Determination of Oxygen and Carbon Dioxide Gas Transmission Rates of Mango (*Mangifera indica* L. cv *'Carabao'*) Peel Using Exponential Decay Method and Respiration Mass Balance

Fidelina T. Flores[1], Kevin F. Yaptenco[2], and Edralina P. Serrano[3]

[1]Assistant Professor 1, Agricultural and Bio-Process Division, Institute of Agricultural Engineering, College of Engineering and Agro-Industrial Technology, University of the Philippines Los Baños, 4031 College, Laguna, Philippines (Author for correspondence email: ftflores@up.edu.ph)

[2]Professor 2, Agricultural and Bio-Process Division, Institute of Agricultural Engineering, College of Engineering and Agro-Industrial Technology, University of the Philippines Los Baños, 4031 College, Laguna, Philippines

[3]Adjunct Professor, Institute of Crop Science, College of Agriculture and Food Science, University of the Philippines Los Baños, 4031 College, Laguna, Philippines

ABSTRACT

The quality of the commodity should be maintained during handling, storage and transport. Commodities undergo series of physiological processes like respiration, transpiration, and ethylene production which could affect the quality and market value of products. One important factor that could affect these physiological processes is the exchange of gases between the commodity and the environment. Exchange of gases is affected by commodity characteristics like maturity, storage conditions and the permeability of the packaging material. Diffusion barriers like the peel of the fruit and the packaging material restrict movement of gases like oxygen and carbon dioxide to cells in fruits. Two methods of determining the oxygen and carbon dioxide transmission rates (O_2TR and CO_2TR) of mango (Mangifera indica L.) peel were done. The first method was the Exponential Decay Method of Gas Transmission Rate of Films by Moyls (1992) where a modified Fick's law relates the gas transmission rate with the partial pressure inside and outside a gas chamber. The other method was the respiration rate mass balance where the internal gas concentration within the fruit was measured. The results of the two methods showed that overmature fruits at 27°C had the highest O_2TR and CO_2TR (1.64 mLO_2/cm^2-hr and 4.74 mLCO_2/cm^2-hr for Method 1 and 1.26 mLO_2/cm^2-hr and 3.85 mLCO_2/cm^2-hr for Method 2) while immature fruit at 14°C had the lowest O_2TR and CO_2TR (1.10 mLO_2/cm^2-hr - 3.32 mLCO_2/cm^2-hr for Method 1 and 0.72 mLO_2/cm^2-hr and 2.36 mLCO_2/cm^2-hr for Method 2). Results also showed that storing the fruits at low temperature decreased the gas transmission rate between the fruit and the environment; and that the difference of the gas transmission rate values between the two methods was significant.

Keywords — oxygen transmission rate, carbon dioxide transmission rate, respiration rate mass balance, internal gas, fruit peel

INTRODUCTION

Exchange of gases between the commodity and the surrounding environment affects physiological processes that the commodity usually undergoes. The exchange of gases is affected by several factors like the barrier between the commodity and the environment. The packaging material used, and the peel of the fruit are two important factors that affect the gas exchange.

When the fruits or commodity lose or gain oxygen and water, it can cause deterioration. Ways to improve packaging is important to prolong the shelf life of products. It includes use of airtight seals and the use of better barrier materials like edible coatings. Some new trends in the industry include the gas permeation control through packaging and the gas composition inside packages was also controlled (Wang *et al.*, 2018). A study by Diaz *et al.* (2012) found out that the application of alginate coatings was able to reduce the gas exchange as it created a barrier between the environment and the fruit. Figure 1 shows the gas passing through the film barrier and the four steps involved which are (1) adsorption, (2) solution, (3) transmission, and (4) desorption. It shows the exchange of gases between the fruit and the environment (Li *et al.,* 2010).

The resistance of plant tissue to water vapor and gas diffusion, and ethylene is dependent on the structure of fruit or vegetables (Irtwange, 2006). It could be estimated using the Fick's law that describes the gas diffusion between the commodity and the environment. It is dependent on the characteristics of the fruit like the structure of the peel and the gas concentration inside the fruit and the environment (Zhang and Bunn, 1999). A study by Huang *et al.* (2016) observed that the fruit skin has a strong influence on gas exchange dynamics. Gas permeability of the peel and the packaging material like edible coating to be used in storage and transportation of the fruit can also help in estimating and predicting the gas composition in the atmosphere to which the commodity interacts.

Atmosphere modification helps in extending the shelf life and in maintaining the quality of the commodity. It can be achieved using package films and application of surface coatings on the commodity. Edible coating application also uses the knowledge on movement and transfer of gases. Gas exchange can be measured by determining the transmission rates of barriers such as the fruit peel. This could help in the design of appropriate packaging material for the commodity that would also match the stage of development of the commodity.

The objectives of this study were to determine the oxygen and carbon dioxide transmission rates of mango peel using exponential decay method and respiration rate mass balance and to compare the oxygen and carbon dioxide transmission rates of mango obtained using the two methods.

