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# EXTENDING LIFE OF MANGO AND MELON FRUITS BY MODIFIED ATMOSPHERE PACKAGING


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**Executive Summary**

The experiments were conducted in both countries, The Israelis worked only with mango while the Costa Rican partner investigated both mangoes and melons

The Israeli partners provided necessary technical information and consultations to the Costa Rican partner as for the preparation of the facilities in CITA (Costa Rica) and for the work with fresh produce The major contribution of the project is the establishment of a new postharvest research laboratory in CITA and the training of its leader

The research was aimed to improve keeping quality of mango and melon fruits without decline of its consumer characteristics The keeping qualities were improved by hot water treatments followed by sealing the fruit with different films Packaging Tommy Atkins mangoes in perforated films prevented disorders caused by non-perforated packages such as impaired ripening, off-flavor development, discoloration, and at the same time markedly alleviated physiological problems characteristic for non-sealed fruit such as inadequate life, desiccation, etc A series of modified-atmosphere packages with different $O_2$ and $CO_2$ levels were obtained by varying the package perforation area In all these perforated packages, the fruit was capable of ripening, but the ripening rate differed markedly depending on in-package atmosphere This result opens a possibility to choose the characteristics of the package in accordance with the desired duration of storage and or transportation period, in order to obtain just by the end of this period a fruit combining low weight loss, absence of shrivelling with the good quality The addition of $Ca(OH)_2$ – containing pouches ($CO_2$ absorbers) to non-perforated packages allowed the fruit to attain the yellow peel color without a noticeable increase in weight loss However, hastened decay development in such packages canceled their positive effects on mango color

The research has aroused the interest of several Costa Rican exporters to carry on large trials with these technologies in collaboration with the CITA reserch leader

A mathematical model was developed to study the influence of film preforation on $O_2$ concetration and relative humidity in the atmosphere of the package containing fresh fruit The model included equtions describing fruit respiration and traspiration as well as permeation of oxygen and water vapor through the perforated film Closed-system experiments with mango fruit revealed a linear dependence of respiration rate on $O_2$ concentration The model allowed analytical computation of the time course of in-package $O_2$ concentration and relative humidity, and the results were in good agreement with experimentally measured values Perforations had a much more pronounced effect on $O_2$ concentration than on relative humidity The model enables practical predictions for designing modified-atmosphere packaging

**A) Research Objectives**

The overall aim of this project was to extend the storage life of mangoes and melons by the use of modified atmosphere packaging, and to combine this technique with treatments at high temperatures, or with the addition of $CO_2$ absoèbers

The research was aimed at optimization of perforation level of the packages containing heat-treated mangoes

Increasing the storage life and maintaining quality of fresh fruits and vegetables are the primary objectives of applied research in postharvest physiology Controlled atmospheres specifically reduced $O_2$ and increased $CO_2$ have long been known to extend the postharvest life of many horticultural commodities Modified atmosphere packaging (MAP) provides an alternative approach for altering the gaseous environment and thus prolonging the shelf life of fresh commodities enabling its export to distant markets (Ben Yehoshua et al 1995) Seal packaging technique, which is a simple, and original application of MAP, has been developed by the principed investigator and used already for different citrus fruit as well as for vegetables such as bell pepper In the past, the application of MAP to tropical fruit such as Mango was not successful The sealed fruit became soft but did not ripen well The application foe melons was also controversial (Ben Yehoshua et al, 1996)

Postharvest heat treatment of fruit and vegetables, such as curing or hot water dips reduced decay and accelerated healing of fruit injuries and reduced decay (Ben Yehoshua et al, 1996)

**B) Methods and Results**

**Israel,**

Mature-green mangoes of Tommy Atkins cultivar grown in Jordan valley in Israel were obtained from the packing house at the day of harvest The fruit did not receive any packing-house treatment except washing (1, 3)

The fruit were subjected to heat treatment within 24 h after reaching the laboratory Mangoes were dipped for 5 min in a thermostatic bath containing heated tap water (51±1°C)

The fruit were sealed in packages of 40 μ- thick low-density polyethylene (LDPE) Two fruit of known initial weight were sealed in each package The perforation levels were characterized by total perforation area per package (TPA) which was ranged as follows 0, 1, 4, 19, and 69 sq mm Control fruit were kept in standard mango packages - open cardboard trays

Packaged fruit were stored at 14°C and relative humidity (RH) of 85±3% The storage duration varied from 2 to 4 weeks The storage period was followed by a shelf-life imitation, when the packaged fruit was kept for 4 days at 20°C and RH 85±3% At the end of shelf-life period, the packages were opened and part of the fruit was used for quality analysis If necessary, the rest of the fruit were kept open for one additional week at 20°C to complete ripening

The following parameters were checked in the experiments in-package atmosphere composition, decay incidence, fruit weight loss, shrivelling, firmness, percentage of total soluble solids, titratable acidity, peel and flesh color, taste

*Composition of in-package atmosphere*

In non-perforated packages, the oxygen concentration decreased quickly to the level of 2-3% The anaerobic fermentation process prevailed in fruit at those conditions Accordingly, the atmosphere of non-perforated packages was rich in $CO_2$, ethanol and acetaldehyde Even the smallest perforation level tested (1 sq mm/package) practically prevented anaerobiosis In perforated packages, the $O_2$ concentration varied from 10 to about 20% with the increase of total perforation area (TPA) from 1 to 69 sq mm/package Accordingly, the $CO_2$ concentration varied in those packages from 10 to about 1%

At all perforation levels tested, the in-package ethylene concentration had a peak after 2 weeks of storage The highest and the most pronounced ethylene peak was observed at TPA of 4 sq mm/package At lower perforation levels, the ethylene production might be inhibited by high $CO_2$ concetration, while at higher perforation levels its accumulation could be reduced because of better package ventilation As a rule, the in-package ethylene level increased after transfer from 14C to 20C

*Weight loss and decay*

Seal-packaging prevented the fruit shrivelling Even when the fruit were taken out from the packages and kept open for an additional week at 20°C, only negligible shrivelling was evident At that period, about 50% of non-sealed control fruit were shrivelled

Perforated seal-packaging reduced greatly the fruit weight loss, even at highest perforation level As a rule, the weight loss percentage was directly related to TPA value In non-perforated sealed packages, the weight loss was surprisingly high, possibly, as a result of intensive exudation of liquid from the fruit

The fruit seal-packaged without perforation had no decay until opening of the package but then rotted rapidly The decay level in fruit stored in perforated packages was consistently lower than that in the non-sealed control For example, after 3 weeks of storage at 14°C and 4

days at 20°C, the decay incidence in perforated packages did not exceed 10-12% as compared to 20% in the control

*Fruit ripening*

*Softening* Keeping mango fruit in non-perforated sealed LDPE packages inhibited their softening, so that the fruit stayed hard even after 4 weeks of storage and 4 days of shelf life The smallest perforation level was sufficient to enable softening similar to that of the control fruit

*Total soluble solids (TSS)* Similar to fruit softening, the minimal package perforation was enough to enable the normal accumulation of soluble solids in mango fruit during storage In non-perforated sealed packages, this process was completely inhibited and TSS percentage was kept at the initial level

*Titratable acidity* The rate of acidity changes depended on perforation level In highly perforated sealed packages (TPA of 69 and 19 sq mm/package), as well as in non-sealed fruit, the titratable acidity declined rapidly and had little difference at the three storage periods checked Mangoes seal-packaged with TPA of 4 sq mm/package, at first storage period (2 weeks at 14°C and 4 days at 20°C) were more acid than , but a week later fruit reached the acidity level even slightly lower than that of non-sealed ones After 4 weeks of storage and 4 days of shelf life, fruit sealed with 1 sq mm of TPA also approached the acidity level close to that of the control In non-perforated sealed packages, the acidity never reached the level of non-sealed fruit

*Taste* After 3 weeks of storage at 14°C and 4 days at 20°C, the taste panel preferred the fruit kept in perforated sealed packages over those from the non-packaged control, mainly because it was not over-ripe The highest taste score was given to the fruit packaged at TPA of 4 sq mm The fruit kept in non-perforated sealed packages was inedible because of extremely strong alcoholic off-flavor, excessive acidity and firmness The slight off-flavor was sometimes evident also in fruit packaged at TPA of 1 sq mm

*Flesh color* After 2 weeks of storage at 14°C and 4 additional days at 20°C, the non-sealed fruit and the fruit seal-packaged with TPA of 69 sq mm, had the same intense yellow flesh color This color was reached by the flesh of fruit kept at TPA of 4 and 19 sq mm one week later, and it was enhanced slightly after additional week of storage TPA lower than 4 sq mm per package was insufficient to allow full flesh color development The sealing prevented an excessive flesh darkening observed in non-sealed control after prolonged storage as a result of over-ripening

*Peel color* Of all ripening-related processes, the peel color change was the most sensitive to the conditions of in-package atmosphere In non-perforated sealed packages, fruit maintained its green color for more than two weeks, and later demonstrated a dark (grayish to dark-brown) discoloration The heat treatment enhaced color development enabling sealed and perforated fruit to achieve fruit coloration

After 3 weeks at 14°C and 4 days at 20°C, only fruit packaged with TPA of 69 sq mm had turned yellow At least 19 sq mm TPA was essential for fruit to reach a yellow peel color after 4 weeks of storage and additional 4 days of shelf life After opening the sealed packages, fruit kept at TPA of 4 sq mm also reached yellow color, while peel of fruit packaged at TPA of 69 sq mm/package turned yellow-orange However, it still did not reach the color intensity of the control fruit The TPA of 1 $mm^2$/package was not sufficient for complete fruit yellowing

Direct relationship was observed between the advance of peel color and the in-package oxygen concentration, as well as $O_2/CO_2$ ratio

*In-package atmosphere and ripening rate* Table 1 summarizes the approximate time necessary for mango fruit to reach "ripeness level" of different qualitative parameters, as effected by in-package oxygen and $CO_2$ concentrations

Table 1 Effect of in-package atmosphere on the number of weeks* necessary for Tommy Atkins mango to reach ripeness level

| Steady-state | | | Ripening parameters | | | | |
|---|---|---|---|---|---|---|---|
| TPA, | $O_2$, % | $CO_2$, % | Acidity | TSS | Firm | Flesh color | Peel color |
| $mm^2$/pac | (range) | (range) | <0 25% | >13% | <1kG | Hue°<85° | yellow |
| 0 | 2-3 | 25-40 | NR | NR | NR | NR | NR |
| 1 | 9-10 | 11-13 | 4 | 2 | 3 | NR | NR |
| 4 | 16-17 | 4-5 | 3 | 2 | 2 | 3 | 3+1** |
| 19 | 18-20 | 2-3 | 2 | 2 | 2 | 3 | 4 |
| 69 | 19-21 | 0 7-1 | 2 | 2 | 2 | 2 | 3 |
| ∞ (N/seal ) | 20 5-21 | 0 03- 05 | 2 | 2 | 2 | 2 | 2 |

* followed by 4 days at 20°C, NR - never reached

** 1 additional week unpackaged at 20°C

In conclusion, keeping the fruit in sealed non-perforated packages of 40μ-thick LDPE irreversibly spoiled the commodity because of anaerobic fermentation, dark discoloration, off-flavors and impaired ripening Altogether, these disorders canceled the benefits of non-perforated seal-packaging for Tommy Atkins mango

Packaging Tommy Atkins mangoes in perforated films prevented disorders caused by non-perforated packages, and at the same time markedly alleviated physiological problems characteristic for non-sealed fruit (inadequate life, desiccation) A series of modified-atmosphere packages with different steady-state $O_2$ and $CO_2$ levels was obtained by varying the perforation area from 1 to 69 sq mm In these perforated packages, the rate of fruit ripening was determined by the perforation level

The objectives of this research were to test the effect of packaging in commercially manufactured perforated heat-shrinkable polyolefin films and of the carbon dioxide-absorbing

package inserts on postharvest life of 'Tommy Atkins' mangoes The performances of two films having the same density of perforations (8 holes/sq inch) but differing by perforation diameter (0 4 mm for Cryovac SM60M and 1 6 mm for Cryovac MPY8) were compared with those of two different non-perforated Cryovac polyolefins, MD and MY The fruit were sealed either within a polystyrene tray (in different trials, one or two fruit per tray) or without a tray (individual seal-packaging) The non-perforated film caused certain reduction of $O_2$ concentration and enhanced the accumulation of $CO_2$ and ethanol vapor in the in-package atmosphere The atmosphere composition in perforated packages did not differ significantly of the ambient one

After three weeks of storage at 14C and up to one week of shelf-life at 17C, the non-sealed control fruit were of the inferior quality because of the over-ripening, shriveling and decay development Both perforated and non-perforated films practically prevented the fruit shriveling Packaging mangoes in the non-perforated films or in the perforated SM60M or MPY8 films saved respectively 70-90, 40-55 and 25-33% of the weight loss Packaging in non-perforated films inhibited the development of yellow peel ground color and slowed down the reduction of the titratable acidity With perforated films, the fruit reached its full color inside the package No film removal was necessary for color development

The addition of $Ca(OH)_2$ - containing pouches ($CO_2$ absorbers) to non-perforated packages allowed the fruit to attain the yellow peel color without a noticeable increase in weight loss However, hastened decay development in such packages canceled their positive effects on mango quality

In addition to the practical experiments described above, a mathematical model was developed to study and predict the influence of film perforations on $O_2$ concentration and relative humidity inside a package containing fresh fruit The model included equations describing fruit respiration and transpiration as well as permeation of oxygen and water vapour through the perforated film Closed-system experiments with mango revealed a linear dependence of respiration rate on $O_2$ concentration The model allowed analytical computation of the time course of in-package $O_2$ concentration and relative humidity, the results wrere in good agreement with experimentally measured values Perforation had a greater effect on $O_2$ concentration than on relative humidity The practical aspect of this model was its ability to predict gas concentrations in modified-atmosphere packages

New developments in MAP were described in a special report invited by the journal Plasticulture which is the major publication of the International Association of the Plastics in Agriculture

**Costa Rica**

CANTALOUPE MELON The effect of individual packaging in plastic films and its combination with a hot water treatment on the quality characteristics of Cantaloupe melon was evaluated

Fruit was sealed in the following films LDPE with perforation area from 0 04 to 0 12 $cm^2$ per package, a heat shrinkable polyolefin (D-940 CRYOVAC), and an orientated microperforated polyolefin (SM-250 CRYOVAC) The combination of a hot water treatment (55°C/2 min) together with sealing in heat shrinkable polyolefin and orientated microperforated polyolefin was examined later Unsealed fruit, treated and non-treated, was used as control The efficacy of the hot water treatment on decay control and its consequnces on fruit quality were evaluated in preliminary trials The product was evaluated after one, two and three weeks of storage at 4 5°C followed by an additional week of storage at 18°C Sensory attributes, weight loss, peel and flesh color, external and flesh firmness, decay, TSS, pH and acidity of the fruit were determined

Individual sealing was very effective for weight loss control but other characteristics of the product might be affected The heat shrinkable film tried in this study, although considered to be highly permeable, significantly reduced the acceptability of the fruit Perforated LDPE affected the intensity of sweetness (0 12 $cm^2$ perforation) and strange taste (0 04 $cm^2$ perforation) Using highly perforated materials like and orientated microperforated polyolefin ensures a considerable weight loss reduction together with unaltered sensory attributes A hot water treatment of 55°C for 2 minutes showed to be significantly effective for decay control of Cantaloupe melon Though this treatment also made the fruit less juicy, sweet and tasty It also stimulated a lighter peel color and increased weight loss It is suggested that the effectiveness of hot water treatments, including slightly higher temperatures, should be compared with the commercial treatments under similar conditions

The combination of individual seal packaging with hot water treatments still looks very promising as a way to obtain better quality characteristics in the final product The results of this study have raised condsiderable interest among Costa Rican melon exporters and packaging material suppliers, who are willing to support further research

All the tables and data are enclosed in the Appendix

MANGO The effect of individual packaging in plastic films and its combination with a hot water treatment on the quality characteristics of Tommy Atkins mango was evaluated

Fruit was individually sealed into four different films LDPE 40 μm thick with 0 08 $cm^2$ perforation per package, orientated microperforated polyolefin (SM-250 CRYOVAC), heat shrinkable polyolefin (D-940 CRYOVAC) and LDPE with 0 04 $cm^2$ perforation A hot water

treatment, "HWT" (55°C/5 min) followed by sealing into the last two matereials was also examined Unsealed fruit, treated and non-treated, was used as control Fruit was evaluated after storage at 10°C for one, two and three weeks, plus an additional week of storage at 18°C Sensory attributes, weight loss, external and flesh firmness, peel and flesh color, titrable acidity, pH, total soluble solids and decay were measured

Our results show that perforation area as low as 0 04 $cm^2$ allows for adequate color development when individial seal packaging in LDPE is used Packing the fruit in the heat shrinkable polyolefin film did interfere with peel and flesh color development The HWT applied did not have detrimental effects on fruit quality but was not very effective for decay control (slightly higher temperatures and/or exposure times should be tried in the future) Titratable acidity and pH were not affected by seal packaging but significant differences were found in the total soluble solids content Fruit sealed in LDPE at both levels of perforation and in the heat shrinkable polyolefin showed TSS values and sweetness scores significantly lower along storage than the non-sealed control The use of LDPE with 0 04 $cm^2$ perforation and heat shrinkable polyolefin films had negative consequences on the sensory quality of the product Conversely a delay in ripening apparently with no other negative effects was obtained by the use of LDPE with 0 08 $cm^2$ perforation All the materials were very effective in weight loss control

The use of packaging films with controlled levels of perforation is a favorable option to achieve the benefits that seal packaging can provide It is clear that readily available low cost materials like low-density polyethylene can be advantageous if the adequate levels of perforation are carefully determined Heat shrinkable materials still seem to have ambiguous effects on fruit quality

**C) Impact, Relevance and Technology Transfer**

The results described in this report, open a possibility to choose a package - characteristics in accordance with the desired duration of storage and transportation period, in order to reduce spoilage, extend the postharvest life and obtain just by the end of storage period a fruit combining low weight loss, absence of shrivelling with the good quality

The Costa Rican institution (CITA) has 20-years practice in the area of food processing/engineering but only a limited previous experience in the work with fresh fruits and vegetables At the beginning of this project, the Costa Rican researcher, M Sc Ruth De la Asuncion, was trained in Israel in Ben-Yehoshua labratory in postharvest handling for a whole year and returned to Costa Rica She carried out then Trials with Mango and Melon fruits with the advice and guidance of the Israeli team

The Israeli partners provided also the necessary consultations to the Costa Rican part as for the preparation of the postharvest facilities in CITA Cold rooms for storage were built and shrink sealing machine (CLAMCO Co USA) was purchased

In March-May 1995, the Costa Rican collaborator participated in a postharvest science course at the Institute of Natural Resourses (Chatam, UK) financed from sources other than USA AID

During the experiments the CITA sensory analysis facilities were used and the postharvest laboratory has been equipped with a colorimeter CITA is arranging with the OEA (Organisation of American States) about the equipment for measurement and control of relative humidity (RH) and for gas analysis Another source of funding agreed to provide literature and subscriptions to periodicals in the relevant field

This project has opened possibilities for CITA to work with fresh produce, not only in research activities but also in extension and training/teaching As a result of this project CITA has broaden its capabilities to support and serve, not only the food processing sector, but also the horticultural sector CITA provided a professional trained in fresh produce handling and packaging, new store rooms and packaging equipment, as well as the experience gained by conducting storage trials Experimental results have been promising, and have raised interest among Costa Rican enterprises exporting mango and melon Several exporters are interested in supporting the required additional research Larger scale trials could be considered later Several companies handling produce for the local market are also willing to support future research related with packaging of other horticultural commodities

Establishment of postharvest research laboratory in CITA and training the appropriate staff will be the major contribution of this project to strengthening the research and development capacities in Costa Rica

**D) Project Activities/Outputs**

The following meetings were attended and in each of these meeting a lecture about our work had been presented and cited in section G Litreture cited

1 The Australasian Postharverst Hotriculture Conference in Melbourne, Australia at September 1995

2 International Postharvest Conference in Taupo, New-Zealand at August 1996

3 The 4th International Symposium Computer Modeling in Fruit Research, France, September 1996

4 The 5th International Mango Symposium in Tel-aviv, Israel, September 1996

5 International congress of Plastics in Agriculture, Tel-Aviv, Israel at March 1997

**Training** M Sc Ruth De La Asuncion, the Costa Rican reasearch leader had been trained for a whole year in S Ben-Yehoshua labratory in 1994

The publications that were submitted, and mostly already published, are listed in section G

In February 1998 S Ben-Yehoshua visited Costa Rica for 3 weeks During this time both investigators have reviewed in detail all research done in both countries All the Costa Rican work that have been carried out throughout this project had been summarized into the 2 scientific reports in the appendix

**E) Project Productivity**

The project has accomplished all of the proposed goals

The research on both mango melon has come to the level that several exporters in Costa Rica exoressed their interest in carrying out together with CITA large scale trials to check the possibility to reach its commercial application

The perforation and the modeling of the relative humidity has been pioneering pieces in the rapidly developing field of modified atmosphere packaging

**F) Future Work**

A survey conducted by CITA in 1996-97 determined that Costa Rican fresh produce exporting companies face a number of constraints at different stages of the marketing chain Although handling and packaging were found to be very relevant issues, a more integrated approach is required in order to get the desired impact

The mathematical model will be used for optimizing the design of perforated mango package

The search for decay-controlling measures for seal-packaged fruits will be continued Both mangoes and melons have several options of effective fungicides They were not checked in this project as it was meant to be free of any fungicides However, at present mangoes and melons are being treated by posrtharvest fungicides Such a decay control treatment would probably combine synergistically with the extension of the life of the fruit by the seal packaging

Additional trials with melon will be conducted by CITA during the harvest season in 1998 (Feb -April)

The individual seal-packaging developed in this project for mango and melon has to be compared to the modifical atmosphere packages of several fruit or a whole carton

**G) Literature cited**

1 Ben-Yehoshua, S , V Rodov, S Fishman, J Peretz, R De la Asuncion, J Sornsrivichai and T Yantarasri 1995 Perforation effects in modified-atmosphere packaging model and applications to bell pepper and mango fruits Australasian Postharvest Horticulture Conference, Melbourne, Australia, Sept

2 Ben-Yehoshua, S ,Fang, S ,Rodov,V , Fishman, S 1995 Progre's re'cents du conditionnement en atmosphe're modifie'e/ New developments in modified atmosphere packaging / Plasticulture, Part 1 106 29-37 Part 2 107 33-40 (in french and in english)

3 Ben-Yehoshua,S ,Rodov, V , Fishman, S ,Peretz, J 1996 Modified atmosphere packaging of fruit and vegetables reducing condensation of water in bell peppers and mangoes International Postharvest conference, 1996, Taupo, New-Zealand (in press)

4 De la Asuncion R 1998 Effect of packaging in plastic films and hot water treatment on the characteristics of 'Tommy Atkins' mango New report attached to the Appendix of this final report

5 De la Asuncion R 1998 Effect of packaging in plastic films and hot water treatment on the characteristics of cantaloupe melons New report attached to the Appendix of this final report

6 Fishman S , Rodov V , and Ben-Yehoshua S , 1996 Mathematical model for perforation effect on oxygen and water vapor dynamics in modifieid-atmosphere packages J Food Sci 61 956-961

7 Fishman S , Ben Yehoshua, S and Rodov, V 1997 Gas exchange in modified atmosphere fruit dynamics of carbon dioxide concentration International congress for plastics in agriculture, Tel-Aviv, Israel, March 9-15,1997 (in press)

8 Fishman, S , Rodov, V , Ben Yehoshua, S 1995 Potharvest life of fruits and vegetable Model of modified-atmosphere packages with film perforation Proc 4th Int Sym Comp Mod on Fruit Research Ed R Habib and Ph Blaise Arch Hort 416 ISHS, pp 129-137

9 Rodov, V , De la Asuncion, R Peretz, J Ben-Yehoshua S and Fishman S 1996 Modified atmosphere packaging (MAP) of 'Tommy Atkins' Mango in perforated film 5th International Mango Symposium, Tel Aviv, Israel _September 1996

10 Rodov, V De la Asuncion, R Peretz, Y Gotlieb, S and Ben-Yehoshua S 1997 Testing Perforated Heat-Shrinkable Polyolefin Films and Carbon Dioxide Absorbers for Packaging 'Tommy Atkins' Mango New report attached to the Appendix of this final report

# H) Appendix

The appendix comprises of last year reports of the two partners and all the published papers resulted from this project

*A Report of the work carried out in Costa Rica*

Effect of packaging in plastic films and hot water treatment on the characteristics of 'Tommy Atkins' mango

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**Abstract**
The effect of individual packaging in plastic films and its combination with a hot water treatment on the quality characteristics of 'Tommy Atkins' mango was evaluated
Fruit was individually sealed into four different films LDPE 40 µm thick with 0 08 $cm^2$ perforation per package, orientated microperforated polyolefin (SM-250 CRYOVAC), heat shrinkable polyolefin (D-940 CRYOVAC) and LDPE with 0 04 $cm^2$ perforation A hot water treatment, "HWT" (55°C/5 min) followed by sealing into the last two matereials was also examined Unsealed fruit, treated and non-treated, was used as control Fruit was evaluated after storage at 10°C for one, two and three weeks, plus an additional week of storage at 18°C Sensory attributes, weight loss, external and flesh firmness, peel and flesh color, titrable acidity, pH, total soluble solids and decay were measured
Our results show that perforation area as low as 0 04 $cm^2$ allows for adequate color development when individial seal packaging in LDPE is used Packing the fruit in the heat shrinkable polyolefin film did interfere with peel and flesh color development The HWT applied did not have detrimental effects on fruit quality but was not very effective for decay control (slightly higher temperatures and/or exposure times should be tried in the future) Titratable acidity and pH were not affected by seal packaging but significant differences were found in the total soluble solids content Fruit sealed in LDPE at both levels of perforation and in the heat shrinkable polyolefin showed TSS values and sweetness scores significantly lower along storage than the non-sealed control The use of LDPE with 0 04 $cm^2$ perforation and heat shrinkable polyolefin films had negative consequences on the sensory quality of the product Conversely a delay in ripening apparently with no other negative effects was obtained by the use of LDPE with 0 08 $cm^2$ perforation All the materials were very effective in weight loss control
The use of packaging films with controlled levels of perforation is a favorable option to achieve the benefits that seal packaging can provide It is clear that readily available low cost materials like low-density polyethylene can be advantageous if the adequate levels of perforation are carefully determined Heat shrinkable materials still seem to have ambiguous effects on fruit quality

**Methods and Materials**

The effect of individual packaging in plastic films and its combination with a hot water treatment on the quality characteristics of Tommy Atkins mango was evaluated

Tommy Atkins mangos from plantations located in the Costa Rican Central Pacific area were used Fruit harvested in the early hours, without being subjected to any packing house treatment, was selected, placed into cardboard boxes, and transported to CITA Fruit was kept at room temperature (20-25°C) until experiments were set, 24 hours after harvest

In a first experiment sealing in four different packaging films was evaluated The first two materials were LDPE with perforation area 0 04 and 0 08 $cm^2$ per package containing one fruit These films will be referred to as LDPE0 04 and LDPE0 08, respectively The other two materials were a heat shrinkable polyolefin D-940 CRYOVAC (water vapor transmission rate 5 0g / 100 $m^2$ * 24 $h^1$, oxygen transmission rate 23000 cc / $m^2$ * 24 $h^1$), and an orientated microperforated polyolefin SM-250 CRYOVAC (water vapor transmission rate 250 g / 100 $m^2$ * 24$h^1$) These last two materials will be referred to as HSP and OMP, respectively An unsealed control was used

A hot water treatment (55 °C / 5min) together with sealing in HSP and LDPE0 04 was examined in a second experiment Non-treated fruit was also sealed in both materials Unsealed fruit, treated and non-treated, was used as control

Fruit was stored at 10 °C for one, two and three weeks Evaluations took place always after an additional week of storage at 18 °C When a storage time of 2 weeks is mentioned it means one week at 10 °C plus one week at 18 °C Three weeks of storage include two weeks at 10 °C plus one week at 18 °C A storage time of 4 weeks would imply three weeks at 10 °C plus one week at 18 °C

An unrestricted random design was always applied Five replications per treatment were used, 10 fruit per replication A complete set of any one experiment was used for each evaluation time

The following characteristics were evaluated in the stored fruit

- Titratable acidity was determined using 10g of homogenized pulp diluted in 100mL distilled water A 10 mL aliquot was then titrated with NaOH 0 1M, using phenolphthalein indicator Results were expressed as mL NaOH 0 1M / 10 g
- pH was tested in a 1 2 pulp and water blend
- Firmness was measured using an Instron (model 1000) texturometer with a 50 Kg cell Penetration in the equator of the fruit was used for external firmness (needle diameter = 1 cm) Flesh firmness was measured through penetration with the same needle in the peeled pulp at both sides of the fruit Each fruit was tested twice
- Total soluble solids were determined in the juice using a digital table refractometer (ABBE type)
- Peel and flesh color were measured with a colorimeter (Hunter Lab DP-9000, sensor D25M)
- Weight loss was determined in four randomly selected fruit per replication (scale accuracy 0 01 g)
- Decay was visually scored in every fruit using the following categories 0=no decay , 1=slightly decayed, 2=moderately decayed and 3=severely decayed A weighed index was calculated for each replica

All the analyses, except for weight loss and decay, were duplicated in two fruit per replication

Sensory attributes of the product were evaluated through descriptive sensory analysis using categorical scales A panel of 24 experienced judges was used in the different evaluations Judges were asked to assess the intensity of the characteristic aroma, the strange aroma, the characteristic taste, the strange taste and the sweetness Also hardness, juiciness, and general liking were assessed A scale of 150 mm, with the categories "absent"-"weak"-"moderate"-"strong"-"very strong" was used to evaluate intensity Similar scales with categories from "very soft" to "very hard", and from "very low" to "very high" were applied for hardness and juiciness General liking was measured through a hedonical scale (150 mm scale, from "dislike a lot" to "like a lot") Samples were prepared by dicing the flesh of 15 fruit per treatment into 1 cm cubes

The SPSS software was used for statistical analysis Statistical differences were determined by analysis of variance and Tukey's significant difference test

**Results**

INITIAL CONDITIONS

The initial characteristics of the fruit varied from one experiment to the next Harvest season was shorter than usual due to adverse climatic conditions Earlier fruit had significantly lower ($P<0\ 05$) values for "a" of the peel, "a" and "b" of the flesh, total soluble solids content (Brix), and pH External and flesh firmness were significantly lower in the later fruit Values at the time of harvest are mentioned in each table of results

COLOR

The flesh color varied along storage Parameters "L" and "a" significantly decreased and increased, respectively, with storage time The packaging film had a significant effect on "a" Values of fruit packed in HSP and LDPE at both perforation levels were lower than the control after four weeks of storage (Table 1) "b" was not affected by the packaging material but did increase significantly with storage time when earlier fruit was used Differences between packaging materials were evident in "a" values even when the initial fruit was riper (Table 2) Fruit sealed in HSP had the lowest values, LDPE0 04 had a little higher and both had significantly lower values than the control

The color of fruit sealed into OMP was always similar to the control Heat treating the fruit did not interfere at all with the normal color development

The color of the peel also varied as related with the packaging material Values for "a" were significantly lower in the HSP sealed fruit than in the non-sealed control (Table 3) The LDPE at both levels of perforation, and the OMP did not affect significantly the color changes of the peel (data not shown) Changes in lightness and "b" were not affected by the packaging materials The HWT applied had no significant effect on peel color development

FIRMNESS

External and flesh firmness decreased significantly ($P<0\ 001$) with storage time but, in general, were not affected by seal packaging in the tested materials After 3 weeks of storage the LDPE sealed fruit was significantly firmer than the control (Table 4) These difference disappeared with longer storage time, and was not seen when initial fruit was riper (Table 5) The HWT did not affect the normal softening of the fruit

