Modeling for the modified atmosphere packaging of Sapota fruit

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Abstract: Modified atmospheric packaging utilizes polymeric films with selective permeability for O_2 and CO_2, and modifies the storage environment by lowering O_2 concentration and increasing CO_2 concentration. Modeling and design of the Sapota fruit for modified atmosphere storage were done with different packaging materials for the higher shelf life. Based on the respiration rate and permeability of the packaging material, the suitable packaging films obtained for the modified atmospheric packaging of Sapota fruit were low density Polyethylene, Polyvinyl chloride, Polypropylene and Polystyrene film. Saran and Polyester films were found to be unsuitable for MAP storage of the Sapota fruit. The developed model provides an effective way for selection of the proper packaging material for Sapota fruit and this model can also be employed for designing packaging films for other fruits and vegetables.

Keywords: modified atmospheric packaging, extended shelf life, respiration rate, packaging films, permeability of packaging material

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1 Introduction

Fresh fruits and vegetables, after their harvest, continue to respire by consuming oxygen (O_2) and giving off carbon dioxide (CO_2). During the process, carbohydrates stored within the tissues of the commodities are utilized and energy in the form of heat is released. Decreasing O_2 level and increasing CO_2 level reduces the respiration rate, with the benefit of delaying senescence and browning, reducing metabolic activity, maintaining color, lowering microbial proliferation, and reducing chilling injury symptoms, thus, extends the shelf life of the product (Beaudry, 1999; Jacxsens, Devlieghere and Debevere, 2001, 2002; Brecht et al., 2003; Saltveit, 2003; Valero et al., 2008). Modification of the atmosphere inside the package by lowering O_2 concentration and increasing CO_2 concentration depends on the characteristics of the produce and the type of the packaging film (Mahajan et al., 2007; Mangaraj, Goswami and Mahajan, 2009). Investigations carried out have shown that within a narrow range of O_2 and CO_2 concentrations and storage temperature, shelf life of the produce such as fruits and vegetables can be a maximum. Addition of different amounts of chitosan during cheese making, combined with modified atmosphere packaging (MAP) was used to prolong the shelf life of stracciatella cheese (Gammariello et al., 2009). Limits of concentration of two gases and the temperature vary with the type of fruit and vegetable. Lowering O_2 concentration, increasing CO_2 concentration and reducing temperature beyond certain limits is harmful. Concentrations in volume of O_2 below about 1.5% or that of CO_2 above 18 % may lead to spoilage due to anaerobic respiration (Lee et al., 1991). During respiration, concentration of O_2 inside the package will reduce and that of CO_2 will increase. Modified Atmosphere Packaging (MAP) is mostly suitable for fruits and vegetables. Modified Atmosphere reduces respiration

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rate, ethylene production and textural losses, improves chlorophyll and other pigment retention, delays ripening and senescence and reduces the rate of microbial growth and spoilage (Kader, Zagory and Kerbel, 1989; Lopez-Briones et al., 1993; Rodriguez-Aguilera and Oliveira, 2009). Sivakumar and Korsten (2006) reported that MAP of litchi fruits using bi-axially oriented polypropylene (BOPP) film minimized the rate of transpiration, prevented weight loss and deterioration of fruit quality. Since O_2 concentration inside the package will be lowered than that present in outside the package, O_2 will permeate into package space through the packaging material. Likewise, CO_2 will permeate out of the packaging material to the outside of package. This passive / natural modification relies on the interplay between the product respiration rate and the gas exchange rate through the package (Mahajan et al., 2008).

