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Modeling for modified atmospheric packaging of sapota

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In the storage and transportation process of fresh fruits and vegetables, respiration rate control plays major role in prolonging the self life of the product. The lowering of O_2 gas concentration and the elevating the CO_2 gas concentration surrounding the produce are usually effective for respiration depression. Respiration rate can be determined by measuring the consumption of O_2 and evolution of CO_2. So based on respiration rate, surface area of packaging material, storage temperature and permeability of packaging material this model was developed for obtaining time for equilibration by which design of packaging parameters was determined for the better self life of the commodity.

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INTRODUCTION

Fresh fruits and vegetables, after their harvest, continue to respire by consuming oxygen (O_2) and giving off carbon dioxide (CO_2). Lowering of respiration rate increases the shelf life of product. Modification of storage environment by reducing temperature, lowering O_2 concentration and increasing CO_2 concentration can reduce respiration rate and increase shelf life. Lowering O_2 concentration, increasing CO_2 concentration and reducing temperature beyond certain limits is harmful. Below about 1.5 volume per cent of O_2 or above 18 volume per cent of CO_2 lead spoilage due to anaerobic respiration (Lee *et al*., 1991; Das, 2005). For maximum shelf life, optimum concentration of two gasses lies normally between 0.02 and 0.05 (volume fraction) for both O_2 and CO_2. It is possible to attain these concentrations by packing the commodities inside flexible type packaging material. Packing materials differ in their CO_2 and O_2 permeability. Normal values of this permeability are such that they allow increased CO_2 concentration and decreased O_2 concentration at the inside of package. Since, due to the respiration of the commodities, atmosphere that is present inside the package gets 'modified' from the environment, this type of packaging and storage is given the name as 'modified atmosphere packaging and storage'.

For the experimental purpose here sapota was selected which is known as Chikoo/Chiku in India having scientific name (*Achrus sapota*). The fruit of sapota is small, ranging from 5 to 9 cm in diameter with a round to egg-shaped appearance, from 75 to 200 g in weight. It consists of a rough brown skin, which encloses a soft, sweet, light brown to reddish-brown flesh. Hence, for prolonging the self life of sapota a model was developed for modified atmospheric packaging based on its respiration rates.

Parameters of modified atmosphere packaging:

In modified atmosphere packaging and storage system according to the permeability of the packaging material and respiration of the commodities, atmosphere that is present inside the package gets 'modified' from the environment. Equilibrium

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concentration that is finally attained inside the package is affected by factors such as i) weight of fruit or vegetable kept inside the package, ii) surface area of packaging material that is exposed to atmosphere and across which permeation of O_2 and CO_2 takes place, iii) volume of void space present inside the package, iv) storage temperature, v) permeability of packaging materials for O_2 and CO_2 and vi) respiration rates *viz.*, O_2 consumption rate and CO_2 production rate, which in turn are affected by O_2 and CO_2 concentrations inside the package and the storage temperature. For a given type of packaging material, values of parameters i) – iv) are to be so fixed that the equilibrium concentrations of CO_2 and O_2 are reached within shortest possible time and these concentrations lie within the range required for maximum shelf life of stored commodity.

Rates of O_2 consumption and CO_2 production as functions of O_2 and CO_2 concentration at a particular temperature can be determined by packing a certain weight of the commodity inside a hermetically sealed container, placing the container inside a controlled temperature environment and measuring periodically the concentration of the two gases present inside the container. The analyzed data obtained by study of respiration kinetics are used for modeling for modified atmosphere packaging system.

METHODOLOGY

Raw materials:

For the study on rate of respiration mature unripened 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 fruit were of uniform size and weight. Besides, the commercial importance of the fruit was also taken into consideration while selecting the fruit.

Respiration rate of sapota:

Respiration rate was measured experimentally by closed system respirometer to predict the O_2 and CO_2 concentration. On the basis of this respiration rate the control strategies were designed for maintaining the O_2 and CO_2 concentrations within the set limits of modified atmospheric packaging system.

Closed system respirometer:

Closed systems can provide a convenient way of characterizing respiration of fresh produce using a single set of experiment (Hagger *et al.,* 1992). The changes in O_2 and CO_2 concentrations within a sealed container, which result from respiration is measured directly by closed system respirometer. In closed system, the container is flushed with air of known composition and all the inlet and outlet valves are closed. Changes in the concentration of O_2 and CO_2 over a certain period of time are measured and used to estimate respiration rates. After an interval of time gas samples of the container are analyzed for O_2 and CO_2 concentration. The respiration rate calculated from the concentration difference, weight of produce and free volume of chamber.