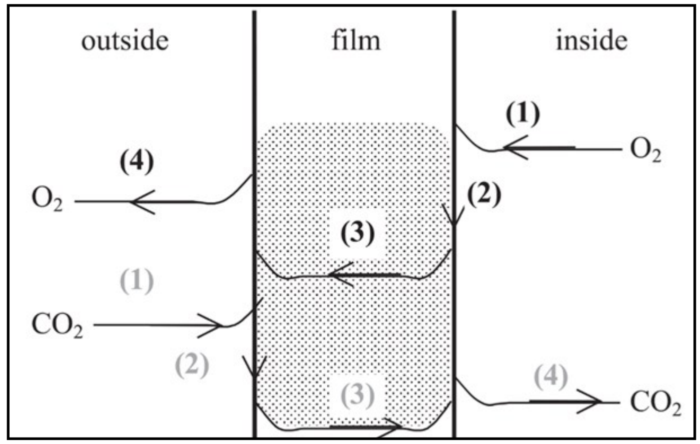

Figure 1. Gas molecule penetrating course is divided into four steps: (1) adsorption, (2) solution, (3) transmission, and (4) desorption.
Source : Li *et al.* (2010)

METHODOLOGY

Fruit Samples

Fruit samples were from a farm in Calamba City, Laguna. Record on days after flower induction (DAFI) was used to determine the maturity and the fruits were also subjected to water flotation method during harvest for verification of maturity. Samples were harvested from one tree at 110 DAFI (immature), 115 DAFI (mature) and 120 DAFI (overmature). The stage of ripeness was based on the peel color index (PCI) of the fruits. The fruits were harvested at full green stage (PCI 1) and were allowed to ripen until breaker - not more than 10% yellow (PCI 2) and until PCI3 stage or when there is more green than yellow. The weight and volume of the fruit samples were measured before storage using an electronic balance (Ohaus ARB120) and water displacement method, respectively.

Gas Transmission Rate by Exponential Decay Method

Gas Diffusion Chamber and Leakage Testing

The design of the gas diffusion chamber used for method 1 was adapted from Malilay *et al.* (2011). The gas chamber was fabricated using polyvinyl chloride (PVC) pipe, clear acrylic sheet and a galvanized iron sheet. The top portion of the gas chamber had holes for the peel samples. The sample cover which was made from a PVC rod held the fruit peel in the gas chamber. Metal screws were used to fasten the sample cover and holder. Two rubber caps were attached at opposite sides of the chambers that served as ports for gas flushing and sampling.

Leakage test for a period of 24 hours was performed on the gas chambers. In this test, pure nitrogen gas was flushed in the chambers for 5 minutes or until the level of oxygen concentration in the chamber was approximately 17%. After that, the gas concentration was measured using gas analyzer (PBI Dansensor Checkmate 3) every hour for the first 8 hours and every 3 hours until 24 hours. The average leak was computed using Equation 1. To minimize leakage during the test, vacuum grease was also applied on the circumference of the sample holder and sample cover.

$$\% \, Error \, due \, to \, leakage = \left(\frac{P_i - P_f}{P_i}\right) x100$$

Equation 1

P_i is the initial partial pressure of the gas in the chamber and P_f is the final partial pressure of the gas in the chamber.

Volume of chamber and diffusion area

The volume of air was calculated using the dimensions of the gas chamber while the diffusion area was determined by the dimension of each hole. Diffusion area is the area where the gas from the chamber would diffuse to the surroundings and into the chamber.

The peel samples (thickness = 1.5mm) taken using a cylindrical disc corer were placed in the sample holders in the gas chamber. The thickness set was the average thickness of mango cultivars as cited by Ahmed and Mohamed (2015).

Gas flushing and sampling

Initially the gas concentration inside the gas chamber was at ambient condition [78% nitrogen (N_2), 21% oxygen (O_2) and 0.03% carbon dioxide (CO_2)]. The chamber was flushed with pure nitrogen to lower the oxygen level until 5% inside the chamber. This was immediately followed by flushing a gas mix (5% O_2 and 5% CO_2). The chambers where then placed in cold and ambient condition where the air temperature and relative humidity were being monitored using a data logger. The gas chambers were then covered with plastic sheets to minimize the effect of the airflow rate from the blowers in the cold room. Measurement of the gas concentration in the chambers were done every hour for 7 hours using a gas analyzer (PBI Dansensor Checkmate).

Gas Transmission Rate Determination

Gas transmission rates were computed using the method described by Moyls (1992). The method was a modification of the Fick's law that relates the gas transmission rate with the partial pressures of the gas composition inside the gas chambers and the condition outside. In the Fick's law, gas permeability is the product of the gas solubility and diffusivity and given by Equation 2.

$$Perm = \tau D$$

Equation 2

Perm is gas permeability of the film (cm^2/h), τ is solubility of the gas in the film (g / g), and D is diffusion coefficient of the gas into the film (cm^2/h).

Moyls (1992) modified the equation and was expressed as Equation 3.

$$\frac{dm}{dt} = -Perm \, A \frac{d\rho}{dx}$$

Equation 3

A is film area (cm^2), m is mass of gas in the diffusion chamber (g), t is elapsed time during run (h), ρ is density of the gas in the diffusion chamber (g/cm^3) and dx is film thickness (cm).

The relationship of the mass flux of gas in the chamber to the change in pressure of the gas was expressed in Equation 4.

$$\frac{dP}{dt} = -Trans\frac{A}{V}(P - P_A) \qquad \text{Equation 4}$$

Trans is transmission rate of gas through the film.

From Equation 4, the parameters ΔP and ΔP° was defined as $\Delta P = (P\text{-}P_A)$ = Partial pressure in the chamber – Partial pressure in the ambient, and $\Delta P° = (P°\text{-}P_A)$ = Initial partial pressure in the chamber - Partial pressure in ambient.

Equation 5 was obtained after integration and taking the logarithm.

$$\ln\frac{\Delta P}{\Delta P°} = -\left(Trans\frac{A}{V}\right)t \qquad \text{Equation 5}$$

V is volume of the test cell, mL and A is effective area of the film, cm^2.

The computed O_2 and CO_2 pressure measurements followed the Ideal Gas Law and the expression ln (ΔP/ΔP°) versus time was plotted. The resulting slope ("S") of the line was used to determine the exponential decay constant of the gas chamber. After solving for the slope of the line, the transmission of the specific gas (oxygen or carbon dioxide) in consideration through the fruit peel can be expressed as Equation 6.

$$Trans\left(\frac{mL}{cm^2h}\right) = \frac{-S_{trans}V}{A} \qquad \text{Equation 6}$$

Gas Transmission Rate by Respiration Mass Balance

Internal Gas

Internal gas concentration of the fruits was measured using the vacuum extraction method. The procedure and setup were adapted from Saltviet (1982). The setup used was shown in Figure 2. It was composed of an evacuation chamber (desiccator) and a collection flask (bottle).

