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A Systematic Approach of Formulating Chitosan– Nanosilica Coating for Mango (*Mangifera indica* L. 'Carabao') Fruit

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ABSTRACT

The application of fruit coatings reduces gas exchange between the environment and the fruit by creating additional layer to the fruit's surface. If there is insufficient gas exchange, fruit coatings could induce anaerobic respiration and physiological disorders. Chitosan (CS) and nanosilica (NS) composite coatings for fresh 'Carabao' mango fruits were developed by calculating the required oxygen (O_2) transmission rate of the coating given the fruit's respiration rate, surface area and mass. To maintain the respiration requirements of the fruit, computed O_2 transmission rates of the coating material should be equal or higher to 0.3270 $mL \cdot cm^{-2} \cdot hr^{-1}$, 0.4530 $mL \cdot cm^{-2} \cdot hr^{-1}$ and 0.9608 $mL \cdot cm^{-2} \cdot hr^{-1}$, at 15°C, 20°C and 25°C, respectively. At all temperature regimes, 0.75% CS has higher O_2 transmission rate (0.814 $mL \cdot cm^{-2} \cdot hr^{-1}$, 0.935 $mL \cdot cm^{-2} \cdot hr^{-1}$, 1.136 $mL \cdot cm^{-2} \cdot hr^{-1}$) than 1% CS (0.450 $mL \cdot cm^{-2} \cdot hr^{-1}$, 0.582 $mL \cdot cm^{-2} \cdot hr^{-1}$, and 0.595 $mL \cdot cm^{-2} \cdot hr^{-1}$). Subsequent laboratory trials using 0.75% CS for mango at 20°C showed that the fruit coating could slow down weight loss and retard the peel color change for five days when compared to the uncoated fruits. Sensory tests in terms of color, taste, flavor, and aroma showed that the coated fruits are acceptable and of comparable quality as the control. Fruits coated with 1% CS exhibited delayed peel color change and weight loss but have symptoms of anaerobic respiration and acetaldehyde formation.

Keywords: *Chitosan, Nanosilica, Fruit Coatings, 'Carabao' Mango Fruit*

INTRODUCTION

The ‘Carabao’ mango is identified as one of the finest and sweetest varieties of mango fruits in the world. It is considered a major dollar earner agricultural commodity in the Philippines (Fernandez-Stark et al., 2017). From 2016 to 2020, the total volume of production of mango averaged 747.98 thousand metric tons amounting to 26,008.48 million pesos (Philippine Statistics Authority, 2021). In the third quarter of 2021, the total volume of production of ‘Carabao” mango was 49.22 thousand metric tons or 82.1% of the total mango production at 59.93 thousand metric tons (Philippine Statistics Authority, 2021).

However, mangoes are climacteric and ripen immediately after harvest, limiting storage, handling, and long-distance transport (Lalel et al., 2003 as cited by Ochiki et al., 2015). Several studies have reported the effectiveness of CS coatings in prolonging the shelf life of mango fruits (Zhu et al., 2008 and Cissé et al., 2015). However, in the study by Adan (2017), coating the mango fruits with CS-NS resulted in increased ethanol production and flavor problems. The coatings only delayed the change in peel color but no other ripening indicators such as pulp color, softening and the increase in total soluble solids (TSS) were inhibited. This might be a result of anaerobic respiration that is caused by insufficient O_2 diffusion through the fruit peel (Kader, 1980).

Fruit coatings function similarly to modified atmosphere packages (MAP); they create a physical barrier that alters gas exchange between the inside of the fruit and the environment, raising CO_2 concentrations while reducing O_2 levels (Nor and Ding, 2020 as cited by de Oliveira Filho et al., 2021). Proper selection of fruit coatings and other MAPs is very critical to avoid physiological disorders caused by insufficient gas exchange (Kader, 1980). According to Ben-Yehoshua et al. (1993), the main considerations in developing an appropriate packaging for a commodity are packaging materials’ properties, product’s biological characteristics and storage conditions. Coating material properties such as gas permeability, transmission rate, surface area, and thickness, as well as the fruits’ respiration rate, susceptibility to chilling injury, enzymatic reactions, and biochemical composition must be properly studied to maximize the full benefits of fruit coating.