TOTAL SOLUBLE SOLIDS, pH and ACIDITY

Total soluble solids content and pH significantly increased (P<0 01) with storage time The packaging materials had a significant effect on TSS Fruit sealed in LDPE at both levels of perforation and in HSP showed TSS values significantly lower (P<0 05) along storage than the non-sealed control These three treatments did not differ among themselves (Table 6) Sealing in OMP did not affect the TSS levels as compared to the control fruit No differences between treatments could be observed in TSS levels when the initial fruit was riper (Table 7)

Seal packaging in the tested films had no effect on pH The hot water treatment applied had no influence over the total soluble solids content, the pH or the acidity of the fruit Acidity decreased significantly with storage time (P<0 001), and was not influenced by seal packaging (data not shown)

WEIGHT LOSS

Sealing in LDPE at both levels of perforation and in HSP reduced weight loss by at least 85% as compared to the non-sealed control after 3 weeks of storage (P<0 001) The OMP reduced weight loss only by 26% after the same period of time (Table 8) The hot water treatment showed no significant effect on weight loss

DECAY

No signs of decay were found up to 4 weeks of storage when earlier, non-hot water treated fruit was used With later fruit slight decay became evident only after 3 weeks of storage (5-10% of fruit slightly decayed) After 4 weeks decay levels were higher (15-30% of fruit slightly to moderately decayed) Decay significantly increased with storage time and no differences were observed between sealed and non-sealed fruit The hot water treatment was significantly effective in reducing decay levels (P<0 05) but reduction was only about 30%

SENSORY CHARACTERISTICS

The sensory quality of the fruit deteriorated along storage Storage time was related with significant reductions in scores for general liking and characteristic taste, together with raising intensity of strange taste and aroma (Table 9)

Significant influence of the packaging materials on the sensory attributes was found Seal packing fruit in LDPE0 04 and HSP lead to lower general liking, sweetness and characteristic taste In addition LDPE0 04 intensified strange aroma Sweetness was significantly lower with LDPE0 08 and no other adverse effects were found Fruit packed into OMP was always similar to the non-sealed control

The hot water treatment applied had no significant effect on the sensory characteristics of Tommy Atkins mango Hardness evaluation by the panel gave no consistent results

**Discussion**

The application of modified atmosphere packaging to better preserve the quality of fresh mango fruit has been the subject of numerous investigations Different authors mention advantages such as reduced weight loss (Miller and Hale, 1983), reduced chilling injury (Ketsa and Raksritong, 1992) and delayed ripening (Sornsrivichai *et al* , 1989) Higher decay levels, insufficient color development of the peel and the pulp, and higher incidence of off flavors (Miller *et al* , 1986) are frequently commented as the major constraints in the application of this technique

Fruit packed in LDPE0 04 and LDPE0 08, as well as OMP changed color normally Yantarasri *et al* (1994) stated that a perforation area over 0 392 $cm^2$ was required in order to achieve an

acceptable peel color in packages containing three fruit Our results show that perforation area as low as 0 04 $cm^2$ allow for adequate color development when individual seal packaging with LDPE is used According with Rodov *et al* (1997) fruit sealed in highly perforated polyolefin films, like the OMP used in these trials, reached its full color without any trouble Packing the fruit in the HSP film did interfere with peel color development

Peel color development is considered to be a more sensitive mechanism than flesh color development Thus, it is contradictory that flesh color resulted more altered by packaging not only in the HSP, but also in LDPE0 04 and LDPE0 08 Yantarasri *et al* (1994) mentioned that acceptable flesh color development was possible with perforation area as low as 0 002 $cm^2$ for three fruit packages

In contrast to Rodov *et al* (1997), who found that a hot water dip enhanced color development, we did not find any significant effect of the HWT on peel or flesh color In fact the HWT applied did not have a significant effect on any of the quality characteristics evaluated along the study This HWT (55 °C / 5 min) did not seem to be very effective for decay control Though decay levels were in general very low, the effect of the HWT was similar for sealed and non-sealed fruit It is suggested that longer storage time should be allowed for decay evaluations Considering that this HWT did not interfere at all with the normal quality characteristics of the fruit, it could be possible to try slightly higher temperatures and / or exposure times in the future

Important factors in the normal ripening process of mangoes are a relatively rapid decrease in acidity (Yoneya *et al* , 1990) together with an increase in total soluble solids (Wang and Shiesh, 1990) This normal behavior is sometimes modified, delayed and even reversed because of external factors Rodov *et al* (1997) show that fruit packed in non perforated films had markedly higher acidity than the non-sealed or the one sealed in perforated materials Kapse *et al* (1988) commented that these processes were significantly slowed down when mango was stored at 10 °C rather than at ambient conditions Storage at low temperature (10 °C and less) was related with an increase in the acid content of mangoes (Chaplin *et al* , 1991)

Our results showed that the pH and the titratable acidity were not affected by seal packaging in the tested materials However, significant differences were found in total soluble solids content due to the packaging films Fruit sealed in LDPE at both levels of perforation and in HSP showed TSS values significantly lower along storage than the non-sealed control Delayed ripening was also evident on the lower scores for sweetness that fruit sealed into these materials got The use of LDPE0 04 and HSP films lead to other detrimental consequences on the sensory quality of the product Conversely a delay in ripening apparently with no other negative effects was obtained by the use of LDPE0 08

The use of packaging films with controlled levels of perforation is a favorable option to achieve the benefits that seal packaging can provide It is clear that readily available low cost materials like low density polyethylene can be advantageous if the adequate levels of perforation are carefully determined In this study a perforation area of 0 08 $cm^2$ per individual package granted important weight loss reduction together with delayed ripening and without detrimental effects on the quality characteristics The use of highly perforated materials like the orientated microperforated polyolefin tested can provide considerable weight loss reduction Though a similar effect could be expected from a highly perforated LDPE film, at much lower cost Heat shrinkable materials still seem to have ambiguous effects on fruit quality

The effectiveness of hot water treatments should be further assessed in the Costa Rican environment Trying slightly higher temperatures and / or exposure times, as well as testing fruit from different sources is recommended for future work

**Table 1** Effect of packaging with different films on the flesh color ("L", "a" and "b") of Tommy Atkins mango

| *Storage Time (weeks)* | *Packaging film* | | | | |
|---|---|---|---|---|---|
| | LDPE0 04 | LDPE0 08 | OMP | HSP | Control |
| "L" | | | | | |
| 2 | 75 65[a] | 73 71[a] | 74 61[a] | 75 50[a] | 77 41[a] |
| 3 | 78 07[a] | 78 01[a] | 75 66[a] | 77 61[a] | 77 25[a] |
| 4 | 74 01[a] | 75 26[a] | 72 01[a] | 74 13[a] | 73 57[a] |
| "a" | | | | | |
| 2 | 2 96[a] | 6 34[a] | 6 83[a] | 4 21[a] | 3 29[a] |
| 3 | 1 49[a] | 2 48[a] | 6 47[a] | 1 39[a] | 4 15[a] |
| 4 | 5 62[a] | 5 76[a] | 10 04[ab] | 4 99[a] | 12 25[b] |
| "b" | | | | | |
| 2 | 42 71[a] | 42 16[a] | 43 73[a] | 43 69[a] | 43 39[a] |
| 3 | 42 68[a] | 41 27[a] | 43 28[a] | 41 40[a] | 42 82[a] |
| 4 | 43 80[a] | 44 48[a] | 43 31[a] | 44 13[a] | 43 43[a] |

[a b] Values in the same row with different superscripts are different (P<0 05)
Values at the time of harvest "L"= 80 43, "a"= -2 34, and "b"= 40 69

**Table 2** Effect of packaging with LDPE0 04 and HSP films, alone and in combination with a hot water treatment, on the flesh color ("L", "a" and "b") of Tommy Atkins mango

| *Storage Time (weeks)* | *Packaging film / treatment* | | | | | |
|---|---|---|---|---|---|---|
| | LDPE0 04[a] | | HSP[a] | | Control[a] | |
| "L" | CW | HWT | CW | HWT | CW | HWT |
| 2 | 76 52 | 77 81 | 76 39 | 77 76 | 79 52 | 76 75 |
| 3 | 74 06 | 75 64 | 77 11 | 76 90 | 74 78 | 76 09 |
| 4 | 73 58 | 75 04 | 76 92 | 76 64 | 73 40 | 71 92 |
| | LDPE0 04[a] | | HSP[b] | | Control[c] | |
| "a" | CW | HWT | CW | HWT | CW | HWT |
| 2 | 3 02 | 2 18 | 2 00 | 0 65 | 2 27 | 5 12 |
| 3 | 5 46 | 3 16 | 1 67 | 1 21 | 6 73 | 5 91 |
| 4 | 4 48 | 4 25 | 1 78 | 2 58 | 8 60 | 8 97 |
| | LDPE0 04[a] | | HSP[a] | | Control[a] | |
| "b" | CW | HWT | CW | HWT | CW | HWT |
| 2 | 44 10 | 43 09 | 43 17 | 43 65 | 43 06 | 43 92 |
| 3 | 43 68 | 43 71 | 43 44 | 42 85 | 43 88 | 43 37 |
| 4 | 42 87 | 43 71 | 43 42 | 43 69 | 43 07 | 42 35 |

[a b] Headings in the same row with different superscripts are different (P<0 05)
Values at the time of harvest "L"= 81 44, "a"= 1 45, and "b"= 44 43

**Table 3** Effect of packaging with LDPE0 04 and HSP films, alone and in combination with a hot water treatment, on the peel color ("L", "a" and "b") of Tommy Atkins mango

| *Storage Time (weeks)* | *Packaging film / treatment* | | | | | |
|---|---|---|---|---|---|---|
| | LDPE0 04[a] | | HSP[a] | | Control[a] | |
| "L" | CW | HWT | CW | HWT | CW | HWT |
| 2 | 42 48 | 44 44 | 44 95 | 55 60 | 53 66 | 40 65 |
| 3 | 46 40 | 49 32 | 44 72 | 43 92 | 55 22 | 51 74 |
| 4 | 40 56 | 37 34 | 45 33 | 48 45 | 40 93 | 50 46 |
| | LDPE0 04[ab] | | HSP[a] | | Control[b] | |
| "a" | CW | HWT | CW | HWT | CW | HWT |
| 2 | 26 11 | 18 16 | 19 06 | 6 33 | 23 97 | 32 74 |
| 3 | 25 37 | 11 82 | 14 51 | 12 82 | 19 62 | 21 91 |
| 4 | 28 37 | 21 56 | 18 31 | 20 06 | 31 21 | 25 22 |
| | LDPE0 04[a] | | HSP[a] | | Control[a] | |
| "b" | CW | HWT | CW | HWT | CW | HWT |
| 2 | 14 22 | 16 72 | 15 64 | 22 68 | 21 00 | 13 38 |
| 3 | 16 40 | 19 72 | 15 74 | 15 04 | 23 26 | 22 34 |
| 4 | 13 30 | 10 23 | 16 07 | 18 73 | 13 03 | 20 93 |

[a b] Headings in the same row with different superscripts are different (P<0 05)
Values at the time of harvest "L"= 41 02, "a"= 19 85, and "b"= 15 63

**Table 4** Effect of packaging with different films on the external and flesh firmness of Tommy Atkins mango

| *Storage Time (weeks)* | *Packaging film* | | | | |
|---|---|---|---|---|---|
| | LDPE0 04 | LDPE0 08 | OMP | HSP | Control |
| External firmness ($Kg/cm^2$) | | | | | |
| 2 | 13 4[a] | 11 7[a] | 14 7[a] | 14 4[a] | 15 7[a] |
| 3 | 12 0[a] | 13 5[a] | 7 5[ab] | 6 4[ab] | 3 3[b] |
| 4 | 6 8[a] | 8 5[a] | 4 7[a] | 6 0[a] | 4 7[a] |
| Firmness of the flesh ($Kg/cm^2$) | | | | | |
| 2 | 5 8[a] | 6 0[a] | 7 0[a] | 8 8[a] | 8 8[a] |
| 3 | 5 6[a] | 6 1[ab] | 8 6[ab] | 12 5[b] | 10 3[ab] |
| 4 | 2 7[a] | 3 4[a] | 1 4[a] | 1 7[a] | 1 0[a] |

[a b] Values in the same row with different superscripts are different (P<0 05)
Values at the time of harvest "Ex firm " = 18 83 and "Flesh firm " = 10 44

**Table 5** Effect of packaging with LDPE0 04 and HSP films, alone and in combination with a hot water treatment, on the external and flesh firmness of Tommy Atkins mango

| *Storage Time (weeks)* | *Packaging film / treatment* | | | | | |
|---|---|---|---|---|---|---|
| External firmness (Kg/cm2) | LDPE0 04[a] | | HSP[a] | | Control[a] | |
| | CW | HWT | CW | HWT | CW | HWT |
| 2 | 6 8 | 5 9 | 7 7 | 6 4 | 7 5 | 7 7 |
| 3 | 4 2 | 5 0 | 4 3 | 4 4 | 3 9 | 5 4 |
| 4 | 2 4 | 2 4 | 3 3 | 2 2 | 3 5 | 3 5 |
| Firmness of the flesh ($Kg/cm^2$) | LDPE0 04[a] | | HSP[a] | | Control[a] | |
| | CW | HWT | CW | HWT | CW | HWT |
| 2 | 1 0 | 1 8 | 1 7 | 2 3 | 1 6 | 1 6 |
| 3 | 0 8 | 1 2 | 1 1 | 1 0 | 0 8 | 1 1 |
| 4 | 0 7 | 0 8 | 0 7 | 0 5 | 0 7 | 0 9 |

[a b] Headings in the same row with different superscripts are different (P<0 05)
Values at the time of harvest "Ex firm " = 9 39 and "Flesh firm " = 5 20

**Table 6** Effect of packaging with different films on the total soluble solids and pH of Tommy Atkins mango after storage

| *Storage Time (weeks)* | *Packaging film* | | | | |
|---|---|---|---|---|---|
| | LDPE0 04 | LDPE0 08 | OMP | HSP | Control |
| Total soluble solids (Brix) | | | | | |
| 2 | 7 3[a] | 8 2[a] | 10 9[ab] | 6 6[a] | 12 0[b] |
| 3 | 13 3[a] | 12 0[a] | 13 4[ab] | 12 0[a] | 14 2[b] |
| 4 | 13 5[a] | 12 1[a] | 13 6[a] | 15 2[a] | 14 6[a] |
| pH | | | | | |
| 2 | 3 62[a] | 3 66[a] | 3 50[a] | 4 06[a] | 3 43[a] |
| 3 | 3 44[a] | 3 56[a] | 3 48[a] | 3 46[a] | 3 19[a] |
| 4 | 3 76[a] | 3 58[a] | 4 15[a] | 3 79[a] | 3 98[a] |

[a b] Values in the same row with different superscripts are different (P<0 05)
Values at the time of harvest "Brix"=6 9 and "pH"=3 51

**Table 7** Effect of packaging with LDPE0 04 and HSP films, alone and in combination with a hot water treatment, on the total soluble solids and pH of Tommy Atkins mango after storage

| *Storage Time (weeks)* | *Packaging film / treatment* | | | | | |
|---|---|---|---|---|---|---|
| Total soluble solids (Brix) | LDPE0 04[a] | | HSP[a] | | Control[a] | |
| | CW | HWT | CW | HWT | CW | HWT |
| 2 | 12 3 | 10 8 | 11 4 | 10 2 | 10 6 | 11 9 |
| 3 | 12 4 | 11 9 | 11 9 | 11 9 | 12 5 | 12 5 |
| 4 | 12 1 | 11 5 | 11 5 | 12 0 | 12 1 | 12 5 |
| pH | LDPE0 04[a] | | HSP[a] | | Control[a] | |
| | CW | HWT | CW | HWT | CW | HWT |
| 2 | 3 51 | 3 55 | 3 55 | 3 48 | 3 34 | 3 47 |
| 3 | 3 61 | 3 51 | 3 46 | 3 46 | 3 76 | 3 43 |
| 4 | 3 92 | 6 96 | 3 61 | 3 84 | 3 96 | 4 01 |

[a b] Headings in the same row with different superscripts are different (P<0 05)
Values at the time of harvest "Brix"=8 6 and "pH"=3 69

**Table 8** Effect of packaging with different films on the weight loss of Tommy Atkins mango after storage

| *Storage Time (weeks)* | *Packaging film* | | | | |
|---|---|---|---|---|---|
| | LDPE0 04 | LDPE0 08 | OMP | HSP | Control |
| Weight loss (%) | | | | | |
| 2 | 0 1[a] | 0 1[a] | 1 7[b] | 0 0[a] | 2 2[b] |
| 3 | 0 6[a] | 0 3[a] | 3 0[b] | 0 4[a] | 4 1[c] |

[a b] Values in the same row with different superscripts are different (P<0 05)

**Table 9** Effect of storage time, hot water treatment and packaging film on the sensory characteristics of Tommy Atkins mango after storage

| | Storage time | HWT | LDPE 0 04 | LDPE 0 08 | OMP | HSP | Mean of the Control |
|---|---|---|---|---|---|---|---|
| General liking | - | N S | - - | N D | N D | - - | 98 |
| Juiciness | + | N S | N D | N D | N D | N D | 78 |
| Sweetness | N S | N S | - - | - - | N D | - - | 95 |
| Characteristic taste | - - | N S | - - | N D | N D | - - | 93 |
| Strange taste | + | N S | + | N D | N D | + | 24 |
| Characteristic aroma | N S | N S | N D | N D | N D | N D | 76 |
| Strange aroma | + + + | N S | + | N D | N D | N D | 26 |

- Significant, or significantly lower than the control (-) P<0 05, (- -) P<0 005, (- - -) P<0 001
+ Significant, or significantly higher than the control (+) P<0 05, (+ +) P<0 005, (+ + +) P<0 001
N S Not significant (P>=0 05)
N D Not significantly different than the control (P>=0 05)

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Effect of packaging in plastic films in combination with hot water treatments on the quality characteristics of cantaloupe melon

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**Abstract**
The effect of individual packaging in plastic films and its combination with a hot water treatment on the quality characteristics of Cantaloupe melon was evaluated
Fruit was sealed in the following films LDPE with perforation area from 0 04 to 0 12 $cm^2$ per package, a heat shrinkable polyolefin (D-940 CRYOVAC), and an orientated microperforated polyolefin (SM-250 CRYOVAC) The combination of a hot water treatment (55°C/2 min) together with sealing in heat shrinkable polyolefin and orientated microperforated polyolefin was examined later Unsealed fruit, treated and non-treated, was used as control The efficacy of the hot water treatment on decay control and its consequnces on fruit quality were evaluated in preliminary trials The product was evaluated after one, two and three weeks of storage at 4 5°C followed by an additional week of storage at 18°C Sensory attributes, weight loss, peel and flesh color, external and flesh firmness, decay, TSS, pH and acidity of the fruit were determined
Individual sealing was very effective for weight loss control but other characteristics of the product might be affected The heat shrinkable film tried in this study, although considered to be highly permeable, significantly reduced the acceptability of the fruit Perforated LDPE affected the intensity of sweetness (0 12 $cm^2$ perforation) and strange taste (0 04 $cm^2$ perforation) Using highly perforated materials like and orientated microperforated polyolefin ensures a considerable weight loss reduction together with unaltered sensory attributes A hot water treatment of 55°C for 2 minutes showed to be significantly effective for decay control of Cantaloupe melon Though this treatment also made the fruit less juicy, sweet and tasty It also stimulated a lighter peel color and increased weight loss It is suggested that the effectiveness of hot water treatments, including slightly higher temperatures, should be compared with the commercial treatments under similar conditions
The combination of individual seal packaging with hot water treatments still looks very promising as a way to obtain better quality characteristics in the final product The results of this study have raised condsiderable interest among Costa Rican melon exporters and packaging material suppliers, who are willing to support further research

**Methods and Materials**

The effect of individual packaging in plastic films and its combination with a hot water treatment on the quality characteristics of Cantaloupe melon was evaluated

Cantaloupe melons from plantations located in the Costa Rican North Pacific area were used Fruit harvested in the early hours, without being subjected to any packing house treatment, was selected, placed into cardboard boxes, and transported to CITA Fruit was kept at room temperature (20-25°C) until experiments were set, 24 hours after harvest

The experiments described next were conducted during the harvest seasons of 1996 and 1997 at the National Center of Food Science and Technology (CITA), University of Costa Rica

The effectiveness of a hot water treatment (55°C / 2 minutes) on decay control and its consequences on the sensory attributes of the fruit were evaluated in preliminary trials Fruit was either treated with hot water or only immersed in cold water for a similar time The product was then placed in ventilated cardboard boxes and stored at 18 °C for 10 days Evaluations done after 3 and 6 days included the following Sensory difference detection using a duplicated triangular test, liking of appearance, color, aroma, taste, texture, and general quality using 150 mm hedonical scales with categories from "dislike a lot" to "like a lot" (24 judges) Total and reducing sugars, sucrose, glucose and fructose by HPLC (AMINEX HPX87C Bio Rad column, mobile phase deionised water at 0 6 ml/min, column temperature 85°C, sample extracted with water and filtered to 0 45 μm) Weight loss, color, external and flesh firmness, decay, TSS, pH and acidity were determined as described later After 10 days at 18°C a group evaluation (8 judges) of the fruit was conducted

Sealing in low density polyethylene (LDPE) 40 μm thick with different levels of perforation was tested in a first experiment Perforation area was 0 04, 0 06, 0 08 and 0 12 $cm^2$ per package containing one fruit These films will be referred to as LDPE0 04, LDPE0 06, LDPE0 08 and LDPE0 12, respectively An unsealed control was included

In a second experiment sealing in four different packaging films was evaluated The materials were LDPE0 04, LDPE0 12, heat shrinkable polyolefin D-940 CRYOVAC (water vapor transmission rate 5 0g / 100 $in^2$ * 24 $h^1$, oxygen transmission rate 23000 cc / $m^2$ * 24 $h^1$), and orientated microperforated polyolefin SM-250 CRYOVAC (water vapor transmission rate 250 g / 100 $in^2$ * 24$h^1$) These last two materials will be referred to as HSP and OMP, respectively An unsealed control was used

A combination of the hot water treatment (55 °C/2min) together with sealing in HSP and OMP was examined in a third experiment Non-treated fruit was also sealed in both materials Unsealed fruit, treated and non-treated was used as control

Fruit was stored at 4 5 °C for one, two and three weeks Evaluations took place always after an additional week of storage at 18 °C When a storage time of 2 weeks is mentioned it means one week at 4 5 °C plus one week at 18 °C Three weeks of storage include two weeks at 4 5 °C plus one week at 18 °C A storage time of 4 weeks would imply three weeks at 4 5 °C plus one week at 18 °C

An unrestricted random design was always applied Five replications per treatment were used, at least 9 fruit per replication A complete set of any one experiment was used for each evaluation time

The following characteristics were evaluated in the stored fruit along the different experiments

- Titratable acidity was determined using 10g of homogenized pulp diluted in 100mL distilled water A 10 mL aliquot was then titrated with NaOH 0 1M, using phenolphthalein indicator Results were expressed as percentage of citric acid
- pH was tested in a 1 2 pulp and water blend
- Firmness was measured using an Instron (model 1000) texturometer with a 50 Kg cell Penetration in the equator of the fruit was used for external firmness (needle diameter = 1 cm) Flesh firmness was measured through compression of pulp cylinders with a 5 cm diameter head Cylinders were 2 5 cm in diameter, 2 5 cm in height, and were taken from the equatorial zone of the fruit Each fruit was tested twice
- Total soluble solids were determined in the juice using a digital table refractometer (ABBE type)
- Peel and flesh color were measured with a colorimeter (Hunter Lab DP-9000, sensor D25M)
- Weight loss was determined in four randomly selected fruit per replication (scale accuracy 0 01 g)
- Decay was visually scored in every fruit using the following categories 1=slightly decayed, 2=moderately decayed and 3=severely decayed A weighed index was calculated for each replica

All the analyses, except for weight loss and decay, were duplicated in two fruit per replication

Sensory attributes of the product were evaluated through descriptive sensory analysis using categorical scales A panel of 24 experienced judges was used in the different evaluations Judges were asked to assess the intensity of the characteristic aroma, the strange aroma, the characteristic taste, the strange taste and the sweetness Also hardness, juiciness, and general liking were assessed A scale of 150 mm, with the categories "absent"-"weak"-"moderate"-"strong"-"very strong" was used to evaluate intensity Similar scales with categories from "very soft" to "very hard", and from "very low" to "very high" were applied for hardness and juiciness General liking was measured through a hedonical scale (150 mm scale, from "dislike a lot" to "like a lot") Samples were prepared by cutting the flesh of 15 fruit per treatment into 2 cm hemispheres Whenever a difference in color or appearance was perceived during sample preparation, the corresponding evaluation was conducted under red light

The SPSS software was used for statistical analysis Statistical differences were determined by analysis of variance and Tukey's significant difference test

## Results

### INITIAL CHARACTERISTICS

Characteristics of the raw material varied along the study Fruit used for the trials including hot water treatments was riper Significant differences (P<0 05) were found in the initial color of the peel Fruit collected later in the season had higher "L", "a" and "b" values This difference was evident and a lighter surface could be seen in the later fruit External and flesh firmness as evaluated with the Instron were significantly higher (P<0 05) in the earlier fruit used only for packaging evaluation The color of the flesh, total soluble solids and acidity at the time of harvest did not vary significantly from one experiment to another

## COLOR

Lightness of the peel (Table 1) after storage was not affected by the packaging materials tested Fruit packed in LDPE with 0 12 $cm^2$ perforation showed "L" values significantly (P=0 02) lower than the control after two weeks of storage Nevertheless this difference was not evident after storing for three weeks or longer "L" was usually higher in stored fruit and varied significantly (P=0 0001) with storage time, showing a decrease after 3 weeks of storage with a subsequent increase after 4 weeks The hot water treated fruit had significantly higher (P=0 01) "L" values of the peel than the control (Table 2) after three weeks of storage

Neither the packaging materials nor the hot water treatment caused any consistent difference in "a" and "b" values of the peel Although significant differences associated with the packaging material were found in "b" after two weeks of storage (Table 1), no differences between treatments were found with longer storage times

The color of the flesh intensified with storage, "a" and "b" values were always higher in the stored fruit (Table 3) The packaging films and the hot water treatment tested did not affect the flesh color (Table 4) Some significant variations (P<0 05) in "a" values, as related to different packaging materials, could be observed in the initial evaluations Nevertheless, these differences disappeared after a storage period longer than 2 weeks, and none of the treatments ever differed from the control fruit No changes whatsoever were found in "L" and "b" - values did not change with storage time and were not significantly influenced (P>0 05) by any treatment along the study

## FIRMNESS

The fruit softened normally and, in the overall, no significant differences (P>0 05) were found in the external firmness of stored fruit due to packaging film or storage time Firmness of the flesh was not significantly affected by the packaging material when storage time was higher than two weeks (Table 5) The heat shrinkable polyolefin (HSP) seemed to keep fruit flesh firmer (P=0 005) along storage (Table 6) The HWT had no significant effect on external and flesh firmness for fruit stored at 4 5°C or at 18°C

## SUGARS, TOTAL SOLUBLE SOLIDS, pH AND ACIDITY

A significant increase (P<0 05) of the sucrose content was observed in fruit stored at 18°C, associated with a significant decrease in glucose and fructose after 3 and 6 days Sucrose raised from an initial 2 5% to 4% after 6 days Mean values for glucose and fructose decreased from 2 9% to 1 75% and from 2 9% to 2 4% respectively Total sugars level remained constant These changes in sugars concentration were not affected by the hot water treatment

The total soluble solids content, the pH and the titratable acidity of the fruit (Tables 7 and 8) did not change significantly with storage In general terms these features were not affected by the packaging materials or the hot water treatment Significant differences were occasionally found that disappeared with a longer storage time, or did not imply a difference from the control fruit

## WEIGHT LOSS

All the packaging films tested reduced weight loss of the fruit very effectively (Table 9) Weight loss values were always significantly lower (P<0 0001) than those of the control fruit The heat shrinkable polyolefin (HSP) and the LDPE with 0 04 $cm^2$ perforation (LDPE0 04) were the most effective in preventing weight loss Fruit packed in these materials lost 95% less weight than the control fruit LDPE0 12 and OMP reduced weight loss in 90 and 70% respectively, as compared to the control Treating the fruit with a hot water dip significantly increased (P=0 01) weight loss (Table 10) The same effect was observed when fruit was stored at 18°C (data not shown)

## DECAY

The hot water treatment applied was significantly effective (P<0 05) for decay control throughout storage Treated fruit showed up to 66% less decay than untreated fruit Fruit packed in the different materials without been treated with hot water showed similar or higher decay levels than the control fruit (Table 11) Preliminary trials also demonstrated the efficacy of the hot water treatment as decay levels were significantly lower (P<0 05) for the treated fruit than for the cold water dipped control after 9 days at 18°C The commercially fungicide/wax treated fruit included in preliminary trials showed similar decay as the control (data not shown)

## SENSORY CHARACTERISTICS

Scores for sensory attributes are presented in Tables 12 and 13 Table 14 presents the effect and associated significance level for each treatment The fruit sensory characteristics were significantly affected by the length of storage and the hot water treatment applied A significant reduction (P<0 05) in the scores for juiciness, sweetness, and characteristic taste was observed Additionally, the scores for strange taste and strange aroma increased significantly with storage time (Table 14) Though, when HWT was tested in preliminary trials (without film packaging and after 3 and 6 days at 18°C) no significant difference was found between the flesh of treated and non-treated fruit in the triangular tests A group evaluation of the fruit stored for 10 days at 18°C indicated that the hot water treated fruit had slightly better general appearance, was firmer, and the seeds were in better condition as compared to the non-treated control and the commercially treated fruit

Packaging films utilized, with the exception of the heat shrinkable polyolefin (HSP), had little effect on the sensory characteristics of the fruit Although significantly higher scores for strange taste were related with the use of LDPE0 04, the scores were very low, meaning absent to weak, and they did not carry a significant change in the scores for general liking Sealing the fruit in HSP did cause significant detrimental changes higher strange taste scores and lower sweetness, juiciness and general liking (Table 14) General liking scores of these fruit markedly decreased with storage time, and, after a storage period of 4 weeks, were significantly lower than those of the control fruit (Table 12)

### Discussion

Costa Rican melon is mostly grown in large plantations, and harvested following consistent and adequate criteria for export quality fruit These criteria were relaxed in 1997 due to early rain that caused severe losses to major growing areas in the Pacific region Harvest season was considerably shorter than usual, and the possibilities to gather very homogeneous high quality export fruit, even

from large exporters, were somehow altered For these reason, the characteristics of the raw material, particularly the peel color, external and flesh firmness, varied significantly along this study

Normal color development of the peel along storage was not interfered by any of the packaging materials tested Lightness was usually higher in stored fruit and varied significantly with storage time, showing a decrease after 3 weeks of storage with a subsequent increase after 4 weeks Similar variations in peel lightness were observed in different experiments, despite initial color of the fruit been significantly different Changes in "L" seem to be more related to dehydration and brittleness of the net -a highly netted cultivar was used-, rather than to variations in the ground color Marketability of the export fruit is not diminished by these changes The hot water treatment had a significant effect in lightness of the peel Values for "L" were higher in the treated fruit after three weeks of storage

Weight loss reduction has been considered to be the major benefit when using film packaging of fresh produce Reduced water loss has been related with firmer fruit or delayed softening in melon when packing in polyethylene bags (Mayberry and Hartz, 1992) In our study, all the packaging films applied greatly reduced weight loss However only the fruit wrapped in the HSP was significantly firmer This might be more related to delayed ripening, as evidenced by the sensory evaluations, than to the reduction in water loss Sensory evaluations of hardness showed no significant differences between treatments