The evacuation chamber was filled with a saturated salt solution and the fruit was placed inside the collection flask before immersing it to the solution. Vacuum was applied in the chamber and the bubbles that developed at the top of the collection flask were collected using a syringe. The sample gas was injected to a gas chromatograph (Shimadzu GC-8A TCD) for analysis.

Respiration Rate

Respiration rate of the fruit was measured by static method. Fruits were placed in static jars (Figure 3) and the gas concentration was measured using gas analyzer (PBI Dansensor Checkmate 3). The area of the fruit peel was estimated using the image analysis program, Image J2X.

Respiration rates in terms of oxygen consumption and carbon dioxide production were computed using Equations 7 and 8, respectively.

Figure 2. Setup used for the vacuum extraction of internal gas of fruit samples.

Figure 3. Setup for the respiration rate measurement.

$$\text{Respiration Rate}\left(\frac{mgO_2}{kg-hr}\right)=\left[\frac{\%O_{2f}-\%O_{2i}}{100}\right]V_f\left(\frac{1}{t}\right)\left(\frac{1}{w}\right)\left(\frac{32mgO_2}{24mL\ O_2}\right)$$

Equation 7

$$\text{Respiration Rate}\left(\frac{mgCO_2}{kg-hr}\right)=\left[\frac{\%CO_{2f}-\%CO_{2i}}{100}\right]V_f\left(\frac{1}{t}\right)\left(\frac{1}{w}\right)\left(\frac{44mgCO_2}{24mL\ CO_2}\right)$$

Equation 8

$\% O_{2f}$ is concentration of oxygen after 1 hour in %, $\%O_{2i}$ is concentration of oxygen at time zero in %, $\% CO_{2f}$ is concentration of carbon dioxide after 1 hour in %, $\% CO_{2i}$ is concentration of carbon dioxide at time zero in %, V_f is the headspace volume in mL, t is the time in hr, and w is the weight of the fruit in kg.

Calculated Transmission Rate

The calculated values of oxygen and carbon dioxide transmission rates were computed using the data for the measured respiration rate and internal gas. Equations 9 and 10 were used to compute the calculated oxygen and carbon dioxide transmission rates of the mango peel, respectively.

$$O_2TR_c=\frac{100\ RR_{O_2}W_f}{A\ (O_{2_a}-O_{2_i})}$$

Equation 9

$$CO_2TR_c=\frac{100\ RR_{CO_2}W_f}{A\ (CO_{2_a}-CO_{2_i})}$$

Equation 10

O_2TRc is the calculated oxygen transmission rate in mL O_2/cm^2-hr, CO_2TRc is the calculated carbon dioxide transmission rate in mLCO_2/cm^2-hr, O_{2a} is the oxygen concentration of surrounding air in %, O_{2i} is the internal oxygen concentration in %, CO_{2a} is the carbon dioxide concentration of surrounding air in %, CO_{2i} is the internal carbon dioxide concentration in %, RR O_2 is the measured respiration rate in mL O_2/kg-hr, RR CO_2 is the measured respiration rate in mL CO_2/kg-hr, W_f is the weight of the fruit in kg, A is the surface area of the fruit in cm^2.

Temperature and Respiratory Quotient

The effect of change in temperature on the respiration rate of the fruit samples was measured by calculating the Q_{10} value given by Equation 11.

$$Q_{10}=\left(\frac{R_2}{R_1}\right)^{\frac{10}{(T_2-T_1)}}$$

Equation 11

R_1 is the respiration rate at T_1, mL CO_2 / kg h, R_2 is the respiration rate at T_2, mL CO_2 / kg h, T_1 is the temperature, °C or K, T_2 is the temperature, °C or K.

Respiratory quotient (RQ) is a measure of the volume of gas (oxygen and carbon dioxide) involved in the respiration process and was given by Equation 12.

$$RQ=\frac{mL\ CO_2\ evolved}{mL\ O_2\ consumed}$$

Equation 12

Statistical Analysis

The statistical analyses were done using R Studio. Analysis of variance (ANOVA) was used to evaluate the variation between measurements and significant difference were analyzed using the Tukey's Honestly Significant Difference (HSD) Test. RStudio was also used to determine the difference of the values obtained using the methods of determining the gas transmission rate of the peel.

RESULTS AND DISCUSSION

Fruit Samples

Mangoes harvested at 110DAFI, 115DAFI and 120DAFI had a density of 1.00 g/mL, 1.01g/mL and 1.06g/mL, respectively. Temperature in the cold storage condition is 14.5°C and 26.9°C at ambient condition.

Gas Transmission Rate by Exponential Decay Method

Leakage testing and gas sampling

Moyls (1992) stated that a correction of 4% change in partial pressure for O_2 and CO_2 is small. The computed average leak for the gas chambers was 2.94%. Since this value was less than 4%, no correction for the partial pressure in the gas chambers was considered. The effect of the volume of gas extracted from the chamber was also determined to be 0.4% and since this was less than the allowed value of 1%, no correction for the change in pressure inside the chamber was also considered.

Table 1. Gas transmission rates of mango peel measured using the exponential decay method.