Hence, a closed system respirometer was adopted for generating the respiration data. The respirometer is an air-tight chamber of size 0.142 m made up of acrylic (Perspex) sheets. A NiCr-Ni thermocouple was inserted into one side of the respirometer and used to control the storage temperature. Fruits were kept in respirometer from the open topside and were closed with the lid while inserting neoprene gasket in between. Lid was closed with nuts and bolts provided on the respirometer to make it airtight. After an interval of time gas samples from the container was taken and analyzed for concentrations of O_2 and CO_2.

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

$$R_{O_2} = \left[\frac{(Y_{O_2})_t - (Y_{O_2})_{t+1}}{\Delta t}\right]\frac{V}{M} \quad (1)$$

$$R_{CO_2} = \left[\frac{(Y_{CO_2})_t - (Y_{CO_2})_{t+1}}{\Delta t}\right]\frac{V}{M} \quad (2)$$

where,

R = respiration rate for the respective gases, (ml/kg h)

G = concentrations of the respective gases, (%)

V_{fR} = free volume of respirometer, (ml)

W = weight of produce, (kg)

Δt = time difference between two gas measurements, (h)

OBSERVATIONS AND ASSESSMENT

The results obtained from the present investigation as well as well as relevant discussion have been presented under following heads :

Generation of respiration data:

In order to predict the respiration rate of sapota, experiments were conducted at different storage temperatures to find out the corresponding concentrations of O_2 and CO_2 gases with the help of the respirometer. Free volume of respirometer was the total volume of respirometer minus volume occupied by its content. Fruits were kept in the respirometer and were perfectly closed with the nuts and bolts and were kept in humidity control chamber (Digital system) which was maintained at the desired temperature with a tolerance limit of ± 0.2^{0}C. Gas composition of respirometer was analyzed at regular intervals depending on the storage temperature of sapota. Typically the intervals chosen were 2h for the temperatures at 30^{0}C and 25^{0}C, 4h at 20^{0}C and 15^{0}C, 8h at 10^{0}C, 5^{0}C and 0^{0}C. Gas analysis was done till the CO_2 concentration reached to 18 per cent, till aerobic respiration

(Hagger, 1992).

Process for modeling of modified atmospheric packaging:

Modeling for prediction of O_2 and CO_2 concentration inside a flexible package-containing the sapota is established here. Sapota fruits were packed inside a polyvinylchloride (PVC) type packaging material and stored them in reduced temperature environment.

For modified atmosphere packaging and storage 1 kg of sapota was packed in PVC film. The surface area of the packaging material through which O_2 and CO_2 permeates was 0.05 m^2 (Ap =0.05 m^2). The volume of void space present inside the packaging material was 1000 cm^3 (Ve = 1000 cm^3). The atmospheric concentration of O_2 (Y_{O_2}) and CO_2 (Y_{CO_2}) is 0.21 and 0.003 cm^3/cm^3 of atmospheric air, respectively. The storage temperature Tp was maintained at 12^0C. The O_2 permeability (k_y) of PVC film was 412 $cm^3/h/m^2$/concentration difference of O_2 in volume fraction and CO_2 permeability (k_z) of PVC film was 2439 $cm^3/h/m^2$/concentration difference of CO_2 in volume fraction.

Variation of O_2 and CO_2 concentration inside modified atmosphere package:

The schematic diagram for exchange of O_2 and CO_2 through packaging material, inside which the fruit is stored, is represented in Fig. 1. In the Fig. Y_{O_2} (cm^3 per cm^3 of air) refers O_2 concentration and Y_{CO_2} (cm^3 per cm^3 of air) the CO_2 concentration inside the package. $Y_{a(O_2)}$ cm^3 per cm^3 of air) and $Y_{a(CO_2)}$ are the O_2 and CO_2 concentrations in atmospheric air, respectively.

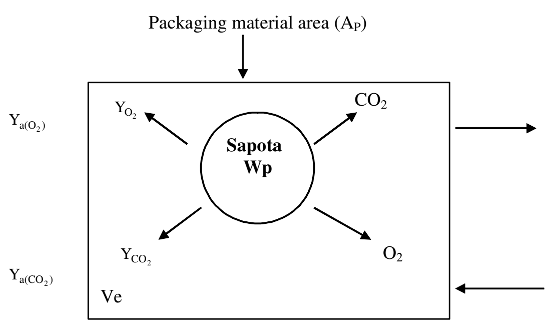

Fig. 1: Schematic diagram showing the transfer of O_2 and CO_2 through the packaging material

For the transfer of oxygen from atmospheric air through packaging material into the package space, following generalized equation would apply.