No significant effect of the hot water treatment applied was observed on external and flesh firmness of the fruit, as has also been reported by Teitel *et al* (1989) Though HWT significantly increased weight loss Weight loss was higher in treated fruit as compared to the non-treated by 12%, 38%, and 85% for non-sealed, OMP sealed and HSP sealed fruit respectively

Decay is usually not evident immediately after storage at transit temperatures, but it becomes a problem when melon is left for some time (3 days or more) at higher temperatures to allow for ripening Heat treatments have long been studied as a means for decay control that could lead to the reduction or the elimination of fungicide applications in the postharvest treatment of melon fruits (Carter, 1981, Teitel *et al* , 1991, Teitel *et al* , 1989, Dunlap *et al* , 1990) As could be expected from the most basic microbiological principles, treatments using wet heat, such as hot water treatments, are more effective in decay control than dry heat procedures (Teitel *et al* , 1989)

The hot water treatment applied (55°C/2 min) was significantly effective for decay control throughout storage either at 4 5 or at 18°C Fruit packed in the different films without been treated with hot water showed similar or higher decay levels than the control fruit Hot water treatments using higher temperature or longer exposure time have been reported to induce heat damage to the product (Teitel *et al* , 1991) Nevertheless, Mayberry and Hartz (1992) found that a treatment of 60°C/3min was very effective for decay control on muskmelon, obtaining a high quality product

The commercial fungicide/wax application seemed to be less effective for decay control than the hot water treatment when fruit was stored at 18°C This observation should be carefully considered because of several reasons First, commercially treated fruit ran all along the packing house production line, suffering more superficial abrasion than the fruit treated at CITA This superficial damage may have rendered the fruit more susceptible to pathogens infection Second, it was more exposed to recontamination at the packing house level, while all the other treatments were set at a pilot plant where recontamination is less likely to occur It is suggested that the effectiveness of hot water treatments, including slightly higher temperatures, should be compared with the commercial treatment under similar conditions

Sugar content is an important aspect of fruit quality in melon Although total sugars content remained constant, our results show a significant increase in sucrose content along 6 day storage at 18°C, associated with decreases in the levels of glucose and fructose Sucrose accumulation after harvest at full slip, along with reducing content of glucose and fructose has been reported by Lester and Dunlap (1985) for "Perlita" muskmelon Reduction in glucose and fructose was also mentioned by Cohen and Hicks (1986) for several melon cultivars Discrepancies with respect to sugar metabolism can be found between different investigations Lingle *et al* (1987) found the sucrose content of netted muskmelon to remain constant until 12 days of storage at 4°C, followed by a decline between 12 and 18 days These decline was not coincident with any increase in glucose or fructose According to Lester and Bruton (1986) the sucrose content of netted muskmelon decreased and levels of glucose and fructose increased during 10 day storage at 4°C

Heat treatments have been related with changes in carbohydrates metabolism after harvest Heating muskmelon at 45°C for 3 hours inhibited the decline in sucrose during storage as described by Lingle *et al* (1987) However, the changes in sugars content observed in this study were not significantly affected by the hot water treatment

The effect of storage time, film packaging and heat treatments on the sensory characteristics of melon fruit has been the subject of several investigations Cohen and Hicks (1986) found no differences between freshly harvested muskmelons of different cultivars and the respective fruit stored for 7 days at 5°C or 12 5°C Our results show that the sensory characteristics of Cantaloupe melon are significantly affected by the length of storage and also by the hot water treatment

Heat treatments have been found to be accompanied by the development of off-flavors (Teitel *et al* , 1989) However, strange taste and strange aroma were not among the characteristics where the effect of the HWT could be observed in our study The treated fruit presented lower scores for juiciness, sweetness, and characteristic taste Though scores for general liking were not significantly reduced by the HWT Scores for strange taste and strange aroma significantly increased with storage time but were not affected by the HWT Hot water treated fruit could not be distinguished from the non-treated after 3 and 6 days at 18°C After 10 days at 18°C treated fruit was better than non-treated in general appearance, firmness and condition of the seeds

Studies involving the use of heat shrinkable films or other film wrapping, for muskmelon, point out advantages such as weight loss control (Teitel *et al* , 1989), prevented overripening, reduced chilling injury (Rij and Ross, 1988, Edwards and Blennerhassett, 1990) and avoidance of reinfection (Teitel *et al* , 1991) However, most investigations did not take into account the evaluation of sensory characteristics Variable effects have been reported when sensory analysis has been included Collins *et al* (1990) found that shrink film wrapping in high density polyethylene (12 7 µm HDPE Clysar 50 EHC-F) negatively affected the flavor and taste of muskmelon, while Yahia and Rivera (1992) did not find off-flavors in PVC (20 3 µm) wrapped fruit

In our study the sensory characteristics of the fruit after storage were significantly impaired when packaged in the heat shrinkable polyolefin (HSP) This packaging film was associated with a significant reduction of juiciness and sweetness that could be related to a delay in ripening, as was also suggested by the flesh firmness evaluations Unfortunately the detrimental effect due to the presence of strange taste and the lower scores for general liking make this film inadequate Other films affected the intensity of sweetness (LDPE0 12) and strange taste (LDPE0 04) but without significantly reducing the scores for general liking

Fruit sealed in the OMP film did not differ from the control Fruit was most of the times scored as moderately juicy, having a weak to moderately strong level of sweetness The intensity of the

characteristic taste varied from weak to moderately strong, while the presence of strange taste and aroma was usually judged as lower than weak The initial conditions of the fruit played a relevant role in sensory results The intensity of strange taste and strange aroma after storage were always scored higher when the initial fruit was riper

Individual sealing is very effective for weight loss control but other characteristics of the product might be affected The heat shrinkable film tried in this study, although considered to be highly permeable, significantly reduced the acceptability of the fruit Using highly perforated materials like an orientated microperforated polyolefin ensures a considerable weight loss reduction together with unaltered sensory attributes A hot water treatment of 55°C for 2 minutes showed to be significantly effective for decay control of Cantaloupe melon Though this treatment also made the fruit less juicy, sweet and tasty It also stimulated a lighter peel color and increased weight loss It is suggested that the effectiveness of hot water treatments, including slightly higher temperatures, should be compared with the commercial treatments under similar conditions

The combination of individual seal packaging with hot water treatments still looks very promising as a way to obtain better quality characteristics in the final product The results of this study have raised considerable interest among Costa Rican melon exporters and packaging material suppliers, who are willing to support further research

**Table 1** Effect of packaging with different films on the peel color ("L", "a" and "b") of Cantaloupe melon

| *Storage Time (weeks)* | *Packaging film* | | | | |
|---|---|---|---|---|---|
| | LDPE0 04 | LDPE0 12 | HSP | OMP | **Control** |
| *"L"* | | | | | |
| 2 | 59 43[ab] | 56 32[a] | 58 82[ab] | 58 24[ab] | 60 55[b] |
| 3 | 53 47[a] | 53 38[a] | 53 74[a] | 52 99[a] | 53 30[a] |
| 4 | 57 65[a] | 59 34[a] | 57 26[a] | 57 01[a] | 56 05[a] |
| "a" | | | | | |
| 2 | 6 43[a] | 3 34[a] | 3 34[a] | 5 31[a] | 5 81[a] |
| 3 | 4 38[a] | 4 75[a] | 4 89[a] | 4 93[a] | 4 12[a] |
| 4 | 3 00[a] | 4 65[a] | 4 87[a] | 4 75[a] | 5 55[a] |
| "b" | | | | | |
| 2 | 21 92[a] | 17 63[b] | 20 04[ab] | 20 92[ab] | 22 98[a] |
| 3 | 19 23[a] | 19 09[a] | 18 92[a] | 18 73[a] | 18 68[a] |
| 4 | 19 79[a] | 20 06[a] | 20 21[a] | 18 54[a] | 18 58[a] |

[a b] Values in the same row with different superscripts are different (P<0 05)

**Table 2** Effect of packaging with HSP and OMP films, alone and in combination with a hot water treatment, on the peel color ("L", "a" and "b") of Cantaloupe melon

| *Storage Time (weeks)* | *Packaging film / treatment* | | | | | |
|---|---|---|---|---|---|---|
| | HSP[a] | | OMP[a] | | Control[a] | |
| *"L"* | CW | HWT | CW | HWT | CW | HWT |
| 2 | 60 79 | 60 96 | 61 95 | 62 57 | 61 95 | 61 14 |
| 3 | 52 89 | 55 51 | 50 75 | 59 45 | 55 49 | 55 93 |
| | HSP[a] | | OMP[a] | | Control[a] | |
| "a" | CW | HWT | CW | HWT | CW | HWT |
| 2 | 6 08 | 7 39 | 7 20 | 7 03 | 7 43 | 6 81 |
| 3 | 18 44 | 21 01 | 30 94 | 14 11 | 16 83 | 11 30 |
| | HSP[a] | | OMP[a] | | Control[a] | |
| "b" | CW | HWT | CW | HWT | CW | HWT |
| 2 | 22 68 | 21 84 | 24 31 | 23 78 | 23 83 | 23 07 |
| 3 | 22 00 | 23 16 | 21 92 | 24 10 | 23 47 | 22 72 |

[a b] Headings in the same row with different superscripts are different (P<0 05)

**Table 3** Effect of packaging with different films on the flesh color ("L", "a" and "b") of Cantaloupe melon

| *Storage Time (weeks)* | *Packaging film* | | | | |
|---|---|---|---|---|---|
| | LDPE0 04 | LDPE0 12 | HSP | OMP | Control |
| *"L"* | | | | | |
| 2 | 65 67[a] | 66 91[a] | 66 01[a] | 67 93[a] | 67 62[a] |
| 3 | 66 99[a] | 65 34[a] | 66 03[a] | 65 96[a] | 66 62[a] |
| 4 | 67 64[ab] | 64 23[a] | 68 33[b] | 68 38[ab] | 66 09[ab] |
| "a" | | | | | |
| 2 | 21 78[a] | 21 02[ab] | 21 71[a] | 19 01[b] | 19 88[ab] |
| 3 | 21 63[a] | 22 46[a] | 22 15[a] | 21 65[a] | 19 75[a] |
| 4 | 20 15[a] | 22 53[a] | 17 16[a] | 19 25[a] | 21 26[a] |
| "b" | | | | | |
| 2 | 31 68[a] | 32 32[a] | 31 99[a] | 32 18[a] | 32 16[a] |
| 3 | 32 47[a] | 32 29[a] | 32 40[a] | 32 29[a] | 32 36[a] |
| 4 | 31 93[a] | 32 00[a] | 30 92[a] | 31 86[a] | 32 02[a] |

[a b] Values in the same row with different superscripts are different (P<0 05)
Values at the time of harvest "L"=69 14, "a"=16 11 and "b"=31 02

**Table 4** Effect of packaging with HSP and OMP films, alone and in combination with a hot water treatment, on the flesh color ("L", "a" and "b") of Cantaloupe melon

| *Storage Time (weeks)* | *Packaging film / treatment* | | | | | |
|---|---|---|---|---|---|---|
| | HSP[a] | | OMP[a] | | Control[a] | |
| *"L"* | CW | HWT | CW | HWT | CW | HWT |
| 2 | 66 82 | 66 34 | 66 26 | 65 81 | 66 08 | 66 57 |
| 3 | 67 52 | 66 60 | 65 71 | 66 46 | 66 66 | 66 95 |
| | HSP[a] | | OMP[a] | | Control[a] | |
| "a" | CW | HWT | CW | HWT | CW | HWT |
| 2 | 22 05 | 22 12 | 22 26 | 22 69 | 22 92 | 21 91 |
| 3 | 21 68 | 22 14 | 23 01 | 22 47 | 21 89 | 22 20 |
| | HSP[a] | | OMP[a] | | Control[a] | |
| "b" | CW | HWT | CW | HWT | CW | HWT |
| 2 | 32 51 | 32 12 | 32 71 | 32 89 | 32 80 | 32 74 |
| 3 | 32 53 | 32 33 | 32 51 | 32 16 | 32 42 | 32 36 |

[a b] Headings in the same row with different superscripts are different (P<0 05)

**Table 5** Effect of packaging with different films on the external and flesh firmness of Cantaloupe melon

| *Storage Time (weeks)* | *Packaging film* | | | | |
|---|---|---|---|---|---|
| | LDPE0 04 | LDPE0 12 | HSP | OMP | Control |
| ***External firmness*** | | | | | |
| 2 | 3 8[a] | 4 4[a] | 4 2[a] | 3 5[a] | 4 2[a] |
| 3 | 4 5[a] | 4 9[a] | 4 5[a] | 4 4[a] | 3 3[a] |
| 4 | 4 7[a] | 3 4[a] | 3 5[a] | 3 9[a] | 4 5[a] |
| Firmness of the flesh | | | | | |
| 2 | 1 2[a] | 1 2[ab] | 1 4[ab] | 1 6[ab] | 1 8[b] |
| 3 | 2 4[a] | 1 5[a] | 1 7[a] | 1 3[a] | 3 3[a] |
| 4 | 2 3[a] | 1 4[a] | 1 5[a] | 2 0a | 2 1[a] |

[a b] Values in the same row with different superscripts are different (P<0 05)

**Table 6** Effect of packaging with HSP and OMP films, alone and in combination with a hot water treatment, on the external and flesh firmness of Cantaloupe melon

| *Storage Time (weeks)* | *Packaging film / treatment* | | | | | |
|---|---|---|---|---|---|---|
| | HSP[a] | | OMP[a] | | Control[a] | |
| ***External firmness*** | CW | HWT | CW | HWT | CW | HWT |
| 2 | 4 4 | 4 8 | 4 0 | 4 4 | 4 1 | 4 5 |
| 3 | 6 8 | 4 0 | 3 6 | 3 2 | 3 0 | 4 4 |
| Firmness of the flesh | HSP[a] | | OMP[b] | | Control[b] | |
| | CW | HWT | CW | HWT | CW | HWT |
| 2 | 2 1 | 2 2 | 1 7 | 1 7 | 1 8 | 1 9 |
| 3 | 3 8 | 2 1 | 2 1 | 1 8 | 1 8 | 2 2 |

[a b] Headings in the same row with different superscripts are different (P<0 05)

**Table 7** Effect of packaging with different films on the total soluble solids, pH and titratable acidity of Cantaloupe melon after storage

| *Storage Time (weeks)* | *Packaging film* | | | | |
|---|---|---|---|---|---|
| | LDPE0 04 | LDPE0 12 | HSP | OMP | Control |
| ***Total soluble solids (Brix)*** | | | | | |
| 2 | 8 4[a] | 6 7[a] | 6 1[a] | 6 9[a] | 6 7[a] |
| 3 | 6 5[a] | 7 2[a] | 7 2[a] | 5 9[a] | 5 1[a] |
| 4 | 7 7[ab] | 8 9[a] | 7 0[b] | 7 2[ab] | 7 8[ab] |
| pH | | | | | |
| 2 | 6 83[a] | 6 69[a] | 6 44[a] | 6 44[a] | 6 73[a] |
| 3 | 6 66[a] | 6 57[a] | 6 62[a] | 6 63[a] | 6 62[a] |
| 4 | 6 69[a] | 6 78[a] | 6 75[a] | 6 58[a] | 6 64[a] |
| Acidity (% citric acid) | | | | | |
| 2 | 0 65[ab] | 0 68[ab] | 0 75[ab] | 0 80[a] | 0 47[b] |
| 3 | 0 62[a] | 0 77[a] | 0 69[a] | 0 66[a] | 0 56[a] |
| 4 | 0 82[a] | 0 78[a] | 0 73[a] | 0 83[a] | 0 82[a] |

[a b] Values in the same row with different superscripts are different (P<0 05)

**Table 8** Effect of packaging with HSP and OMP films, alone and in combination with a hot water treatment, on the total soluble solids, pH and titratable acidity of Cantaloupe melon after storage

| *Storage Time (weeks)* | *Packaging film / treatment* | | | | | |
|---|---|---|---|---|---|---|
| | HSP[a] | | OMP[a] | | Control[a] | |
| ***Total soluble solids (Brix)*** | CW | HWT | CW | HWT | CW | HWT |
| 2 | 8 4 | 9 1 | 9 0 | 8 7 | 8 9 | 8 2 |
| 3 | 8 9 | 8 6 | 8 4 | 8 8 | 8 7 | 8 0 |
| | HSP[a] | | OMP[b] | | Control[ab] | |
| pH | CW | HWT | CW | HWT | CW | HWT |
| 2 | 6 73 | 6 70 | 6 55 | 6 59 | 6 64 | 6 55 |
| 3 | 6 70 | 6 57 | 6 50 | 6 58 | 6 55 | 6 53 |
| | HSP[a] | | OMP[a] | | Control[a] | |
| Acidity (% citric acid) | CW | HWT | CW | HWT | CW | HWT |
| 2 | 0 75 | 0 80 | 0 93 | 0 94 | 0 86 | 0 98 |
| 3 | 1 00 | 0 93 | 0 93 | 0 84 | 0 95 | 0 90 |

[a b] Headings in the same row with different superscripts are different ($P<0\ 05$)

**Table 9** Effect of packaging with different films on the weight loss of Cantaloupe melon after storage

| *Storage Time (weeks)* | *Packaging film* | | | | |
|---|---|---|---|---|---|
| | LDPE0 04 | LDPE0 12 | HSP | OMP | Control |
| ***Weight loss*** (%) | | | | | |
| 2 | 0 5[a] | 1 7[a] | 0 5[a] | 0 6[a] | 6 2[b] |
| 3 | 0 4[a] | 0 5[a] | 0 6[a] | 2 8[b] | 9 1[c] |
| 4 | 0 6[a] | 0 8[ab] | 0 6[a] | 3 8[b] | 14 3[c] |

[a b] Values in the same row with different superscripts are different (P<0 05)

**Table 10** Effect of packaging with HSP and OMP films, alone and in combination with a hot water treatment, on the weight loss of Cantaloupe melon after two weeks of storage

| *Storage Time (weeks)* | *Packaging film / treatment* | | | | | |
|---|---|---|---|---|---|---|
| | HSP[a] | | OMP[a] | | Control[b] | |
| ***Weight loss*** (%) | CW | HWT | CW | HWT | CW | HWT |
| 2* | 0 27 | 0 50 | 2 00 | 2 77 | 6 24 | 7 01 |

[a b] Headings in the same row with different superscripts are different (P<0 05)

* The HWT was significant (P=0 01) at this storage time

**Table 11** Effect of packaging with HSP and OMP films, alone and in combination with a hot water treatment, on the decay of Cantaloupe melon after storage

| *Storage Time (weeks)* | *Packaging film / treatment* | | | | | |
|---|---|---|---|---|---|---|
| | HSP[a] | | OMP[a] | | Control[a] | |
| ***Decay*** | CW | HWT | CW | HWT | CW | HWT |
| 2 | 41 | 14 | 18 | 9 | 9 | 11 |
| 3* | 60 | 21 | 54 | 21 | 21 | 12 |
| 4* | 90 | 75 | 87 | 75 | 75 | 30 |

[a b] Headings in the same row with different superscripts are different (P<0 05)

* The HWT was significant (P=0 01) at this storage time

**Table 12** Effect of packaging with different films on the sensory characteristics of Cantaloupe melon after storage

| *Storage Time (weeks)* | *Packaging film* | | | | |
|---|---|---|---|---|---|
| | LDPE0 04 | LDPE0 12 | HSP | OMP | Control |
| ***General liking*** | | | | | |
| 2 | $72^{a}$ | $87^{a}$ | $85^{a}$ | $83^{a}$ | 92 |
| 3 | $94^{ac}$ | $71^{ab}$ | $65^{b}$ | $100^{c}$ | $85^{abc}$ |
| 4 | $73^{ab}$ | $77^{ab}$ | $56^{b}$ | $87^{a}$ | $95^{a}$ |
| ***Hardness*** | | | | | |
| 2 | $94^{a}$ | $65^{b}$ | $58^{b}$ | $58^{b}$ | $65^{b}$ |
| 3 | $62^{a}$ | $69^{ab}$ | $93^{b}$ | 67 | $77^{ab}$ |
| 4 | $70^{ab}$ | $61^{a}$ | $93^{b}$ | $69^{ab}$ | 61 |
| ***Juiciness*** | | | | | |
| 2 | 68 | $89^{b}$ | $95^{b}$ | $94^{b}$ | $87^{ab}$ |
| 3 | $89^{a}$ | $75^{ab}$ | $53^{b}$ | 87 | $77^{a}$ |
| 4 | 76 | $81^{a}$ | $51^{b}$ | 87 | $96^{a}$ |
| ***Sweetness*** | | | | | |
| 2 | $59^{a}$ | $73^{a}$ | $64^{a}$ | $83^{a}$ | $74^{a}$ |
| 3 | $72^{ac}$ | $53^{ab}$ | $37^{b}$ | $82^{c}$ | $59^{a}$ |
| 4 | $60^{ac}$ | $40^{ab}$ | $33^{b}$ | $64^{c}$ | $90^{d}$ |
| Char taste | | | | | |
| 2 | 58 | $81^{b}$ | $77^{ab}$ | $88^{b}$ | $87^{b}$ |
| 3 | 79 | $70^{ab}$ | $48^{b}$ | $89^{a}$ | $70^{ab}$ |
| 4 | $62^{ab}$ | $59^{ab}$ | $45^{a}$ | $85^{b}$ | $82^{b}$ |
| Strange taste | | | | | |
| 2 | $27^{a}$ | 18 | 21 | 10 | $15^{a}$ |
| 3 | 25 | 33 | 28 | 11 | 16 |
| 4 | $57^{a}$ | $24^{b}$ | $51^{ab}$ | $22^{b}$ | $25^{b}$ |
| Char aroma | | | | | |
| 2 | 54 | 73 | 57 | 75 | 70 |
| 3 | 62 | 69 | 53 | 54 | 62 |
| 4 | 77 | 63 | 54 | 65 | 67 |
| Stran aroma | | | | | |
| 2 | 38 | 44 | 35 | 38 | 34 |
| 3 | $12^{a}$ | 8 | $9^{a}$ | 16 | 18 |
| 4 | 58 | 26 | $47^{a}$ | $31^{a}$ | 33 |

$^{a-b}$ Values in the same row with different superscripts are different (P<0 05)

**Table 13** Effect of packaging with HSP and OMP films, alone and in combination with a hot water treatment, on the sensory characteristics of Cantaloupe melon after storage

| *Storage Time (weeks)* | *Packaging film / treatment* | | | | | |
|---|---|---|---|---|---|---|
| | HSP[a] | | OMP[a] | | Control[a] | |
| | CW | HWT | CW | HWT | CW | HWT |
| ***Gen liking*** | | | | | | |
| *2* | 70 | 71 | 89 | 81 | 78 | 89 |
| *3* | 69 | 78 | 88 | 58 | 86 | 85 |
| | HSP[a] | | OMP[b] | | Control[b] | |
| | CW | HWT | CW | HWT | CW | HWT |
| ***Hardness*** | | | | | | |
| *2* | 77 | 72 | 50 | 59 | 57 | 56 |
| *3* | 59 | 82 | 74 | 50 | 64 | 62 |
| | HSP[a] | | OMP[ab] | | Control[b] | |
| | CW | HWT | CW | HWT | CW | HWT |
| ***Juiciness*** | | | | | | |
| 2 | 61 | 79 | 85 | 67 | 78 | 83 |
| *3** | 76 | 65 | 91 | 75 | 86 | 79 |
| | HSP[a] | | OMP[a] | | Control[b] | |
| | CW | HWT | CW | HWT | CW | HWT |
| ***Sweetness*** | | | | | | |
| 2 | 50 | 56 | 76 | 56 | 52 | 81 |
| 3* | 48 | 59 | 72 | 30 | 84 | 75 |
| | HSP[a] | | OMP[a] | | Control[b] | |
| Char taste | CW | HWT | CW | HWT | CW | HWT |
| 2 | 75 | 65 | 95 | 59 | 73 | 93 |
| 3* | 66 | 64 | 76 | 48 | 82 | 80 |

| Stra taste | HSP[a] | | OMP[a] | | Control[a] | |
|---|---|---|---|---|---|---|
| | CW | HWT | CW | HWT | CW | HWT |
| 2 | 41 | 39 | 24 | 38 | 23 | 22 |
| 3 | 29 | 55 | 40 | 48 | 30 | 35 |

| Cha aroma | HSP[a] | | OMP[a] | | Control[a] | |
|---|---|---|---|---|---|---|
| | CW | HWT | CW | HWT | CW | HWT |
| 2 | 64 | 53 | 69 | 67 | 53 | 58 |
| 3 | 51 | 62 | 62 | 57 | 49 | 51 |

| Stra aroma | HSP[a] | | OMP[a] | | Control[a] | |
|---|---|---|---|---|---|---|
| | CW | HWT | CW | HWT | CW | HWT |
| 2 | 39 | 48 | 50 | 41 | 48 | 58 |
| 3 | 53 | 38 | 33 | 43 | 37 | 46 |

[a b] Headings in the same row with different superscripts are different (P<0 05)
* The HWT was significant (P=0 01) at this storage time

**Table 14** Effect of storage time, hot water treatment and packaging film on the sensory characteristics of Cantaloupe melon after storage

| | Storage time | HWT | LDPE 0 04 | LDPE 0 12 | HSP | OMP | Mean of the Control |
|---|---|---|---|---|---|---|---|
| General liking | N S | N S | N D | N D | - - | N D | 91 |
| Hardness | N S | N S | N D | N D | N D | N D | 67 |
| Juiciness | - | - | N D | N D | - - - | N D | 87 |
| Sweetness | - - | - | N D | - - - | - - - | N D | 74 |
| Characteristic taste | - | - | N D | N D | N D | N D | 80 |
| Strange taste | + + + | N S | + + | N D | + + | N D | 19 |
| Characteristic aroma | N S | N S | N D | N D | N D | N D | 66 |
| Strange aroma | + + + | N S | N D | N D | N D | N D | 28 |

\- Significant, or significantly lower than the control (-) P<0 05, (- -) P<0 005, (- - -) P<0 001
\+ Significant, or significantly higher than the control (+) P<0 05, (+ +) P<0 005, (+ + +) P<0 001
N S Not significant (P>=0 05)
N D Not significantly different than the control (P>=0 05)

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*B Work carried out in Israel*

Testing perforated heat-shrinkable polyolefin films and carbon dioxide absorbers for packaging 'Tommy Atkins' mango

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**Abstract**
The objectives of this research were to test the effect of packaging in commercially manufactured perforated heat-shrinkable polyolefin films and of the carbon dioxide-absorbing additives on postharvest life of 'Tommy Atkins' mangoes The performances of two films having the same density of perforations (8 holes/sq inch) but different perforation diameter (0 4 mm for Cryovac SM60M and 1 6 mm for Cryovac MPY8) were compared with those of two non-perforated Cryovac polyolefins, MD and MY The fruit were sealed either within a polystyrene tray (one fruit per tray) or without a tray (individual seal-packaging) The non-perforated films caused certain reduction of $O_2$ concentration and enhanced the accumulation of $CO_2$ and ethanol vapor in the in-package atmosphere The atmosphere composition in perforated packages did not differ significantly of the ambient one After three weeks of storage at 14C and up to one week of shelf-life at 17C, the non-sealed control fruit were of inferior quality because of over-ripening, shriveling and decay development Both perforated and non-perforated films practically prevented the fruit shriveling Packaging mangoes in the non-perforated films or in the perforated SM60M or MPY8 films saved respectively 70-90, 40-55 and 25-33% of the weight loss Packaging in non-perforated films inhibited the development of yellow peel ground color and slowed down the reduction of titratable acidity With perforated films, the fruit reached yellow color inside the package No film removal was necessary for color development The addition of $Ca(OH)_2$ - containing pouches ($CO_2$ absorbers) to non-perforated packages allowed the fruit to attain the yellow peel color without a noticeable increase in weight loss However, hastened decay development in such packages canceled their positive effects on mango quality

**Introduction**
'Tommy Atkins' is one of the major mango cultivars grown in Israel Its postharvest life-span does not exceed 2-3 weeks and is limited by physiological deterioration of the fruit related to its over-ripening, and by pathogen development Additionally, desiccation of mango during the prolonged storage causes its shriveling and reduces the market value of the fruit Improving the keeping quality is necessary in order to reach the distant export markets by marine transportation with fruit of high quality

Packaging in plastic films is steadily becoming more important as a tool to prolong the storage life of perishable commodities due to modified-atmosphere and modified-humidity conditions created inside the packages (Ben-Yehoshua, 1985, Gorris and Peppelenbos, 1992) Although a number of experiments on modified or controlled atmosphere storage of mangoes have been conducted until now (for review, see Yahia, 1997), the results are not always consistent and depend much on cultivar tested

Previous attempts to seal 'Tommy Atkins' mangoes in non-perforated films were unsuccessful due to off-flavors and impaired ripening caused by the inappropriate atmosphere composition resulted from the fruit's respiration combined with too high barrier properties of packaging material (Miller et al , 1986, McCollum et al , 1992) In order to avoid these problems, the use of perforated films was proposed and successfully tested with 'Tommy Atkins' cultivar (Ben-Yehoshua et al , 1994, Ben-Yehoshua et al , 1996), as well as with other mango varieties such as the Thai cultivar Nam

Dork Mai (Yantarasri et al , 1995) The effect of perforation on oxygen and relative humidity levels in mango package was described by the mathematical model developed by Fishman et al (1996) In agreement with this model, the beneficial perforation range for the Tommy Atkins mango was estimated experimentally using the manually-perforated packages made of low-density polyethylene (Rodov et al , 1997)

Elevated carbon dioxide level might be one of the factors affecting the quality of mangoes sealed in non-perforated films Accordingly, insertion of $CO_2$-absorbing chemicals into the package may serve as a possible alternative or an aid to perforation in order to improve the quality of the sealed 'Tommy Atkins' mango Application of various chemical inserts (oxygen scavengers, carbon dioxide absorbers and producers, ethylene absorbers, hygroscopic materials etc ) termed in general as active packaging (Rooney, 1995) was demonstrated to be helpful in achievement of desirable in-package conditions with several commodities, such as tomatoes (Shirazi and Cameron, 1992, Furlani et al , 1993), asparagus spears (Furlani et al , 1993), bell peppers (Rodov et al , 1995), and fresh figs (Rodov et al , 1997a)

The objectives of the present research were to test the performance of commercially manufactured perforated films and of carbon dioxide-absorbing materials in packaging 'Tommy Atkins' mangoes

**Materials and Methods**

Mature-green mangoes of Tommy Atkins cultivar grown in Jordan valley (Israel) were obtained from the packing house at the day of harvest The fruit did not receive any packing-house treatment except washing

*Packaging and storage* Several kinds of heat-shrinkable polyolefin films (15-19 μ thick) supplied by Cryovac Grace Italiana Co (Milano, Italy) were tested for their suitability for packaging 'Tommy Atkins' mangoes The trials included nonperforated films MD and MY, and perforated polyolefins MPY8 (8 holes of 1 7 mm in diameter per sq inch), and SM60M (8 holes of 0 4 mm in diameter per sq inch) The fruit were sealed either within the polystyrene tray (one fruit per tray) or without a tray (individual seal-packaging), the films were heat-shrunk as described previously (Ben-Yehoshua, 1985) Control fruit were kept in standard mango packages - open cardboard boxes, one layer of 10 fruit per box

Calcium hydroxide $Ca(OH)_2$ was used in the trials checking the effects of $CO_2$ absorption The pouches of gas-permeable spun-bonded polyethylene (Tyvek, Du Pont Co, Geneva, Switzerland) with 10 g of $Ca(OH)_2$ were added to tray-packages containing one or two fruit The trays were sealed in non-perforated MD and/or MY polyolefin films
Packaged fruit were stored for 3 weeks at 14C and relative humidity (RH) of 85±3% The storage period was followed by a shelf-life imitation, when the packaged fruit was kept for up to 7 days at 17C and RH 85±3% At the end of the shelf-life period, the packages were opened and subjected to quality analysis