In modified atmosphere packaging and storage system, atmosphere that is present inside the package gets 'modified' from the environment according to the permeability of the packaging material and respiration of the commodities. The composition of the atmosphere within a package depends on factors like weight of the fruit, surface area of the packaging material, equilibrium concentration that is finally attained inside the package, void space inside the package, storage temperature, permeability of the packaging materials and respiration rates (Das, 2005; Davies, 1995; Jayas and Jeyamkondan, 2002). Modified atmospheric packaging utilizes polymeric films with selective permeability for O_2, CO_2, and H_2O vapor to create a modified atmosphere around the packaged product due to the respiration of the product and the selective permeability of the packaging material (Guevara et al., 2003). For the experimental purpose, Sapota, which is known as Chikoo / Chiku in India bearing the scientific name as *Achrus sapota* has been selected for the present investigation. The fruit of Sapota is small, ranging from 5 to 9 cm in diameter, with a round to egg-shaped appearance, 75 to 200 g in weight. It consists of a rough brown skin, which encloses a soft, sweet, light brown to reddish-brown flesh. On the basis of the respiration of Sapota and the permeability of different packaging materials the objective of the study was to develop a model for modified atmospheric packaging system.

2 Materials and methods

2.1 Raw materials

For the present study on rate of respiration, mature, unripe Sapota fruit of local variety (*Achrus sapota*) were obtained from commercial sources. Fruits were washed to remove adhering dirt, and used for the investigations. Attention was paid to ensure that the fruits were of uniform size and weight. Besides, the commercial importance of the fruit was also taken into consideration while selecting the fruit.

2.2 Generation of respiration data

A closed system respirometer was adopted for generating the respiration data. The respirometer was an air-tight chamber of size 0.142 × 0.174 × 0.229 m, made up of acrylic (Perspex) sheets. Fruits were kept in the respirometer from the open topside and were closed with the lid inserting neoprene gasket in between. Lid was closed with nuts and bolts provided on the respirometer to make it airtight. This sealed respirometer was kept in a humidity control chamber (Digitech, Kolkata make with an accuracy of ±2%), which was maintained at the desired temperature with a tolerance limit of ±0.2℃ (accuracy ±1%). Gas composition of the respirometer was analyzed at regular intervals depending on the storage temperature of Sapota. Typically, the intervals chosen were 2 h for the temperatures at 30 and 25℃, 4 h at 20 and 15℃, 8 h at 10, 5 and 0℃. Gas analysis was done till the CO_2 concentration reached to 18%, corresponding to the attainment of anaerobic respiration condition (Hagger, Lee and Yam, 1992).

The respiration rates in terms of O_2 and CO_2 at a given temperature were calculated using Equations (1) and (2) respectively as given by Kays (1991).

$$R'_{O_2} = \left[\frac{(Y_{O_2})_t - (Y_{O_2})_{t+1}}{\Delta t}\right]\frac{V_f}{M} \tag{1}$$

$$R'_{CO_2} = \left[\frac{(Y_{CO_2})_t - (Y_{CO_2})_{t+1}}{\Delta t}\right]\frac{V_f}{M} \tag{2}$$

where, R' = respiration rate for the respective gases, mL kg^{-1} h^{-1}; Y = concentrations of the respective gases, %;

V_f = free volume of the respirometer, mL; M = weight of the produce, kg; Δt = time difference between two successive gas measurements, h.

The average values of concentration of oxygen (Y_{O_2}) and carbon dioxide (Y_{CO_2}) inside the container at an average time, t_{avg}, as given in Equation (3), were calculated using equation (4) and equation (5) respectively.

$$t_{avg} = \frac{t_i + t_{i+1}}{2} \tag{3}$$

$$Y_{O_2} = \frac{(Y_{O_2})_t + (Y_{O_2})_{t+1}}{2} \tag{4}$$

$$Y_{CO_2} = \frac{(Y_{CO_2})_t + (Y_{CO_2})_{t+1}}{2} \tag{5}$$

The values of R'_{O_2} and R'_{CO_2} are functions of Y_{O_2} and Y_{CO_2}. From the experimental values of Y_{O_2} and Y_{CO_2}, values of R'_{O_2} and R'_{CO_2} were calculated. Values of R_{O_2} and R_{CO_2} can be expressed as a function of Y_{O_2} and Y_{CO_2} by the second order regression equations as represented by Equation (6) and Equation (7) respectively.

