J. Trop. Agric. and Fd. Sc. 27(1) (1999): 109–115

Modelling modified atmosphere packaging of Eksotika papaya

(Pemodelan pembungkusan atmosfera terubahsuai betik Eksotika)

P. Mohd. Salleh*, M. Z. Zaipun* and M. Norhayati*

Key words: mathematical model, package design, steady-state concentration, permeability

Abstrak

Sebuah model matematik telah diwujudkan untuk meramalkan saiz pembungkus buah pada persekitaran atmosfera terubahsuai. Model tersebut bersandarkan nisbah pembungkusan yang diperlukan untuk mewujudkan kepekatan stabil O_2 yang dikehendaki. Model tersebut telah ditentusahkan dengan menggunakan betik Eksotika yang disimpan pada suhu rendah. Hasil daripada kajian menunjukkan bahawa model matematik ini berupaya meramal dengan jitu pembungkusan atmosfera terubahsuai untuk betik. Kepekatan stabil O_2 dan CO_2 yang dikehendaki dapat diperoleh selepas kira-kira 3 hari penyimpanan dan terus kekal pada aras yang hampir dengan ramalan sehingga tamat penyimpanan selama 3 minggu. Kepekatan gas etilena yang rendah di dalam bungkusan menunjukkan kemasakan tidak berlaku semasa buah disimpan.

Abstract

A mathematical model was developed to predict package size for fruit in modified atmosphere environments. The model was based on the packaging ratio required for providing a specific steady-state O_2 concentration. The model was verified using Eksotika papaya kept at low temperature. Results of the experiment showed the ability of the mathematical model to predict precise modified atmosphere package for papaya. The desired steady-state O_2 and CO_2 concentrations were achieved after about 3 days in storage and maintained close to the predicted levels until the end of the 3-week storage period. Ethylene concentration recorded in the package was low indicating that no ripening process occurred during storage.

Introduction

Fruit quality preservation by atmospheric manipulation, especially reduced oxygen (O_2) and increased carbon dioxide (CO_2) concentrations, has been widely used. Both low O_2 and high CO_2 concentrations reduce respiration rate, delay ripening and hence extend shelf life of the fruits. This principle has been adopted by many researchers for the development of modified atmosphere packaging (MAP) of fresh fruits including banana, papaya, rambutan, guava and starfruit (Kader et al. 1989; Abdullah et al. 1992). MAP in combination with low temperature storage may double the shelf life of fresh fruit as compared with the fruit without MAP. For maximum benefits of atmosphere storage, Powrie and Skura (1991) recommended an average combination of 2–5% O_2 and 5–10% CO_2 in MAP of highly respiring produce including banana, mango, papaya and pineapple.

Polymeric film has been used tremendously in MAP designs. Fruit packed

---

*Horticulture Research Centre, MARDI Headquarters, P.O. Box 12301, 50774 Kuala Lumpur, Malaysia
Authors' full names: Mohd. Salleh Punan, Zaipun Md. Zain and Norhayati Maning

with sealed polymeric film consumes O_2 and produces CO_2 from respiration activity. The outcome will be low O_2 and high CO_2 concentrations in the headspace of the package. The permeability of the film allows O_2 diffusion into the package and CO_2 diffusion out of the package. The mechanism creates an environment of acceptable low O_2 and high CO_2 concentrations for retention of fruit quality. Some of the common polymeric films used for fruit package include low density polyethylene (LDPE), high density polyethylene and polyvinyl chloride (Exama et al. 1993).

Many researchers developed MAP using mathematical models (Hayakawa et al. 1975; Henig and Gilbert 1975; Emond et al. 1991). Selection of suitable film and package dimensions for specific weight of fruit can be done using mathematical equations (Exama et al. 1993). The concentration of gases in the package can be predicted using computer programming with input parameters such as fruit respiration rate, film permeability and storage temperature. The performance of MAP to date, however, is inconsistent, especially for highly respiring produce such as tropical fruits.