The trials were conducted in triplicate, at least 20 fruit per replication, and repeated three times during two successive harvesting seasons The data presented in this paper belong to one experimental series The repeated experiments brought similar results Within each trial, data were analyzed by analysis of variance, and means were separated by Duncan's multiple range test
*Analysis of in-package atmosphere* Septa of silicone rubber were stuck on the packages for gas sampling Samples of in-package atmosphere (5 ml) were withdrawn from the packages using gas-tight syringes With individually shrunk-sealed fruit, the sampling was complicated because of

extremely limited void space in the package In order to ensure sampling, some of the individual shrunk packages contained small pieces of foamed polystyrene (the dimensions ca 12 x 12 x 3 mm) between the fruit surface and the film, one piece per package The air samples were withdrawn from the void spaces formed around these pieces

Concentrations of oxygen, carbon dioxide, ethylene, as well as ethanol and acetaldehyde vapors in the sample were determined by gas chromatography (GC) using external standards for data quantification Oxygen and carbon dioxide concentrations were determined by Packard 7500 gas chromatograph (Packard, Downers Grove, Ill ) with thermal conductivity detector and CTR-I packed column using helium as the carrier gas Ethylene concentration was determined with a Varian 3300 gas chromatograph equipped with a flame ionization detector and a C-5000 packed column using nitrogen as the carrier gas, column, injector and detector temperatures were 80, 50 and 56C, respectively The concentrations of ethanol and acetaldehyde vapors were determined with a Varian 3300 gas chromatograph equipped with a flame ionization detector and a 20% Carbowax 20M packed column using nitrogen as the carrier gas, column, injector and detector temperatures were 80, 110 and 180C, respectively

*Quality analysis* Fruit firmness was determined by Chatillion penetrometer The percentage of total soluble solids in the fruit juice was measured refractometrically The titratable acidity was determined by titration of the juice with 0 1 N NaOH and expressed as citric acid concentration (%) The flesh color was evaluated on the cut surface at the depth of 2 mm from the peel using the CROMA METER CR-200 (Minolta, Japan) The same instrument was used for peel color evaluation Additionally, the peel color was assessed visually by grading the fruit in every sample according to the following scale 1 - green, 2 - light-green, 3 - greenish-yellow, 4 - yellow, 5 - yellow-orange The visual color index was calculated as a weighted average of scores gained by all the fruit of the sample Fruit taste was evaluated by 10 to 14 experienced panelists according to a 5- grade scale

**Results**

***Composition of in-package atmosphere***

Fig 1 represents the typical time courses of $O_2$ and $CO_2$ concentrations in the atmosphere of mango packages sealed with perforated or non-perforated films The non-perforated film caused certain reduction of $O_2$ concentration and $CO_2$ accumulation These changes were especially evident in the packages including polystyrene trays Ethylene concentration in the packages was low (0 02 to 0 06 ppm), without significant difference between films tested

Certain increase of ethanol and acetaldehyde levels was observed in non-perforated packages (10-15 and 33-39 ppm, accordingly, against 2-6 ppm in perforated packages and less than 1 ppm in ambient atmosphere) At the same time, the atmosphere composition in perforated packages did not differ significantly of the ambient one

Addition of $Ca(OH)_2$-containing pouches markedly reduced the in-package $CO_2$ concentration during the period of low-temperature storage Interestingly, this effect was accompanied by the enhancement of oxygen consumption by mangoes packaged in the presence of $Ca(OH)_2$, most likely due to nullifying the inhibitory effect of $CO_2$ on the fruit respiration On the other hand, the $CO_2$-absorbing capacity of $Ca(OH)_2$-containing pouches usually ceased after the transfer of the fruit to shelf-life (Fig 1) or even earlier, probably because of saturation or caking of the absorbent At this stage, the $CO_2$ level in such packages raised sharply, even exceeding that in the control

***Quality of Tommy Atkins mangoes sealed in heat-shrinkable polyolefin films***

*Weight loss* Packaging in non-perforated films MD and MY reduced the fruit weight loss by about 70-90%, as compared to that of the non-sealed mangoes (Fig 2) The perforated films SM60M

and MPY saved 40-55 and 25-33% of the weight loss, respectively Within the same film type, the individual shrunk sealing had a trend to a slightly lower weight loss as compared to the tray-packaging, although this difference usually was not statistically significant Both perforated and non-perforated films practically prevented the fruit shriveling which developed in non-sealed mangoes during storage and shelf life imitation (Fig 3)

*Decay* The fungal decay of Tommy Atkins mango was represented in our experiments mainly by the black rot caused by *Alternaria alternata*, and by the stem-end rots By the end of the experiment, almost 50% of the non-sealed fruit were infected by the decay agents Sealing Tommy Atkins mangoes in non-perforated MD film consistently resulted in the lowest decay level, as compared to the non-sealed fruit or to the fruit sealed in other films tested Sealing in perforated films also provided certain decay reduction as compared to the non-sealed control (Fig 2) However, this measure was not efficient enough so that by the end of the shelf-life imitation period (one week at 17C after 3 weeks of storage at 14C) the decay incidence in perforated packages reached 20-30%

*Peel and flesh color* The non-sealed mangoes changed their peel ground color during storage from green to yellow, and the flesh color from pale yellow to yellow-orange Sealing in non-perforated films inhibited these color changes The strongest inhibition was observed in the fruit individually shrunk-sealed in MD polyolefin, as documented both by visual observations (Fig 4) and instrumental measurements (Fig 5) The negative values of a/b ratio of these mangoes indicate that by the end of the shelf-life period their peel still stayed green Certain yellowing was observed in these fruit during several additional days at 17C after the removal of the non-perforated packages However, the fruit usually deteriorated within this period and never attained the fully developed ground color

In contrast to the ground color, neither intensity nor area of the red blush on 'Tommy Atkins' mangoes were significantly affected by sealing (data not shown)
With fruit sealed in perforated films within the polystyrene tray, none of the color parameters, - peel ground color, peel blush color, flesh color - differed significantly of the non-sealed control The fruit reached its full color inside the packages and did not need film removal for color development

*Firmness* The non-sealed fruit underwent noticeable softening during storage and shelf-life periods so that its firmness decreased from 70 to 9-13 N The fruit packaged in Cryovac films, either perforated or non-perforated, softened by the end of the experiment similar to the non-sealed control, except for the mangoes individually sealed in MD polyolefin which retained firmness of 20 to 26 N

*Soluble solids, titratable acidity and taste* No significant difference between the treatments was found in the level of total soluble solids (TSS) (Fig 6) At the same time, the titratable acidity in fruit packaged in non-perforated film was markedly higher than in the control or in the perforated package (Fig 6) Consequently, the fruit packaged in perforated film got the highest score of the taste panel (4 to 4 5 in 5-grade scale) while the non-sealed fruit got 3 8 score and the fruit sealed in non-perforated film 3 7 to 4 0 The panelists marked certain overripening of the control fruit and sourness in fruit kept in non-perforated film Additionally, some off-flavor was reported in mangoes packaged with non-perforated film

***Effect of $CO_2$ absorption on ripening and storage life of 'Tommy Atkins' mango***
Fig 7 represents the quality of mangoes sealed in non-perforated MD and MY films within the polysyrene trays (one fruit per tray) with or without $CO_2$ absorbers, as compared to the non-sealed fruit

Insertion of $Ca(OH)_2$-containing pouches did not enhance the fruit weight loss which stayed as low as in the non-perforated sealed packages without any additive At the same time, the $CO_2$ absorber tended to reduce the inhibitory effect of non-perforated package on the peel color development This color improvement depended on the kind of film used, being stronger with mangoes packaged in MY film rather than in the MD one (Fig 7) Indeed, the addition of $CO_2$ absorber to the non-perforated MY packages allowed the fruit peel to attain the yellow ground color without a noticeable increase in weight loss However, the decay incidence in such packages increased in parallel with color stimulation and eventually canceled their positive effects

**Discussion**

General benefits of packaging fruit in plastic films, i e reduced weight loss and prevented shriveling, are well documented for various commodities including mango (Miller et al , 1983, Shapiro et al , 1990, Sornsrivichai et al , 1989, Gonzales et al , 1990) The main challenge of applying this technique to climacteric fruit, such as mango, is to combine the named advantages with desirable ripening rate in order to reach good quality of the fruit at marketing stage As far as retail packages are regarded, the fruit should attain optimal quality without film removal

*Effects of non-perforated films* In our previous experiments, sealing Tommy Atkins mangoes in non-perforated low-density polyethylene (LDPE, 40 μ thick) completely and irreversibly arrested their ripening and was aggravated by dark discoloration and extremely strong alcoholic off-flavor (Rodov et al , 1997) In contrast to these results, the non-perforated heat-shrinkable polyolefins MD and MY tested in this work did not cause peel discoloration and allowed some ripening-related processes, such as the fruit softening and soluble solids increase This difference could be explained by better gas exchange through the polyolefin packages due to lower thickness and different permeability characteristics of the films, as well as spontaneous perforations formed in the package during heat-shrinkage (Ben-Yehoshua et al 1994)

However, non-perforated polyolefins still inhibited the onset of important ripening traits, first of all the evolution of peel ground color from green to yellow-orange and the decline of juice acidity Fruit kept in nonperforated individual packages never reached the full color and got inferior taste scores because of the sourness and in certain cases due to presence of off-flavor, in agreement with early reports of Miller et al (1983 and 1986) These negative phenomena diminished the advantages of non-perforated seal-packaging for the Tommy Atkins mango

At the same time, some other mango cultivars still may benefit from packaging in non-perforated polyolefins For example, sealing typically green-colored Keitt mango in the MD film was not accompanied by the off-flavor, so that after prolonged storage the panelists consistently preferred the sealed fruit to the non-sealed one because of prevented overripening (Rodov et al , 1994, Yantarasri et al , 1995) Earlier, seal-packaging in non-perforated films was found to be beneficial for extending postharvest life of Thai mango variety Keaw Sawoey traditionally consumed in unripe state (Sornsrivichai et al , 1989) Tommy Atkins seems to be a mango cultivar relatively sensitive to altered atmosphere composition Indeed, optimal $CO_2$ concentration for controlled-atmosphere (CA) storage of Tommy Atkins mangoes was found to be twice as low as that for the Kent variety (Lizana and Ochagavia, 1997)

It should be noted that changes in the composition of in-package atmosphere as small as those observed in this work ($CO_2$ accumulation not higher than 2-3%) were enough to effect the ripening pattern of Tommy Atkins mango Using thicker films such as above-mentioned LDPE (40 μ) or increasing number of fruit per non-perforated package (Rodov and Ben-Yehoshua, non-published data) brought about stronger atmosphere changes and, accordingly, stronger negative effects on the fruit quality

The enhancement of peel color by $CO_2$ absorbent confirmed the inhibitory effect of $CO_2$ on color development demonstrated earlier in CA experiments (Bender et al , 1994) At the same time, there is no enough data to conclude if $CO_2$ accumulation was the only factor effecting mango ripening in plastic packages, and what was the influence of other atmosphere components on this process For example, Jordan and Smith (1993) showed that softening of Alfonso mangoes in controlled atmosphere was effected by oxygen concentration rather than by $CO_2$ Recently Burdon et al (1996) have proposed that acetaldehyde can retard mango ripening by inhibiting the ethylene biosynthesis through supression of ACC oxydase In our work, the inhibited ripening in non-perforated packages was indeed accompanied by cetain increase in acetaldehyde and ethanol accumulation, although no significant effect on in-package ethylene levels was detected Measurement of internal gas concentrations in mesocarp tissue and determination of ethylene production rates, as well as the activity of the relevant enzymes, might be helpful for interpretation of physiological basis of the phenomena observed

*Effects of perforated films* In accordance with mathematical model's prediction (Fishman et al , 1996), the in-package $CO_2$ and $O_2$ levels were effected by perforation to much greater extent than the air humidity inside the package Because of relatively high perforation of both SM60M and MPY8 films, the concentrations of $O_2$ and $CO_2$ inside the perforated packages did not differ significantly of the ambient ones

Using perforated polyolefins prevented the disorders caused by the improper atmosphere inside non-perforated packages, such as impaired ground color development and off-flavors The fruit reached the yellow color inside perforated packages and did not need film removal for color development At the same time, these films alleviated fruit desiccation and to a certain extent delayed their overripening and reduced decay, altogether allowing to maintain the fruit in marketable condition for additional two or three days of shelf-life Of the two kinds of perforated Cryovac films tested, SM60M was preferred over MPY8 since it was more effective in weight loss reduction Since no significant $CO_2$ and $O_2$ modifications were caused by these films, the delayed overripening and reduced decay of mangoes kept in perforated packages might be attributed to alleviated water stress In fact, water loss was shown to hasten ripening and senescence in various fruits, including such typical climacteric commodities, as banana (Burdon et al, 1994) and avocado (Akkaravessapong et al , 1996)

On the other hand, the potential of the highly-perforated polyolefins to prolong the storage of mangoes was limited as compared to less-perforated films Sealing Keitt mangoes within 4-kg cartons lined with microperforated plastic films significantly slowed down their ripening (Pesis et al , 1997) Perforated polyethylene packages (16 fruit/package) were successfully tested by Sornsrivichai and Yantarasri (1997) in trial shipment of Nam Dork Mai mangoes from Thailand to Japan, extending the postharvest life by about one week In both works cited, early removal of the film and keeping the fruit for one to two weeks at retail marketing conditions were needed in order to reach a desirable fruit quality, leaving the fruit unprotected at the final and the most vulnerable stage of their postharvest life Combination of highly perforated retail packages like those tested in our experiments, with less perforated bulk packages which can be removed after low-temperature shipment ("package-in-package" principle), may be promising for maintaining the fruit quality during the whole postharvest chain Alternatively, the fruit may be repackaged in highly perforated "retail" films prior to marketing period, after the removal of less perforated "transportation" wraps

In situation when physiological deterioration of the fruit is alleviated by a plastic package, pathogen development turns to be a major factor limiting the storage life It was concluded that seal-packaging by itself is not enough to control mango decay and should be combined with additional means to prevent disease development Hot water dip was tested as such means in our

previous experiments (Rodov et al , 1997) The successful use of perforated packaging with Nam Dork Mai mango in Thailand was allowed by its combination with hot benomyl (Sornsrivichai et al , 1992) and vapor heat (Sornsrivichai and Yantarasri, 1997) treatments Recent development of "hot water brush" method (Prusky et al , 1997) may provide a promising approach for the decay control in seal-packaged mangoes

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**Legend For Figures**

Fig 1 Effect of film type, polystyrene tray and carbon dioxide absorber on time-courses of oxygen (above) and carbon dioxide (below) concentrations in packages containing one 'Tommy Atkins' mango sealed in perforated SM60M or MPY8 or in non-perforated MD polyolefins

Fig 2 Effect of package type on the weight loss (above) and the decay incidence (below) of 'Tommy Atkins' mangoes stored for 3 weeks at 14C and 1 week at 17C
NS - non-sealed control, MD and MY - non-perforated films (with or without polystyrene tray), SM60M and MPY - perforated films (with or without polystyrene tray) Bars signed with the same letter are not significantly different (p=0 05) by the Duncan's multiple range test

Fig 3 Appearence of 'Tommy Atkins' mangoes after 3 weeks of simulated shipment at 14C and 1 week of simulated retail marketing at 17C
Package types, from left to right non-sealed control, non-perforated MD film (without tray), nonperforated MD film (with tray), perforated SM60M film (with tray), perforated MPY8 film (with tray)

Fig 4 Effect of package type on the ground peel color (assessed as visual index) of 'Tommy Atkins' mangoes stored for 3 weeks at 14C and 1 week at 17C
Visual index scale 1 - green, 2 - light-green, 3 - greenish-yellow, 4 - yellow, 5 - yellow-orange
NS - non-sealed control, MD and MY - non-perforated films (with or without polystyrene tray), SM60M and MPY - perforated films (with or without polystyrene tray) Bars signed with the same letter are not significantly different (p=0 05) by the Duncan's multiple range test

Fig 5 Effect of plastic film on the ground peel color of 'Tommy Atkins' mangoes stored without polystyrene tray for 3 weeks at 14C and 1 week at 17C
The color expressed as ratio of a and b parameters measured by Minolta CROMA METER CR-200 instrument NS - non-sealed control, MD and MY - non-perforated films, SM60M and MPY - perforated films, INIT - initial fruit color before storage Bars signed with the same letter are not significantly different (p=0 05) by the Duncan's multiple range test

Fig 6 Effect of package type on the percentage of total soluble solids (above) and titratable acidity (below) of 'Tommy Atkins' mangoes stored for 3 weeks at 14C and 1 week at 17C The titratable acidity is expressed as concentration of citric acid (%)
NS - non-sealed control, MD and MY - non-perforated films (with or without polystyrene tray), SM60M and MPY - perforated films (with or without polystyrene tray) Bars signed with the same letter are not significantly different (p=0 05) by the Duncan's multiple range test

Fig 7 Effect of $CO_2$ absorbers on the quality of 'Tommy Atkins' mangoes sealed within polystyrene trays in non-perforated MD (above) and MY (below) polyolefins, after 3 weeks of storage at 14C and one additional week at 17C Within each quality parameter, bars signed with the same letter are not significantly different (p=0 05) by the Duncan's multiple range test

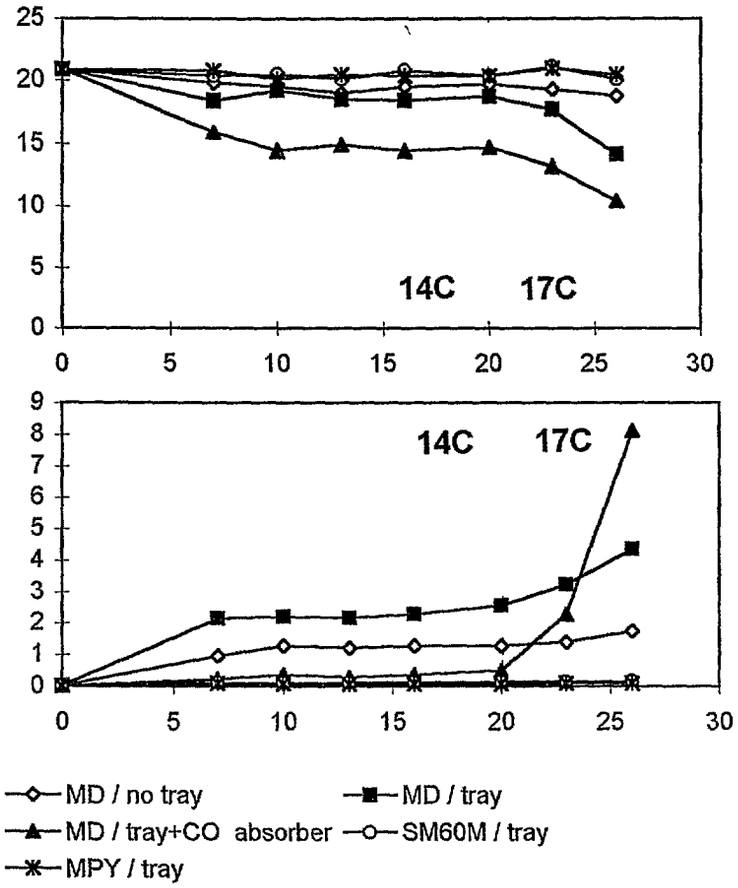

25
20
15
10
5
0
0
5
10
15
20
25
30
14C
17C
9
8
7
6
5
4
3
2
1
0
0
5
10
15
20
25
30
14C
17C
MD / no tray
MD / tray
MD / tray+CO absorber
SM60M / tray
MPY / tray

Fig 1

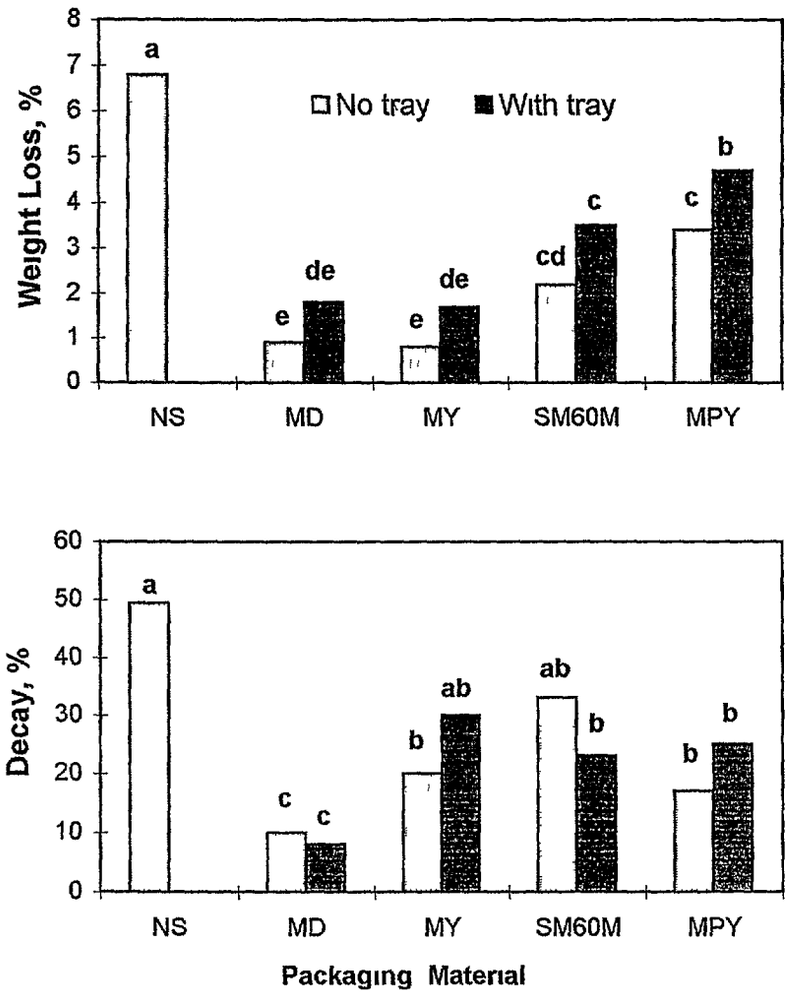
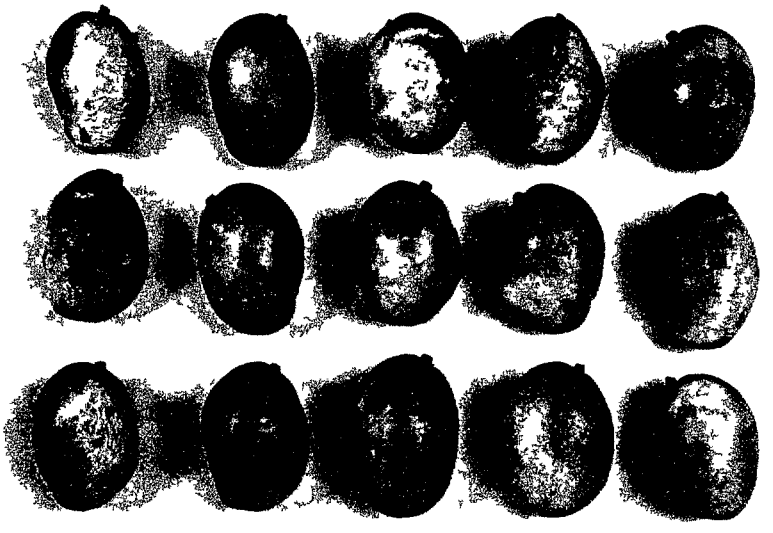

Weight Loss, %
No tray
With tray
a
e
de
e
de
cd
c
c
b
NS
MD
MY
SM60M
MPY
Decay, %
a
c
c
b
ab
ab
b
b
b
NS
MD
MY
SM60M
MPY
Packaging Material

Fig. 2

EFFECT OF SEALING IN CRYOVAC
POLYOLEFIN FILMS ON MANGO APPEARENCE



TRAY SEALING

| CONTROL NON SEALED | SHRINK SEALING | WITHOUT PERFORATION | PERFORATION 0 4 mm diam | PERFORATION 1 7 mm diam |
|---|---|---|---|---|

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F 3 3

61

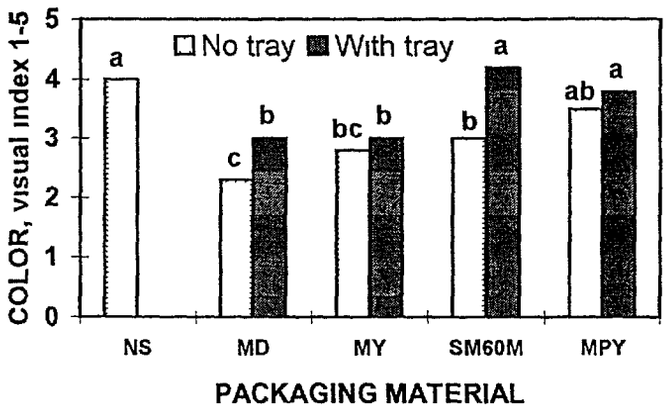
COLOR, visual index 1-5
5
4
3
2
1
0
No tray
With tray
a
c
b
bc
b
b
a
ab
a
NS
MD
MY
SM60M
MPY
PACKAGING MATERIAL

Fig 4

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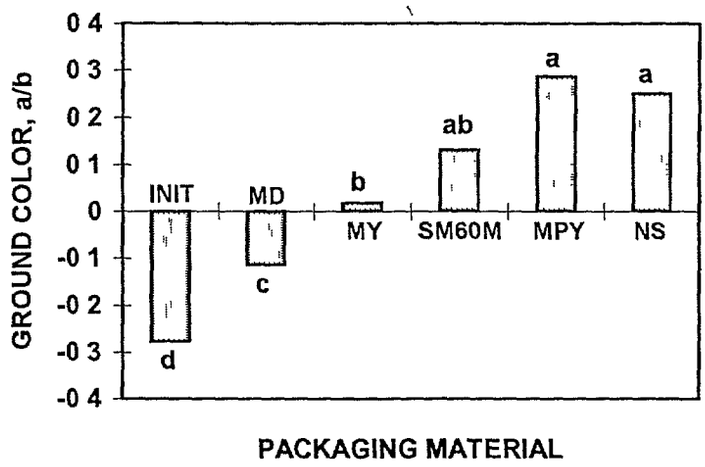

GROUND COLOR, a/b
0 4
0 3
0 2
0 1
0
-0 1
-0 2
-0 3
-0 4
INIT
MD
MY
SM60M
MPY
NS
a
ab
b
c
d
a
PACKAGING MATERIAL

Fig 5

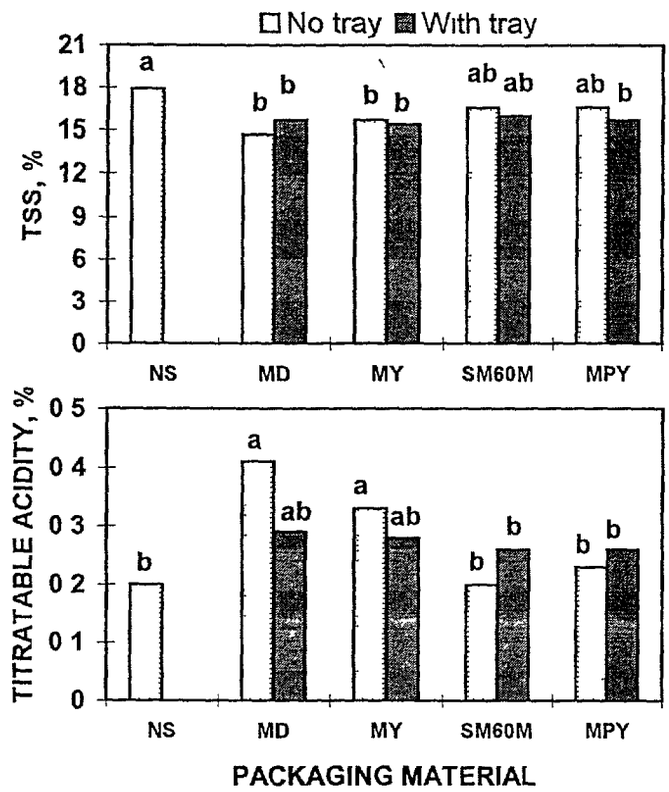
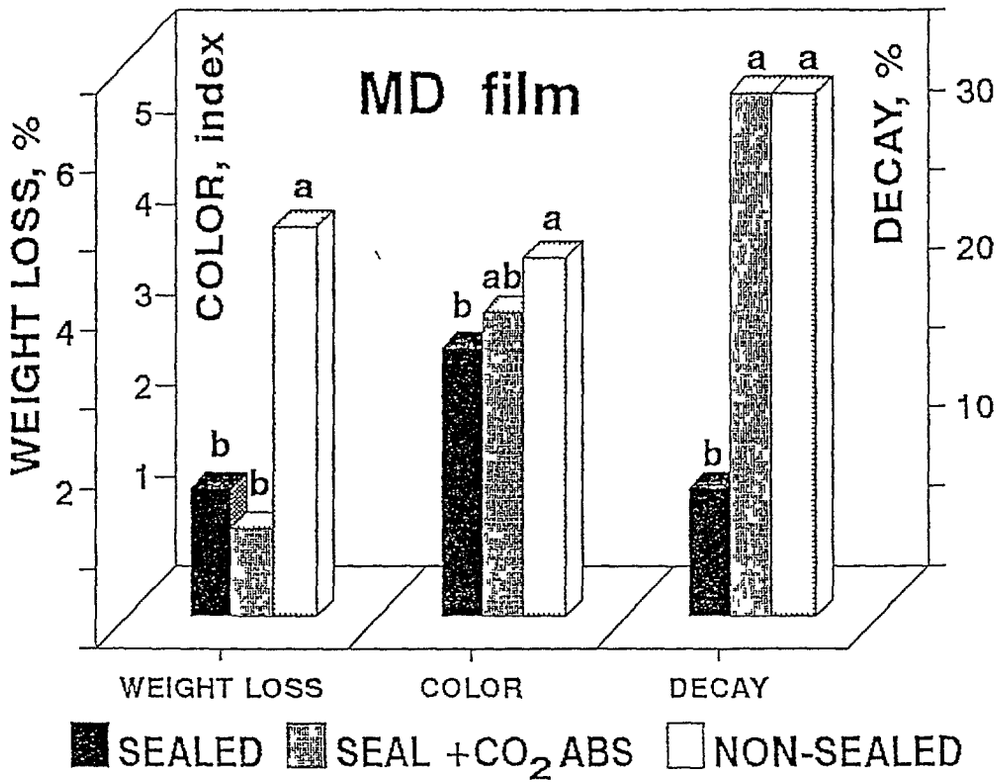

No tray
With tray
TSS, %
21
18
15
12
9
6
3
0
a
b b
b b
ab ab
ab b
NS
MD
MY
SM60M
MPY
TITRATABLE ACIDITY, %
0 5
0 4
0 3
0 2
0 1
0
b
a
ab
a
ab
b
b
b
b
NS
MD
MY
SM60M
MPY
PACKAGING MATERIAL

Fig 6


MD film
WEIGHT LOSS, %
COLOR, index
DECAY, %
WEIGHT LOSS
COLOR
DECAY
SEALED
SEAL +CO2 ABS
NON-SEALED

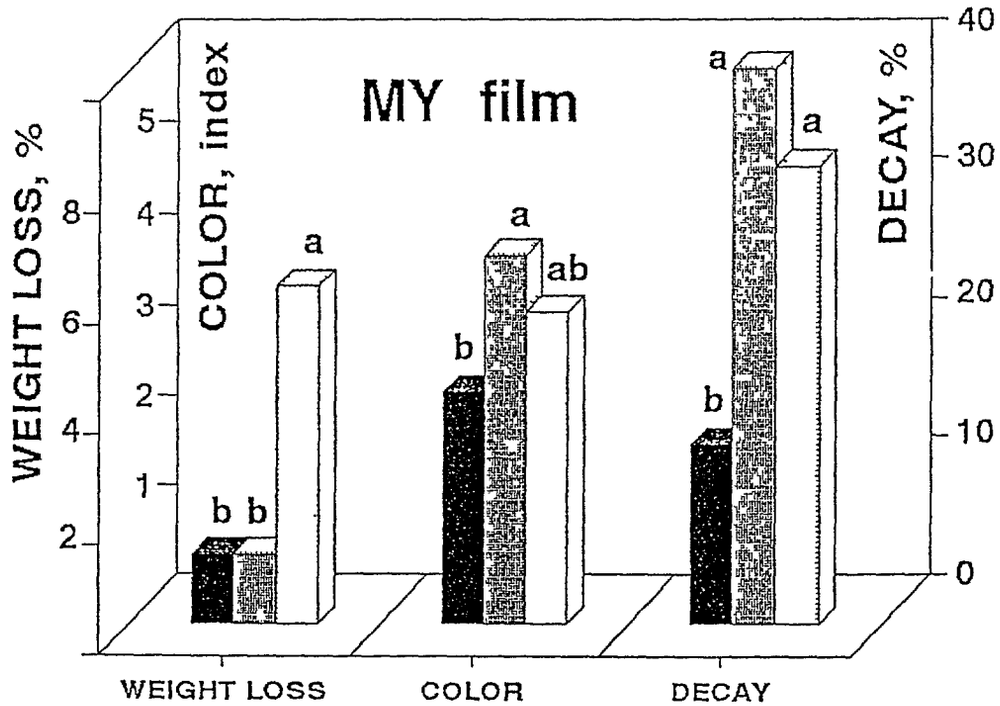

MY film
WEIGHT LOSS, %
COLOR, index
DECAY, %
WEIGHT LOSS
COLOR
DECAY

Fig 7

# PERFORATION EFFECTS IN MODIFIED-ATMOSPHERE PACKAGING: MODEL AND APPLICATIONS TO BELL PEPPER AND MANGO FRUITS

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**Abstract**· The technique of modified-atmosphere (MA) packaging is steadily becoming more important as an additional tool to prolong the storage life of perishable commodities Optimisation of several parameters of the MA system for mango and bell pepper was promoted by perforating the packaging film. This perforation greatly affected $O_2$ and $CO_2$ concentrations and water condensation but much less the in-package relative humidity Consequently regulation of the extent of perforation could be used to control atmosphere composition and water condensation in the package without a significant increase in fruit's weight loss

Bell peppers packaged in perforated film lost less weight during storage and maintained higher quality than fruit stored in open carton boxes, and at the same time demonstrated lower decay level than fruit sealed in non-perforated packages Perforation as well as the introduction of hygroscopic materials, such as NaCl, effectively reduced the percentage of Botrytis decay in bell pepper fruit. Perforating the film cancelled inhibition of the ripening process that prevailed in mango in non-perforated packages Perforated packaging of mango and pepper retained most of the advantages of the non-perforated packages

A dynamic model of gas and water vapour exchange in perforated and non-perforated packages containing fresh fruit or vegetables was developed on the basis of Michaelis-Menten equation in combination with Fick's diffusion law Use of computer simulations enables evaluation of package specifications which would provide optimal conditions for storage of a given commodity Model predictions were confirmed by measured observations

Key words dynamic model, modified-atmosphere packaging, respiration, perforation, in-package humidity, mango, bell-pepper

## Introduction

The keeping quality of fruits and vegetables is affected by temperature, and by concentrations of oxygen, carbon dioxide and water vapour in the surrounding atmosphere (Kader *et al*, 1989) The technique of modified-atmosphere (MA) packaging is steadily becoming more important as an additional tool to prolong the storage life of perishable commodities (Ben-Yehoshua *et al*, 1985, Gorris and Peppelenbos, 1992) The search for the optimal set of parameters for an MA system may be promoted by a theoretical analysis which can predict the temporal changes in the package atmosphere in terms of package characteristics and temperature. Several models of MA packaging (MAP) systems have been discussed in the literature (Jurin and Karel, 1963, Hayakawa *et al*, 1975, Cameron *et al*, 1989, Mannapperuma *et al*, 1989, Emond *et al*, 1991) In most cases the authors restricted themselves to a choice of empirical equations fitting the observed changes in gas concentration. Models of this type are not based on a consideration of biophysical mechanisms for the processes occurring in MA packages, and utilised different equations in different studies, making the comparison and application of their results difficult.