A systematic approach, as described by Jacxsens et al. (1999), can be employed to select the appropriate MAP for a commodity. In that study, equilibrium modified atmosphere packages (EMAP) for fresh-cut produce were developed by measuring the respiration rate of the produce and computing the O_2 and CO_2 transmission rates of the packaging film that will provide a steady-state condition. As shown in **Figure 1**, the method assumes that the amount of O_2 consumed, or CO_2 produced by the fruit during respiration equals the amount of O_2 and CO_2 diffusing through the film. This method, according to Jacxsens et al. (1999), is simpler than the use of mathematical models presented in the study of Banks et al. (1997) to optimize surface coatings for fruits and for vegetables like broccoli (Christie et al., 1995). This method of developing EMAP were successfully applied to the development of EMAP for ‘Carabao’ mango (Yaptenco et al., 2010), for tomato (Gong and Corey, 1994), for various fresh-cut produce (Mahajan et al., 2007).

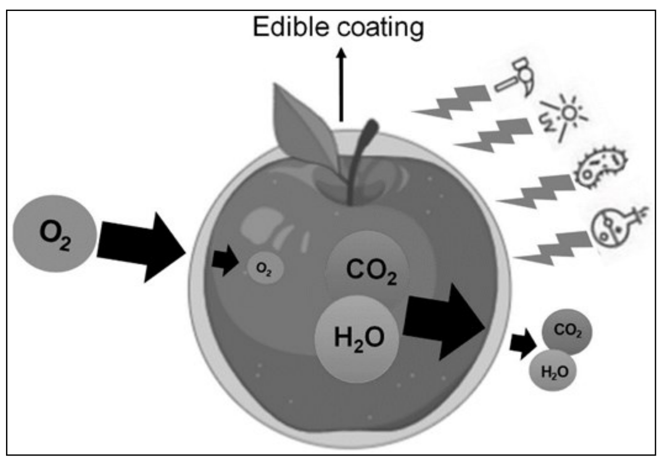

Figure 1. Main functions of edible coatings on fruits and vegetables.
Source: de Oliveira Filho et al. (2021)

However, there are limited literatures that provide how the proper selection of fruit coating materials was performed. Studies for most fruit coatings only focused on the effect of different coating formulations on the physicochemical characteristics and physiological activities of fruits during storage. Hence, this study focuses on determining the formulation of CS-NS coating to extend the green-life of mango fruit based on its respiration rate and the coating's oxygen transmission rate.

MATERIALS AND METHODS

Respiration Rate Measurement

Mango fruits at full green stage (Peel Color Index 1 or PC1) were bought from a local market in Calamba City, Laguna. Only mature fruits with no defects were selected for the experiment. Maturity was evaluated using the flotation method where fruits that sank in a 1% NaCl solution were considered mature (Abarra et al., 2018). After determining their maturity, the mangoes were washed with distilled water and air-dried. The storage temperatures were based on earlier research on the chitosan coating of mango fruits, specifically Zhu et al. (2008) for 15°C and 85 – 90% RH, Cissé et al. (2015) for 20°C, and Jongsri et al. (2016) for 25°C. Temperature and relative humidity were monitored every hour using EL-USB-2 RH/TEMP Data Logger (Omega Engineering, United States).

Static method for measuring respiration rate of fruits was employed in the study (Hagger et al., 1992). Twelve green mature mango fruits were used in the experiment, with four replications for each temperature. Each fruit was weighed in an electronic balance, and volume was determined using the gravimetric method described by Mohsenin (1986, p. 66). The fruits were individually sealed in a 1,344.37 mL leak-free respiration jar with initial atmospheric conditions of 20.94% O_2, 78.08% N_2 and 0.03% CO_2. The jars were tightly sealed and placed inside the cold room. The gas inside the jar was homogenized using syringe before gas sampling. The gas concentrations inside the jar were measured using a gas analyzer (PBI Dansensor Checkmate 3) every hour for the first six hours, every 3 hours for the next 18 hours and every 6 hours until %O_2 level dropped to below 5% (Hagger et al., 1992). The respiration rate was computed by non-linear regression using the Gauss-Newton method on Statistica 7. Equation 1 was used for the regression of O_2 consumption and Equation 2 for CO_2 production; where $[O_2]$ = O_2 level inside the respiration jar, $[CO_2]$ = CO_2 level inside the respiration jar, t =time in hours and a, b, c = regression coefficients (Hagger et al., 1992; Jacxsens et al., 1999).

