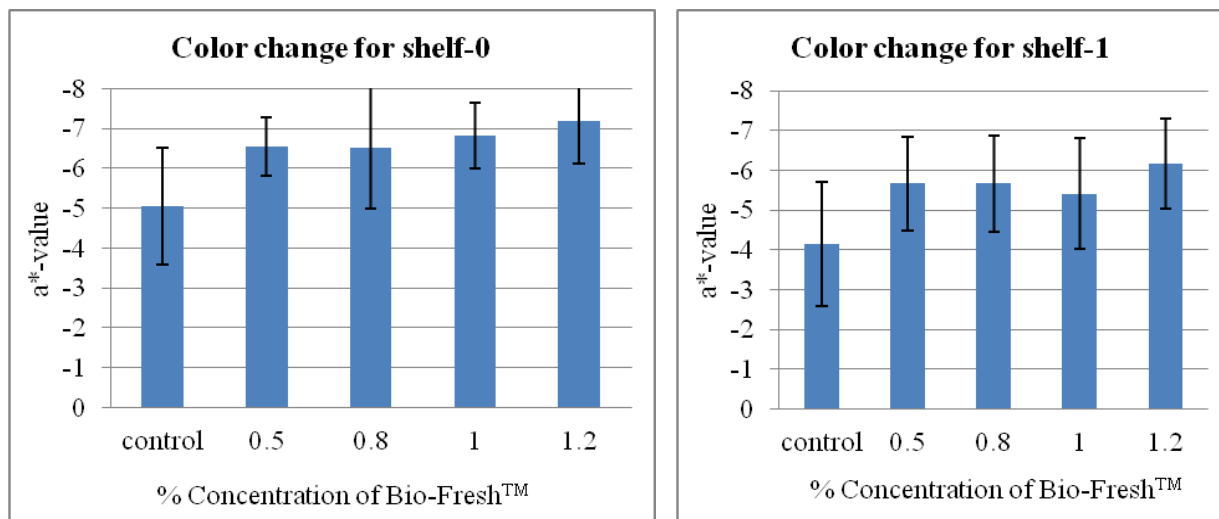


Figure 2. Changes of color among different concentration of Bio-Fresh™ during shelf life study.

Soluble solids content (SSC)

The soluble solids content is a common physical quality (maturity) indicator for fruits and fruit juices. Statistical analysis of the data revealed that all coating concentrations were not significantly different for retention of the soluble solid content during different shelf conditions but showed similar level of soluble solid content (Figure 3).

Weight loss

The weight loss has a strong impact on the pears appearance due to shrinkage or shriveling. Coating of pears with Bio-Fresh™ showed the variation of weight loss with storage time for coated and uncoated pears.

The results (Figure 4) showed that coating of 1.2% Bio-fresh™ significantly reduced the weight loss among all coating concentration.

Incidence of disorders

Edible coating can increase disorder of pears associated with high CO₂ or low O₂ by modifying the internal atmospheres of pears. To check the effects of Bio-Fresh™ edible coating, the following disorders were observed