$$R_{O_2} = a_0 + a_1 Y_{O_2} + a_2 Y_{CO_2} + a_{11} Y^2_{O_2} + a_{22} Y^2_{CO_2} + a_{12} Y_{O_2} Y_{CO_2} \tag{6}$$

$$R_{CO_2} = b_0 + b_1 Y_{O_2} + b_2 Y_{CO_2} + b_{11} Y^2_{O_2} + b_{22} Y^2_{CO_2} + b_{12} Y_{O_2} Y_{CO_2} \tag{7}$$

Relative deviation percent $E_{R_{O_2}}$ between actual O_2 consumption rate, R'_{O_2} obtained from experimental data and the predicted O_2 consumption rate, R_{O_2} as obtained from Equation (6) at a given temperature can be obtained from Equation(8).

$$E_{R_{O_2}} = \frac{100}{N-1} \sum_{i=1}^{n} \frac{\left| R'_{O_2} - R_{O_2} \right|}{R'_{O_2}} \tag{8}$$

where, N = number of observed data on O_2 or CO_2 concentration (Das, 2005).

In a similar manner, the relative deviation percent $E_{R_{CO_2}}$ between actual CO_2 consumption rate, R'_{CO_2} obtained from experimental data and the predicted CO_2 consumption rate, R_{CO_2} as obtained from Equation (7) at a given temperature can be obtained from equation (9) (Das, 2005).

$$E_{R_{CO_2}} = \frac{100}{N-1} \sum_{i=1}^{n} \frac{\left| R'_{CO_2} - R_{CO_2} \right|}{R'_{CO_2}} \tag{9}$$

2.3 Process for Modeling of modified atmospheric packaging

Modeling for the prediction of O_2 and CO_2 concentration inside various flexible packaging materials containing the fruit Sapota is established in the present study. Sapota fruits were packed inside some suitable packaging materials which were permeable to gas. The packaged Sapota was stored in a reduced temperature environment. The various gas permeable packaging materials used were low density Polyethylene, Polyvinyl chloride, Polypropylene, Polystyrene, Saran and Polyester. For modified atmosphere packaging and storage, 1 kg of Sapota was packed separately in different packaging films and stored at temperature of 12℃. The surface area of the packaging material through which O_2 and CO_2 permeated was 0.05 m^2. The volume of the void space present inside the packaging material was 1,000 cm^3. The atmospheric concentration of O_2 (Y_{O_2}) and CO_2 (Y_{CO_2}) was 0.21 and 0.003 (cm^3 cm^{-3} atmospheric air, respectively). O_2 and CO_2 exchange occurred through the different packaging materials. For some intermediate temperature T_i (℃), values of the constants can be obtained through interpolation. The values of constants of equation (6) and (7) at storage temperature of 12℃ could be calculated by the interpolation of the constant values obtained at storage temperature of 10 and 15℃.