This paper reports a study conducted to improve MAP designs of fresh fruits through modelling and computer simulation. Various factors influencing the performance of the package were analysed and considered in the model. The performance of the package developed was verified using Eksotika papaya.

Materials and methods

Model development

The main aim of any MAP design is to provide a suitable package for maintaining the concentration of gases needed to optimise a fruit storage system. Most of the available package models for respiring produce have been developed based on the Fick’s law of diffusion (Hayakawa et al. 1975; Henig and Gilbert 1975; Exama et al. 1993). The same law was also used to derive a package model at steady-state condition as follows:

$$0 = \frac{PA}{l}\,\frac{(C_a - C_{eq})}{100} \pm WR \qquad (1)$$

where P = film permeability ($mm^3.mm/mm^2.s.atm$)
A = film surface area (mm^2)
C_a = gas concentration outside the package (%)
C_{eq} = steady-state gas concentration inside the package (%)
l = film thickness (mm)
W = fruit weight (kg)
R = fruit respiration rate ($mm^3/kg.s$)
$\pm$ = O_2 (–) and CO_2 (+) respiratory gas

The equation is simplified further into:

$$\frac{A}{W} = \frac{R_o l}{P_o}\,\frac{100}{(21 - C_{oeq})} \qquad (2)$$

$$\frac{A}{W} = \frac{R_c l}{P_c}\,\frac{100}{C_{ceq}} \qquad (3)$$

where $\frac{A}{W}$ = packaging ratio (mm^2/kg)
o = O_2 gas
c = CO_2 gas

Both equation 2 and equation 3 can be used for predicting the required size of polymeric film for MAP according to the desired O_2 and CO_2 concentrations. However, in most polymeric packages, O_2 is a limiting factor and will normally come to an equilibrium much earlier than CO_2 (Holland, R., CSIRO, New South Wales, Australia, Consultancy report on food packaging programme in Food Technology Research Centre, MARDI, not published 1992). Furthermore, the minimum tolerance of O_2 concentration for avoiding physiological injury in most fruits is estimated at 2%, while the maximum limit for CO_2 is at 10% (Kader et al. 1989). Therefore, it is essential to consider equation 2 for predicting package design based on the O_2 concentration, as CO_2 will come to equilibrium below 10%. Assuming that the respiratory quotient for fruit is about unity ($R_o = R_c$), the correlation between O_2 and CO_2 concentrations in the package can be derived from equation 2 and equation 3, and simplified as follows:

$$C_{ceq} = \frac{(21 - C_{oeq})}{P_R} \tag{4}$$

where P_R = permeability ratio or P_c/P_o

Package design

A computer program was developed to assist in the prediction of the optimum package size for fruit. The flowchart diagram of the program is shown in *Figure 1*. The program was fed with parameters such as fruit type, rate of respiration *(R)*, type of packaging material, film permeability *(P)*, film thickness *(l)*, weight of fruit per package *(W)* and steady-state O_2 concentration *(C_o)* desired for the fruit. In this study, the package for individual fruit of Eksotika papaya was designed using LDPE film. Respiration rate of Eksotika papaya measured at MARDI (Rohani, M. Y., MARDI, Serdang, data not published 1992) and permeability of LDPE film reviewed by Pauly (1989) were used as input parameters for the design (*Table 1*). All parameters were converted accordingly to reflect the temperature and surrounding atmosphere of the experiment. As recommended for most tropical fruits (Kader et al. 1989), the O_2 concentration of about 5% was selected as the desired steady-state concentration of Eksotika papaya in the package. However, the predicted steady-state O_2 and CO_2 concentrations in the package were calculated based on actual area of film and weight of fruit used in the verification.