$$[O_2]_t = 21 - \left[\frac{t}{(a_1 t + b_1)^{c_1}}\right] \qquad \textit{Equation 1}$$

$$[CO_2]_t = \left[\frac{t}{(a_2 t + b_2)^{c_2}}\right] \qquad \textit{Equation 2}$$

The values of respiration rate, in terms of O_2 consumption and CO_2 production, at a certain internal O_2 level of the mango fruit, were obtained using Equation 3 and Equation 4, respectively; where V_f = headspace volume in mL and W = weight of fruit in kg (Lee et al., 1996). At the end of the experiment, the mango fruits were peeled for surface area determination using Image J, version 1.52j.

$$Respiration\ Rate \left(\frac{mLO_2}{kg-hr}\right) = \frac{d[O_2]}{dt}\frac{V_f}{100W} \qquad \textit{Equation 3}$$

$$Respiration\ Rate \left(\frac{mLCO_2}{kg-hr}\right) = \frac{d[CO_2]}{dt}\frac{V_f}{100W} \qquad \textit{Equation 4}$$

Fruit Coating Selection

The required O_2 transmission rate of the coating material to maintain the desired O_2 level was computed based on respiration mass balance using Equation 5 (Flores et al., 2019); where $RTRO_2$ = required O_2 transmission rate in $mLO_2 \cdot cm^{-2} \cdot h^{-1}$, RR_{O2} = measured respiration rate in $mLO_2 \cdot kg^{-1} \cdot h^{-1}$, W_f = fruit's weight in kg, A = fruit's surface area in cm^2, O_{2a} = O_2 concentration of surrounding air in %, and O_{2i} = internal O_2 concentration in %.

$$RTR_{O_2} = \frac{100 RR_{O_2} W_f}{A(O_{2_a} - O_{2_i})} \qquad \textit{Equation 5}$$

The equation suggests that a steady state will occur inside a packaging film if the respiration of the fruit matches the transmission rate of gases through the film (Jacxsens et al., 1999). The oxygen permeability of plastic film packaging plays a significant role in determining the shelf life of many fresh produces since they are oxygen-sensitive (Kester and Fennema, 1986 as cited by Rico-Pena and Torres, 1990). Lowering the quantity of available O_2 concentration is more effective in slowing respiration than raising CO_2 concentration in MAP (Lizada et al., 2004 as cited by Yaptenco et al., 2010; Kader, 1980). Gong and Corey (1994) and Yaptenco et al. (2010) conducted earlier studies on the development of EMAP based solely on O_2 concentrations for the 'Heinz 1370' tomato and 'Carabao' mango, respectively. Therefore, in this study, the selection of appropriate fruit coating was solely based on the fruit's respiration rate in terms of O_2 consumption and the computed O_2 transmission rate of the coating material.

The required O_2 transmission rate of mango fruits was compared to the gas transmission rates of 'Carabao" mango peel coated with CS-NS composite found in Acabal et al. (2020). When the fruits are packed with plastic films of a lower transmission rate, diffusion of O_2 gas through the plastic film will be insufficient causing a hypoxic environment to the fruits that will eventually lead to anaerobic respiration. Moreover, fruit coatings with a higher O_2 transmission rate than the fruit's requirement can only provide a minimal effect on the modification in the internal atmosphere of the fruits (Jacxsens et al., 1999 and Kader, 1980).

Treatment and Validation

Preparation of Fruit Coating

High molecular weight CS powder was purchased from Sigma Aldrich (United States). 0.75% CS and 1% CS fruit coatings were prepared by dispersing 7.5 g and 10 g CS powder in 900 mL distilled water, which was then added with 2.5 mL glacial acetic acid to dissolve the CS. Using a magnetic stirrer, it was stirred for two hours at 800 rpm and 60°C to produce a viscous solution. The solutions were added with 0.1% (w/v) Tween 80, stirred for 30 minutes at room temperature, and then added with 1 M NaOH until pH dropped to 5.6. The total volume of the solution was made to 1000 mL. This method was based on Zhu et al. (2008) with only minor changes.