3 Results and Discussion

3.1 Generation of respiration data

The concentration of O_2 and CO_2 was plotted against storage period from the respiration data obtained by using the closed system respirometer for Sapota fruits. The periodical changes in O_2 and CO_2 concentrations of Sapota at different storage temperatures are represented in Figure 1 and Figure 2 respectively. It is observed from Figure 1 and Figure 2 that the CO_2 concentration increased as the O_2 concentration of the respirometer decreased along with the storage period, the rate being more at the higher storage temperatures. Since the enzyme kinetics is valid only for aerobic respiration and the maximum allowable limit of CO_2 concentration for aerobic respiration being 0.18 in decimal (Hagger, Lee and Yam, 1992), the respiration data points beyond 0.18 for CO_2 concentration were neglected. From the initial concentration of CO_2 of about 0.0003 in decimal, which was nevertheless the concentration of CO_2 in ambient air, it reached to its highest permissible level of 0.18 in decimal, after 122, 105, 88, 68, 52, 40, and 32 h at 0, 5, 10, 15, 20, 25 and 30℃ storage temperatures respectively. Of course, the corresponding O_2 concentrations were well above 0.025 in decimal indicating the least chance of anaerobic respiration. From Equations (6) and (7), the values of constants a_0, a_1, a_2, a_{11}, a_{22}, a_{12}, b_0, b_1, b_2, b_{11}, b_{22}, b_{12} were obtained at different temperatures at which experiments were done. The values obtained at temperatures of 0, 5, 10, 15, 20, 25 and 30℃ were applied in Equations (6) and (7) to obtain the different constants using least square method. Relative deviation percent $E_{R_{O_2}}$ and $E_{R_{CO_2}}$ were calculated by applying Equations (8) and (9) respectively. Values of the constants such as a_0, a_1, a_2, a_{11}, a_{22}, a_{12}, b_0, b_1, b_2, b_{11}, b_{22}, b_{12} at different temperatures are tabulated in Table 1 and Table 2 respectively. It is observed from Tables 1 and Table 2 that the relative deviation between modeled value and experimental value for O_2 laid between 2% to 23% and for CO_2 lied between 4% to 24%. If the values of the relative deviation percent lie between 0 to 30%, the closeness of the predicted values and that of the experimental values are considered to be very good. Hence the model and experimental values are in close agreement. The values of the constants a_0, a_1, a_2, a_{11}, a_{22}, a_{12} and b_0, b_1, b_2, b_{11}, b_{22}, b_{12} at storage temperature of 12℃ obtained by interpolation of the values from Table 1 and Table 2 were applied to Equations (6) and (7) to obtain the respiration rate of the Sapota fruit at storage temperature of 12℃.

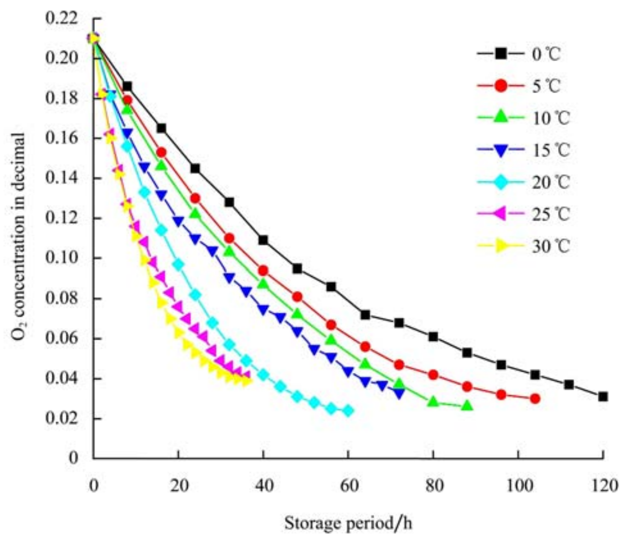

Figure 1 Changes in O_2 concentrations with storage time inside respirometer containing sapota for different temperatures

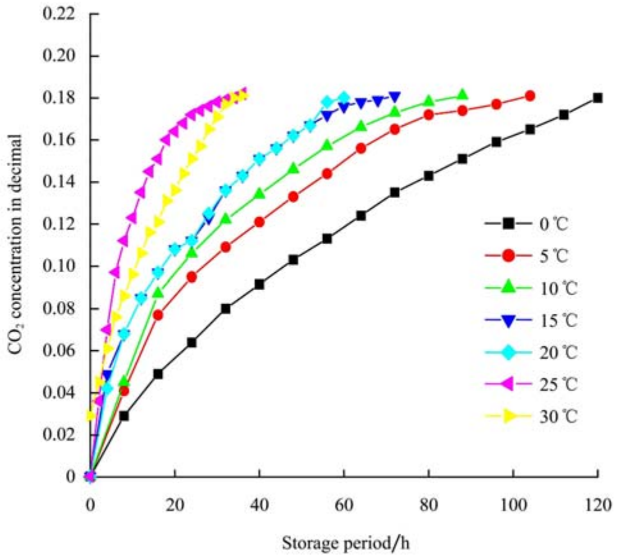

Figure 2 Changes in CO_2 concentrations with storage time inside respirometer containing sapota for different temperatures