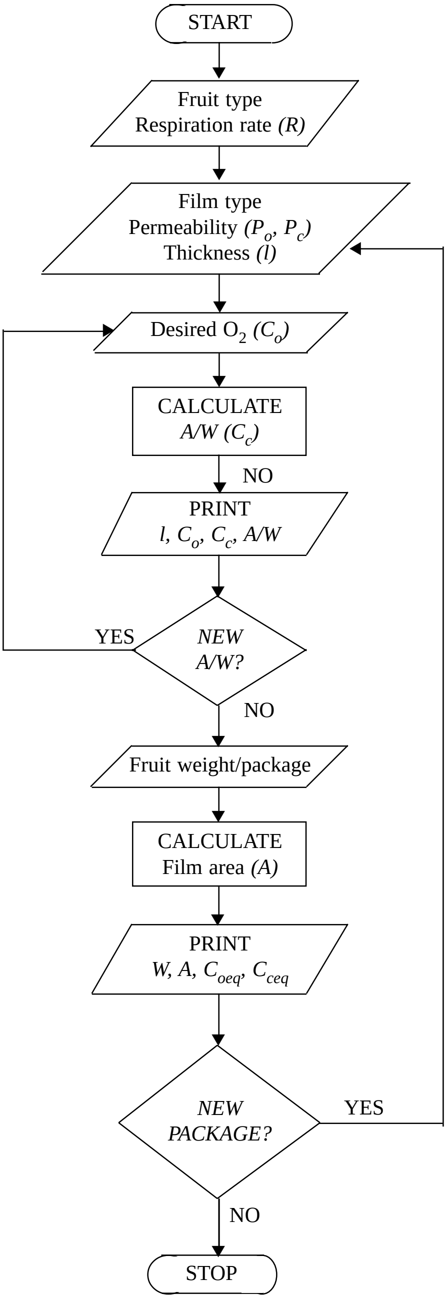

Figure 1. Computer flowchart diagram for predicting the optimum package size of papaya

Table 1. Design parameters fed into the computer program

Parameter	Data	Condition	Source
Respiration rate of Eksotika papaya ($mm^3/kg.s$)			
Oxygen or carbon dioxide	2.83	Air, at 10 °C	MARDI
	2.00	MA, at 15 °C	Conversion
Permeability of LDPE film ($mm^3.mm/mm^2.s.atm$)			
Oxygen	1.21×10^{-6}	15 °C	Pauly (1989)
Carbon dioxide	5.53×10^{-6}	15 °C	Pauly (1989)

Table 2. Predicted packaging ratio for package designs of Eksotika papaya using LDPE film

Film thickness (mm)	O_2 (%)	CO_2 (%)	Packaging ratio (mm^2/kg)
0.03	2	4.17	2.60×10^5
	5	3.51	3.09×10^5
	8	2.85	3.81×10^5
	10	2.41	4.50×10^5
0.04	2	4.17	3.47×10^5
	5	3.51	4.12×10^5
	8	2.85	5.07×10^5
	10	2.41	6.00×10^5
0.05	2	4.17	4.34×10^5
	5	3.51	5.15×10^5
	8	2.85	6.34×10^5
	10	2.41	7.49×10^5

Model verification

Performance of the package was verified using Eksotika papaya fruit obtained from a commercial farm at Bidor, Perak. Fruit at maturity stage 2 (skin colour green with traces of yellow) were selected, washed and allowed to dry at ambient. The fruit were weighed individually and values were used for computation of film area needed in the package design. Three thicknesses of LDPE film (0.03, 0.04 and 0.05 mm) were selected as package design treatments for verification. Based on the predicted output *(Table 2)*, packaging ratios *(A/W)* of about 3×10^5, 4×10^5 and 5×10^5 mm^2/kg were used for 0.03, 0.04 and 0.05 mm thickness of films respectively. The area of film required was computed by multiplying the selected packaging ratio with the exact weight of fruit. In the experiment, fruit were packed individually and sealed properly to avoid any leaking. Each package design treatment was replicated six times. The fruit were kept in cold storage at 15 °C for 3 weeks.