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

That is,

$$A_p k_{O_2} = \left(Y_{a(O_2)} - Y_{O_2}\right) - W_p \text{ x } R_{O_2} = V_e\left(\frac{dY_{O_2}}{d\theta}\right) \quad (3)$$

$$\text{or}\left(\frac{dY_{O_2}}{d\theta}\right) = -\left(\frac{W_p}{V_e}\right)R_{O_2} + \left(\frac{A_p k_{O_2}}{V_e}\right)\left(Y_{a(O_2)} - Y_{O_2}\right) \quad (4)$$

where Ap is the surface area of packaging material through which O_2 and CO_2 permeates. k_y [$cm^3.h^{-1}.m^{-2}$ (conc. Diff. Of O_2 in fraction)$^{-1}$] is the O_2 permeability of packaging material and W_p (kg) is the weight of fruit stored inside the packaging material. $\frac{dY_{O_2}}{d\theta}$ is the rate of change of O_2 concentration Y within the package at time θ (h) storage. RO_2 is is the ingress rate of oxygen by the fruit.

Similarly, transfer rate for CO_2 from inside to outside of packaging material can be written as,

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

That is,

$$W_p \text{ x } R_{CO_2} - A_p k_{CO_2}\left(Y_{CO_2} - Ya_{(CO_2)}\right) = Ve\left(\frac{dY_{CO_2}}{d\theta}\right) \quad (5)$$

$$\left(\frac{dY_{CO_2}}{d\theta}\right) = -\left(\frac{W_p}{V_e}\right)R_{CO_2} + \left(\frac{A_p k_{CO_2}}{V_e}\right)\left(Y_{a(CO_2)} - Y_{CO_2}\right) \quad (6)$$

where, $\frac{dY_{CO_2}}{d\theta}$ is the is the rate of change of CO_2 concentration within the package at time q(h) of storage, (m^2) is the surface area of the packaging material through which

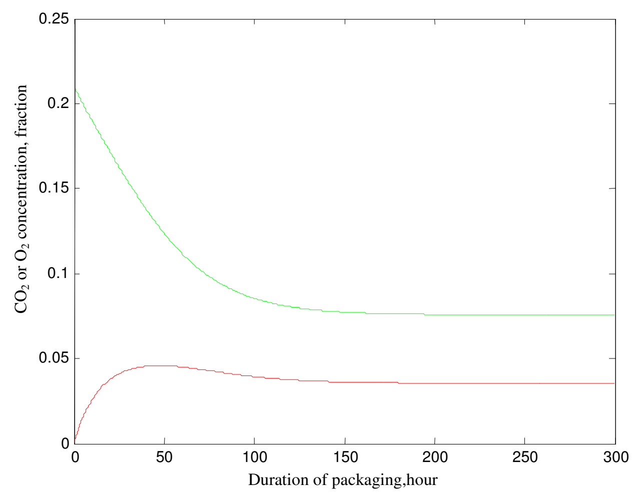

Fig. 2: Variation of O_2 and CO_2 concentration inside the modified atmosphere package at 12°C for sapota

CO_2 permeation takes place. k_{CO_2} [$cm^3.h^{-1}.m^{-2}$. (conc. difference of CO_2 in fraction)$^{-1}$] is the CO_2 permeability of packaging material and R_{CO_2}(cm^3 carbon dioxide. kg sapota^{-1}.h^{-1}) is the respiration rate of fruit for CO_2.

Using regression coefficients, simultaneous solution of Equations (4) and (6) by numerical means would 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 equilibrium concentration of O_2 and CO_2 will be reached after 90 hours of packaging (Fig. 2). Equilibrium concentration of O_2 will be 0.9 cm^3/cm^3 of atmosphere within modified atmosphere package and CO_2 will be 0.042 cm^3/cm^3 of atmosphere inside the package.

Conclusion:

By taking the respiration rate, modeling and design for modified atmosphere storage is done. From this for sapota, the equilibrium concentration of O_2 and CO_2 will be reached after 90 hours of packaging. Equilibrium concentration of O_2 will be 0.9 cm^3/cm^3 of atmosphere within modified atmosphere package and CO_2 will be 0.042 cm^3/cm^3 of atmosphere inside the package. Hence, by considering the respiration rate of the fruit packaging material can be designed for better self life of the commodity.

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