Table 1 Values of constants a_0, a_1, a_2, a_{11}, a_{22}, a_{12} and $E_{R_{O_2}}$

Storage temperature/℃	a_0	a_1	a_2	a_{11}	a_{22}	a_{12}	$E_{R_{O_2}}$ /%
0	73	-513	-882	902	2548	3440	17
5	249	-2181	-2287	4890	5232	10194	9
10	-52	454	374	-788	-536	-1628	2
15	-67	682	335	-1435	-69	-1961	23
20	260	-2181	-2743	4774	7214	11875	4
25	40	-904	-417	3810	1280	3524	13
30	208	-1847	-2029	4348	4901	9261	6

Table 2 Values of constants b_0, b_1, b_2, b_{11}, b_{22}, b_{12} and $E_{R_{CO_2}}$

Storage temperature/℃	b_0	b_1	b_2	b_{11}	b_{22}	b_{12}	$E_{R_{CO_2}}$ /%
0	-160	1584	1720	-3759	-4522	-8510	7
5	-714	6222	7204	-13308	-18106	-31406	13
10	-1173	10217	11180	-21911	-26602	-48752	4
15	1796	-14922	-16914	31220	39816	70275	24
20	1219	-10532	-12943	23099	34472	55710	19
25	-573	4607	4885	-8432	-10278	-20090	22
30	-221	2374	2177	-5829	-5195	-11924	15

3.2 Selection of packaging film

The type of packaging film required to achieve the equilibrium depends on permeability of different films and respiration rate of the specific fruit. Different fruits have different respiration rate and hence only few types of films suits for a specific fruit on the basis of its respiration rate. The permeability, k_{O_2} and k_{CO_2} in cm^3 of O_2 and CO_2 at STP diffusing per hour per m^2 of cross sectional area through the packaging material of unit thickness under a pressure difference of 1 atm pressure can be expressed in terms of Equations (10) and (11).

$$k_{O_2} = D_{O_2} S_{O_2} \quad (10)$$

$$k_{CO_2} = D_{CO_2} S_{CO_2} \quad (11)$$

where, '*D*' is diffusivity in m^2 h^{-1} of O_2 and CO_2 through various packaging materials and '*S*' is the solubility of O_2 and CO_2 in cm^3 (STP) per m^3 of packaging material per atm partial pressure (cm^3 (STP) atm^{-1} m^{-3} solid). On the basis of this the permeability values obtained in cm^3 h^{-1} m^{-2} for O_2 and CO_2 of the different films are given in Table 3.

Table 3 Permeability values of different types of packaging films at 12℃

Film type	O_2 permeability k_{O_2}	CO_2 permeability k_{CO_2}
Polyethylene: low density	3900	7700
Polyvinyl chloride	412	2439
Polypropylene	1300	7700
Polystyrene	2600	10000
Saran	8	52
Polyester	60	190

Exchange of O_2 and CO_2 occurs through the different packaging materials, inside which the fruit is stored. Y_{O_2} (cm^3 cm^{-3} air) refers to O_2 concentration and Y_{CO_2} (cm^3 cm^{-3} air) refers to the CO_2 concentration inside the package. $Y_{a(O_2)}$ (cm^3 cm^{-3} air) and $Y_{a(CO_2)}$ (cm^3 cm^{-3} air) are the respective concentrations of O_2 and CO_2 in atmospheric air.

For the transfer of oxygen from atmospheric air through the packaging material into the package space, generalized Equation (12) and Equation (13) can be applied.