Measurement of gas

The concentrations of O_2, CO_2 and ethylene in all packages were measured twice a week. The O_2 and CO_2 were measured using a Varian 1420 gas chromatograph (GC) equipped with a thermal conductivity detector, while ethylene concentration was measured using a Varian 1400 GC equipped with a flame ionization detector. For each measurement, 1 mL of the headspace gas was withdrawn from each package using an air-tight hypodermic syringe and injected into a particular stainless steel GC column. The data were statistically analysed with analysis of variance and regression analysis for comparison with predicted output.

Results and discussion

Packaging ratios on LDPE film of varying thicknesses were predicted for package designs of Eksotika papaya. As shown in *Table 2*, packaging ratio varies according to the thickness of film and desired steady-state O_2. The thicker the packaging film, the larger the packaging ratio needed to achieve the specific MA environment in the package. For LDPE film, output result in *Table 2* can be used as guidelines for developing appropriate size of package per weight of fruit. The computation is accurate provided that the value of permeability used in the prediction is not influenced by variation in thickness of film and the polymeric material used in the manufacturing of the film (Pauly 1989). However, in actual situation, different permeability values may be recorded for different thickness of film and produced by different manufacturer due to the differences in drawing, orientation and crystallinity. Furthermore, small fluctuation of the storage temperature may also influence the permeability of the film. Although the temperature of the cold room used in the experiment was recorded at about 15 ± 2 °C, the effect of temperature fluctuation was not considered in the prediction.

Result from the verification trials showed that the O_2 concentration in all packages declined and moved towards equilibrium after about 3 days in storage, although it was slightly delayed in 0.03 mm package *(Figure 2)*. Similar trends were also observed for CO_2 concentration, where the steady-state condition was achieved after about 3 days of storage. The pattern of the result was in agreement with previous studies on broccoli and strawberry (Emond et al. 1991), tomato (Gong and Corey 1994) and bell pepper (Fishman et al. 1995). The observed steady-state O_2 and CO_2 in all packages were 4.9–5.6% and 3.4–4.1% respectively, which were significantly close (p <0.05) to the respective predicted concentrations of about 4.5% and 3.6% *(Table 3)*. The steady-state condition was maintained until the end of the 3-week experimental period.

The correlation between CO_2 concentration and O_2 concentration in MA package can be calculated using equation 4 and compared with observed correlation for all three films (0.03, 0.04 and 0.05 mm). As shown in *Figure 3*, the regression analysis of observed result performed a linear correlation of $C_o = 21 - 4.29C_c$ (with $R^2 = 0.74$) and agreed closely (p <0.05) with predicted correlation of $C_o = 21 - 4.57C_c$. The slope of the equation is known as the permeability ratio (P_R) for the LDPE film. The observed permeability ratio was about