Fruit Coating Application

The fruits used in this part of the experiment were selected and handled similar during the respiration rate measurement. Sixteen fruits per treatment were dipped in 0.75% CS and 1% CS solution, respectively, for 1 minute and were air-dried for 1 hour (Zhu et al., 2008). Uncoated fruits served as the Control treatment. The fruits were kept inside 10" x 5" x 2" 3-ply fruit packaging box with holes for ventilation, and then stored at 20˚C until the fruits turned yellow (PCI 5 or PCI 6). Storage conditions were maintained to be the same as the conditions during the respiration rate measurement.

Cumulative Weight Loss and Peel Color Index

Physiological weight loss (PWL) of the fruits was determined by weighing the fruits using a digital weighing scale every 4 days during storage. Cumulative weight loss was expressed in percentage of the initial weight. The peel color index (PCI) was evaluated using the following scale: 1 = green; 2 = green with a tinge of yellow; 3 = more green than yellow; 4 = more yellow than green; 5 = yellow with a tinge of green; and 6 = yellow (Zhu et al., 2008).

Sensory Evaluation

Eight untrained panelists were randomly chosen to evaluate sensory qualities as pulp color, aroma, flavor, and texture using a 9-point hedonic scale when the fruits turned to PCI 5 or 6 (Adan, 2017).

Statistical Analysis

Each experiment, except for sensory evaluation, was carried over four replications. In each replication, one fruit was used to measure respiration rate, quantify weight loss, and determine peel color index. The analysis of variance (ANOVA) was performed to examine how storage temperature affected measures of respiration rate and required O_2 transmission rate, as well as how coating treatments affected cumulative weight loss, peel color index, and sensory ratings. Using the Tukey's Honestly Significant Difference (HSD) Test at $p < 0.05$, significant differences were analyzed (Flores et al., 2019). R Studio (Version 3.5.3) was used in the statistical analyses.

RESULTS AND DISCUSSIONS

Respiration Rate of Mango Fruits

The average weight of mango fruits used was 0.23 kg with a volume of 228. 44 mL and surface area of 180.09 cm^2. The average temperatures in the three cold rooms were maintained at 15°C and 85% RH, 20°C, and 25°C, with RH of 85%, 76%, and 65%, respectively. **Figure 2** shows the representative O_2 and CO_2 concentrations inside the static chambers overtime at different storage temperatures. A decrease in temperature decreases the slope of the curve, indicating a slower respiration rate caused by lower enzymatic reactions (Lee et al., 1996). A similar trend was observed by Agudelo et al. (2016) where the temperature has a positive effect on the respiration rate of the 'Tommy Atkins' mango. Reduction of temperature reduces ethylene production and slows down the response rate of tissues to gases (Mendoza et al., 2016 as cited by Agudelo et al., 2016).

Fruit Coating Selection

Serrano and Lizada (1991) reported that 'Carabao' mango fruits subjected to humidified air (18% O_2 level) at 27 - 29°C maintained an internal O_2 concentration of 14% before the fruits turned table ripe. Flores et al. (2019) also reported that the internal O_2 of mature 'Carabao' mango fruits (PCI 1 to PCI 3) measured at ambient and cold conditions ranged from 12 - 15%. Mature 'Tommy Atkins' mango fruits stored at 15°C and 99% RH have internal O_2 of 16%. Therefore, for this study, the respiration rate and the required gas transmission rate of mango fruits were computed at 14% internal O_2 level. **Table 1** shows the derived regression coefficients, fruit's O_2 consumption rate, and computed O_2 transmission rate at 14% internal O_2 for the three storage temperatures.