		MATURITY	MEASURED TRANSMISSION RATE (mL O_2/cm^2 hr) Mean		SE		(mL CO_2/cm^2 hr) Mean		SE	
14	1	Immature	1.10	±	0.04	a	3.32	±	0.13	a
		Mature	1.11	±	0.04	a	3.51	±	0.18	a
		Overmature	1.18	±	0.03	a	3.43	±	0.08	a
	2	Immature	1.29	±	0.07	a	3.35	±	0.05	a
		Mature	1.42	±	0.04	a	3.83	±	0.18	a
		Overmature	1.38	±	0.07	a	3.69	±	0.17	a
	3	Immature	1.49	±	0.04	a	3.64	±	0.13	a
		Mature	1.49	±	0.07	a	4.09	±	0.23	a
		Overmature	1.61	±	0.06	a	4.26	±	0.18	a
27	1	Immature	1.19	±	0.02	b	3.20	±	0.15	a
		Mature	1.43	±	0.02	a	3.76	±	0.17	a
		Overmature	1.36	±	0.04	a	3.87	±	0.15	a
	2	Immature	1.31	±	0.05	a	3.54	±	0.10	b
		Mature	1.45	±	0.04	a	4.19	±	0.18	ab
		Overmature	1.42	±	0.07	a	4.41	±	0.19	a
	3	Immature	1.56	±	0.05	a	4.37	±	0.25	a
		Mature	1.58	±	0.03	a	4.70	±	0.21	a
		Overmature	1.64	±	0.09	a	4.74	±	0.14	a

Means within group in a column followed by a common letter do not differ with each other at Tukey's Honest Significance Difference (HSD) at 5% level.

Gas Concentration

Oxygen concentration inside the chamber increases with time as shown in Figures 4, 5, and 6. The concentration of oxygen outside the chamber is higher than the surroundings which shows that oxygen goes into the chamber. On the other hand, carbon dioxide decreases with time, thus the gas leaves the chamber. This is because the concentration of carbon dioxide inside the chamber is higher than the concentration of the gas outside the chamber.

Oxygen and carbon dioxide transmission rates of mango peel was determined using the Exponential Decay Method as described by Moyls (1992) and the values are presented in Table 1. Results showed that overmature mango peel at ripening index 3 and stored at ambient condition had the highest O_2 TR M and CO_2 TR M. Immature mango peel at full green stage stored in the cold room had the lowest O_2 TR M and CO_2 TR M, respectively. Analysis of variance showed that at each storage condition, maturity and stage of ripeness had significant effects on O_2 TR M and CO_2 TR M. That is, as the fruit matures and ripens, gas exchange increases. The increase in the transmission rate is due to the arrangement and structure of cells in the peel that changes as the fruit matures and ripens. The results using this method were also discussed by Flores *et al.* (2014). The cell wall of mango is compact and rigid at mature and unripe stage and losses the structure as the fruit ripens (Yashoda *et al.* 2006). Gas diffusion rate was also significantly affected by the maturity stages and storage conditions. The exchange of gases is due to the behavior of cells during maturity and ripening (Thewes, *et al.* 2017, Paul and Pandey, 2014).

Pereira (2009) observed that the degradation of tissue progresses as the fruit matures and as it starts to ripen, there is separation of cells and, transmission of intercellular spaces and softening of tissue. The intercellular spaces in the cells of the banana peel increases as it ripens (Kheng *et al.,* 2011). The ratio between carbon dioxide and oxygen was small since both gases diffuse mainly through pores of the skin of the pear. No change in diffusivity was found when fruits are harvested before or after optimal harvest dates (Schotsmans *et al.,* 2003).

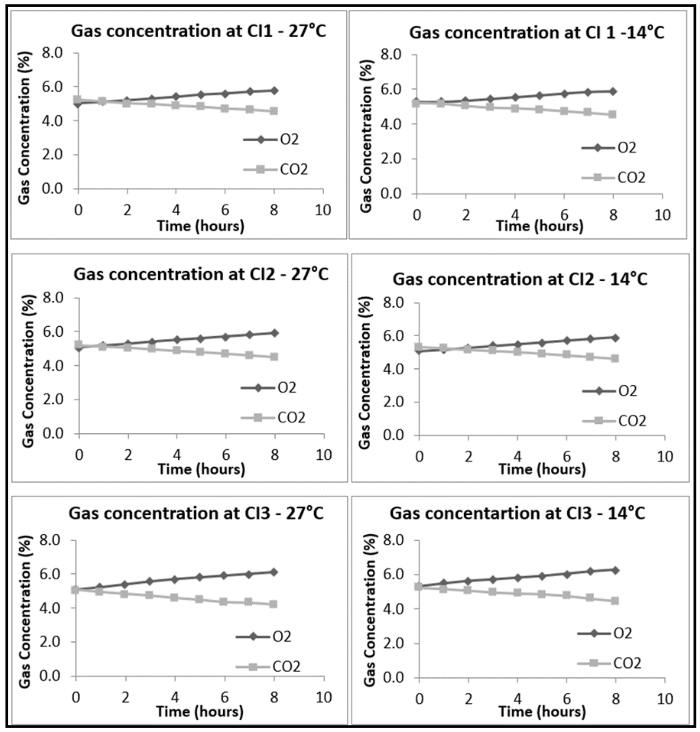

Figure 4. Gas concentration vs. time of mango peel (110DAFI) at different color index (CI) and temperature.

Gas Transmission Rate by Respiration Mass Balance

Respiration Rate

The computed respiration rates of mango fruit in terms of oxygen consumption and carbon dioxide production are shown in Table 2. Respiration rates of mango fruits at ambient condition were higher than the respiration rates under cold condition of the same stage of maturity and ripeness.

The onset of climacteric peak is delayed when fruits are stored under low temperature. Respiration rate increases as the fruit matures and as it ripens.