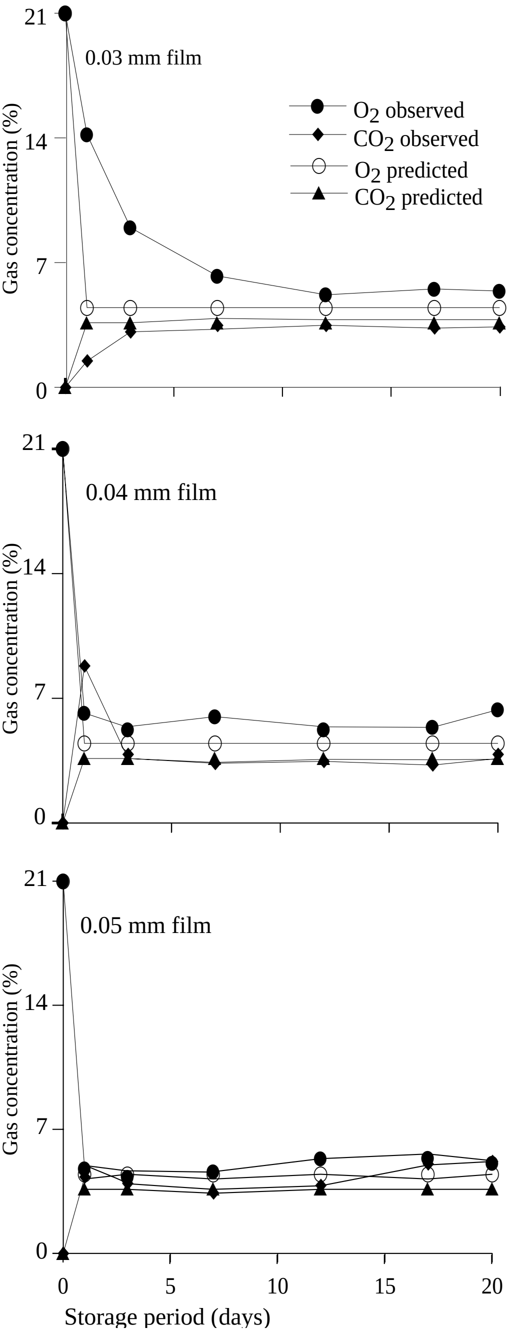

Figure 2. Oxygen and carbon dioxide concentrations inside papaya packages using three thicknesses of LDPE films and stored at 15 °C (mean of 6 replicates)

Table 3. Mean steady-state O_2 and CO_2 composition in papaya packages

Film thickness (mm)	O_2 (%)	CO_2 (%)
0.03	5.59a	3.42a
0.04	5.46ab	3.48ab
0.05	4.91bc	4.05b
Predicted	4.51c	3.62ab

Mean values in the same column with the same letters are not significantly different at $p < 0.05$ according to DMRT

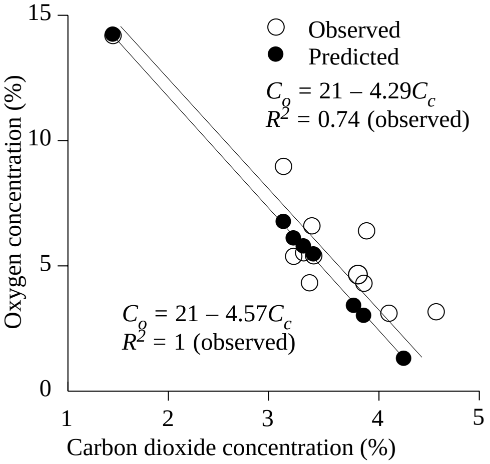

Figure 3. Correlation between oxygen and carbon dioxide concentrations inside papaya packages using LDPE films and stored at 15 °C

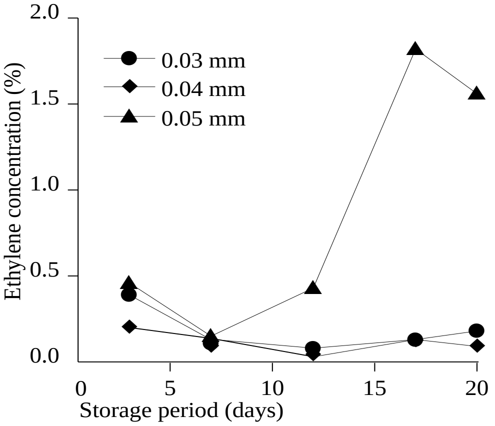

Figure 4. Ethylene concentration inside papaya packages using three thicknesses of LDPE films and stored at 15 °C (mean of 6 replicates)

4.29, which was close to the predicted value of 4.57. The result of the correlation suggested that for any level of O_2, the CO_2 concentration accumulated in the MAP was less than 5%. This is one of the advantages in using LDPE film for packing fruits. It allows modification of CO_2 atmosphere below 10%, that is the maximum tolerance limit to avoid physiological disorder in most tropical fruits (Kader et al. 1989).