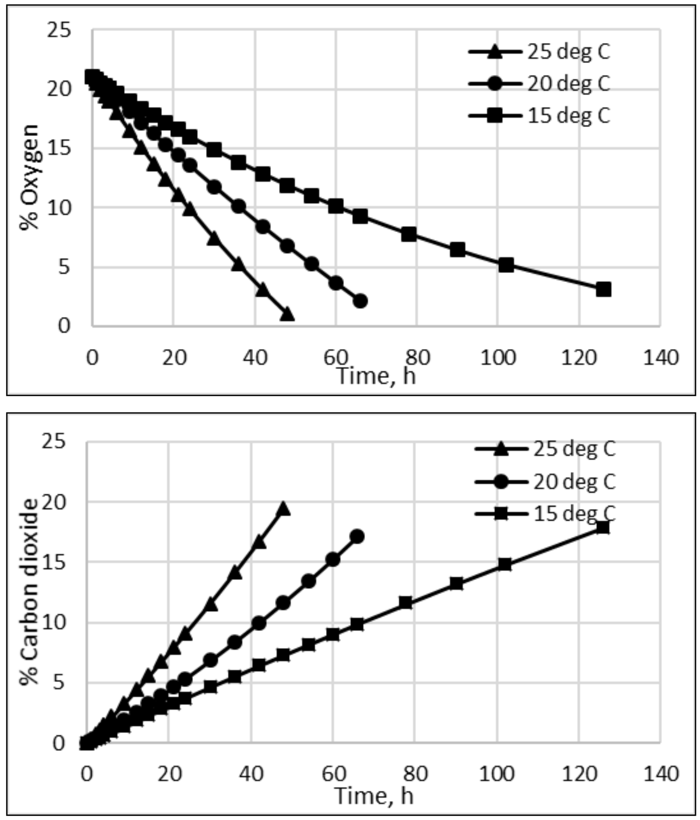

Figure 2. Representative O_2 and CO_2 concentrations inside the static chambers at

ANOVA yielded p-value = 0.0101 < 0.05 for the respiration rate and p-value = 1.87×10^{-5} < 0.05 for the required O_2 transmission rate, indicating variations among measurements in the three temperatures. Because respiration is inhibited at low temperatures, as was previously stated, the required O_2 transmission rate of mango is significantly lower at lower temperatures than it is at higher temperatures. The required O_2 transmission rates imply that O_2 must diffuse through the peel at the rates of 0.299 - 0.364 $mL \cdot cm^{-2} \cdot h^{-1}$, 0.270 - 0.600 $mL \cdot cm^{-2} \cdot h^{-1}$, and 0.924 - 1.00 $mL \cdot cm^{-2} \cdot h^{-1}$ for 15°C, 20°C, and 25°C, respectively, to maintain the respiration rate measurements found in **Table 1**.

The O_2 transmission rates of 'Carabao' mango peel with CS-NS coating at three storage temperatures are listed in **Table 2** (Acabal et al., 2020). These values were measured at the same storage conditions as in the measurement of respiration rate.

Table 1. Regression coefficients, respiration rate, and required O_2 transmission rate of mango fruits.

TEMPERATURE (°C)		REGRESSION COEFFICIENTS		RESPIRATION RATE ($mLO_2 \cdot kg^{-1} \cdot h^{-1}$)	O_2 TRANSMISSION RATE ($mL \cdot cm^{-2} \cdot h^{-1}$)
		O_2	CO_2	Mean ± SE	Mean ± SE
15	a	0.0003	0.00015	10.73 ± 1.38 b	0.327 ± 0.0373 b
	b	1.1045	1.24486		
	c	14.8391	8.45676		
	R^2	0.98936	0.99258		
20	a	0.0003	-0.0001	14.40 ± 5.26 ab	0.435 ± 0.1650 b
	b	1.1397	1.11173		
	c	9.84574	20.2822		
	R^2	0.98874	0.99232		
25	a	0.0003	-0.0001	20.55 ± 2.73 a	0.961 ± 0.0363 a
	b	1.06297	1.09141		
	c	13.9932	13.2677		
	R^2	0.97621	0.9915		

Means (4 replicates) followed by common letter (s) are not significantly different by Tukey's HSD at 5%.

Table 2. O_2 transmission rates of 'Carabao' mango peel coated with different formulations of coating at 15°C, 20°C, and 25°C.