Cavities and internal browning

The analysis of variance revealed that there were no

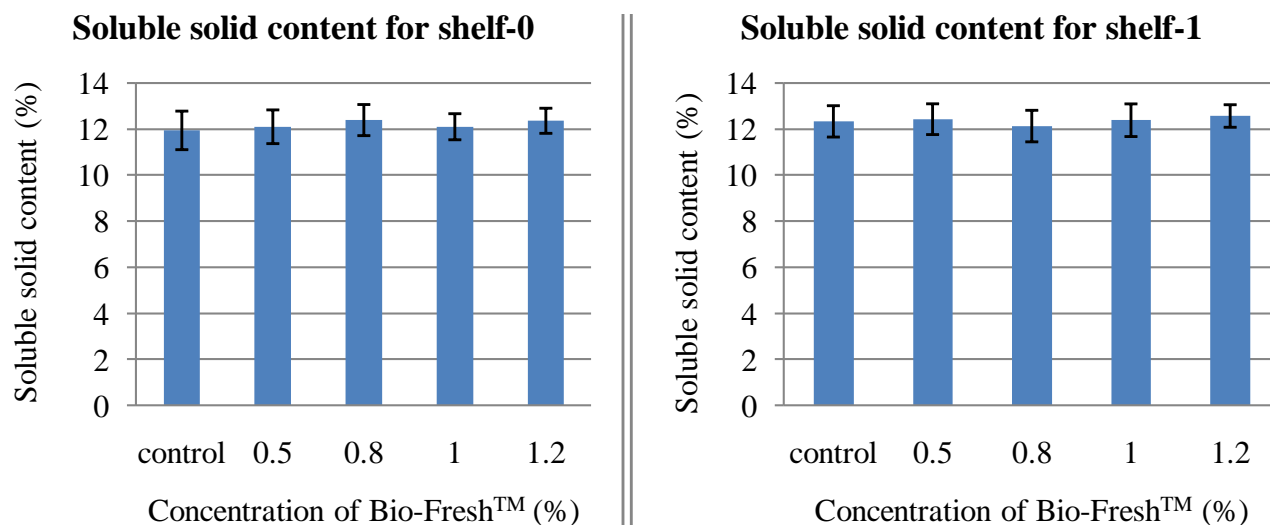


Figure 3. Changes of soluble solid content among different concentration of Bio-Fresh™ during shelf life study.

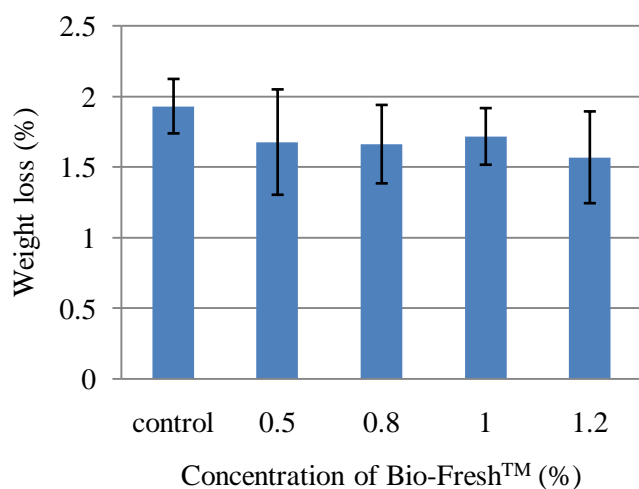


Figure 4. Weight loss among different concentration of Bio-Fresh™.

significant observations of cavities and internal browning in pears during different shelf conditions as compared to control sample in pears for different concentration of Bio-Fresh™ (Figure 5).

Shriveling

Fresh produce is susceptible to shriveling due to water loss. The effects of Bio-Fresh™ coating on pears to reduce shriveling which allows the retardation of water loss were evaluated. The statistical analysis showed that high standard error among all coatings concentration during different shelf conditions that could be due to few amounts of shriveling observation (Figure 6).

Gas exchange

The results of gas exchange measurement have been discussed with respiration and the permeability of Bio-Fresh™ coating of pears described by means of Michaelis-Menten kinetics.

Permeability of coatings

Pears were coated by dipping in coating solution after storage and the permeability of Bio-Fresh™ was measured. The effects of Bio-Fresh™ coating on pears showed the permeability to gases were low at concentrations of 0.8, 1.0 and 1.2% Bio-Fresh™ as compared to 0.5% coating (Table 1).

Oxygen permeability was higher than carbon dioxide for these coating concentrations. Coating of 1.2% Bio-Fresh showed the low permeability as compared to other treatments. Coating of 0.5% Bio-Fresh™ was not successful due to high standard error. The concentration profile of O₂ (Figure 8) showed the more O₂ gradient which had substantial effect to modify the internal atmosphere of pears. The respiratory gas concentration profile with time for coating of 1.2% Bio-Fresh™ is shown in Figure 7.

DISCUSSION

Quality evaluation

Previous research indicated that the inhibition activities of pectin degrading enzymes was closely related to fruit softening and contributed to firmness maintenance by reducing the rate of metabolic process during ripening (Zhou et al., 2008). The results indicate that 1.2% coating