Rate of O_2 entry into the package space – Rate of O_2 consumed by the fruit = Rate of O_2 accumulation inside the package space

This can be translated mathematically as shown in Equation (12) and Equation (13):

$$A_p k_{O_2} (Y_{a(O_2)} - Y_{O_2}) - W_p \times R_{O_2} = V_e \left[\frac{dY_{O_2}}{d\theta} \right] \quad (12)$$

Or,

$$\left(\frac{dY_{O_2}}{d\theta} \right) = -\left(\frac{W_p}{V_e} \right) R_{O_2} + \left(\frac{A_p k_{O_2}}{V_e} \right) (Y_{a(O_2)} - Y_{O_2}) \quad (13)$$

where, A_p is the surface area of the packaging material through which O_2 and CO_2 permeates; k_{O_2} is the O_2 permeability through the packaging material and W_p (kg) is the weight of the fruit stored inside the packaging material; V_e is the volume of void space present inside the packaging material; R_{O_2} is the respiration rate of the fruit for O_2; and $\frac{dY_{O_2}}{d\theta}$ is the rate of change of O_2 concentration within the package at time θ (h) of storage.

Similarly, for transfer rate of CO_2 from inside to the outside of the packaging material equation (14) and (15) can be applied.

Rate of CO_2 generated by the fruit – Rate of CO_2 leaving out of package space by the fruit = Rate of accumulation of CO_2 inside the package space.

This can be translated mathematically as shown in Equation (14) and Equation (15):

$$W_p \times R_{CO_2} - A_p k_{CO_2} (Y_{CO_2} - Y_{a(CO_2)}) = V_e \left[\frac{dY_{CO_2}}{d\theta} \right] \quad (14)$$

Or,

$$\left(\frac{dY_{CO_2}}{d\theta} \right) = \left(\frac{W_p}{V_e} \right) R_{CO_2} - \left(\frac{A_p k_{CO_2}}{V_e} \right) (Y_{a(CO_2)} - Y_{CO_2}) \quad (15)$$

where, $\frac{dY_{CO_2}}{d\theta}$ is the rate of change of CO_2 concentration within the package at time θ(h) of storage; k_{CO_2} is the CO_2 permeability of the packaging material; and R_{CO_2} is the respiration rate of the fruit for CO_2.

The values of W_p, A_p, V_e were 1 kg, 0.05 m^2 and 1,000 cm^3 respectively and the permeability values of different packaging material at storage temperature of 12℃ were obtained from Table 3. Using regression coefficients, simultaneous solution of Equation (13) and Equation (15) by numerical means can give variation of oxygen concentration Y_{O_2} (volume fraction) and carbon dioxide concentration Y_{CO_2} (volume fraction) inside the package with time θ(h) of storage. The graphical representations of change in concentrations of O_2 and CO_2 with respect to the duration of storage are shown in Figure 3 to Figure 8.

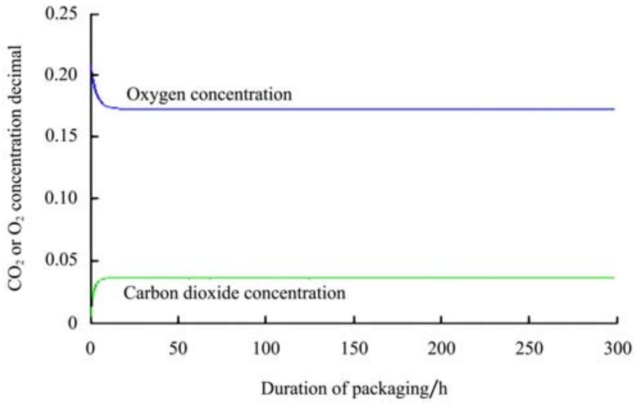

Figure 3 Variation of O_2 and CO_2 concentration inside the modified atmosphere package at 12℃ for Sapota for low density Polyethylene