COATING FORMULATION	O_2 TRANSMISSION RATE ($mL \cdot cm^{-2} \cdot h^{-1}$)		
	15°C	20°C	25°C
0.75% CS	0.814 a	0.935 a	1.136 a
0.75% CS + 0.03% NS	0.656 b	0.833 a	0.989 a
1% CS	0.450 c	0.528 b	0.595 b
1% CS + 0.03% NS	0.406 c	0.449 b	0.534 b

Means followed by common letter (s) are not significantly different by Tukey's HSD at 5%.

Since the measured O_2 transmission rates were higher than the fruit's requirement at 15°C, all fruit coatings are expected to modify the internal atmosphere of the fruit. For 20°C, 0.75% CS and 0.75% CS + 0.03% NS were selected, whereas 0.75% CS was selected for 25°C. Tukey's HSD ($p < 0.05$) at 20°C showed that incorporation of 0.03% NS has no significant effect on O_2 transmission rate for the same CS concentration, therefore, only 0.75% CS was used.

Since the measured O_2 transmission rates were higher than the fruit's requirement at 15°C, all fruit coatings are expected to modify the internal atmosphere of the fruit. For 20°C, 0.75% CS and 0.75% CS + 0.03% NS were selected, whereas 0.75% CS was selected for 25°C. Tukey's HSD ($p < 0.05$) at 20°C showed that incorporation of 0.03% NS has no significant effect on O_2 transmission rate for the same CS concentration, therefore, only 0.75% CS was used.

Treatment and Validation

For this experiment, mango fruits with 0.75% CS and 1% CS coatings were compared to uncoated fruits stored at 20°C. The recorded RH during the 16 -day storage was 82.02 ± 2.06% RH.

Cumulative Weight Loss

Water loss is one of the main causes of fruit deterioration. It directly affects the salable weight of the product and causes losses in appearance, texture, and quality. Weight loss induces wilting, shriveling, softening, loss of crispness and juiciness, and color changes, all of which are important characteristics for fresh produce (Ben- Yehoshua et al., 1993). The ANOVA for cumulative weight loss confirmed that there is a significant difference between the control and coated treatment. As shown in **Table 3**, the coated fruits (0.75% CS and 1% CS) have significantly ($p < 0.5$) lower cumulative weight loss compared to the control. This delayed weigh loss could be attributed to the ability of chitosan coatings to partially cover the stomates of the mango peel (Paull et al., 1989 as cited by Cisse et al., 2015; Lee et al., 1996).

Table 3. Cumulative weight loss (%) of fruits at 20°C storage temperature.

TREATMENT	NUMBER OF DAYS				
	4	8	12	13	16
Control	3.6 a	6.1 a			
0.75% CS	2.6 b	5.1 b	7.3 a	7.8 a	
1% CS	2.8 b	4.7 b	7.1 a	7.6 a	9.2
p-value	0.00102	0.00091	0.394	0.452	

Means (4 replicates) followed by common letter (s) are not significantly different by Tukey's HSD at 5%.

Peel Color Index

One important index of maturity of mango fruits is the degree of yellowing on the skin and pulp (Lizada, 1991). Significant differences in the PCI among treatments were observed in each day of measurement, as confirmed by the ANOVA results (p-value < 0.05). All coating formulations are effective in delaying the yellowing of the peel of the fruits as shown in **Table 4**. The same results were observed by Zhu et al. (2008), where the application of CS coating effectively delayed the color development of mango skin. Fruit coatings modify the internal CO_2, O_2, and ethylene levels of the fruits, thereby reducing respiration rate and delaying the conversion of chlorophyll to carotenoids (Cissé et al., 2015; Jongsri et al., 2016).

Table 4. Peel color index of fruits at 20°C storage temperature.

TREATMENT	NUMBER OF DAYS				
	4	8	12	13	16
Control	3.8 a	5.8 a			
0.75% CS	2.3 b	3.5 b	4.3 a	5.3 a	
1% CS	1.5 b	2.3 c	2.3 b	2.8 b	2.8
p-value	$6x10^{-4}$	$2x10^{-5}$	0.01	0.0036	

Means (4 replicates) followed by common letter (s) are not significantly different by Tukey's HSD at 5%.