Gas diffusion and fruit respiration are

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the two main processes which affect the in-package atmosphere Fick's diffusion law was found to govern gas exchange in apples and several other fruits (Burg and Burg, 1965) The respiration of fruits and vegetables was treated in terms of enzyme kinetics by Tucker and Laties (1985) Recently, several attempts were made to apply the principles of enzyme kinetics to MA package modeling (Lee *et al*, 1991, Cameron *et al*, 1994, Fishman *et al*, 1995, 1996)

Experiments undertaken with bell pepper and mango fruits showed problems with the non-perforated MAP Previous data showed that MAP of bell pepper in non-perforated plastic film may promote decay when water droplets condensate inside the package (Rodov *et al*, 1994) and that seal-packaging inhibited mango ripening (Shapiro *et al*, 1989) In both cases perforation appeared to present a possible solution to these difficulties Consequently, the aim of our team was to evaluate the effects of perforation in modified atmosphere packaging and to perform a theoretical analysis of the gas exchange dynamics introducing a new model which also considers the water vapour in a perforated and non-perforated MA package (Fishman *et al*, 1995, 1996) This allowed us to predict the time course of water vapour, oxygen and carbon dioxide concentrations in MAP in order to perform optimisation of the MA in accordance with the commodity requirements The absence of the climacteric rise in the respiratory processes of bell pepper simplified the system for establishing the suitable model described in the section. Gas Dynamics in Non-Perforated Packages (Fishman *et al*, 1995) The mango served as a good example of the effects of package perforations discussed in the section. Perforation Effects on Dynamics of $O_2$ and $H_2O$ Concentrations (Fishman *et al*, 1996) This work established the potential of perforated plastic packaging in extending the life and reducing spoilage of mango fruit presented in the section. Experimental Trials Perforation Effects on Various Parameters of Modified Atmosphere Packaging of Mangoes The beneficial effects of perforation on water condensation and decay were briefly described in the section. Perforation Effects on Water Condensation and Decay (Rodov *et al*, 1995) In the first two sections, only the highlights are given since the material has already been published (Fishman *et al*, 1995, 1996), but in the last two sections, much of the data is presented in this work.

**MAP modeling**

*Gas Dynamics in a Non-Perforated Package*

A model for calculation of $O_2$ and $CO_2$ concentrations in a non-perforated package based on a combination of Fick's law with Michaelis-Menten equation as applied to bell pepper was presented in our previous communication (Fishman *et al*, 1995) Although packaging in plastic film extends the storage life of bell pepper primarily by alleviation of water stress (Ben-Yehoshua *et al*, 1983), combining the optimal relative humidity with desirable concentrations of $O_2$ and $CO_2$ brings additional benefits to bell pepper storage (Polderdijk *et al*, 1993, Rodov *et al*, 1994) The model developed by Fishman *et al* (1995) was utilised to optimise various package parameters to achieve the desired MAP conditions Results were validated by comparison of its predictions with observations performed on the pepper fruit placed in the chamber closed with the low density poly-ethylene (LDPE) film. Figure 1 demonstrates the results of the dynamic simulation (curves) as compared with the experimental results (points) for the time course of $O_2$ and $CO_2$ concentrations The predicted gas dynamics is in good agreement with the observed time course during the long-term experiments The steady-state concentrations of $O_2$ and $CO_2$ predicted for this system are 3 0 and 4 2%, respectively

<u>$CO_2$ maximum during the transient phase</u>

An additional important observation was made first by theoretical analysis and later validated with experimental observations (Fishman *et al*, 1995) According to the prediction of the model, the $CO_2$ time course for most plastic films does not reach steady state smoothly but rather rises to a maximum and then declines to an equilibrium level, a sort of overshooting effect. This phenomenon was confirmed experimentally The predicted

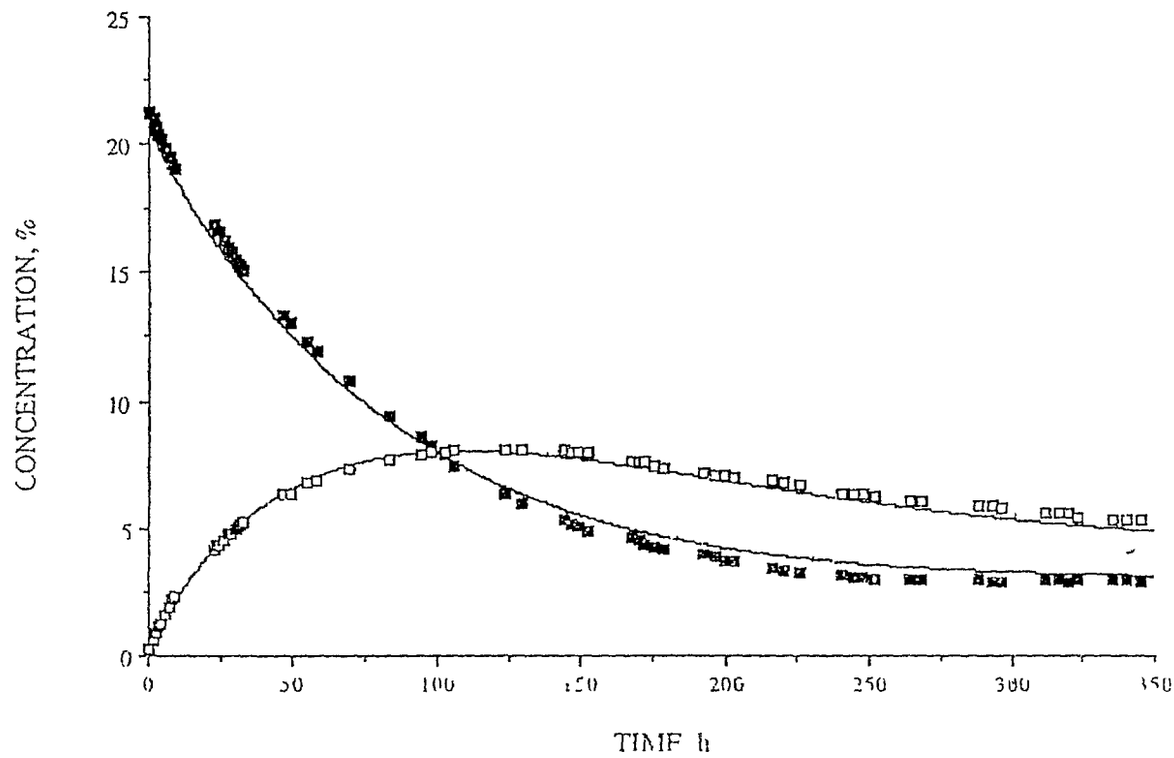


Figure 1 The curves represent time course of $O_2$ and $CO_2$ concentrations predicted by the model for bell peppers The points represent the experimental data carried out at 20°C.

maximum on the $CO_2$ concentration curve fits the recorded one and is about 8%, which markedly exceeds the steady-state value (4 2 %) over a rather long time period. The maximum on the curve for $CO_2$ kinetics has often been seen (Jurin and Karel, 1963, Hayakawa *et al*, 1975), but is not as yet considered an intrinsic characteristic of the system dependent on its parameters Consequently, estimation of the optimal $CO_2$ content for MAP should be aware of this fact because the $CO_2$ maximum may erroneously be considered to be the steady state The study of the transient period, as performed in this work, is important because the produce may spend a prolonged part of the storage period under transient conditions and during part of the transient period, the concentration of $CO_2$ in the system may be markedly greater than the evaluated steady-state value This conclusion must be taken into account when optimal conditions for MA packaging of fruits and vegetables are under investigation. Most previous works on MA packaging concentrated on the analysis of the in-package atmosphere under conditions of steady state The study of the transient period and the model will enable prediction of the $O_2$ and $CO_2$ levels over time, as well as estimating the time necessary to approach the steady state

Model Predictions

After being validated, the model can be utilised to study other designs of the MA packages by means of computer simulation instead of conducting time consuming and expensive experiments The model allows for changing the design parameters of the package (such as free volume, film thickness, area of the film, etc) and to compute how these changes will affect the gas dynamics and steady-state gas levels

As a first example, thickness of LDPE film ($\Delta X$) was varied. The model was run for $\Delta X = 2x10^{-5}$, $4x10^{-5}$, $6x10^{-5}$ and $8x10^{-5}$ m. Figure 2a shows the model prediction for the dynamics of $O_2$ concentration with these four values of $\Delta X$ The equilibrium values of $O_2$ are reached at about 300 hours for all four films Figure 2b shows the prediction for the time course of $CO_2$ The time needed to



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approach the steady-state is markedly longer and depends on the film thickness: the thicker the film, the longer the transient period and the higher the overshooting.

Henceforth, effects of the free volume of the package parameter, - V, were studied. Figure 3 represents the results of the model which runs with V=0.00124, 0.001, 0.00075 and 0.0005 $m^3$. The time course of $O_2$ and $CO_2$ concentrations is shown in Figures 3a and 3b, respectively. One may see that the variation of

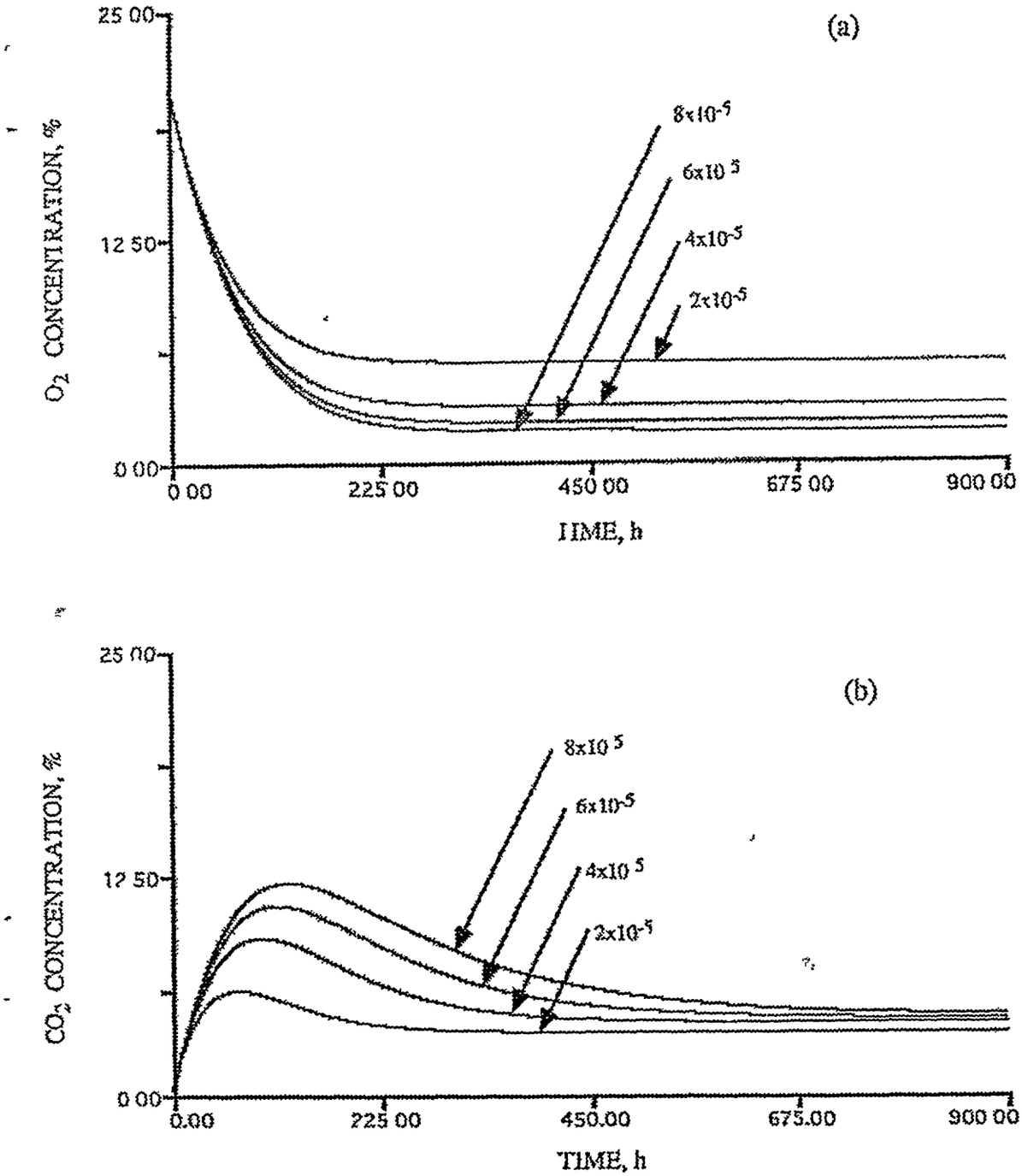


Figure 2. The model predictions for the films of different thicknesses, DX= ($2x10^{-5}$, $4x10^{-5}$, $6x10^{-5}$ and $8x10^{-5}$) m. (a) - time course of $O_2$ concentration, (b) - time course of $CO_2$ concentration. Predictions are for 20°C storage of bell peppers.

V changes the time scale but affects neither the steady-state level of concentrations nor the extent of the overshooting in the $CO_2$ dynamics Diminishing V "deforms" the curves along the time axis shortening the interval needed to approach the steady-state or the $CO_2$ maximum. Running the model simulations with different sets of parameters makes it possible to find the film specifications and the package dimensions to provide the recommended conditions for storage of a given commodity Considerable saving of experiments and time could be achieved by employing the model We have not yet dealt with the interrelation between temperature and MAP Cameron *et al* (1994) investigated profoundly the effect of temperature on MAP of several fruits

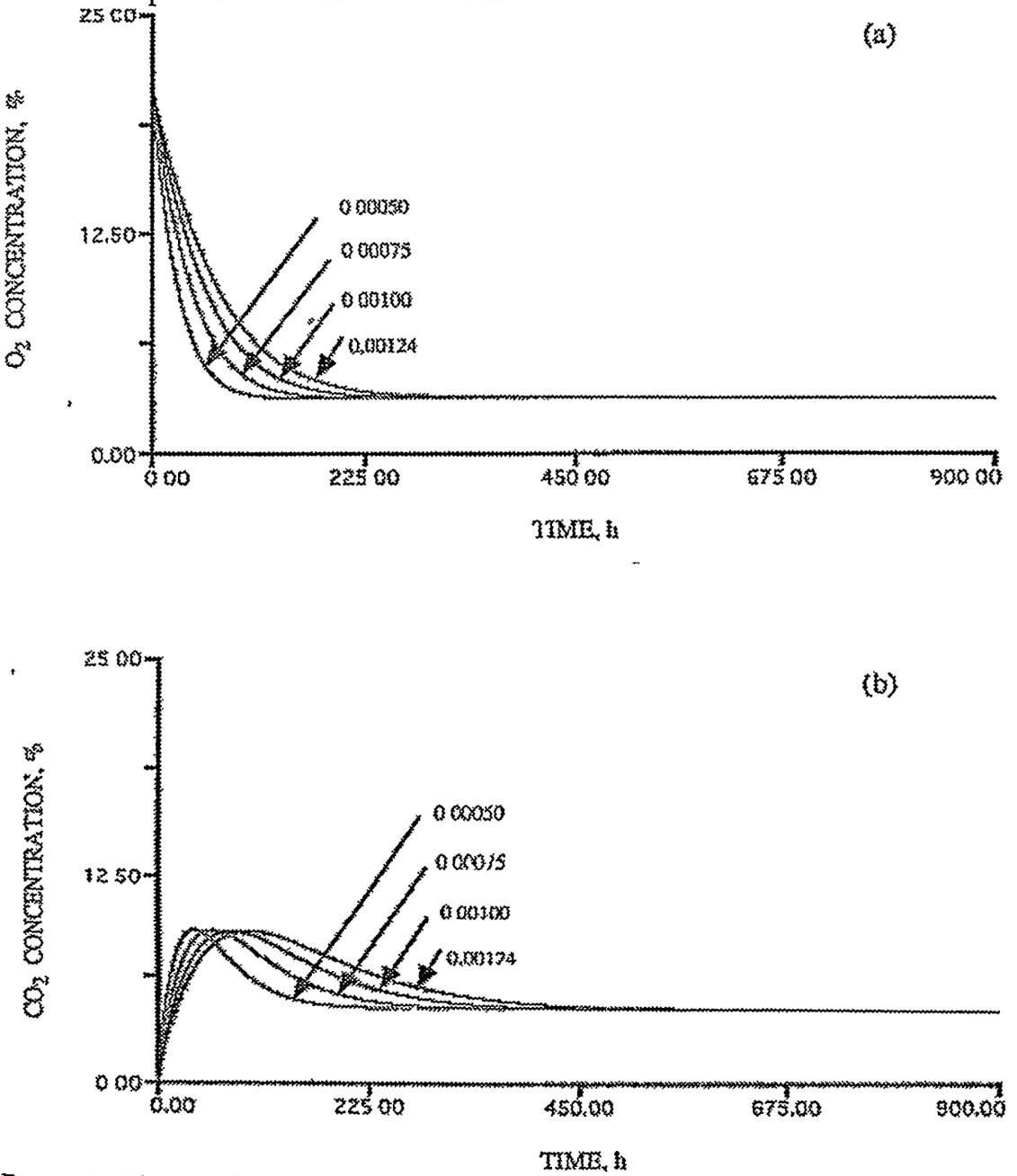


Figure 3 The model predictions for the packages of different free volumes, V= (0 00124, 0 001, 0 00075 and 0 0005) $m^3$ (a) - time course of $O_2$ concentration, (b) - time course of $CO_2$ concentration. Predictions are for bell peppers at 20°C



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*Perforation Effects on Dynamics of $O_2$ and $H_2O$ Concentrations*

As stated previously, a specific problem appeared with mangoes (Shapiro *et al*, 1989), when the altered in-package atmosphere was shown to impair ripening The use of perforated films was recommended for mango fruit and was successfully tested under certain experimental conditions (Shapiro *et al*, 1989, Rodov *et al*, 1994, Yantarasri *et al*, 1994, 1995a and b) Optimal conditions for mango packaging could be found with the aid of a model which included consideration of the film perforation. Accordingly, such a model was developed to help calculate $O_2$ concentration and RH in a perforated-film MA package aiming at the optimisation of MAP conditions for mango fruit (Fishman *et al*, 1996)

Respiration and transpiration of mangoes were studied in independent experiments to estimate the parameters included in the model The results of theoretical predictions were validated by comparison with experiments on MA packages of mango Due to space limitations, only a few highlights regarding the data can be presented here

Figure 4 shows the dramatic effects of perforation on the in-package oxygen concentration. Four holes of 2 mm diameter changed the steady state concentration of $O_2$ from 1% (0 1 non-dimensional) for the non-perforated to 19% (0 19) for the perforated film

Completely different results were found for relative humidity (RH) The time variation of RH during the same period, shown in Figure 5, demonstrated good correspondence between predicted and observed steady-state RH levels and showed practically no difference between the atmospheres inside perforated and non-perforated packages, which were both water saturated. The visible lag in the experimental approach to the steady-state RH (Fig 5), as compared with the model prediction, was related to the time necessary to reach equilibrium between the in-package atmosphere and the near-sensor environment.

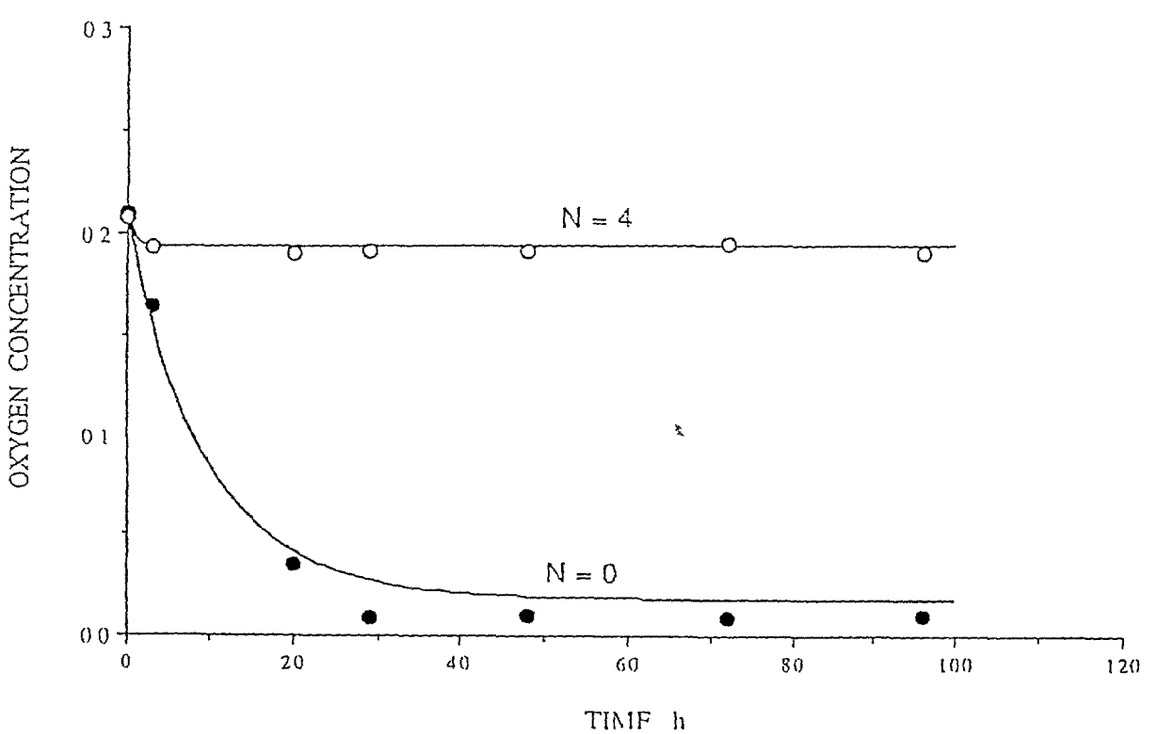


Figure 4 Effect of perforation on time course of oxygen concentration in a plastic package containing two mangoes at 20°C. N - number of pores (2 mm in diameter) Circles represent observations, curves - predictions

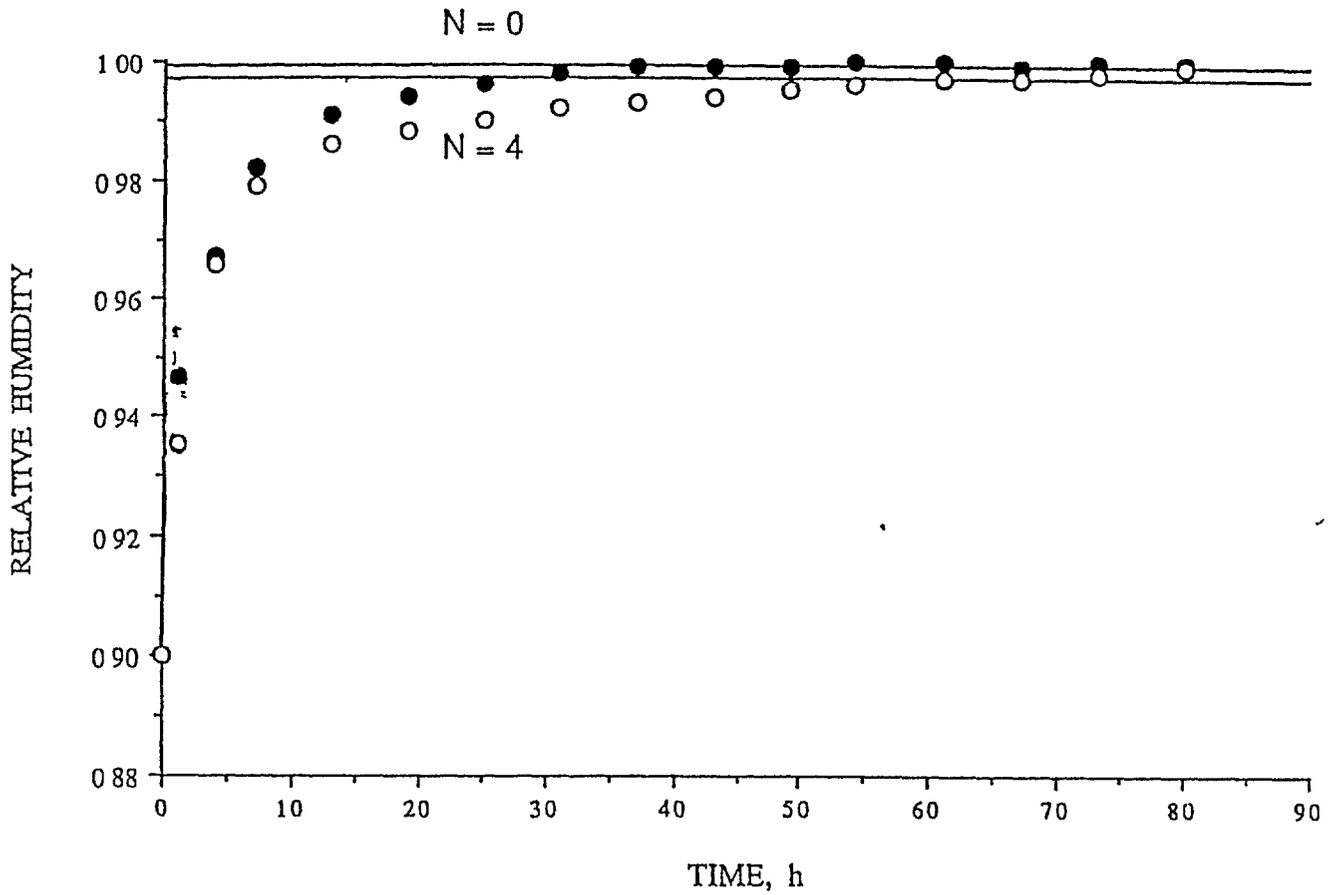


Figure 5 Effect of perforation on relative humidity in a plastic package containing two mangoes at 20°C. N - number of pores (2 mm in diameter) Circles represent observations, curves - the predicted steady state level

These results show that perforations affect the in-package dynamics and steady-state concentration of oxygen much more than those of water vapour (Fishman *et al*, 1996) The holes present a new route to transmit oxygen and water The relative contribution of permeation through film and holes for the creation of MA in packages was estimated for oxygen and for water vapour Under the conditions of our experiments specified in Fig 5 the oxygen transmission ability of LDPE package, with an area of 0 03 $m^2$ and thickness of $2x10^{-5}$ m, containing four holes of 2 mm diameter is 131 times greater than that of the same package but, without holes Whereas the water vapour transmission ability of this perforated package was only three times of that of non-perforated package Thus, the effect of holes is more pronounced in improving the transmission of $O_2$ than in that of water vapour

Model predictions

Changing the number of perforations per package is equivalent to changing the transmission capability of the film, while alteration of the relative humidity in the ambient atmosphere means changing the driving force for water vapour permeation through the film.