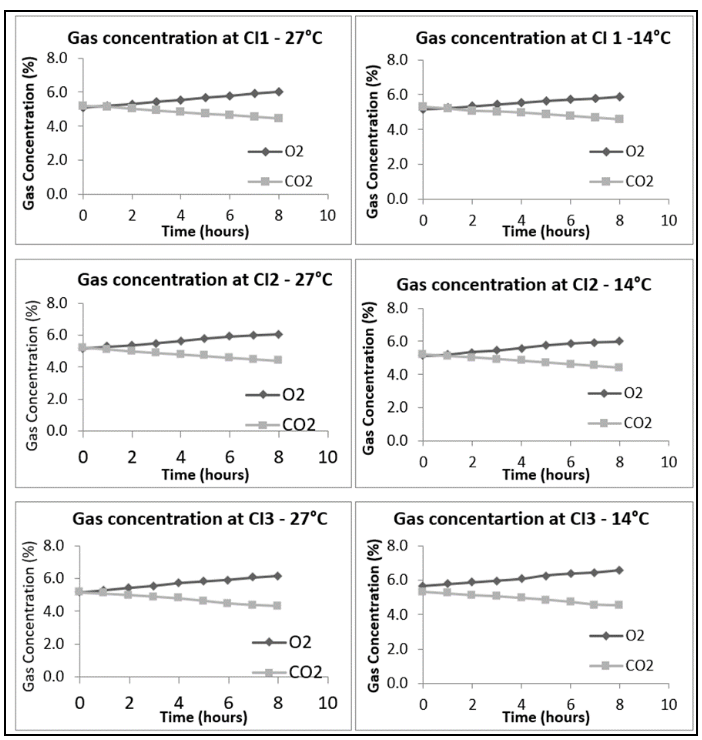

Figure 5. Gas concentration vs. time of mango peel (115DAFI) at different color index (CI) and temperature.

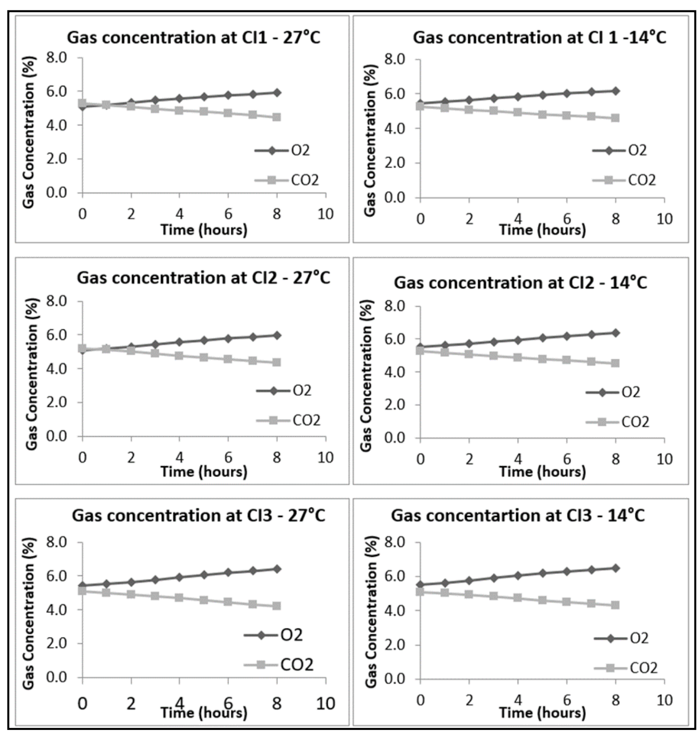

Figure 6. Gas concentration vs. time of mango peel (120DAFI) at different color index (CI) and temperature.

Results showed that temperature can slow down the respiration process. And that as fruit ripens, respiration rate increases. Mango fruits harvested mature has the highest respiration rate and lowest at overmature stage. Cua (1989) reported that 'Carabao' mango exhibits climacteric type and that as the fruit matures and ripens the respiration rate increases.

As the fruit matures and ripens, carbohydrates are broken down and converted into metabolic energy. This increase in respiration during maturation was also observed by Joas *et al.* (2012). In the study it was discussed that as the fruit matures, the metabolites or its precursor continue to develop and affect respiration of the fruit.

Table 2. Respiration rates of mango fruit at different maturity and peel color index under two temperature regimes.

TEMPERATURE (°C)	MATURITY	PCI	RESPIRATION RATE (mL O_2/kg hr) Mean		SE		(mL CO_2/kg hr) Mean		SE	
14	Immature	1	24.41	±	1.47	b	33.16	±	1.87	a
		2	24.64	±	1.74	b	22.29	±	1.41	b
		3	44.65	±	0.60	a	36.05	±	0.26	a
	Mature	1	52.06	±	2.14	b	32.24	±	0.78	a
		2	49.33	±	1.93	b	25.88	±	1.62	b
		3	74.71	±	2.39	a	36.50	±	1.68	a
	Overmature	1	34.05	±	0.98	b	21.82	±	0.29	b
		2	30.52	±	2.26	b	20.81	±	1.10	b
		3	46.01	±	1.55	a	31.77	±	1.68	a
27	Immature	1	73.16	±	0.85	b	52.12	±	0.14	b
		2	69.68	±	1.35	b	40.92	±	0.41	b
		3	108.30	±	5.19	a	74.41	±	4.67	a
	Mature	1	74.70	±	2.57	b	49.13	±	3.15	b
		2	52.54	±	0.54	c	35.29	±	0.65	b
		3	96.16	±	2.24	a	95.02	±	5.08	a
	Overmature	1	48.68	±	1.67	b	34.68	±	1.04	b
		2	46.93	±	3.72	b	24.99	±	1.95	c
		3	128.17	±	8.07	a	68.23	±	1.81	a

Means within group in a column followed by a common letter do not differ with each other at Tukey's Honest Significance Difference (HSD) at 5% level.

Internal Gas

The graph of the internal oxygen and carbon dioxide concentration of mango fruits stored at ambient and cold condition measured at different peel color index is shown in Figure 7.

Results showed that stage of ripeness and maturity has an effect on internal oxygen and carbon dioxide concentration in mango fruits. This means that as the fruit starts to ripen, internal oxygen concentration in mango fruits decrease and internal carbon dioxide concentration increases. The result also showed that storage at low temperature inhibits carbon dioxide production in the fruit.