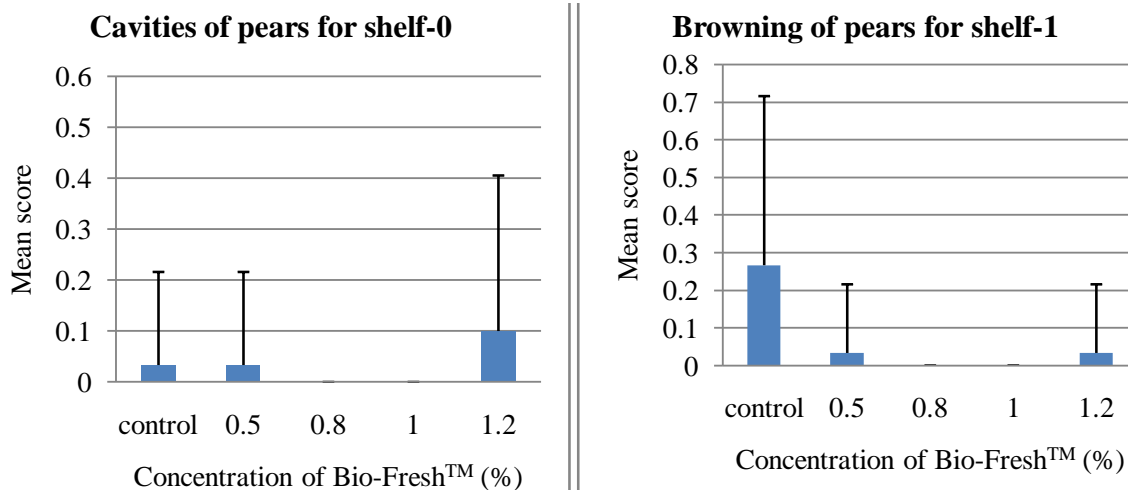


Figure 5. Incidence of cavities and browning on pears among different concentration of Bio-Fresh™ during shelf life study.

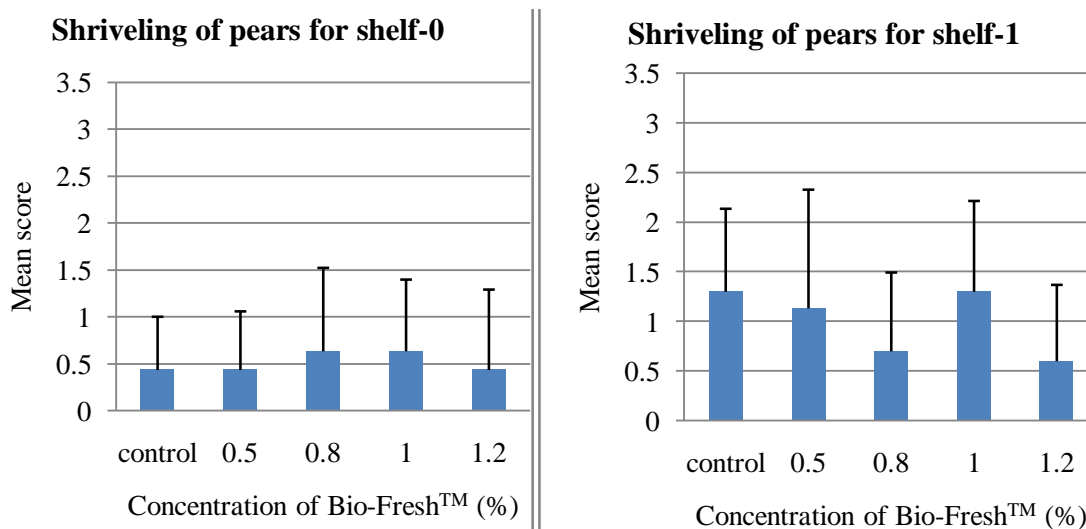


Figure 6. Incidence of shriveling on pears among different concentration of Bio-Fresh™ during shelf life study.

Table 1. Estimation of permeability parameters of coated pears after 6 months of storage and the values represent ± 95% confidence interval.

Treatment	Permeability parameter			
Optimally picked	h_{O_2} (m/s)	h_{CO_2} (m/s)	stdev h_{O_2} (m/s)	stdev h_{CO_2} (m/s)
0.5% Bio-Fresh™	3.66E-05	0.000751	0.0034311	2.2604
0.8% Bio-Fresh™	1.25E-07	5.00E-08	2.48E-08	9.24E-09
1.0% Bio-Fresh™	1.21E-07	2.76E-08	2.35E-08	3.53E-09
1.2 % Bio-Fresh™	1.25E-07	1.37E-08	1.39E-08	6.47E-10

concentration of Bio-Fresh™ may maintain firmness by inhibiting the activities of pectin degrading enzymes and

inhibiting water loss (Figure 1) on pears coated by dipping. Coating of 1.2% Bio-Fresh™ may also make