The relative humidity changes as predicted by the model for packages with four levels of perforation. N = 0, 4, 20 and 40 holes per package, are shown in Figure 6 (Fishman et al, 1996) Three ambient atmosphere RH levels ($H_A$, non-dimensional) were studied for each perforation level 0 8 (upper curve), 0 7 (middle curve) and 0 6 (lower curve) The transient periods for these

combinations of parameters were very short and varied negligibly As can be expected, lowering of $H_A$ reduced the predicted in-package RH because of the increased RH gradient across the packaging film. Increase in the number of perforations, N, makes the package RH more sensitive to the ambient RH and accordingly, the differences between the steady-state in-package RH values corresponding to different $H_A$ increased with increasing perforation level (Fig 6) It should be noted that even at the lowest ambient RH ($H_A$ = 0 6) and highest perforation level (N = 40) studied, the in-package humidity was predicted to be as high as 0 93 Indeed, our measurements confirmed these predictions This prediction of the perforation effect was repeated also in other conditions

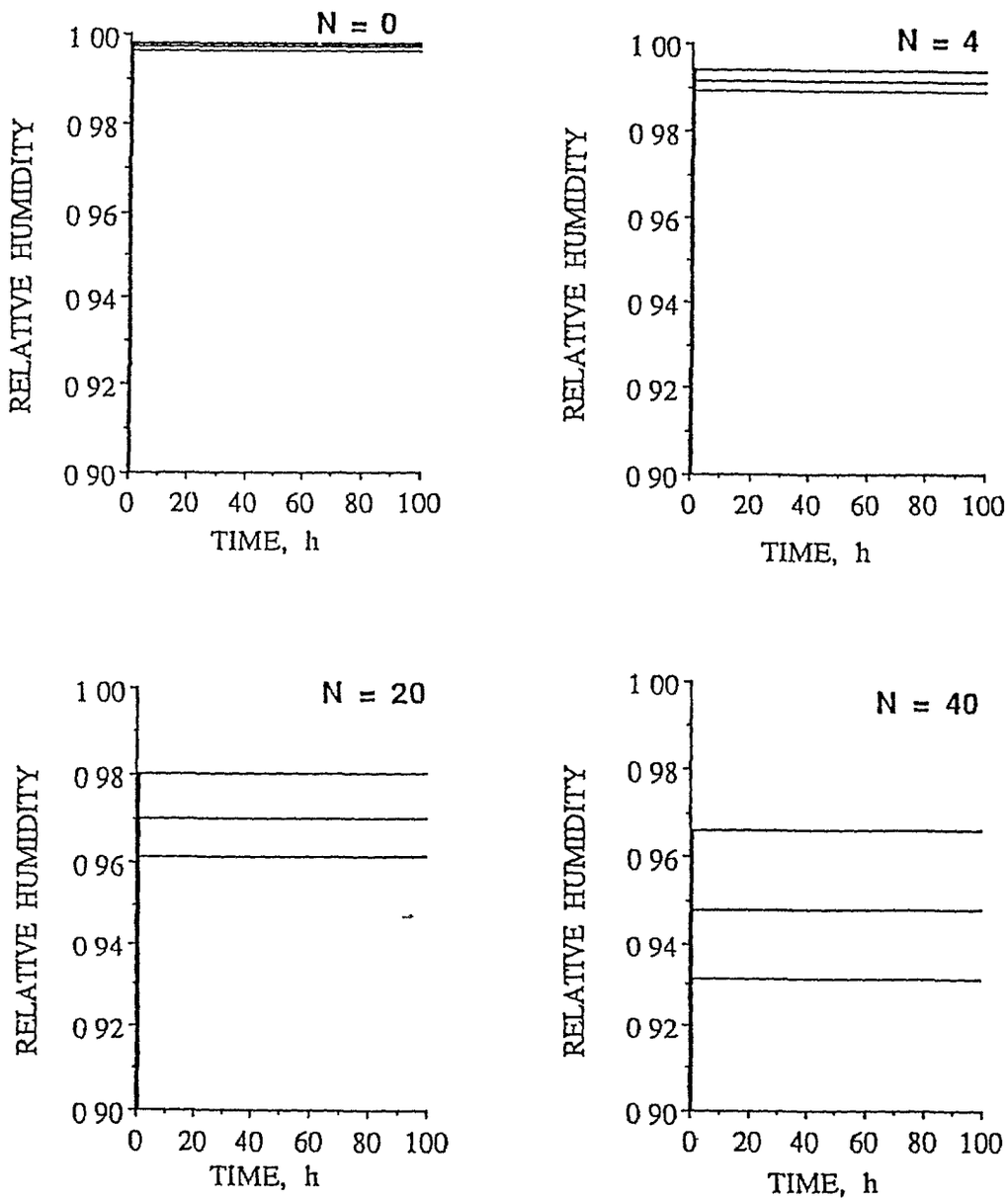


Figure 6 Effect of perforation on steady state levels of relative humidity MA packages with four levels of perforation. N = 0, 4, 20 and 40 Three values of relative humidity in the ambient atmosphere ($H_A$) were considered. 0 8 (top curve), 0 7 (middle curve) and 0 6 (bottom curve) Predictions are for 20°C.

The model simultaneously describes the dynamics of oxygen and water vapour concentrations in perforated MA packages Both predicted and observed data showed that perforation allows to combine elevated in-package RH, similar to that of a non-perforated package with high oxygen concentration, that of the ambient atmosphere This makes it possible to minimise fruit weight loss while maintaining the gas concentrations required for the normal ripening of packaged mangoes The model predicts the effects of the ambient humidity and of package parameters, such as perforation area, film surface, fruit amount, etc on in-package $O_2$ concentration and RH and on fruit weight loss It may serve as an effective tool for optimisation of MA packages It is worth noting that the model was parametrized for mango fruits, but the calculations for in-package RH would be valid for other commodities, subject to insertion of the appropriate transpiration coefficients Another model describing the oxygen behaviour in perforated mango packages was proposed independently by the Thai co-authors of this paper (Yantarasri *et al*, 1995a)

## Experimental Trials

*Perforation Effects on Various Parameters of Modified Atmosphere Packaging of Mangoes*

'Tommy Atkins' is an important mango cultivar grown in Israel The storage period of mango does not usually exceed 2-3 weeks at 14°C and is limited both by physiological deterioration of the fruit related to over-ripening, and by pathogen development. In addition, desiccation of mango during prolonged storage causes shrivelling and reduces the market value of the fruit. Reaching distant export markets via marine transportation with fruit retaining high quality is one of the major tasks of post-harvest research on mango

In this research, modified atmosphere packaging (MAP) of mangoes was tested as a means to improve quality retention. The study examined the effects of perforation level on storage life and quality of mango in order to design an optimal MA-package Experiments were conducted during 1992-94 harvest seasons, at the Volcani Center (Bet Dagan, Israel) In parallel, experiments with the major Thai mango variety 'Nam Dork Mai' were conducted in Chiang Mai University, Thailand. The intensive research carried out in Thailand has been reported elsewhere (Sornsrivichai *et al* 1992, Yantarasri *et al* 1994, 1995a, 1995b) and only highlights are presented here The data in the two laboratories were similar Most of the figures represent the data collected in Israel

In Israel, mature-green mangoes of Tommy Atkins cultivar grown in the Jordan valley were obtained from the packing house on the day of harvest. The fruit was dipped in hot water (51±1°C) for 5 min within 24 h of arrival at the laboratory The mangoes were sealed in packages of 40μ thick low-density polyethylene (LDPE) The perforation area per package (TPA) ranged as follows 0, 1, 4, 19, and 69 $mm^2$ Control fruit were kept in standard mango open cartons

Packaged fruit was stored at 14°C and at 85±2% relative humidity (RH) The storage period of 2 to 4 weeks was followed by imitation shelf-life, when the packaged fruit was kept for 4 days at 20°C and RH 85±2% At the end of shelf-life period, the packages were opened and part of the fruit was used for quality analysis If necessary, the rest of the fruit was kept open for one additional week at 20°C to complete ripening

Concentrations of oxygen, carbon dioxide, ethylene, as well as ethanol and acetaldehyde vapours in the package head space were determined by gas chromatography (GC) The quality analyses included determination of fruit firmness, percentage of total soluble solids and titratable acidity Flesh and peel colours were evaluated using the CROMA METER CR-200 (Minolta, Japan) In addition, peel colour was assessed by a visual index

Composition of in-package atmosphere

In non-perforated packages of 40μ thick LDPE, oxygen content decreased quickly to the level of 2-3% (Fig 7a) Anaerobic

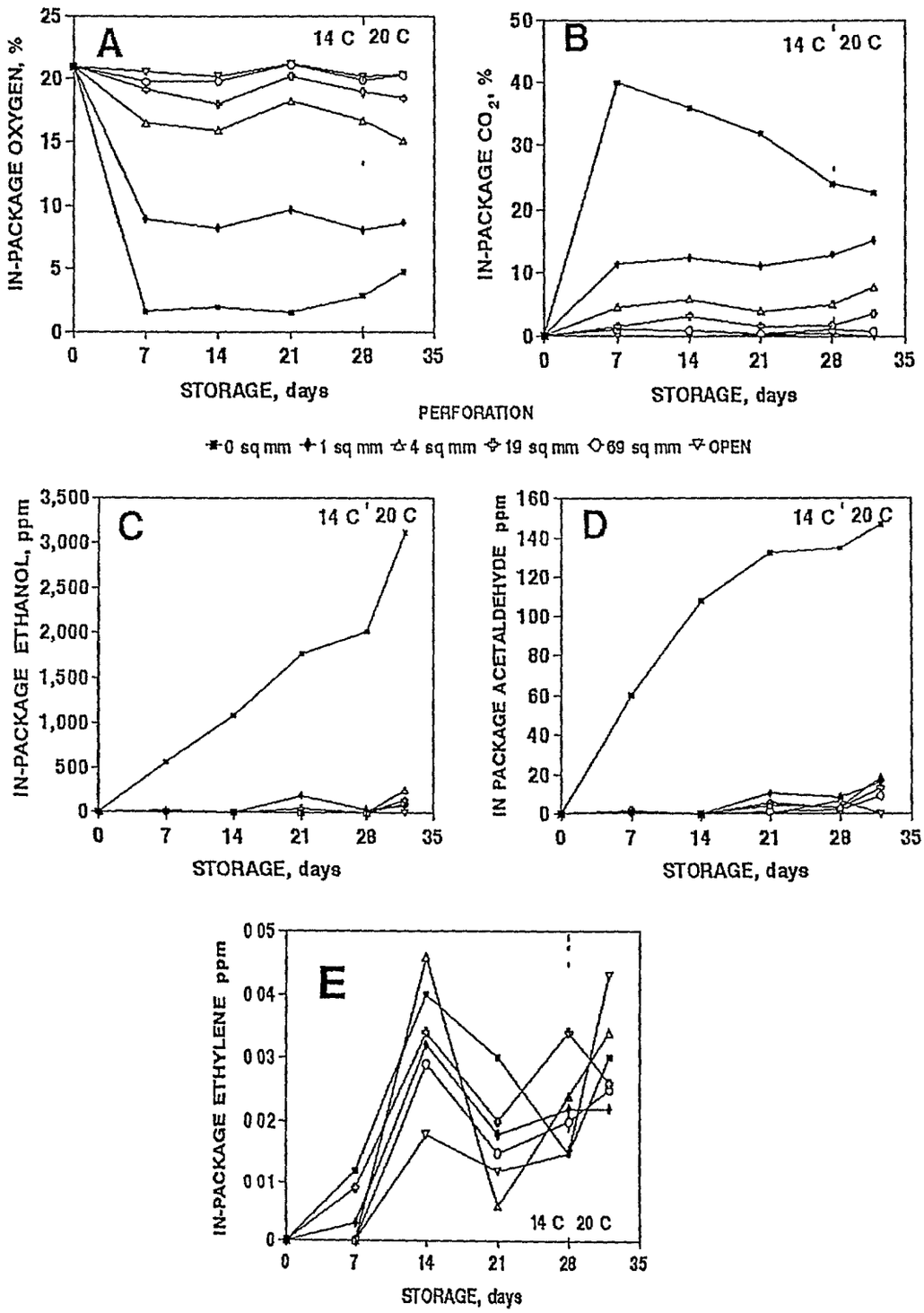


Figure 7 Perforation effects on the atmosphere composition inside 40μ-thick LDPE packages containing two 'Tommy Atkins' mangoes A - oxygen, B - carbon dioxide, C - ethanol, D - acetaldehyde, E-ethylene

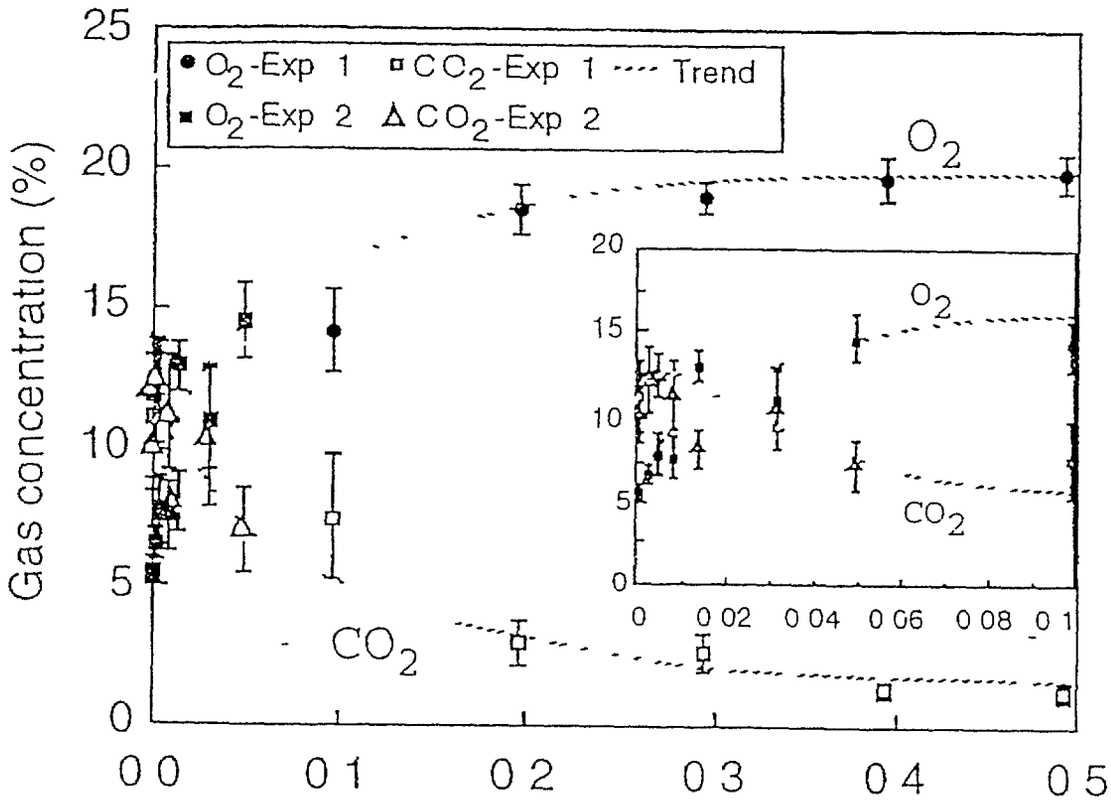


Figure 8 Effect of perforation level on oxygen and carbon dioxide concentrations inside PVC packages of 'Nam Dork Mai' mango stored at 20°C. The stretch PVC film (Fitwrap, MMP Packaging Group Co , Japan) was 0 01 mm in thickness and each package had 2 fruit

fermentation process prevailed in fruit at those conditions Accordingly, the atmosphere of non-perforated packages was rich in $CO_2$, (Fig 7b), ethanol (Fig 7c) and acetaldehyde (Figure 7d) At all perforation levels tested, the in-package ethylene concentration peaked after 2 weeks of storage (Fig 7e)

The highest and most pronounced ethylene peak was observed at TPA of 4 $mm^2$/package At lower perforation levels, the ethylene production may be inhibited by high $CO_2$ concentration, while at higher perforation levels its accumulation could be reduced because of better gas exchange As a rule, the in-package ethylene level increased after transfer from 14°C to 20°C. Even the smallest perforation level tested (1 $mm^2$/package) practically prevented anaerobiosis In a similar independent experiment carried out with perforated packages in Thailand (Yantarasri *et al* 1995), the steady state in the $O_2$ concentration varied from 5% to about 21% with the increase of total perforation area (TPA) from 1 to 50 $mm^2$/package (Fig 8) Accordingly, the $CO_2$ concentration varied in those packages from 11% to about 0 8% The same data were obtained in Israel with the PE film

Decay and weight loss

Fruit that was seal-packaged without perforation had no rots until the package was opened, but then rotted rapidly The decay level in fruit stored in perforated packages was consistently lower than that in the control (Fig 9) In most of the cases, hot water dips reduced decay as compared with untreated fruit (Fig 10)

Perforated seal-packaging greatly reduced fruit weight loss, and prevented its shrivelling even at highest perforation level (Fig 11 and 12) As a rule, the weight loss percentage was directly related to TPA value In non-perforated sealed packages, the weight loss was surprisingly high, as a result of intensive exudation of liquid from the fruit.

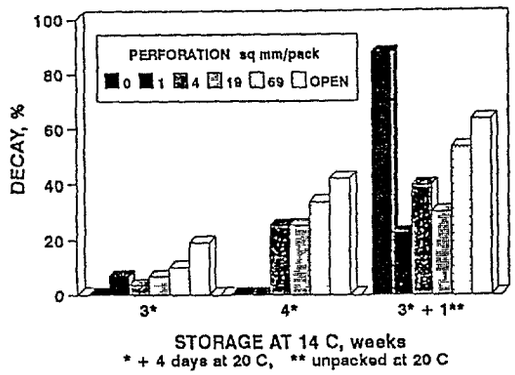


Figure 9 Effect of package perforation and storage period on the decay incidence of 'Tommy Atkins' mango

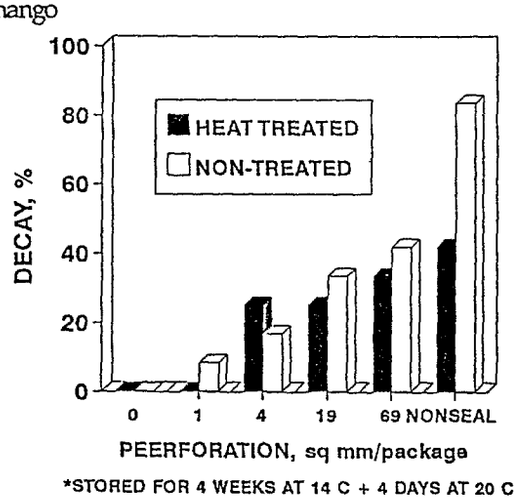


Figure 10 Effect of heat treatment and perforated seal-packaging on the decay of 'Tommy Atkins' mango stored for 4 weeks at 14°C and 4 days at 20°C

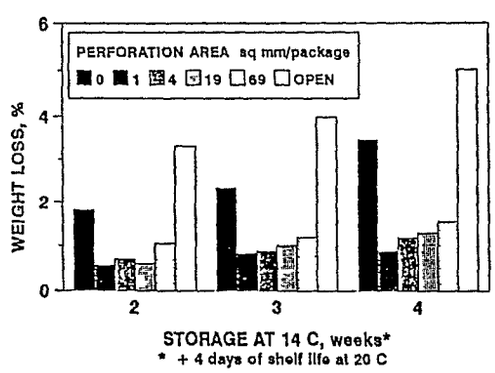


Figure 11 Effect of package perforation and storage period on the weight loss of 'Tommy Atkins' mango

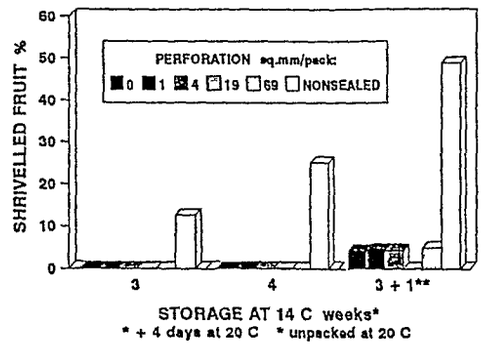


Figure 12 Effect of perforated seal-packaging and storage period on shrivof 'Tommy Atkins' mango

Fruit ripening

Keeping mango fruit in non-perforated sealed LDPE packages inhibited their ripening, so that the fruit remained firm and inedible with low TSS level, high acidity and strong alcoholic off-flavour even after 4 weeks of storage and an additional 4 days of shelf life The fruit maintained its green colour for more than two weeks, and later showed dark discolouration.

Perforating the packages allowed the ripening process to take place The perforation level affected each of the fruit quality parameters independently The minimal package perforation, 1 $mm^2$/package, was enough to enable the normal softening and accumulation of soluble solids in mango fruit during storage (Fig 13)

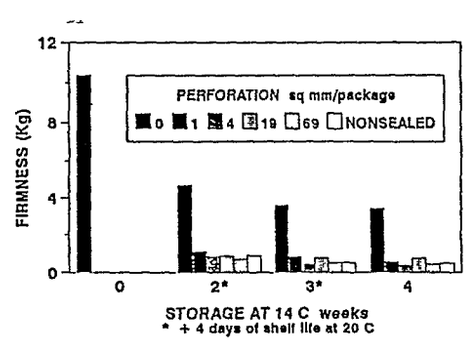


Figure 13 Effect of perforated seal-packaging and storage period on the firmness of 'Tommy Atkins' mango

The rate of acidity changes depended on perforation level (Figure 14) In highly

perforated sealed packages (TPA of 69 and 19 $mm^2$/package) the acidity change followed the same pattern as in the control During the first storage period (2 weeks at 14°C and 4 days at 20°C) the mangoes seal-packaged with TPA of 4 $mm^2$/package were more acid than the control, but a week later the fruit reached an even slightly lower acidity level than that of non-sealed ones After 4 weeks of storage and 4 days of shelf life, fruit sealed with 1 $mm^2$ of TPA also approached the acidity level of that of the control

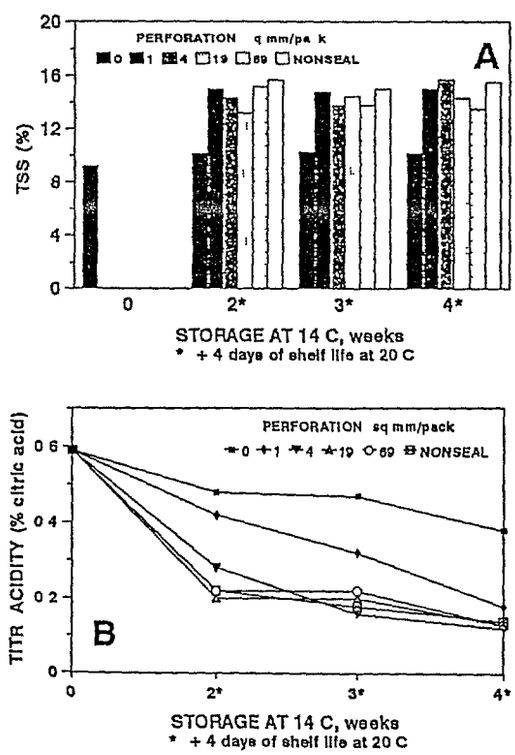


Figure 14 Effect of perforated seal-packaging and storage period on the level of total soluble solids (TSS) and titratable acidity of 'Tommy Atkins' mangoes A - TSS, B - titratable acidity

After 3 weeks of storage at 14°C and 4 days at 20°C, the taste panel preferred the fruit kept in perforated sealed packages over that from the non-packaged control, mainly because it had not over-ripened. The highest taste score was won by the fruit packaged at TPA of 4 $mm^2$ (Fig 15) A slight off-flavour was sometimes evident in fruit packaged at TPA of 1 $mm^2$

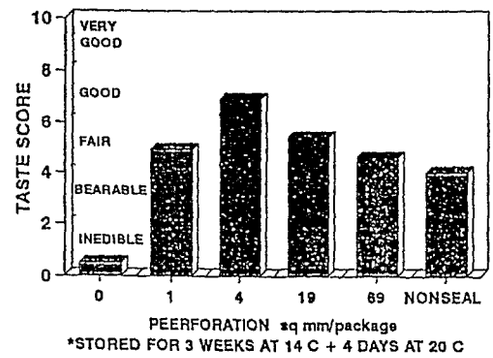


Figure 15 Effect of package perforation on the taste of 'Tommy Atkins' mangoes

Of all ripening-related processes, the peel colour change was the most sensitive to the conditions of in-package atmosphere After 3 weeks at 14°C and 4 days at 20°C, only fruit packaged with TPA of 69 $mm^2$ had turned yellow At least 19 $mm^2$ TPA was essential for fruit to reach a yellow peel colour after 4 weeks of storage and an additional 4 days of shelf life After opening the sealed packages, fruit kept at TPA of 4 $mm^2$ also turned yellow, while peel of fruit packaged at TPA of 69 $mm^2$/package turned yellow-orange However, it still did not reach the colour intensity of the control fruit (Fig 16)

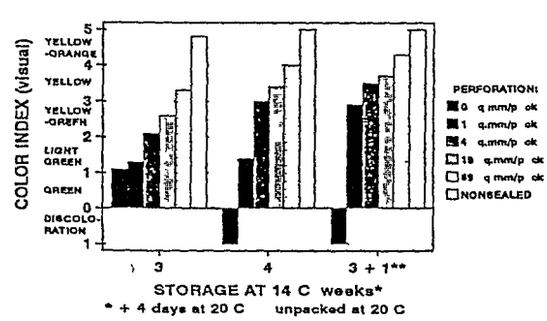


Figure 16 Effect of package perforation and storage period on the peel colour of Tommy Atkins' mango

The TPA of 1 $mm^2$/package was not sufficient for complete fruit yellowing Direct relation was observed between the advance of peel colour and the in-package oxygen concentration ( Fig 17), as well as $O_2/CO_2$ ratio (Fig 18)



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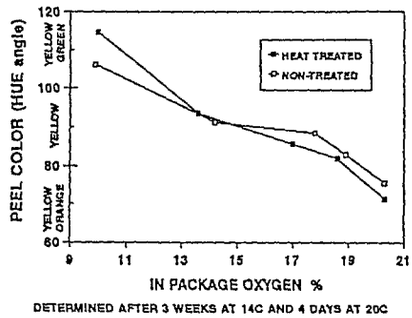


Figure 17 Effect of in-package oxygen concentration and heat treatment on the peel colour of 'Tommy Atkins' mango sealed in 40μ-thick LDPE packages

Table 1 summarises the approximate time necessary for Tommy Atkins mango fruit to reach the "ripeness level" of different qualitative parameters, as effected by in-package oxygen and $CO_2$ concentrations

Experimental commercial shipment of MA-packaged mangoes to Japan was made by the Thai co-authors together with a private company, Krung Thai International Co Ltd. Thailand. The shipment was by sea, in containers equipped with ethylene scrubber facility at 13°C. The level of $O_2$ in the perforated MA package was 5-7% in comparison with 6 6% predicted by the model developed independently by the Thai team. The fruit in this environment reached full ripeness only after transportation and one additional week of shelf life at ambient temperature The fruit in non-sealed trays had become overripe by that time MAP also reduced disease incidence in comparison with the control treatment, but still needed supplemental treatment to control decay

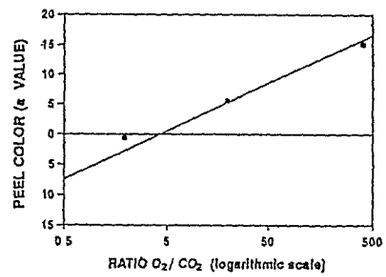


Figure 18 Effect of in-package atmosphere on the peel colour of 'Tommy Atkins' mango at 20°C.

*Reducing In-Package Water Condensation by Perforation of the Plastic Film in Packages of Mango*

Perforation was observed to reduce the condensation of water droplets in mango packages In order to characterise this effect quantitatively, all the water droplets on both fruit and film were absorbed on filter paper and weighed. The amount of condensate in Tommy Atkins mango stored at 14°C and 85% RH was reduced by increasing the TPA (Figure 19)

Table 1 Effect of in-package atmosphere on the number of weeks* necessary for Tommy Atkins mango to reach ripeness in each of its ripening parameters

| | Steady-state | | | | | Ripening parameters | |
|---|---|---|---|---|---|---|---|
| TPA | $O_2$, % | $CO_2$, % | Acidity | TSS | Firmness | Flesh colour | Peel colour |
| $mm^2$/pack | (range) | (range) | <0 25% | >13% | <kg | Hue°<85° | yellow |
| 0 | 2-3 | 25-40 | NR | NR | NR | NR | NR |
| 1 | 9-10 | 11-13 | 4 | 2 | 3 | NR | NR |
| 4 | 16-17 | 4-5 | 3 | 2 | 2 | 3 | 3+1** |
| 19 | 18-20 | 2-3 | 2 | 2 | 2 | 3 | 4 |
| 69 | 19-21 | 0 7-1 | 2 | 2 | 2 | 2 | 3 |
| Not-sealed | 20 5-21 | 0 03-0 05 | 2 | 2 | 2 | 2 | 2 |

* followed by 4 days at 20°C, NR - never reached
** 1 additional week unpackaged at 20°C

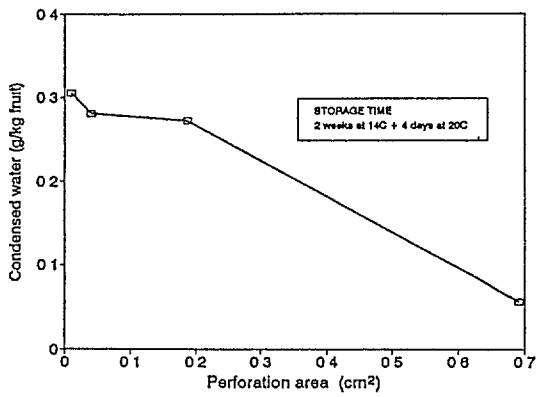


Figure 19 Effect of perforation level on water condensation inside 40 µ-thick LDPE packages containing two 'Tommy Atkins' mangoes

*Reducing Botrytis decay and water condensation by perforation in Bell Pepper packages*

Saltveit (1994) summarised the available literature for the recommended CA conditions for bell peppers which should be the targeted conditions for MAP of this crop He suggested concentrations of 2 to 5% for both $O_2$ and $CO_2$ Four red peppers were placed in a tray package of 40µ thick LDPE film and stored at 8°C and 90±2% RH The in-package atmosphere was after achieving steady state 49% $CO_2$ and 4 8-5 0% $O_2$ These conditions fit Saltveit's (1994) recommendations for CA well Unfortunately, despite the successful achievement of the recommended CA specifications, the fruit in these packages had a high incidence of decay - above 30%, which was caused mainly by Botrytis cinerea. This decay was probably related to the large amounts of water droplets which condensed on both the film and the fruit. Thus, optimal $O_2$ and $CO_2$ are not in themselves sufficient to provide adequate conditions for MAP of peppers Accordingly, effects of perforation and hygroscopic materials on decay incidence in these packages were investigated

The great importance of the reduction of the condensation was demonstrated with pepper fruit. Perforation significantly reduced the extent of Botrytis decay in bell-peppers (Fig 20) Use of perforated polyolefin film (19µ thick) with 8 holes 0 4 mm in diameter/inch$^{-2}$ (1 24 holes cm$^{-2}$) and reduced the amount of water condensate on both the film and the fruit in a package holding 4 peppers This resulted in 5% Botrytis decay as compared with 35% observed in the similar package sealed with non-perforated 20µ thick LPDE film. It is interesting to note that perforation in these experiments did not reduce Alternaria alternata decay (data are not given) Addition of 10g of hygroscopic materials such as NaCl or the Stocksorb polymer in a sealed sachet of spun bonded Tyvec effectively reduced both the condensation and decay caused by Botrytis cinerea, similar to perforation. These treatments also reduced the RH in the package from ≥99% to 92-95% and extended the life of pepper (Rodov *et al*, 1995) Previously, Shirazi and Cameron (1987) had shown that NaCl addition extended the life of tomato fruit. The loss of weight of the fruit kept in perforated packages or in non-perforated packages with hygroscopic insertions, was still markedly lower than that in non-sealed packages (Fig 20)

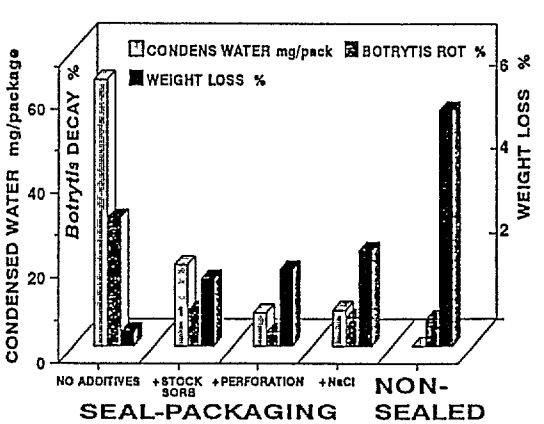


Figure 20 Effect of perforation and hygroscopic additives on in-package water condensation, weight loss and Botrytis decay of seal-packaged bell pepper at 20°C

## Discussion

*Perforated MAP*

The effects of perforation on MAP was evaluated both theoretically with our model (Fishman *et al*, 1995, 1996) and experimentally with mango and pepper fruits

The major effect was that perforation of the film allowed for the ripening process in mango which was inhibited in non-perforated sealed packages. Also, in our experiments, decay in perforated packages was significantly lower than in non-sealed control mango fruit.