Similar trend was observed by Baldwin *et al.* (1999) for uncoated "Tommy Atkins" mangoes. The internal oxygen level in the fruit decreased over time and there was an increase in internal carbon dioxide level. This showed an exchange of gases inside the fruit and the environment.

Calculated Transmission Rate Comparison

Gas transmission rate using the respiration mass balance is presented in Table 3. The trend is also the same with the values using the exponential decay method. The computed standard error for the respiration rate mass balance incorporates all the errors based on the parameters (respiration rate, weight, surface area and internal oxygen and carbon dioxide concentration) involved in computing the oxygen and carbon dioxide transmission rates. The computed oxygen and carbon dioxide transmission rates using the first method were higher than computed values using the second method.

Mean

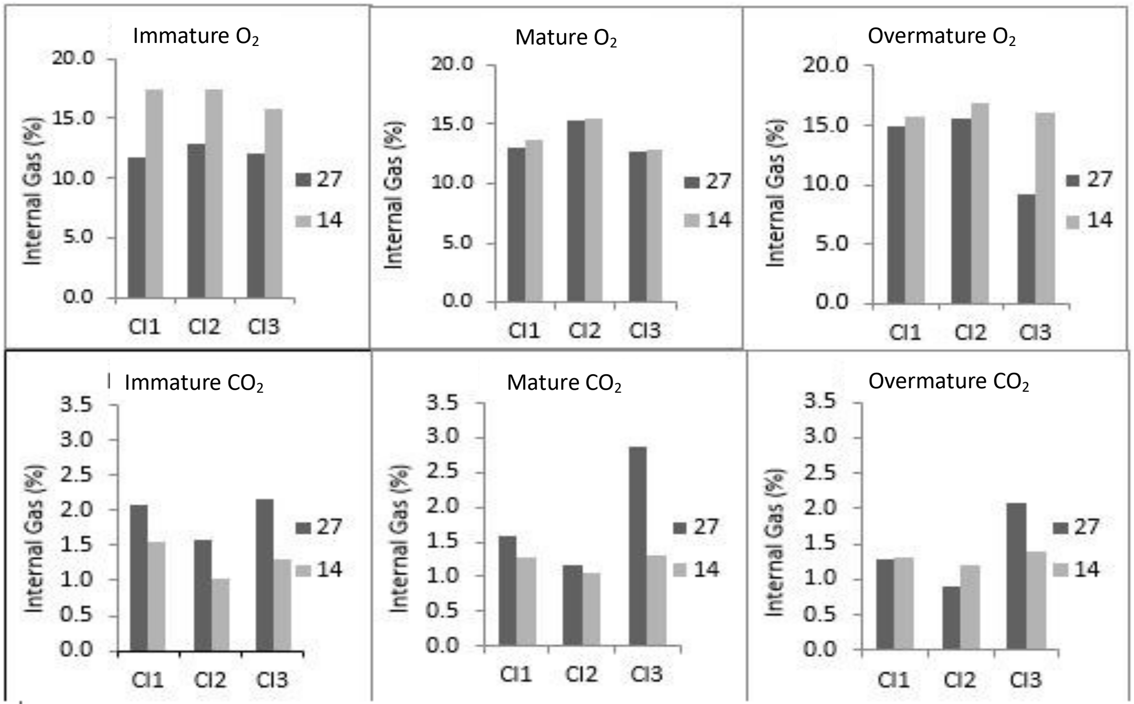

Figure 7. Internal gas concentration (%O_2 and %CO_2) of mango at different maturity and temperature regimes.

values of gas transmission rate using the exponential decay method differed significantly from respiration rate mass balance method according to the results of Welch t-test $t\ (3.7) = 11.8$, $p < 0.003$ for oxygen and $t\ (2.5) = 3.4$, $p < 0.005$ for carbon dioxide. This shows that transmission rate measured using the exponential decay method is higher than the values obtained using the respiration mass balance method. The differences in the computed values might be due to some variations. The fruit samples used in the respiration mass balance has fruit pulp. The movement of gases inside the fruit or in the pulp may be another factor. Since the structure of the pulp is different from the structure of the peel. Ho *et al.* (2009) developed a model for oxygen and carbon dioxide exchange through the intercellular spaces, cell wall

Table 3. Gas transmission rates of mango peel measured using the respiration rate mass balance.

TEMPERATURE °C	MATURITY	PCI	COMPUTED TRANSMISSION RATE mL O_2 / cm^2 hr Mean	SE	mL CO_2 / cm^2 hr Mean	SE
14	Immature	1	0.72 ±	0.18 a	2.36 ±	0.34 b
		2	0.74 ±	0.14 ab	2.39 ±	0.38 b
		3	0.90 ±	0.15 a	2.98 ±	0.27 a
	Mature	1	0.78 ±	0.12 b	2.84 ±	0.37 a
		2	0.98 ±	0.16 a	2.79 ±	0.32 a
		3	0.99 ±	0.12 a	3.08 ±	0.27 a
	Overmature	1	0.90 ±	0.15 b	2.37 ±	0.26 b
		2	1.04 ±	0.26 b	2.42 ±	0.34 b
		3	1.28 ±	0.17 a	3.16 ±	0.30 a
27	Immature	1	0.83 ±	0.09 b	2.67 ±	0.28 b
		2	0.88 ±	0.13 b	2.74 ±	0.36 b
		3	1.24 ±	0.19 a	3.59 ±	0.48 a
	Mature	1	1.02 ±	0.12 b	3.43 ±	0.40 a
		2	1.00 ±	0.09 b	3.34 ±	0.27 a
		3	1.25 ±	0.14 a	3.56 ±	0.39 a
	Overmature	1	0.97 ±	0.16 b	3.34 ±	0.40 a
		2	1.03 ±	0.18 ab	3.39 ±	0.62 a
		3	1.26 ±	0.22 a	3.85 ±	0.59 a

Means within group in a column followed by a common letter do not differ with each other at Tukey's Honest Significance Difference (HSD) at 5% level.

and cytoplasm of cells for pear cortex. In the simulation, it showed that there was an oxygen and carbon dioxide exchange through the intercellular space, the cell wall network and less through the intracellular liquid. A biological variation of the diffusivity of gases in the tissue was related to the random distribution of cells.