Sensory Evaluation

The intensity and uniformity of pulp color (**Figure 3**) for fruits coated with 1% CS is very low indicating a pale-yellow pulp and a patchy distribution. The fruits exhibited ripening abnormalities such as the development of off-flavor and off-odor, and signs of internal breakdown. At very low O_2 levels (2.7 - 7%), mango fruits switch to anaerobic metabolism because of restricting the gas diffusion between the fruits and the environment (Serrano and Lizada, 1991). The control and 0.75% CS showed high color quality rating (**Table 5**), indicating uniform yellow-orange pulp that is due to

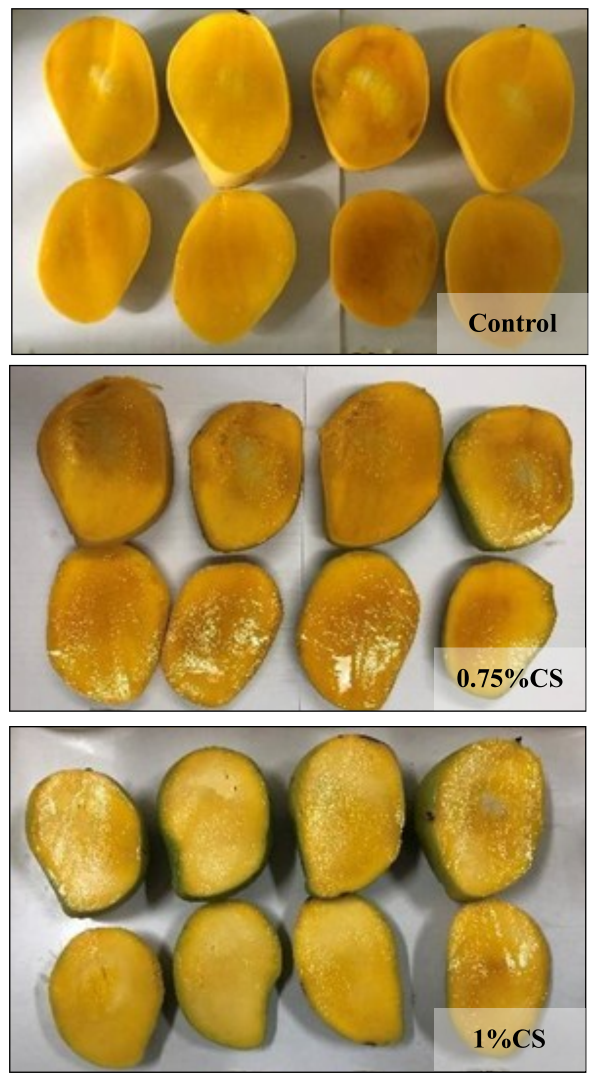

Figure 3. The internal appearance of mango fruits coated with different formulations at 20°C storage temperature.

the high concentrations of carotenoid in the pulp (Baldwin et al., 1999).

As seen in **Table 5**, both control and 0.75% CS have a very characteristic mango aroma with no off-odor, while a very strong off-odor was observed in fruits coated with 1% CS that may be an indication of anaerobic respiration and the formation of acetaldehyde (Bender et al., 2000; Kader, 1980). 'Carabao' mango fruits enclosed in polyethylene bags and waxing restricted gas diffusion that resulted in ripening abnormalities such as off-flavor and internal breakdown (Lizada, 1991). Control fruits and 0.75% CS have no significant difference in sweetness, sourness, and balance of these two flavors, but the fruits coated with 1% CS were too sour. The sweetness of the fruits is attributed to the conversion of starch into sugars via hydrolysis (Abbasi et al., 2009).

Table 5. Sensory evaluation score* of fruits at 20°C storage temperature.