Perforated packaging achieves many of the good results of non-perforated packaging in reduction of water loss and shrivelling without the possible deleterious effects of anaerobiosis such as off-flavours, fermentation or $CO_2$ damage (Ben-Yehoshua *et al*, 1994) and without the deleterious condensation of water droplets and enhanced decay that occurs in non-perforated unshrunk bell pepper packages (Rodov *et al*, 1995). Perforated packaging techniques have also proved effective in retarding deterioration in several other crops, e.g., decay of table grapes (Ben-Arie *et al*, 1995), discolouration of washed parsnips, and improving sugar retention in sweet corn (Geeson *et al*, 1988). In addition, perforation enables MAP for highly respiring produce such as mushrooms (Burton *et al*, 1987). Perforation may also enable MAP for produce that is sensitive to even small changes in concentrations of $O_2$, $CO_2$ and $C_2H_4$.

The perforated films generally fall into two categories--those which are directly perforated and those which contain additives that interfere with the continuity of the plastic materials and thus alter their gas transmission rates (Ben-Yehoshua, 1994).

Perforation may be useful in solving a major challenge in MAP research, which is to develop films that have greater permeability and/or a higher value of ß, which is the ratio of the permeability of $CO_2$ to $O_2$. This ß has a value of between 4 and 6 for most available polymers. Because the permeability of plastic films to $CO_2$ is much higher than the permeability to $O_2$, the level of $CO_2$ obtained inside the packages is limited by the $O_2$ concentration. High $CO_2$ concentration inside the package would potentially expose the product to anaerobic conditions due to the slow $O_2$ permeation. Accordingly, the use of polymers is restricted to produce that requires $CO_2$ concentrations lower than 8% (Mannapperuma *et al*, 1989). Emond *et al* (1991) proposed the use of perforations for produce requiring high $CO_2$ (>10%) with moderately low levels of $O_2$ (2 to 10%). Because the permeability ratios through the holes is approximately 1, perforation-mediated MAP systems can obtain a high $CO_2$ concentration without reducing the $O_2$ concentration inside the package below critical levels tolerated by the produce.

*MAP Modeling*

The use of mathematical models is highly desirable as it reduces the time needed for developing a package. Such a model substitutes for empirical methods, with a planned and programmed research which attempts to match the best film to the commodity. Mathematical models, based on characteristics of films needed to generate or maintain optimum internal concentrations of metabolic gases, could help maximise storage life of perishable produce. The models can answer many questions such as what would the gas content be in certain specific thickness. These 'What-if' questions are an essential part of the design of a MAP for a given commodity. The model designed by Fishman *et al*, (1996) went further than evaluating $O_2$ and $CO_2$ dynamics and included water vapour as well. Using this model proved advantageous in our attempt to design a package with a specified RH.

Mango ripening and MAP

Oxygen and $CO_2$ levels were shown to determine the ripening behaviour of packaged mango (see also Yantarasri *et al*, 1995a, 1995b). A series of modified-atmosphere packages with different steady-state $O_2$ and $CO_2$ levels was obtained by varying the perforation area from 0 to 69 $mm^2$. Scaling in non-perforated LDPE film completely prevented mango ripening. The excessive $CO_2$ concentration (25 - 40%) was probably a cause of the dark discolouration observed in non-perforated sealed LDPE packages since this disorder could be prevented by $CO_2$



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absorber (unpublished data) In all the perforated packages, the fruit was capable of undergoing ripening-related changes, but the rate of change differed markedly in accordance with the in-package atmosphere as shown in Table 1 This phenomenon opens the possibility to choose package characteristics in accordance with the desired duration of the storage/transportation period, in order to obtain fruit combining low weight loss, absence of shrivelling and good quality at the end of this period

On the other hand, Table 1 shows that various ripening parameters differed in sensitivity to modified atmosphere and their development under MA conditions was desynchronized. This effect has been noted by Jordan and Smith (1993) Of all ripening-related processes studied, the evolution of ground colour from green to yellow appeared to be the most sensitive to in-package conditions, so that the yellow peel colour was reached later than other ripeness traits The phase of over-ripening of the mango, which is often the cause of the loss of the commercial life of this fruit was consistently delayed in perforated MAP Consequently, it is still possible to achieve a desirable combination of fruit qualitative characteristics and extended life of mango Jordan and Smith (1993) showed that softening of Kensington mangoes in controlled atmosphere (CA) was effected by oxygen concentration rather than by $CO_2$

MAP and decay

In situations where physiological deterioration of the fruit is alleviated by MA package, pathogen development may turn out to be a major factor limiting the storage life Although the perforated package itself reduced decay, these effects were not adequate In our view, additional decay-preventing measures are of great importance for the application of this technique A hot water dip (51°C, 5 min) was insufficient to prevent mango rots in our trials, although demonstrated pathogen inhibition but not adequate for the expected life of 3 to 4 weeks with an additional 4 days shelf life at 20°C

The search for effective decay-controlling measures for seal-packaged mangoes should be continued. Successful use of perforated packaging with Nam Dork Mai mango in Thailand (Sornsrivichai *et al*, 1992) was achieved by its combination with hot benomyl applications Although benomyl and several other fungicides (carbendazim, imazalil, prochloraz) provide excellent control of post-harvest diseases, their intensive use has resulted in the appearance of fungicide-resistant pathogen biotypes (Prusky, 1991) The non-fungicide approaches to the control of post-harvest diseases of mango are also discussed by Prusky (1991)

MAP and water condensation.

Recently, Joyce and Patterson (1994) thoroughly reviewed the field of the control of condensation in post-harvest handling of fresh produce Packaging that reduces desiccation may encourage water condensation, which in turn, encourages pathogen development. This problem is difficult to solve, but good practice can minimise the damage and a balance should be achieved that would prevent excessive water loss and excessive condensation. Perforation, or the introduction of a sachet containing hygroscopic materials may help achieve such a balance Shrink seal-packaging is also very effective in reducing both weight loss and condensation. The adherence of the film to the fruit peel, the inherent perforation present in shrunk films as well as the selection of the proper plastic film all contribute to the virtual absence of condensation from the shrunk-sealed fruit.

In conclusion, MAP provides a useful tool for extending life and reducing spoilage of perishable agricultural produce This developing technology appears to be of relatively low cost and to require much less investment compared with cooling or CA. Furthermore, it has the great advantage of being environmentally friendly utilising mainly the control of $O_2$, $CO_2$ water and ethylene without exogenous chemicals

**Acknowledgment**

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# Progrès récents du conditionnement en atmosphère modifiée (II)

# New developments in modified atmosphere packaging (Part II)

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## CONDITIONNEMENT SOUS HUMIDITE MODIFIEE

Dans un emballage plastique, l'humidite relative (HR) est en regle generale tres elevee De faibles fluctuations dans la temperature de stockage peuvent suffire a pro voquer des condensations, et par la a accelerer la pro liferation et l'extension des micro organismes generant les avaries (Grierson et Wardowski 1978) C'est pour quoi reduire la HR interne a une valeur optimale peut etre un facteur determinant dans la reussite du conditionnement MAP de produits frais Shirazi et Cameron (1987) ont ainsi lance le concept de "conditionnement sous humidite modifiee" et ont multiplie les travaux dans ce domaine En 1992 ils ont etudie la faisabilite du controle de la HR par l'emploi de composes presentant un comportement isotherme de sorption Type III Dans l'emballage contenant une tomate verte mure, et avant sa fermeture ils ajoutaient 10 g d un tel compose $CaCl_2$ sorbitol, NaCl, xyletol ou KCl A 20°C et pendant 48 jours ils parvenaient ainsi a stabiliser la HR a 35, 75 75 80, et 85 p cent, respectivement HR etant fonction du rap port des masses compose chimique/fruits Dans l emballage temoin HR etait en permanence de l'ordre de 96 -100 p cent Les auteurs ont decrit un systeme simple faisant appel a des sachets PE nontisse pour l application de cette methode de contrôle de l'humidite A 20°C, la duree de conservation de tomates rouges est passee de 5 jours pour le temoin sans sachet a 15 -17 jours pour les sachets contenant du NaCl du fait principalement de l effet retardateur sur les moisissures de sur face La technique du controle de l humidite relative interne des emballages n est pas dependante de la HR exterieure

Rodov *et al* (1995 1996) ont verifie ces observations

En abaissant l humidite relative (HR) a l'interieur de l'emballage l'addition d un materiau hygroscopique (NaCl par exemple) limite la pourriture de poivrons stockes a 8°C dans un plateau hermetiquement enveloppe de film polyethylene basse densite (PEbd) Sans materiau hygroscopique, la HR interieure est proche de la saturation et l eau se condense sous forme de gouttelettes a la sur face des fruits et sur la face interne du film Selon la dose de NaCl la condensation est considerablement reduite ou interdite Le niveau d'humidite varie de 86 - 90 p cent

## MODIFIED HUMIDITY PACKAGING

The relative humidity (RH) in a plastics package is usually very high Small fluctuation in the storage temperature may result in condensation, which would greatly increase the proliferation and spread of spoilage micro organisms (Grierson and Wardowski, 1978) Thus reducing the in-package RH to an optimal amount may be critical for the success of MAP for fresh produce Shirazi and Cameron (1987) introduced the concept «modified humidity packaging» and did much work in this field They (1992) studied the feasibility of controlling RH in MAP using compounds possessing Type III sorption isotherm behaviour Ten gram each of CaCl2, sorbitol NaCl, xylitol, and KCl sealed with one mature green tomato fruit at 20°C in simulated packages for 48 days resulted in stable RH of 35, 75, 75, 80 and 85 p cent respectively RH was a funtion of the ratio of chemical to fruit mass RH in the control was in a range of 96 to 100 p cent throughout the experiments They described a simple system that uses spunbonded polyethylene pouches for the application of this humidity control method to packages The storage life of packaged red-type tomato fruit at 20°C was extended from 5 days using no pouch to 15 to 17 days with a pouch containing NaCl, mainly by retardation of surface mould development The technique of controlling in package RH is independent of outside RH

Rodov *et al* (1995 1996) verified their observation

Lowering the in-package relative humidity (RH) by the addition of hygroscopic material (e g , NaCl) reduced decay of bell pepper fruit sealed in a tray in low density polyethylene (LDPE) and stored at 8°C Without hygroscopic material the in package RH was close to saturation, and water droplets condensed on the fruit and inner film surfaces Depending on the amount of NaCl condensation was prevented or significantly reduced Humidity level varied from 86-90 p cent with 15 g NaCl to 96-98 p cent with 5 g NaCl

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avec 15 g de NaCl a 96 - 98 p cent avec 5 g de NaCl, lorsque l'emballage contient 0,5 0 6 kg de poivrons La presence d'un materiau hygroscopique accentue le deficit de la pression de vapeur d'eau (DPV) a l'interieur de l'emballage et accelere en consequence la perte de poids des fruits Cependant, par rapport aux poivrons non conditionnes sous emballage hermetique, la perte de poids est moindre et la qualite superieure pour les poi vrons conditionnes avec NaCl Le regime hydrique genere par la presence de 10 g de NaCl dans des embal lages de quatre poivrons (HR 92 95 p cent, DPV 77 65 Pa) optimise l'equilibre entre une dessiccation limitee des fruits et une inhibition des pathogenes, allongeant en consequence la conservation des poivrons apres recolte

for a package containing 0 5-0 6 kg of fruit Addition of hydroscopic material increased the water vapor pressure deficit (VPD) in the packages and, accordingly the weight loss of the fruit However, peppers packaged with NaCl still had lower weight loss and better quality than the non sealed fruit The water regime formed in four-fruit packages in the presence of 10 g NaCl (92-95 p cent RH VPD 77 65 Pa) enabled optimal balance between reduced fruit desiccation and inhibited pathogen development thus extending the postharvest life of bell pepper

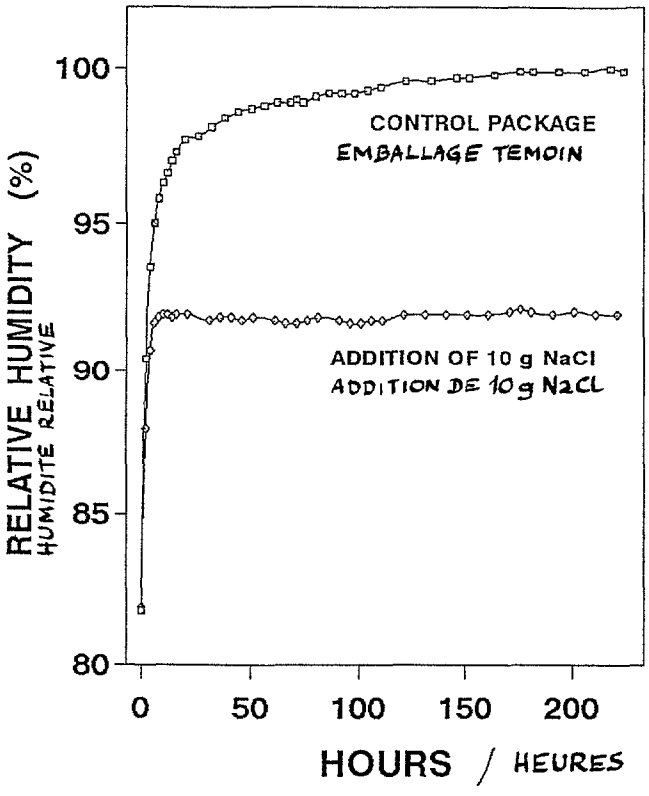


**Figure 1 – Influence d un materiau hygroscopique sur l humidite relative d'un emballage de poivrons**

Les poivrons etaient places dans des plateaux polypropylene (4 fruits) scelles sous film PEbd (20 µm) et stockes a 8°C temoin sans materiaux hygroscopiques et traitement avec addition de 10 g de NaCl contenu dans des sachets nontisse PE

**Figure 1 – Effect of hygroscopic material on the relative humidity in bell-pepper package**

Fruit were sealed in low density polyethylene (20 µm) within polypropylene trays (four fruit per package) and kept at 8°C – package without hygroscopic materials (control) addi tion of 10 g NaCl within pouches of spun bonded polyethylene

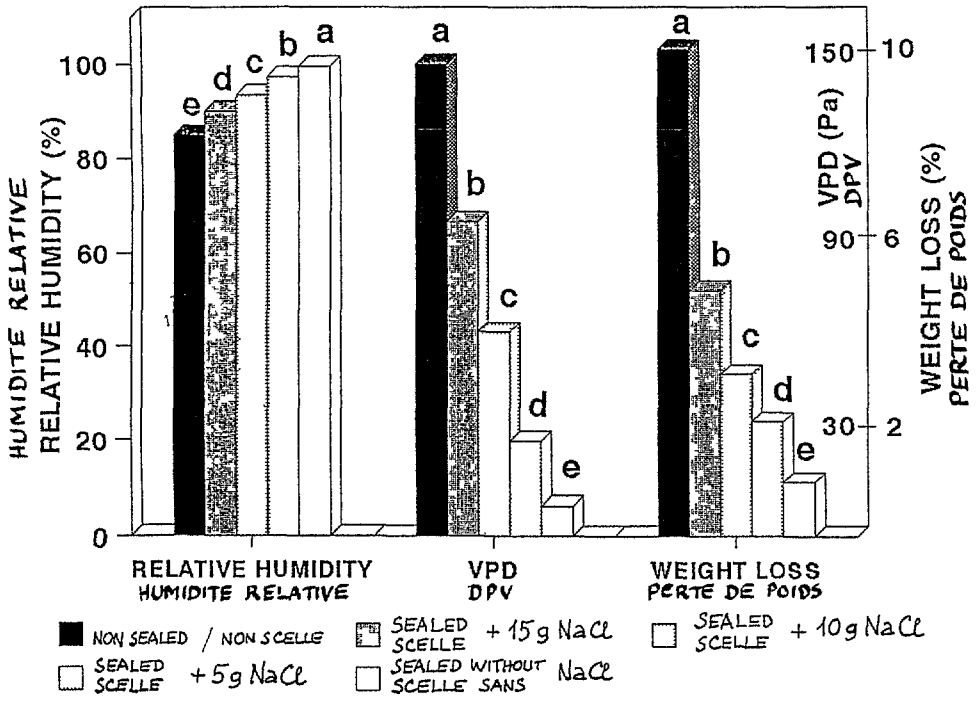


**Figure 2 – Effet de la dose de NaCl sur l'humidite relative et le deficit de pression de vapeur d'eau (DVP) a l'interieur de l'emballage, ainsi que sur la perte de poids des poivrons emballes**

Fruits conditionnes dans les mêmes conditions que sur la Figure 1 Les fruits non scelles sous emballage hermetique etaient places dans des boites en carton On a mesure les etats stables de HR et DPV au bout d'une semaine de conservation les pertes de poids apres trois semaines de stockage a 8°C puis apres trois jours supplementaires a 17°C

**Figure 2 – Effect of NaCl dosage on in-package relative humidity and water vapour pressure deficit (VPD) and on the weight loss of packaged bell-peppers**

The sealed fruit were packaged as described in Figure 1 The non sealed fruit were packaged in carton boxes The steady-state RH and VPD levels were measured after one week of storage, the weight loss determined after 3 weeks of storage at 8°C and three additional days at 17°C

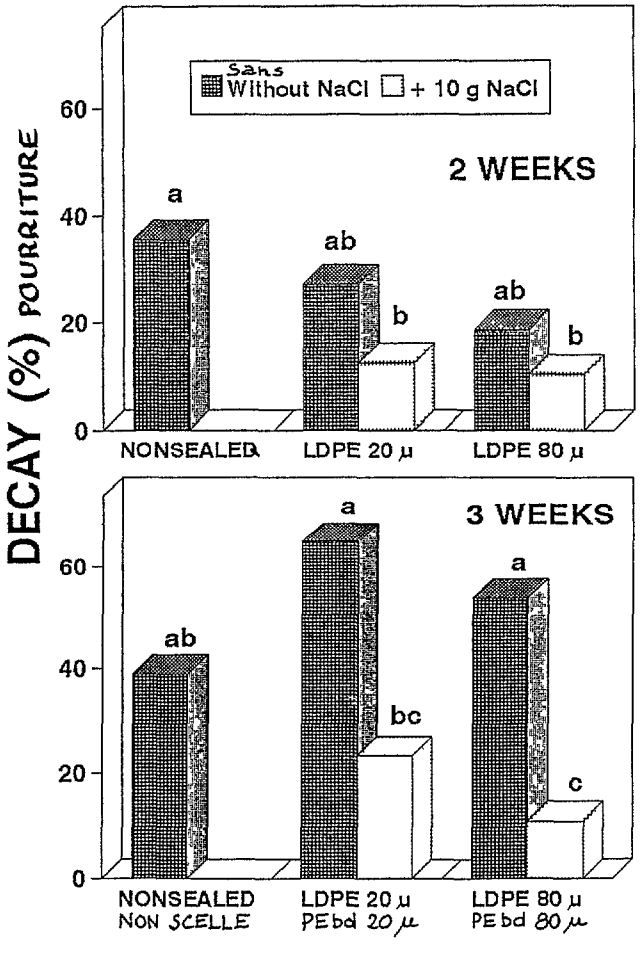


**Figure 3 – Influences de l'epaisseur du film d'emballage, de la presence NaCl et de la duree de stockage sur la pourriture des poivrons**

Fruits conditionnes et stockes comme precedemment Dose de NaCl 10 g On a evalue le degre de pourriture au bout de 2 ou 3 semaines de stockage a 8°C puis apres 3 jours supplementaires a 17°C Les lettres differentes indiquent des valeurs significativement differentes determinees selon le test de Duncan (p = 1 %)

**Figure 3 – Effect of sealing in films of different thickness, NaCl addition and storage duration on bell-pepper decay**

The fruit were packaged and stored as described in Figures 1 and 2 The amount of NaCl added 10 g The decay percentage was determined after 2 or 3 weeks of storage at 8°C and 3 additional days at 17°C Different letters indicate significantly different values as determined by Duncan s multiple range test (p = 1 %)

## FILMS INTERACTIFS ET MICROPOREUX

Il faudrait pour le conditionnement MAP des materiaux d emballage capables de transmettre des quantites contrôlees d'eau $O_2$ $CO_2$ $C_2H_4$ de façon a maîtriser les concentrations de ces gaz dans le milieu interne de l em ballage et a eviter l'anaerobiose C est ainsi qu'est ne le terme de **"conditionnement intelligent" (smart)** un conditionnement qui serait a meme de percevoir d une maniere ou d'une autre les modifications du milieu interne et d'admettre en consequence l'entree de $O_2$ de l'atmosphere exterieure, ou bien de laisser s'echapper le $CO_2$ en exces, voire de faire les deux transferts

Cette technologie s'est ensuite muee en **conditionnement actif** notion qui recouvre un large eventail de materiaux sensibles aux besoins des denrees embal lees et aux caracteristiques de leur environnement par exemple, sachets de composes chimiques inseres dans l'emballage pour absorber des gaz ($O_2$ $C_2H_4$ ou $CO_2$) ou même donner du $O_2$ ou du $CO_2$ quand le milieu interne se trouve appauvri (Angel *et al* 1992 Ben Yehoshua 1995 Kader *et al* 1989)

**Les films microporeux** sont conçus pour transmettre les gaz de faible poids moleculaire, comme $O_2$, $CO_2$ vapeur d'eau, azote, etc a la seule fin d ajuster les concentrations gazeuses a l'interieur de l'emballage Ils peuvent se classer en deux categories ceux qui sont intentionnellement perfores de tout petits trous laissant passer les gaz a un debit tres faible, par rapport a la sur face totale, et ceux qui contiennent des additifs pertur bant la continuite de la matiere plastique, modifiant ainsi son taux de transmission gazeuse (voir Brody 1991)

Les films presentant une haute permeabilite aux gaz du fait de leur nature, ou parce qu'il s'agit de melanges de polymeres, ne sont pas microporeux techniquement On peut citer les films PEbd a forte teneur en EVA (6 18 p cent) comme "Shields Bag" ou "Cryovac", ou le film (terpene polycyclique) naguere fabrique par Bunzl en Grande-Bretagne Leurs permeabilites a $O_2$ depasse 6 000 ml/m²/jour aux temperatures et pressions normalisees (STP) Le film copolymere styrene-butadiene sequence «K-resin» de Phillips et le film copolymere ethylene octene ultra-basse densite "Attane de Dow Chemical avec une transmission depassant 13 000 ml/m²/jour (STP) seraient egalement envisa geables pour le conditionnement MAP de denrees qui respirent (voir Brody 1991)

Le concept d'un materiau d'emballage presentant des transmissions de $O_2$ et $CO_2$ compatibles avec les "besoins" des produits conserves a fait l'objet de pro gres Deux types de films de base ont ete identifies, ont fait l'objet d'essais et ont ete dans une certaine mesure adoptes dans la pratique les films microperfores et les films avec charges minerales (microporeux)

A la premiere categorie appartiennent les films pro poses par Courtaulds et Curwood Courtaulds fabrique son "P-Plus" en pratiquant de tres fines perforations a l'aide de rayons laser Selon Courtaulds les permeabi lites a $O_2$ et $CO_2$ vont de 6 000 a 300 000 ml/m²/jour/atm, et la gamme des films «P Plus» presente un eventail de permeabilites permettant de repondre avec precision aux exigences du produit conditionne Les permeabilites gazeuses sont conçues pour equilibrer le taux de respiration du produit

Curwood propose de son cote un co extrude poly ester/PEbdl, pourvu de micro-entailles qui ameliorent les flux de $O_2$ et $CO_2$ et minimisent donc les risques d'anaerobiose respiratoire

Les deux films microporeux les plus courants sont ceux de Van Leer (Belgique) et de FrischHold (USA), co

## INTERACTIVE AND MICROPOROUS FILMS

MAP application may require packaging materials capable of passing controlled quantities of water $O_2$ $CO_2$ and $C_2H_4$ in order to control the concentrations of these gases in the internal package environment and to avoid anaerobiosis Thus was born the term **«smart» packaging**, or packaging that could somehow sense the changing internal packaging environment and admit $O_2$ from the outer atmosphere or allow excess $CO_2$ to escape or both

This terminology then translated into active packaging which encompasses a broad spectrum of materials sensitive to the packaged produce requirements and its surrounding environement The latter group includes families of package supplements such as in packaging sachets of chemical to absorb $O_2$ $C_2H_4$ or $CO_2$ and even to provide $O_2$ or $CO_2$ when the package environment has been depleted of the desired gas (Angel *et al* 1992, Ben-Yehoshua 1995 Kader *et al* 1989)

**Microporous films** which are engineered to pass low molecular weight gases such as $CO_2$, $O_2$, water vapour nitrogen, etc , expressly for the purpose of adjusting the gaseous concentration within the package, generally fall into two categories those which are perforated with very small orifices which pass gases at a very slow rate relative to the total area, and those which contain additives that interfere with the continuity of the plastics materials and thus alter their gas transmission rates (Brody 1991)

Those films exhibiting high gas permeability by virtue of their nature or by reason of being polymeric blends are technically not microporous Among these are high (6 18 p cent) EVA content polyethylene films such as "Shields Bag" or "Cryovac", or polycyclic terpene film produced in the past by Bunzl in U K Both are reported to have $O_2$ permeabilities in excess of 6,000 ml/m²/day at standard temperature and pressure (STP) Phillips «K-resin» block copolymer styrene film and Dow Chemical's 'Attane" ultra low density ethylene octane copolymer films with transmission of over 13 000 ml/m²/day (STP), are also being proposed as high gas permeability packaging materials for MAP of respiring produce (see Brody 1991)

The concept of a packaging material with $O_2/CO_2$ transmissions compatible with the «needs» of the contained produce has been advanced Two basic types of film materials have been proposed, tested and to some extent, introduced on a commercial scale microperforated and mineral filled

Microperforated films include those of Courtaulds and Curwood The Courtaulds films designated "P-Plus' is manufactured by perforating a polyolefin film with very tiny orifices by using laser beams According to Courtaulds, permeabilities to $O_2$ and $CO_2$ range from 6,000 to 300,000 ml/m²/day/atm Courtaulds claims their «P Plus» films represent a range of base film substrates displaying permeabilities precisely matching the demands of the produce The gas permeabilities are designed to balance the respiration rate of the produce being packed

Curwood has introduced laminations of 0 00035 0 00048 inch gauge polyester and linear LDPE film which has been microcut These microcuts permit better flow of oxygen and $CO_2$ and thus minimise the probability of respiratory anaerobiosis

The two most popular microporous materials are those of Van Leer (Belgium) and FrischHold (USA), co

coupee Ce film permet de garantir une duree de survie de deux semaines a 0 2°C On emploie maintenant, notamment en Europe du polypropylene oriente sans enduction pour des salades melangees et predecou pees emballees dans des sachets contenant de l air afin que la respiration naturelle modifie le milieu interne On conditionne de la meme façon pour la distribution des oignons et poivrons verts haches des baguettes de carotte, de celeri (voir Brody 1991)

Une innovation dans le conditionnement MAP des fruits et legumes consiste a introduire un melange gazeux de la composition voulue dans l emballage avant sa fer meture Des chercheurs de l'Universite de Colombie bri tannique (UBC) au Canada, ont mis au point des sys temes qui amenent des fruits et legumes fraîchement decoupes a une temperature de 0°C et les enveloppent de melanges gazeux pauvres en $O_2$ et riches en $CO_2$, avec de l'argon Des chercheurs de la societe L Air liquide ont confirme certaines des durees de conservation de qualite exceptionnelles obtenues par l'UCB Il y a environ trois ans cette societe a procede a une estimation du potentiel d utilisation des gaz non conventionnels' pour les applications MAP Cette enquête a mis l accent sur les gaz appartenant au groupe helium argon neon krypton et xenon (voir Brody 1991)

La societe L'Air liquide a egalement experimente le conditionnement des aliments dans les conditions usuelles du MAP Dans l un des essais des tomates coupees en tranches etaient placees dans des melanges gazeux contenant soit 75% soit 8% de $O_2$, le complement etant de l azote ou de l argon Le taux de production de $CO_2$ etait tres different selon la nature du complement Tandis qu en presence d argon la production de $CO_2$ etait inversement proportionnelle a l epuisement de l $O_2$, elle etait plus intense dans l atmosphere contenant du $N_2$ sa concentration atteignant alors des niveaux tres elevés en fin d essai (voir Brody 1991)

Bien que l on ne comprenne pas encore entierement les raisons de telles differences entre les melanges conte nant de l argon et ceux avec azote il, est permis de voir dans la solubilite tres superieure de l argon dans l eau une explication pouvant conduire a une reponse ration nelle Il ne faudrait toutefois pas ecarter l interference possible de l'argon avec des recepteurs $O_2$ chimiques ou enzymatiques dans la mesure ou les deux gaz pos sedent un diametre moleculaire presque identique res pectivement de 3, 8 et 4 angstroms

*(A suivre )*

EVA/LDPE film The film permits precut lettuce to guarantee two weeks life at 0 2°C Uncoated oriented polypropylene is now being employed for mixed cut green salads packaged in pouches with air to modify the internal environment by natural respiration for consumer sizes particularly in Europe Other fresh produce items being packed for distribution are chopped onions, green peppers, carrot sticks, celery (see Brody 1991)

One of the novel approaches in MAP of fruits and vegetables is the introduction of the gas mixture of the desirable composition into a package before its sealing Researchers at University of British Columbia (UBC), Canada have been developing systems in which freshly cut fruits or vegetables were reduced in temperature to 0°C and exposed to mixtures of low $O_2$/high $CO_2$ including argon Some of the exceptional quality retention periods achieved reported by UBC have been confirmed by researchers at the Liquid Air company About three years ago this company evaluated the potential use of non conventional gases' for MAP applications Emphasis was placed on gases belonging to the helium group i e , argon neon krypton and xenon (see Brody 1991)

The Liquid Air company conducted experiments with foods in standard MAP conditions In one series sliced tomatoes were placed in gas mixtures containing either 15 or 8% $O_2$ and the balance being nitrogen or argon The $CO_2$ production rate observed was very different depending on whether the gas mixture contained nitrogen or argon Whereas in cases of argon containing mixtures, the $CO_2$ production was inversely proportional to the $O_2$ depletion in $N_2$ containing mixtures, the $CO_2$ production was more intense and its concentration reached very high levels at the end of the test (see Brody 1991)

Although the reasons for observing such differences between gas mixtures containing argon and those containing nitrogen are not yet entirely understood, the much higher solubility of argon in water versus that of nitrogen is a possible explanation in the search for a rational answer The possible interference of argon with chemical or enzymatic $O_2$ receptor sites is not to be excluded as these two gases have almost identical molecular diameter of 3 8 angstroms and 4 angstroms respectively

*(To be followed )*


**XIV CONGRES INTERNATIONAL DES PLASTIQUES EN AGRICULTURE**
***XIV INTERNATIONAL CONGRESS ON PLASTICS IN AGRICULTURE***

**TEL-AVIV - ISRAEL**

***9 - 15 MARS 1997 - MARCH 9 - 15***

**XIV CONGRESSO INTERNACIONAL DE PLASTICOS EN LA AGRICULTURA**
**XIV INTERNATIONAL CONGRESS UBER KUNSTSTOFFE IM LANDBAU**