Table 4. Respiration quotient and Q_{10} values of mango fruits.

DAY	IMMATURE			MATURE			OVERMATURE		
	Q_{10}	RQ		Q_{10}	RQ		Q_{10}	RQ	
		27°C	14°C		27°C	14°C		27°C	14°C
1	1.09	0.71	1.36	1.06	0.66	0.62	1.10	0.71	0.64
2	0.99	0.59	1.97	0.85	0.67	0.61	0.89	0.53	0.68
3	1.94	0.69	0.90	2.09	0.99	0.52	1.64	0.54	0.65
4	1.39	0.84	0.92	1.74	1.41	0.63	1.67	0.53	0.78
5	1.04	0.68	0.81	1.26	1.32	0.49	1.58	0.76	0.74
6	-	-	1.13	1.44	1.37	1.16	1.13	0.66	0.69
7	-	-	0.89	-	-	1.18	-	-	0.78
8	-	-	-	-	-	1.47	-	-	0.75
9	-	-	-	-	-	-	-	-	1.08

Temperature and Respiratory Quotient

Computed Q_{10} values and respiration quotient of mangoes in all the treatments are presented in Table 4. Q_{10} values of mature mangoes showed the highest value followed by immature and over-mature mangoes. This means that mature mangoes have a faster rate or response upon a 10°C drop in the temperature. The computed RQ values show that on the average, immature mangoes at 14°C have the tendencies to experience anaerobic respiration compared with other treatments (Ravindra and Goswami, 2008). This means that if it is harvested early, the process of respiration in the fruit is triggered early and the amount of substrate to be used for the respiration is not sufficient.

Application of Gas Transmission Rates

The values of oxygen and carbon dioxide transmission rates of mango peel can be used to design appropriate packaging materials to be used during storage and transport. It can also be used to formulate appropriate edible coating to be applied on the fruit. This could be done by simulating an edible coating with a known permeance and determine the behavior and shelf life of the fruit. This could help determine whether the fruit will experience injury that is related to exposure to levels of gas concentration during storage and transport.

Studies on the application of edible coatings to fruits showed that the coating was able to control gas exchange. Medeiros *et al.* (2012) observed that the developed nanomultilayer coating system was able to reduce gas transmission and fruit also had a better external appearance as the dehydration of the surface is less. It was also noted that with the application of coating, there was a low oxygen permeability of pectin layers which reduced the gas flow and prolonged the shelf-life of mangoes . The application of galactomannans and collagen blends as edible coating in mangoes reduced the consumption of oxygen by 28% and production of carbon dioxide by 11% as compared to the uncoated fruits (Lima *et al.* 2010).

SUMMARY AND CONCLUSIONS

Fruit peel is a barrier between the fruit and the surrounding air. Transmission rate also depends on the condition of the commodity and the storage condition. Exchange of gases between the commodity and the surrounding atmosphere to which it is exposed is important in designing the packaging material and formulating edible coatings to be used.

Oxygen and carbon dioxide transmission rates of mango peel at different maturity stages and ripening index and storage condition were determined using the Exponential Decay Method and the respiration mass balance. Results showed that at each storage condition, maturity and stage of ripeness had a significant effect on oxygen and carbon dioxide transmission rate of mango peel. As the fruit matures and starts to ripen, the gas transmission rate of the peel also increases. At low temperature storage, the rate of gas transmission across peel also decreases. Oxygen and carbon dioxide transmission rates across the peel that were measured directly were higher than the computed values using the respiration mass balance. Gas transmission rate calculated using the respiration mass balance was significantly different to the values measured using the exponential decay method. This was because of the presence of fruit pulp in the respiration mass balance. The diffusivity of gases in the tissue of the fruit was related to the arrangement of cells (Ho *et al.* 2009).

RECOMMENDATIONS

Measurement of the water vapor transmission rate across the fruit peel could also be considered because it could also affect the shelf life of the commodity and the type of packaging material to be used. Gas transmission rates of mango peel at PCI 4 can also be done to design appropriate packaging materials for ripe fruits.

ACKNOWLEDGEMENT

The authors would like to thank the Engineering Research and Development Technology – Department of Science and Technology for the financial support of this research study and the Postharvest Training and Research Center of the Institute of Crop Science, College of Agriculture for the assistance during the conduct of experiment.

LITERATURE CITED

AHMED, T.H.M and MOHAMED, Z.H.A. (2015). Diversity of Mango (*Mangifera indica* L.) Cultivars in Shendi Area: Morphological Fruit Characterization. International Journal of Research in Agricultural Sciences. Volume 2. Issue No. 4. 141-148.

BALDWIN, E.A., BURNS, J.K., KAZOKAS, W., BRECHT, J.K., HAGENMAIER, R.D., BENDER, R.J., and PESIS, E. (1999). Effect of Two Edible Coatings with Different Permeability Characteristics on Mango (*Mangifera indica* L.) Ripening During Storage. Postharvest Biology and Technology 17 : 215–226

CUA, A. U. (1989). Ethylene Biosynthesis in 'Carabao' Mango Fruit (*Mangifera indica* L.) during Maturation and Ripening. MS Thesis, UP Los Baños, 123 p.