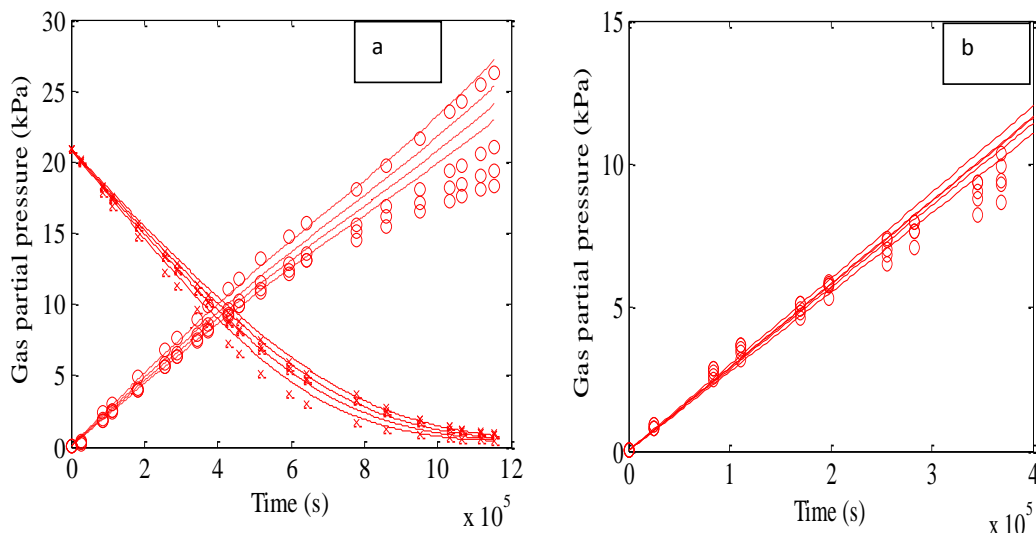


Figure 7. Gas concentrations profile as a function of time in jars contained coated pears with 1.2% Bio-Fresh™ at storage temperature of 10°C. Solid (—) and dashed (---) lines indicate modeled O₂ and CO₂ partial pressure while symbols (x) and (o) indicate O₂ and CO₂ measurement. The initial conditions were (a) 20 kPa O₂, 0 kPa CO₂ and (b) 0 kPa O₂, 0 kPa CO₂.

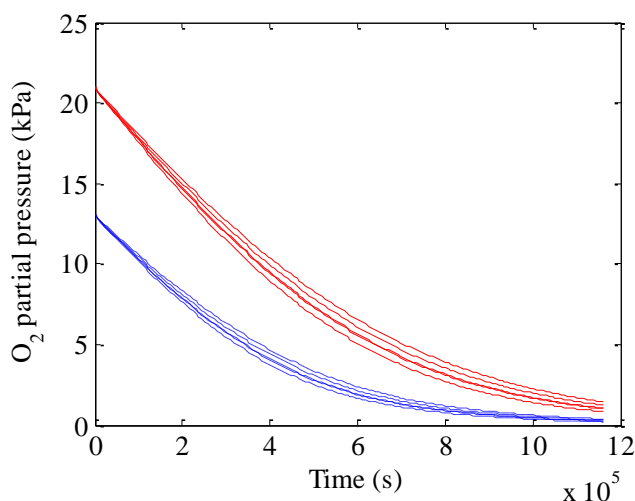


Figure 8. Mean concentration profile of O₂ with time in the outer (solid line: —) and inner (dashed line: - -) side of coatings on pears of 1.2% Bio-Fresh™.

internal atmosphere modification (low oxygen and high carbon dioxide concentrations) on pears. Hence, results of the research nicely reflect the findings of Yaman and Bayindirli (2002) for cherries, Sumnu and Bayindirli (1995) for Amasya apples coated with Semprefresh™, and Amarante et al. (2001) for pears coated with carnauba bases wax.

Coatings of Bio-Fresh™ were more pronounced for the substantial effect on changes in skin color. All coating concentrations were significantly good for maintaining the green color of pears during different shelf life. Coating of

1.2% Bio-Fresh™ was more effective for retention of green color than control sample and other treatments (Figure 2). The beneficial effect of Bio-Fresh™ coatings on skin color can be explained by proper blockage of pores (lenticels and stomata) as well as cracks of the skin (Amarante, 1998). Similar results were found on banana coated with sucrose fatty acid esters (Momen et al., 1997), cherries coated with Semprefresh™ (Yaman and Bayindirli, 2002), and on pears (Amarante et al., 2001).

Soluble solids and organic acids of fruits are substrates that are consumed by respiration during storage (Ozden and Bayindirli, 2002; Yaman and Bayindirli, 2002). In this study, only 1.2% coating were effective for the retention of soluble solid content as compared to the control (Figure 3) and other treatment because lower respiration rates retarded the overall metabolic activities of pears during storage. Similar results were found by Zhou et al. (2008), Hasan and Arslan (2004) and Ju et al. (2000).