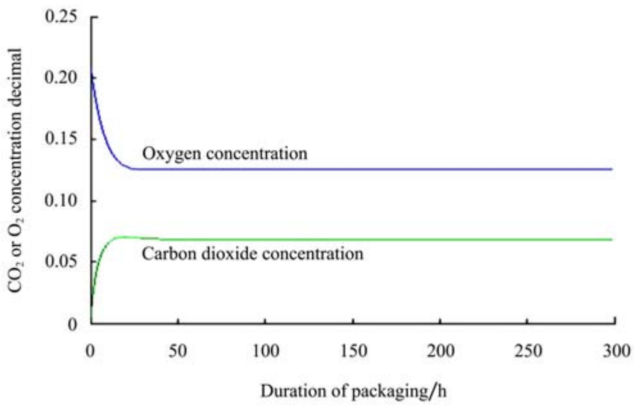

Figure 4 Variation of O_2 and CO_2 concentration inside the modified atmosphere package at 12℃ for Sapota for Polyvinyl chloride

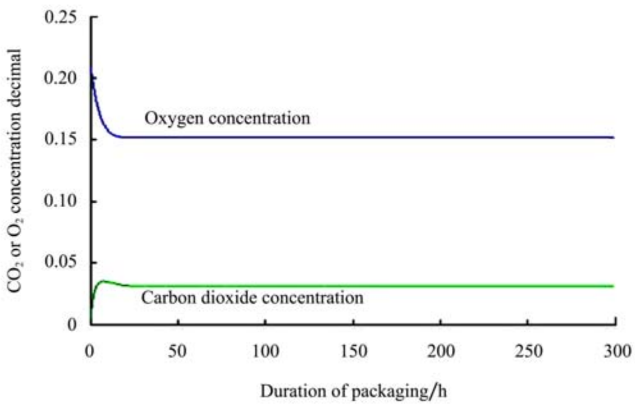

Figure 5 Variation of O_2 and CO_2 concentration inside the modified atmosphere package at 12℃ for Sapota for Polypropylene

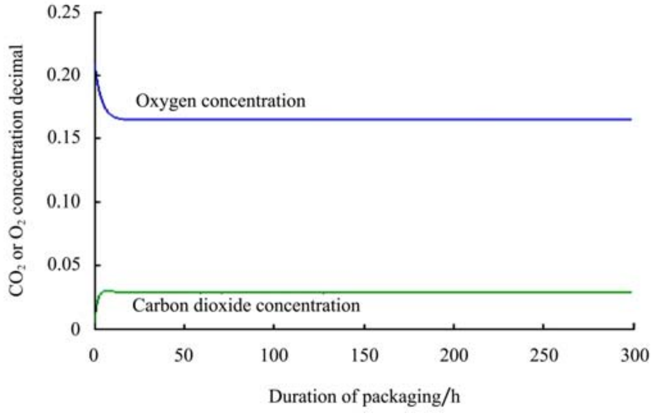

Figure 6 Variation of O_2 and CO_2 concentration inside the modified atmosphere package at 12℃ for Sapota for Polystyrene

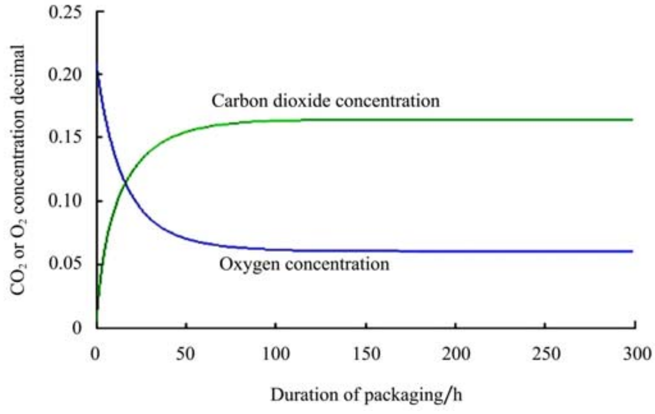

Figure 7 Variation of O_2 and CO_2 concentration inside the modified atmosphere package at 12℃ for Sapota in saran type film