PARAMETERS	p-value	TREATMENT		
		Control	0.75% CS	1% CS
Intensity of pulp color	$6.95x^{-9}$	6.8 a	7.2 a	3.0 b
Uniformity of pulp color	$4.39x^{-5}$	6.9 a	5.5 a	3.3 b
Mango Aroma	$2.4x^{-8}$	7.4 a	7.2 a	3.3 b
Off-odor	$3.27x^{-9}$	8.3 a	8.2 a	3.0 b
Sweetness	$5.53x^{-6}$	7.4 a	6.9 a	3.0 b
Sourness	0.0073	5.0 ab	3.1 a	6.9 b
Balance of sweetness and sourness	0.0021	6.5 a	3.8 b	3.0 b
Characteristic mango flavor	$8.88x^{-7}$	7.2 a	7.2 a	3.7 b
Off-flavor	$7.64x^{-6}$	7.7 a	7.5 a	3.6 b
Firmness	$4.79x^{-5}$	7.5 a	4.0 b	6.8 a

**Rating: 1-Least favorable response, 9-most favorable respose Means (8 replicates/panelists) in the same row followed by common letter (s) are not significantly different at 5% level by Tukey's HSD.*

For the texture, fruits coated with 0.75% CS were soft, whereas control and fruits coated with 1% CS were firm. Softening of fruits is mainly due to cell wall and pectin degradation. During the ripening process, the hydrolyzing action of pectin methylesterase and softening enzymes such as polygalacturonase, b-galactosidase, and cellulase are very high (García-Betanzos et al., 2017). The degradation of insoluble proto-pectins to the more soluble pectic acid in coated fruits is retarded because of inhibition in pectinesterase and polygalacturonase activities caused by low internal O_2 levels (Abbasi et al., 2009). 'Carabao' mango fruit has a well-defined and intact cuticular layer with a thickness of about 50 um and has an epidermal layer made up of closely packed cells. The very low internal O_2 of the fruits coated with 1% CS can be attributed not only to the high respiration rate but also to the barrier to gas exchange in the fruit itself (Nuevo et al., 1984 as cited by Lizada, 1991).

CONCLUSION

The main considerations in developing an appropriate packaging or coating material for a commodity are materials' barrier properties, the product's biological characteristics, and storage conditions. When the respiration rate, fruit mass and surface area are known, the required gas transmission rate of the mango fruit can be easily computed using respiration mass balance. This method was previously applied to various fresh and fresh-cut produce in developing modified atmosphere packages. Using the same mathematical models, it was found out that 1% CS has a low O_2 transmission rate to provide for the respiration requirements of mango fruits. Results showed that storage temperature has a significant effect on the respiration rate, and hence, O_2 transmission rate requirements of mango fruits. At lower temperatures, the transmission rate of gases through the peel also decreases. The computed O_2 transmission rate requirements of mango fruits at 14% internal O_2 level were 0.3270 $mLO_2 \cdot cm^{-2} \cdot hr^{-1}$, 0.4530 $mLO_2 \cdot cm^{-2} \cdot hr^{-1}$, and 0.9608 $mLO_2 \cdot cm^{-2} \cdot hr^{-1}$ for 15°C, 20°C, and 25°C, respectively.

This study also showed the importance of selecting the appropriate coating material that matches the fruit's requirement. Coating materials with the same or higher O_2 transmission rates should be used to provide sufficient O_2 diffusion through the fruit's peel. Experimental trials to validate the results showed that at 20°C, coating the mango fruits with 1% CS caused development of off-flavor and off-odor that are symptoms of anaerobic respiration. Fruits coated with 0.75% CS inhibited peel and pulp color development for five days without affecting the sensory attributes.

Thicker films provide lower gas transmission rate since there is longer path length for diffusion (Ray and Okamoto, 2003). During the application of fruit coating, dipping time could be reduced to attain higher transmission rates, or could be increased to obtain lower transmission rates. Lower CS concentrations and longer dipping time during coating application could be considered as future studies since the use of lower concentrations may be more economical.

RECOMMENDATIONS

The internal O_2 concentration of the fruit held at three storage temperatures should be measured to have actual data on the calculation of gas transmission rate requirements of mango fruits. During the validation or storage of mango fruits, the temperature and relative humidity should be the same as the conditions during the measurement of the gas transmission rates of the coated peel. Finally, image analysis can be used to have a better representation of the peel and pulp color of the fruits since hedonic ratings can be subjective.

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