The main mechanism contributing to the weight loss is the evaporation activated by a gradient in water vapor at different location in fruit (Yaman and Bayindirli, 2002). In this study, pear coated by dipping method showed coating of 1.2% Bio-Fresh™ was effective for inhibition of weight loss during storage (Figure 4). The reason for the reduction in weight loss may be the blockage of lenticels and stomata (Amarante, 1998; Amarante et al., 2001) as evidenced by the reduction in respiration and gas exchange (Hagenmaier and Baker, 1993).

Cavities arise from brown tissue because of time course of internal browning (Lammertyn et al., 2000). Browning disorder caused by imbalance oxidative and reductive processes due to metabolic gas gradients inside the fruit, lead to an accumulation of reactive

Table 2. Comparison of estimated permeability parameters of coated pears after 6 months of storage between two methods and the values represent \pm 95% confidence interval.

Treatment	Permeability parameter			
	*Method 1		*Method 2	
Optimally picked	h_{O_2} (m/s)	stdev h_{O_2} (m/s)	h_{O_2} (m/s)	stdev h_{O_2} (m/s)
0.5% Biofresh	3.66E-05	0.0034311	7.80E-05	0.0004099
0.8% Biofresh	1.25E-07	2.48E-08	8.75E-08	3.73E-09
1.0% Biofresh	1.21E-07	2.35E-08	1.08E-07	7.20E-09
1.2 % Biofresh	1.25E-07	1.39E-08	5.41E-08	2.80E-09

*Method 1: Estimation O_2 and CO_2 permeability simultaneously and *Method 2: Estimation with assuming O_2 and CO_2 permeability following Graham's law ($h_{CO_2}=0.8528h_{O_2}$).

oxygen species which may induce loss of membrane integrity through the enzymatic oxidation of phenolic compounds to brown color polymer compound (Franck et al., 2007). Shriveling is due to water loss by respiration and transpiration (Woods, 1990). The Bio-Fresh™ edible coating was not statistically significant but showed good for retardation of shriveling, cavities and internal browning during shelf life study of pears (Figures 5 and 6).

Permeability of coatings

The respiration is a good index for the quality of fruits during storage. Edible coating of Bio-Fresh™ with a concentration of 1.2% coated by dipping reduced the respiration rate which contributes to longer shelf life with good quality. Similar results were found on green pepper coated with Semperfresh™ (Ozden and Bayindirli, 2002). The suppression of respiration was likely due to the modification of the internal atmosphere of pears caused by the semi-permeable characteristics of the Bio-Fresh™ coating to the respiratory gases (Banks, 1984). The concentration profile of O_2 (Figure 8) confirmed that coatings slightly modified the internal atmosphere of pears.

Effect of coating on O_2 consumption can be found by decreasing the slope of O_2 concentration profiles (Figure 8) but difficult to evaluate for CO_2 due to fermentation at low O_2 concentration. Estimated h_{CO_2} is much lower than those values of O_2 (Table 1).

Assuming O_2 and CO_2 permeability follows Graham's law, estimated h_{O_2} was reported in Table 2. Rather similar h_{O_2} values between two methods (Table 2) indicated that O_2 permeation (Equations 5 and 7) was less affected by CO_2 concentration. Note that at 0.5% Bio-Fresh™, coating was not successful due to high permeability with high variation.

Oxygen is the key factor for oxidation which is responsible for changes in color and firmness. Therefore, coatings that provide proper oxygen barrier can help in improving food quality and extending shelf life. The oxygen permeability is too low, anaerobic respiration will

commence, resulting to production of ethanol and off flavor as well as product deterioration, if coating showed too high permeability, the internal atmosphere will not be modified to have beneficial results to extend the shelf life (Baldwin et al., 1999).

On the other hand, carbon dioxide is very important for respiration and higher permeability value can delay fruits softening (Kader, 1986). The permeability (Table 1) of 1.2% Bio-Fresh™ coating for O_2 and CO_2 was good as compared to other coating concentrations for maintaining the quality of pears.

Conclusion

The benefits of different concentrations of Bio-Fresh™ applied by dipping for the extension of shelf life with good quality were significantly effective for maintaining the color of pears. Coating of 1.2% Bio-Fresh™ modestly delayed the changes of firmness, soluble solid contents and inhibited cavities, internal browning, shriveling and weight loss of pears during storage than other concentrations.

Although, all coating concentrations of Bio-Fresh™ exhibited better reduction of respiration rate and permeation of coating except 0.5% coating and 1.2% Bio-Fresh™ showed low permeability of coating with good quality of pears. With the view of the above findings, 1.2% Bio-Fresh™ can be used for extending the shelf life of pears without significant loss of quality.

Conflict of Interests

The authors did not declare any conflict of interests.

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