Ethylene concentration in the package was measured to evaluate any possible ripening process in the package. The result showed that the overall ethylene concentration in all packages was quite low (less than 1.5%), confirming that ripening process did not occur during storage *(Figure 4)*. However, the concentration in 0.05 mm package began to rise after 15 days of storage indicating that the ripening process was about to commence (Ali et al. 1994). This is obvious since the storage temperature (15 °C) and atmospheric composition (4.9–5.6% O_2 and 3.4–4.1% CO_2) of the experiment were not the optimum condition for the storage of Eksotika papaya. Research results (Abd. Shukor, A. R., MARDI, Serdang, data not published 1995) suggested using atmospheric composition of 2% O_2 and 5% CO_2 at 12 °C for the storage of Eksotika papaya up to 32 days. The use of 15 °C in the present study was only to verify the precision of the mathematical model for designing MA package.

Conclusion

The verification of the model showed that the mathematical equation was able to predict the area of film required for developing MAP. The use of packaging ratio as design output was very practical since it provided a constant packaging ratio for a particular thickness of film. The appropriate packaging ratio of film was selected according to the desired steady-state MA concentration in the package. Gong and Corey (1994) also used packaging ratio when they designed and evaluated MAP for tomato. The actual area of film used in the package can easily be calculated by multiplying the packaging ratio with the exact weight of fruit for each pack. The study also considered the permeability ratio of film as another important parameter influencing the overall steady-state O_2 and CO_2 composition in the package. Film with permeability ratio of about 4.5 was able to develop MA system and ensure CO_2 concentration of less than 10% limit for most tropical fruits.

Acknowledgements

The authors acknowledge Ms Zahiriah Mohamed, Mr Jabir Husin and Mr Ismail Mustam for their assistance in conducting the experiment.

References

Abdullah, H., Lam, P. F., Rohani, M. Y. and Mohd. Salleh, P. (1992). Storage of selected fruits. *Proc. National IRPA Seminar* Vol. II. Kuala Lumpur: Min. of Science, Technology and Environment

Ali, Z. M., Lizada, M. C. C. and Lazam, H. (1994). Ripening and senescence. In *Papaya – fruit development, postharvest physiology, handling and marketing in ASEAN* (Rohani, M. Y., ed.) p. 56–74. Kuala Lumpur: ASEAN Food Handling Bureau

Emond, J. P., Castaigne, F., Toupin, C. J. and Disilets, D. (1991). Mathematical modeling of gas exchange in modified atmosphere packaging. *Trans. of ASAE* ***34(1):*** 239–45

Exama, A., Arul, J., Lencki, R. and Li, Z. (1993). Suitability of various plastic films for modified atmosphere packaging of fruits and vegetables: gas transfer properties and effect of temperature fluctuation. *Acta Horticulturae* ***343:*** 175–80

Fishman, S., Rodov, V., Peretz, J. and Ben-Yehoshua, S. (1995). Model for gas exchange dynamics in modified-atmosphere packages of fruits and vegetables. *J. Food Sci.* ***60(5):*** 1078–83, 1087

Gong, S. and Corey, K. A. (1994). Predicting steady-state oxygen concentrations in modified-atmosphere packages of tomatoes. *J. Amer. Soc. Hort. Sci.* ***119(3):*** 546–50

Hayakawa, K., Henig, Y. S. and Gilbert, S. G. (1975). Formulae for predicting gas exchange of fresh produce in polymeric film package. *J. Food Sci.* ***40:*** 186–91

Henig, Y. S. and Gilbert, S. G. (1975). Computer analysis of the variables affecting respiration and quality of produce packed in polymeric films. *J. Food Sci.* ***40:*** 1033–5

Kader, A. A., Zagory, D. and Kerbel, E. L. (1989). Modified atmosphere packaging of fruits and vegetables. *CRC Reviews in Food Sci. and Nutrition* ***28(1):*** 1–30

Pauly, S. (1989). Permeability and diffusion data. In *Polymer Handbook* 3rd ed. (Brandrup, J. and Immergut, E. H., ed.) p. VI/435–65. New York: John Wiley & Sons

Powrie, W. D. and Skura, B. J. (1991). Modified atmosphere packaging of fruits and vegetables. In *Modified atmosphere packaging of food* (Ooraikul, B. and Stiles, M. E., ed.) p. 169–245. London: Ellis Horwood

Accepted for publication on 3 March 1999