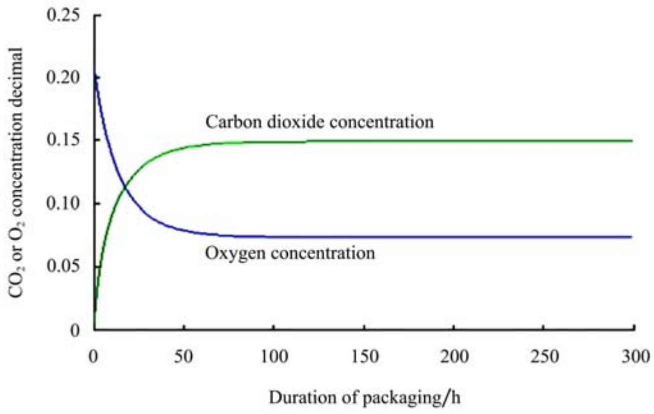

Figure 8 Variation of O_2 and CO_2 concentration inside the modified atmosphere package at 12℃ for Sapota for Polyester film

For different packaging films the equilibrium concentration of O_2 and CO_2 are given in Table 4**.**

From Figure 3 to Figure 6, it is observed that the equilibrium concentrations of CO_2 and O_2 reached within the shortest period of time and these concentrations lie within the range required for maximum shelf life of

Sapota fruit. In Figure 7 and Figure 8 the equilibrium concentration achieved after a longer duration and the corresponding equilibrium concentration values are not in the range for maximum shelf life of the Sapota fruit. From Table 4 it is revealed that for low density Polyethylene, Polyvinyl chloride, Polypropylene and Polystyrene film the equilibrium concentration of O_2 lies in the range from 0.12 to 0.18 in decimal and equilibrium concentration of CO_2 lies in the range from 0.02 to 0.07 in decimal. But for the Saran and Polyester films, the equilibrium concentration of O_2 and CO_2 lies in the range from 0.07 to 0.08 and 0.14 to 0.16 respectively which is unsuitable for maximum shelf life of the Sapota fruit. On the basis of this observation, the suitable packaging films for modified atmospheric packaging of Sapota fruit can be low density Polyethylene, Polyvinyl chloride, Polypropylene and Polystyrene film. Saran and Polyester films are unsuitable for MAP storage of Sapota fruit.

Table 4 Equilibrium concentration of O_2 and CO_2 for different packaging films

No.	Packaging Material	Equilibrium concentration of O_2 in decimal	Equilibrium concentration of CO_2 in decimal
1.	Polyethylene low density	0.173	0.0361
2.	Polyvinyl chloride	0.1252	0.0686
3.	Polypropylene	0.1514	0.0311
4.	Polystyrene	0.1647	0.0286
5.	Saran	0.0708	0.1542
6.	Polyester	0.079	0.1439

4 Conclusions

Modified atmospheric packaging is a dynamic process which reduces respiration, delays ripening, decreases ethylene sensitivity, decreases production of ethylene, retards textural softening and causes extended shelf life of the product. The crucial factor responsible for modified atmospheric storage of Sapota fruit is the permeability of the packaging film and respiration rate of the fruit. The permeability of the packaging film is mainly dependent on the thickness of the film and the type of polymer. As the respiration rate of individual fruit and vegetable varies from each other, hence the type of polymer for MAP will also vary from product to product. The packaging material slows down the normal respiration of the product by creating a lowered level of O_2 and a higher level of CO_2 inside the packaging material. Improper packaging material may deteriorate the fruit condition and hence reduce its shelf life. For higher shelf life of the product packaging material should be such that optimum atmosphere would be created in the package within the shortest possible time. Packing materials differ in their CO_2 and O_2 permeability. This model provides an effective way for selection of the proper packaging material as per the respiration rate of fruit. Hence the model can be applied for other fruits and vegetables for determination of suitability of packaging material for the extended shelf life of the product through modified packaging.

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