DIAZ-MULA, H.M., SERRANO, M., VALERO, D. (2012). Alginate coatings preserve fruit quality and bioactive compounds during storage of sweet cherry fruit. Food Bioprocess Technology 5(8) 2990–2997

FLORES, F.T., YAPTENCO, K.F., PERALTA, E.K. and SERRANO, E.P. (2014). Gas Transmission Rates Across ‘Carabao’ Mango (*Mangifera indica* L.) Peel at Different Stages of Maturity and Ripeness. APCBEE Procedia 8 (2014) 230-235

HO, Q.T., VERBOVEN, P., MEBATSION, H. K., VERLINDEN, B. E., VANDEWALLE, S. and NICOLAÏ, B. M. (2009). Microscale Mechanisms of Gas Exchange in Fruit Tissue. New Phytologist 182: 163–174

HUANG, J., ZHAG, H., LIN, H., LI, T., MEI, L., SVANBERG, K. and SVANBERG, S. (2016). Gas exchange in fruits related to skin condition and fruit ripening studied with diode laser spectroscopy,” Journal of Biomedical Optics 21 (12), 127007

IRTWANGE, S. V. February (2006). Application of Modified Atmosphere Packaging and Related Technology in Postharvest Handling of Fresh Fruits and Vegetables Agricultural Engineering International: the CIGR E-Journal. Invited Overview No. 4. Vol. VIII

JOAS, J., VULCAIN, E., DESVIGNES, C., MORALESA, E. and L´ECHAUDELC, M. (2012). Physiological age at harvest regulates the variability in postharvest ripening, sensory and nutritional characteristics of mango (*Mangifera indica* L.) cv. Coghshall due to growing conditions. Journal of Sci Food Agric 92 : 1282–1290

KHENG, T.Y., DING, P. and RAHMAN, N. A.A. (2011). Physical and cellular structure changes of Rastali banana (Musa AAB) during growth and development. Scientia Horticulturae 129 (3) 382-389

LI, L. LI, X.H. and BAN, Z.J. (2010). A Mathematical Model of the Modified Atmosphere Packaging (MAP) System for the Gas Transmission Rate of Fruit Produce. Food Technol. Biotechnology 48 (1) 71-78

LIMA, A.M., CERQUEIRA, M.A., SOUZA, B.W.S., SANTOS, E.C.M., TEIXEIRA, J.A., MOREIRA, R.A., and VICENTE, A.A. (2010). New edible coatings composed of galactomannans and collagen blends to improve the postharvest quality of fruits – Influence on fruits gas transfer rate. Journal of Food Engineering (97) 101–109

MALILAY, I. X. R. YAPTENCO, K.F., CASAS, E.V and ELEPAÑO, A. R. (2011). Gas Transmission Rates of Unperforated and Perforated Polyethylene Films for Modified Atmosphere Packaging Application. Philippine Journal of Agricultural and Biosystems Engineering. AMDP CEAT, UP Los Baños. Vol. IX. 2011 Issue. p. 51-59

MEDEIROS, B., PINHEIRO, A., CARNEIRO-DA-CUNHA, M. and VICENTE, A. (2012). Development and Characterization of a Nanomultilayer Coating of Pectin and Chitosan – Evaluation of its Gas Barrier Properties and Application on 'Tommy Atkins' Mangoes. Journal of Food Engineering 110 : 457–464

MOYLS, L., HOCKING, R., BEVERIDGE, T., and TIMBERS, G. (1992). Exponential Decay Method for Determining Gas Transmission Rate of Films. In Transactions of the American Society of Agricultural Engineers. 35 (4): 1259-1265

PAUL, V. and PANDEY, R. (2014). Role of internal atmosphere on fruit ripening and storability—A Review. Journal of Food Science and Technology 51(7): 1223–1250.

PEREIRA, T., DE ALMEIDA, P.S.G., DE AZEVEDO, I.G., DA CUNHA, M., DE OLIVEIRA, J., DA SILVA, M.G. and VARGAS, H. (2009). Gas Diffusion in 'Golden' Papaya Fruit at Different Maturity Stages. Postharvest Biology and Technology 54: 123–130

RAVINDRA, M. and GOSWAMI, T. (2008). Modelling the Respiration Rate of Green Mature Mango Under Aerobic Conditions. Biosystems Engineering 99 : 239-248

SALTVIET, JR., and MIKAL E. (1982). Procedure for Extracting and Analyzing Internal Gas Samples from Plant Tissues by Gas Chromatography. HortScience Vol. 17(6) : 878-881

SCHOTSMANS, W., VERLINDEN, B.E., LAMMERTYN, J. AND NICOLAI, B.M. (2003). Simultaneous measurement of oxygen and carbon dioxide diffusivity in pear fruit tissue. Postharvest Biology and Technology 29 : 155-166

THEWES, F.R., BRACKMAN, A., ANESE, R.O., LUDWIG, V., SCHULTZ, E.E., DOS SANTOS, L.F., and WENDT, L.M. (2017). Effect of dynamic controlled atmosphere monitored by respiratory quotient and 1-methylcyclopropene on the metabolism and quality of 'Galaxy' apple harvested at three maturity stages. Food Chemistry 222 (2017) 84-93.

WANG, J., GARDNER, D.J., STARK, N.M., BOUSFIELD, D.W., TAJVIDI, M. and CAI, Z. (2018). Moisture and Oxygen Barrier Properties of Cellulose Nanomaterial-Based Films. ACS Sustainable Chemistry & Engineering 2018 6 (1), 49-70

YASHODA, H.M., PRABHA, T.N. and THARANATHAN, R.N. (2006). Mango Ripening: Changes in Cell Wall Constituents in Relation to Textural Softening. Journal of the Science of Food and Agriculture 86 : 713–721

ZHANG, J. and BUNN, J.M. 1999. Oxygen Diffusivities of Apple Flesh and Skin. Transactions of the American Society of Agricultural Engineers Vol. 43 (2) : 359-363 ■