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## MEXIQUE

### Les plastiques dans l'agriculture mexicaine

Les entreprises de production et de distribution de plastiques agricoles se concentrent pour la plupart dans l agglomeration de Mexico (D F), ainsi que dans les Etats de Jalisco et de Mexico De nouvelles entreprises se sont etablies au centre de la republique endroit strategique pour distribuer dans tout le pays

Comme l a montre une enquete realisee par le CIQA [1] aupres de 21 entreprises (13 transformateurs 7 distributeurs et 1 producteur distributeur), il se revele que les ventes de plastiques agricoles concernent a proportion egale des materiaux d'origine nationale et d'importation Les transformateurs, pour leur part, livrent leur production a 60 % au marche national et exportent le reste principalement en Amerique centrale et Amerique du Sud

De la même façon qu'aux Etats Unis, la plupart des entreprises de transformation se specialisent dans un type de resine et limitent a deux ou trois les produits plastiques qu ils destinent a l agriculture

Selon une etude realisee par le CIQA [2] en 1990, les techniques dominantes a ce moment la etaient l irrigation goutte-a goutte en culture fruitiere (34,2 %) la micro aspersion (20,82 %), l'irrigation goutte-a goutte en culture legumiere (18 61 %), les filets (8 96 %) le paillage (7,44 %) les petits tunnels (7 09 %), avec 2 8 % pour les applications diverses Le Tableau suivant detaille les statistiques disponibles

## MEXICO

### Plastics in Mexican Agriculture

Organisations for the production and distribution of agricultural plastics are concentrated for the main part around Mexico City as well as in the States of Jalisco and Mexico New businesses have also been established in the centre of the republic being strategically placed for distribution throughout the country

A study carried out by the CIQA [1] and involving 21 organisations in the sector (13 converters 7 distributors and 1 producer distributor) has revealed that the sales of agricultural plastics are in equal proportions of materials of national production and imports The converters for their part deliver 60 p cent to the national market with the rest being exported mainly to Central and South Americas

As in the United States most of the converting companies concentrate on one type of resin and limit themselves to two or three plastics products intended for use in agriculture and horticulture

In a survey carried out by the CIQA [2] in 1990 the main applications at that time were drip irrigation for fruit crops (34 2 p cent), micro-spray (20 82 p cent), drip irrigation for vegetable crops (18 61 p cent) nets (8 96 p cent), mulch (7 44 p cent) low tunnels (7 09 p cent) with 2 8 p cent for miscellaneous uses The following table sets out the available statistics

| | surface / area | | consommation / consumption | |
|---|---|---|---|---|
| | (ha) | (%) | (t) | (%) |
| PAILLAGE / MULCHING | 3 982 | 7 44 | 1 392 97 | 4 1 |
| DESINFECTION SOLS / SOIL DESINFECTION | 520 | 0 97 | 178 60 | 0 53 |
| BACHES A PLAT / DIRECT COVERS | 17 28 | 0 032 | 7 09 | 0 021 |
| PETITS TUNNELS / LOW TUNNELS | 3 790 | 7 09 | 1 664 90 | 4 9 |
| SERRES TUNNELS / WALK IN TUNNELS | 113 | 0 21 | 361 60 | 1 06 |
| BRISE VENT / WINDBREAK | 100 | 0 91 | 28 0 | 0 08 |
| FILETS / NETS | 4 79 24 | 8 96 | 3 472 81 | 10 22 |
| SERRES / GREENHOUSES | | | | |
| jeunes plants / seedlings | 91 4 | 0 17 | 298 88 | 0 88 |
| fleurs / flowers | 532 72 | 1 00 | 1 658 30 | 4 88 |
| MICRO ASPERSION | 11 135 | 20 82 | 9 464 75 | 27 86 |
| IRRIG GOUTTE A GOUTTE / DRIP IRRIG | | | | |
| fruitiers / fruit trees | 18 300 | 34 20 | 14 460 05 | 42 57 |
| légumes / vegetables | 10 108 5 | 18 69 | 980 96 | 2 89 |
| TOTAL | 58 484 14 | 100 00 | 33 968 81 | 100 00 |

Au Mexique l'utilisation des plastiques en tant qu intrants agricoles a deja atteint des niveaux respectables dans le nord ouest du pays (Basse Californie Sonora le Bajio) et commence a se developper avec vigueur dans les autres regions

In Mexico the use of plastics for agricultural purposes has already reached reasonable levels in the north west of the country (Lower California Sonora Bajio) and is now beginning to develop strongly in other regions



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# Progrès récents du conditionnement en atmosphère modifiée

# New developments in modified atmosphere packaging

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**Recientes progresos en el embalaje en atmosfera modificada**

*El embalaje en atmosfera modificada (MAP) es una tecnologia nueva aparecida en los anos 70 cuvo objetivo es aumentar la duracion de los productos agricolas perecederos Sin embargo si no se respetan las condiciones requeridas esta tecnologia puede representar riesgos respecto a la seguridad biologica de los productos envasados Los filmes perforados permiten al MAP mantener una atmosfera saturada de $H_2O$ con pequenas modificaciones de 0 y CO Esto se traduce por una reduccion de las perdidas de agua y una disminucion del stress hidrico sin riesgos de efectos perjudiciales debidos a los patogenos a la anaerobiosis o al CO*

*La investigacion se ha orientado ultimamente hacia el desarrollo de filmes interactivos o inteligentes Se espera que estos nuevos filmes logren detectar los cambios de medio ambiente al interior del embalaje y como consecuencia que dejen entrar el oxigeno de la atmosfera exterior o que favorezcan la salida del exceso de CO*

*El embalaje en atmosfera modificada combinado a la incorporacion de fungicidas en los filmes el tratamiento al calor etc constituyen para la investigacion vias nuevas y prometedoras La realizacion de modelos matematicos de los intercambios gaseosos en el MAP esta basada en una combinacion de la ley de Fick asociada a la ecuacion de Michaelis Menten Este modelo permite prever los parametros optimos para el embalaje de productos*

**Neue Fortschritte bei der Lagerung in veranderter Atmosphare**

*Die Lagerung in veranderter Atmosphare (MAP) einer neuen in den 70er Jahren entwikkelten Technologie zielt darauf ab die Lebensdauer verderblicher Agrarprodukte zu verlangern Wenn allerdings die angemessenen Bedingungen nicht eingehalten werden kann diese Technologie auch Risiken hinsichtlich der mikrobiologischen Sicherheit der verpackten Lebensmittel mit sich bringen Die perforierten Folien gestatten bei MAP die Aufrechterhaltung einer H 0 gesattigten Atmosphare mit lediglich schwachen Veranderungen bei O und C0' Das außert sich in einer Reduzierung der Wasserverluste und in einer Entlastung von Feuchtestress ohne Risiken schadlicher Einflusse wie etwa Krankheitserregern Anaerobiose oder C0*

*Die Untersuchung richtete sich seit kurzem auf die Entwicklung von interaktiven oder intelligenten Folien Man erwartet von diesen neuen Folien daß sie Milieuveranderungen im Innern der Verpackung bemerken und entsprechend den Sauerstoff der außeren Atmosphare eintreten lassen beziehungsweise uberschussiges C0 austreten lassen*

*Die Lagerung bei veranderter Feuchtigkeit kombiniert mit fungizid behandelten Folien die Warmebehandlung etc stellen neue und fur die Forschung vielversprechende Wege dar Die mathematische Modellrechnung des Gasaustausches im MAP grundet sich auf einer Kombination des Fick schen Gesetzes und der Gleichung von Michaelis Menten Dieses Modell gestattet eine Vorhersage der optimalen Parameter fur die Lagerung*

## INTRODUCTION

Le conditionnement en atmosphere modifiee (MAP) est une technologie nouvelle apparue dans les annees 70 Elle peut permettre d'allonger la duree de vie des produits agricoles perissables et par la de reduire la proportion de produits avaries

Le MAP implique que le produit soit soumis a l atmosphere engendree a l'interieur d un emballage par l interaction du produit de l emballage et de l atmosphere exterieure L atmosphere initiale peut etre soit de l air

## INTRODUCTION

Modified atmosphere packaging (MAP) emerged in the 1970 s as a new technology that may extend the life of perishable agricultural produce and reduce its spoilage and decay

MAP involves the exposure of produce to the atmosphere generated in a package by the interaction of the produce, the package and the external atmosphere The initial atmosphere may be either air



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soit un melange gazeux Avant de fermer l emballage on peut aussi introduire divers additifs pouvant affecter l atmosphere Ce qui distingue le MAP de l atmosphere controlee (CA) c est que dans le cas du MAP toute inter vention humaine cesse des lors que l emballage est ferme

La technologie du MAP comprend un large eventail de techniques, a partir de la simple methode de l enro bage individuel hermetique des debuts (Ben Yehoshua 1985, 1991, Ben Yehoshua et Nahir 1977) ou chaque fruit peut etre considere sous MAP Elle va jusqu au controle beaucoup plus complique de la microatmo sphere dans les nouveaux emballages pour diverses salades de 'quatrieme gamme (voir Brody 1991)

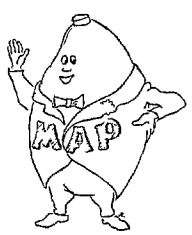
**L enrobage hermetique** consiste a envelopper un fruit dans un film plastique avec ou sans retraction ther mique, pour epouser la forme du fruit Generalement cette technique n'a qu un effet mineur ou nul sur les concentrations internes de O2 et $CO_2$ elle a en revanche un effet marque sur la pression de vapeur d'eau, faisant que l'atmosphere de l'emballage est presque saturee Ben Yehoshua *et al* (1983) ont trouve que l'humidite relative (HR) de l atmosphere etait de 97 % pour des poivrons ainsi conditionnes individuellement L at mosphere du fruit enrobe sous film plastique est la resul tante de nombreux facteurs, les microperforations du film (non voulues) n etant pas le moindre de ces fac teurs Au contraire il est permis de penser que ces micro-perforations jouent un role important dans le succes de cette technique avec nombre de produits

or a gas mixture Different additives that may affect the atmosphere may be introduced into the package before its sealing The main feature distinguishing MAP from controlled atmosphere (CA) is that in the case of MAP the active involvement of man stops at the moment of sealing

MAP technology comprises a wide spectrum of techiques varying from the simple early method of individual seal packaging (Ben Yehoshua 1985 1991 Ben Yehoshua and Nahir 1977) which may be considered as MAP for individual fruit to the more intricate control of the microatmosphere in the new packages for various salad bar items (see Brody 1991)

**Seal-packaging** involves sealing a fruit in a plastics film with or without heat shrinking to conform to the size of the fruit Usually this technique has little or no effect on the internal concentrations of $O_2$ and $CO_2$ and a large effect on the water vapour pressure amounting usually to making the package atmosphere nearly saturated Ben Yehoshua *et al* (1983) found that the relative humidity (RH) of the ambient atmosphere of sealed pepper fruit was 97 % The atmosphere of the sealed fruit is a result of many factors and unintended holes in the film were not the least of them However these minute holes in fact may be an important reason for the success of this technique with many commodities

Nice to meet you




# Mr MAP !

**Dans sa version plus complexe**, le MAP vise a rea liser une composition exacte de l'atmosphere interne de l emballage, par une selection poussee de nombreux parametres utiles et leur orchestration dans le but d ar river rapidement a l atmosphere souhaitee Le choix de ces parametres doit etre prevu de telle sorte que l'at mosphere puisse se maintenir aussi longtemps que le produit emballe l'exige Ce type de MAP est en defini tive contrôle avec plus de minutie que le conditionne ment en atmosphere contrôlee (CA), et avec de bien plus grandes exigences puisqu'il faut programmer tous les controles a l interieur de l emballage avant sa fer meture

Le conditionnement en atmosphere modifiee (MAP) est une technologie multidisciplinaire qui pour conserver la fraîcheur des produits, fait appel aux principes de base de differentes sciences chimie physique physiologie et pathologie vegetales microbiologie agroalimentaire genie et plasturgie Une meilleure connaissance de ce vaste domaine scientifique aidera le MAP a atteindre le stade de l'application pratique

**Intricate MAP** aims at achieving exact composition of the ambient atmosphere of the package by selecting carefully many relevant parameters and orchestrating them harmoniously to achieve the desired atmosphere rapidly The many relevant parameters should be planned so that this atmosphere would be maintained for as long a period as the packaged commodity would require Thus this type of MAP is more carefully controlled than CA and with much greater demands since all the controls have to be programmed into the package before its sealing

MAP is a multidisciplinary technology of maintaining freshness that utilizes basic principles of different sciences such as chemistry physics plant physiology and pathology microbiology, food science engineering and polymer chemistry Better understanding of this wide scope will promote this technology into implementation

Ces dernieres annees, la technologie MAP a connu de rapides developpements (Gorris et Peppelenbos 1992 Kader *et al* 1989 Lioutas 1988) Cette evolution acceleree est due aux deux tendances contradictoires qui aujourd hui caracterisent le traitement apres recolte des fruits, legumes et autres produits perissables

(1) La distribution alimentaire moderne dans les pays industrialises porte sur une quantite de produits peris sables, dont certains font l objet d une transformation minimale laitues decoupees, bâtonnets de carotte ou de celeri salades melangees Même minimale cette preparation accentue la nature perissable des produits ainsi que les risques de pourriture et de dessiccation le besoin en mesures de contrôle de la qualite et de l'etat sanitaire est donc augmente

(2) Parallelement, les consommateurs manifestent une mefiance grandissante a l egard des produits chi miques de synthese utilises pour proteger les aliments des pathogenes et ennemis, ou pour allonger la duree de vie des denrees perissables Cette inquietude du public entraine l'interdiction d'emploi d un nombre tou jours plus grand de conservateurs artificiels et de pesticides

Dans la mesure ou le MAP n utilise que les composants naturels de l'air c est une technologie qui en repon dant a ces deux tendances ne peut que gagner la faveur du public Elle a l avantage de n utiliser aucun produit chimique de synthese et de ne laisser aucun residu toxique Elle est relativement respectueuse de l environnement surtout si les films plastiques peuvent être recycles apres usage

L interet dans le conditionnement MAP des produits frais s est egalement trouve stimule par de recents progres dans la conception et la fabrication de films polymeres presentant une palette elargie de caracteristiques en matiere de diffusion gazeuse Enfin, les divers absorbeurs desormais plus facilement accessibles proposent de nouveaux outils pour manipuler le micro environnement du MAP absorbeurs de $O_2$ et $CO_2$ (Kader *et al* 1989) de vapeur d'eau (Shirazi et Cameron, 1992) de $C_2H_4$ (Ben-Arie et Sonego 1985, Scott *et al* 1970)

Toute une serie d'articles ont ete publies sur l interet du MAP et l allongement extraordinaire de la duree de conservation pour divers produits (voir Lioutas 1988 Kader *et al* 1989) En revanche il n'y a que peu de publi cations qui traitent de la vigilance microbiologique requise pour une mise en œuvre sans faille (Genigeorgis 1985, Hintlian et Hotchkiss 1986 Palumbo 1987) Les travaux futurs devraient sans doute donner priorite a la securite des consommateurs, devant le maintien de la fraîcheur

Cet article de synthese n'a pas la pretention de couvrir tous les aspects traitant de l'emballage sous film plas tique Il n'aborde que quelques domaines, principalement ceux qui ont connu des developpements importants

## PRINCIPES DU CONDITIONNEMENT MAP

Le conditionnement MAP est un systeme dynamique mettant en jeu respiration et permeation Dans la concep tion d'un emballage il convient donc de prendre en compte les facteurs affectant a la fois la respiration et la permeation On sait que la masse de la denree la tem perature, les pressions partielles de $O_2$ $CO_2$ et $C_2H_4$ ainsi que le stade de maturite influent sur la respiration dans l emballage (Kader *et al* 1989) D autre part la per meation est determinee par le type de film d'emballage son epaisseur sa surface des perforations acciden telles ainsi que par la temperature l humidite relative et le gradient des pressions partielles de $CO_2$ et $O_2$ au travers du film (Ashley 1985) Tous ces facteurs inter agissent pour creer des niveaux d equilibre en $CO_2$ et

During past decades, MAP technology developed rapidly (Gorris and Peppelenbos 1992, Kader *et al* 1989 Lioutas 1988) This rapid development is due to two contradictory trends affecting today the postharvest handling of fruit vegetables and other perishable produce

(1) The modern food distribution in developed countries comprises many perishable food items some of which are minimally processed such as shredded lettuce, carrot or celery sticks, fresh salad mixes The minimal processing increases the perishable nature and susceptibility to decay and dessiccation and consequently greater need for quality and decay control measures

(2) The other trend involves the growing anxiety of the consumers against the use of synthetic chemicals in protecting food from pathogens and pests and extending the life of perishable produce One of the consequences of this public anxiety is that more and more synthetic food protectants such as certain fungicide or pesticide are banned for use

The technology of MAP that utilizes only the natural components of air, is in great public favour due to these two trends MAP has the advantages that synthetic chemicals are not used no toxic residue is left and it is relatively environmentally suitable particularly if the plastics films utilized can be recycled

Recent advances in the design and manufacturing of polymeric films with a wide range of gas-diffusion characteristics have also stimulated interests in MAP of fresh produce Also the increased availability of various absorbers of $O_2$, $CO_2$ (Kader *et al* 1989) water vapour (Shirazi and Cameron, 1992), and $C_2H_4$ (Ben-Arie and Sonego 1985, Scott *et al* 1970) provides possible additional tools for manipulating the micro-environment of MAP

Many articles have been published on the benefits of MAP and the dramatic extension of shelf life for various foods (see Lioutas 1988, Kader *et al* 1989) However only few publications deal with the microbiological safety needed for successful MAP implementation (Genigeorgis 1985 Hintlian and Hotchkiss 1986 Palumbo 1987) Future approach should certainly put consumer safety first and freshness second

This review is not intended to cover every published report dealing with packaging produce in plastic films Only a few fields will be discussed mainly those in which important developments have been made

## PRINCIPLES OF MAP

MAP is a dynamic system where respiration and permeation are occuring simultaneously Factors affecting both respiration and permeation must be considered when designing a package Commodity mass, temperature $O_2$, $CO_2$ and ethylene ($C_2H_4$), partial pressures stage of maturity are known to influence respiration in a package (Kader *et al* 1989) Type thickness unintended holes and surface area of the packaging film as well as temperature relative humidity and gradient of $CO_2$ and $O_2$ partial pressures across the film, are known determinants of permeation (Ashley 1985) All of the above factors interact to create equilibrium levels of $CO_2$ and $O_2$ in a sealed package Package equilibrium or steady state is



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$O_2$ dans un emballage hermetiquement clos On definit l etat d equilibre d un emballage comme le point ou les taux de production de $CO_2$ et de consommation d'$O_2$ par la denree emballee sont egaux aux taux de per meation de ces deux gaz au travers du film a une tem perature donnee Un emballage mediocre devient anae robie ou genere des niveaux inacceptables de $CO_2$ avant que l equilibre ne soit atteint En general le MAP ne tire par un parti maximal de toutes les possibilites de controle des concentrations de $CO_2$ et $O_2$ Le systeme d'emballage ideal devrait assurer les equilibres $CO_2/O_2$ et les maintenir aux niveaux connus pour optimiser la conser vation durant l'entreposage le transport et tout au long de la chaine de distribution pour un produit specifique

Lioutas (1988) et Kader *et al* (1989) ont dresse un bon tableau des avantages et inconvenients du MAP Les modalites du MAP ont ete traitees dans le rapport de Kader *et al* (1989), et dans d autres publications de son laboratoire

L'effet favorable le plus frequemment cite est le chan gement de pH lie a la concentration en $CO_2$ (Daniels *et al* 1985, Siriphanich et Kader 1986)

defined as the point at which the commodity $CO_2$ production and $O_2$ consumption rates are equal to the permeation rates of the respective gases through a package at a given temperature A poorly designed package will become anaerobic or develop unacceptable levels of $CO_2$ before equilibrium is achieved Usually MAP does not utilize the full potential of controlling the ambient concentrations of $O_2$ and $CO_2$ An ideal package system will equilibrate and maintain at the levels of $CO_2$ and $O_2$ that are known to be optimal for storage transport and throughout the market chain of a specific commodity

The beneficial and detrimental effects of MAP were well reviewed by Lioutas (1988) and Kader *et al* (1989) The mode of MAP was handled in the review of Kader *et al* (1989), as well as in other publications of his team

The mechanism cited most for the favourable result is the change in pH related to the concentration of $CO_2$ (Daniels *et al* 1985 Siriphanich and Kader 1986)

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**Avantages**

- Pertes de poids, dessiccation et dessechement reduits
- Maturation retardee
- Degâts du froid moins severes
- Possibilite de conditionnement semi centralise
- Rayon des reseaux de distribution augmente
- Moins de travail et moins de refus au stade du detail
- Conservation amelioree de la couleur de la teneur en eau, du parfum et de la maturite
- Excellentes aptitudes aux politiques de marque
- Manutention et distribution limitees des produits impropres ou declasses
- Benefices de la qualite transmis au consommateur

**Inconvenients**

- Exigence d'investissements supplementaires en machines et personnel sur la ligne d'emballage
- Risques d avarie de produits en cas de conditionnement inadapte ou de temperatures abusives
- Apparition possible de nouveaux risques microbio logiques dus au developpement eventuel d une flore pathogene anaerobie
- Impact negatif des films plastiques sur l environne ment en l'absence du moins d'un systeme de recy clage efficace
- La technologie MAP reste encore inapplicable a la majorite des produits

**Advantages**

- Reduction of weight loss, desiccation and shrivelling
- Delay of ripening
- Alleviation of chilling injury
- Semicentralized manufacturing options
- Expanded radius of distribution systems
- Reduction of labour and waste at the retail level
- Quality advantages such as colour moisture flavour and maturity retention
- Excellent branding options
- Reduction of handling and distribution of unwanted or low-grade produce
- Quality advantages transferred to the consumer

**Disadvantages**

- Requirement of additional investment in machinery and labour in the packaging line
- Risks of spoiled produce due to improper packaging or temperature abuse
- Possible occurence of new risks of microbiological safety due to possible development of anaerobic pathogenic flora
- Plastics films may be environmentally undesirable unless effective recycling is installed
- MAP technology is still unavailable for most produce

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## MAP ET ETAT SANITAIRE

Il est possible de freiner la croissance et l activite des micro-organismes en augmentant le $CO_2$ et en dimi nuant l $O_2$ Des teneurs en $CO_2$ portees jusqu a 20 % allongent à la fois les phases de latence et de croissance logarithmique des agents communs de degradation jusqu'a les doubler par rapport a la temperature ambiante (Daniels *et al* 1985) Il faut des teneurs de $O_2$ inferieures a 1 % et de $CO_2$ superieures a 20 % pour interdire de façon significative l activite cryptogamique (El Goorani et Sommer 1981) On peut utiliser des teneurs elevees en $CO_2$ (10 15 %) afin d'assurer un effet fongistatique sur les denrees tolerant de tels niveaux de $CO_2$ (Kader *et al* 1989)

## EFFECTS OF MAP ON DISEASE CONTROL

The growth and activity of micro organisms can be retarded by elevated $CO_2$ and reduced $O_2$ concentrations Levels of up to 20 % $CO_2$ extend both the lag and logarithmic growth phases of common spoilage organisms by as much as double at ambient temperature (Daniels *et al* 1985) Levels of below 1% oxygen and/or above 10 % $CO_2$ are needed to significantly suppress fungal growth (El Goorani and Sommer 1981) Elevated $CO_2$ levels (10 to 15 %) can be used to provide fungistatic effects on commodities that tolerate such $CO_2$ (Kader *et al* 1989)

Un renforcement du $CO_2$ et une diminution de l'$O_2$ permettent de freiner la croissance de la quasi totalite des micro organismes aerobies, en particulier les psychrophiles (Barkai-Golan 1990 Daniels *et al* 1985) Comme ces micro-organismes psychrophiles sont largement responsables de la deterioration des produits frais et de quatrieme gamme" il est evidemment tres souhaitable de bloquer leur activite

L'enrobage individuel hermetique sous film plastique entrave la pourriture du fruit en prevenant toute infection secondaire le fait est d'importance surtout pour les fruits destines a un entreposage ou une expedition a long terme Il suffit d'un seul fruit atteint de *Botrytis, Geotrichum* ou *Phytophthora* pour provoquer a bref delai la pourriture de l'ensemble des fruits du carton Ce mode d'enrobage hermetique ou le MAP modifient egalement la repartition des pathogenes chez les agrumes En general on releve un peu plus d alternariose et moins de moisissure que sur les agrumes non hermetiquement emballes Les pathogenes, notamment ceux qui sont en etat de quiescence commencent en regle generale a se developper rapidement dans l'atmosphere humide C'est pourquoi l'equilibre entre hôte et pathogenes peut par moments pencher en faveur de ces derniers, avec une augmentation du taux de pourriture Il est donc de la plus haute importance d'assurer un contrôle approprie des pourritures sur les fruits hermetiquement emballes (Ben-Yehoshua 1991)

Le conditionnement MAP peut parfois se reveler incapable d assurer a lui seul un tel contrôle Il faut donc envisager des methodes de lutte complementaires L enrobage d Oroblanco ( Sweetie ) sous film polyoefine «Cryovac MD» combine avec un traitement a l eau chaude parvient a reduire la pourriture en même temps que la sensibilite aux degats du froid La combinaison de l enrobage hermetique et de l application de chaleur (36°C 3 jours) se traduit par la diminution des pourritures, de la sensibilite aux degats du froid et des cicatrices et par l'allongement de la duree de vie des agrumes On a demontre que le mode d'action du traitement a la chaleur consistait en

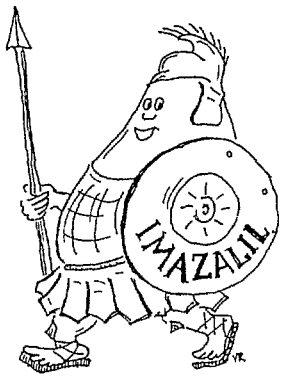
- une inhibition thermique du pathogene,
- l'induction de la synthese de materiaux de type lignine etablissant un rempart mecanique face a l'invasion des pathogenes,
- la prevention de la degradation des substances antifongiques preexistantes

The growth of almost all aerobic micro-organisms, particularly the psychrophilic, can be retarded by elevated $CO_2$ and the reduction of $O_2$ levels (Barkai-Golan 1990, Daniels *et al* 1985) Since a significant cause of deterioration of fresh and minimally processed produce is the action of psychrophilic micro organisms retardation of their growth is highly desirable

Individual seal-packaging reduced fruit decay by prevention of secondary rot infection which is an important factor for fruits, particularly for those destined for longterm storage or shipment An individual fruit infected by *Botrytis, Geotrichum* or *Phytophthora* induces decay in the other fruit in the same carton at a rapid rate Seal packaging or MAP also changed the distribution of pathogens in citrus Sealed fruit generally had slightly more *Alternaria* stem-end rot and fewer moulds than those not seal packaged The pathogens particularly quiescent ones, generally start to develop rapidly in the humid atmosphere Consequently, the balance between host and pathogens may, at times, favour the pathogen, and decay percentage rises For this reason adequate decay control of sealed fruit may be of paramount importance (Ben-Yehoshua 1991)

MAP by itself sometimes may not be effective enough to control decay Thus, additional methods to combat diseases in packages should be sought Sealing in polyolefin «Cryovac MD» film of Oroblanco citrus fruit ( Sweetie ) combined with hot water treatment achieved both reduction of decay as well as the sensitivity to chilling injury Combination of seal packaging and curing (36°C 3 days) reduced decay and sensitivity to chilling injury, healed injury and extended the life of citrus fruits The mode of action of curing was shown to be

- thermic inhibition of the pathogen
- induced synthesis of lignin like materials which form a mechanical barrier to the invasion of the pathogens
- preventing the degradation of the preformed antifungal substances




La combinaison d'un traitement a l'imazalil et de l'en robage hermetique des agrumes et poivrons permet une reduction marquee des pourritures On peut appliquer l'imazalil de plusieurs façons trempage, pulverisation ou, depuis peu, par incorporation du fongicide dans le film plastique Celui ci sert alors de reservoir et libere peu a peu le fongicide, ce qui minimise les residus sur les fruits (Ben Yehoshua et Nahir 1977 Ben Yehoshua *et al* 1987, Miller et Risse 1988)

Le film joue ainsi un rôle de barriere physique, ralen tissant la dissipation des fongicides volatiles, comme l imazalil, le 2-aminobutane et le diphenyl C'est ainsi qu'on peut enrichir a l aide d'un fongicide volatile appro prie la micro atmosphere formee par le conditionnement MAP l enceinte hermetique devient alors une sorte de chambre de fumigation capable de lutter contre les pour ritures sur de longues periodes Une telle methode pour rait s averer d un grand interet pour lutter contre les patho genes provoquant des necroses et taches apicales ces pathogenes en effet sont profondement installes dans le pericarpe sous la cicatrice pedonculaire, point diffi cile a atteindre avec des fongicides

Combined imazalil treatment and seal packaging of citrus and pepper fruits enabled a marked reduction of decay The imazalil could be applied in several ways either as a dip or as a spray or in a novel way, i e , incorporation of the imazalil into the plastics films The films serve as a reservoir that gradually release the fungicide to the produce, thus reducing the residues on the produce (Ben-Yehoshua and Nahir 1977 Ben-Yehoshua *et al* 1987 Miller and Risse 1988)

The film acts also as a physical barrier to slow the dissipation of volatile fungicides such as imazalil 2 aminobutane and diphenyl MAP thereby produces a micro atmosphere that can be enriched with a suitable volatile fungicide so that the sealed enclosure forms a fumigation chamber to control decay over a prolonged period Such action might be of great importance in controlling the pathogens that cause stem-end rot These pathogens are located deep in the fruit tissue below the button a site difficult to reach with fungicides

## MAP RISQUES A EVITER

Les fruits et legumes hebergent une microflore complexe, comprenant des micro organismes de types mul tiples mais dont la plupart contribuent a avarier les den rees, tout en restant sans danger pour l'homme Les micro organismes redoutables pour l'homme sont en effet incapables de se multiplier a un niveau critique, car ils subissent la concurrence de ceux qui s'attaquent aux matieres vegetales Cependant, ce rapport de forces peut fort bien être altere lorsque le MAP modifie le micro milieu perçu par les micro organismes Un cas de deve loppement de toxines dans du chou hache a motive une etude de la Food and Drug Administration des Etats Unis d'Amerique celle-ci a demontre que la toxine pou vait se developper en presence de niveaux suffisants d'inoculum et de temperature sur une periode suffisante (voir Brody 1991)

Combine au froid le MAP ralentit la croissance des micro organismes nuisibles qui en majorite mesophiles, croissent le mieux entre 20 et 40°C, le MAP etouffe donc leur competitivite Mais les pathogenes psychrophiles comme *Yersinia enterocolitica, Listeria monocytogenes, Aeromonas hydrophilia* et *Clostridium botulinum* qui s'accommodent de temperatures basses (jusqu'a 3 5°C) peuvent alors trouver l occasion de proliferer (Hintlian et Hotchkiss 1986 Palumbo 1987) En cas de temperatures inappropriees même les pathogenes mesophiles comme *Staphylococcus aureus Bacillus cereus Salmonella* spp et *Vibrio parahaemolyticus* sont susceptibles d une rapide multiplication surtout sur viandes, poissons et produits laitiers (Brody 1988 Genigeorgis 1985 Hintlian et Hotchkiss 1986, Palumbo 1987)

## RISKS IN UTILIZING MAP

Fruits and vegetables are characterized by an elaborate microflora consisting of many different types of micro-organisms, most of which are involved in the spoilage of produce but are harmless to humans Micro organisms that are dangerous to humans usually cannot establish a dangerous population density because they have to compete with the spoilage and other microflora However, MAP changes the micro environment perceived by the micro organisms and may well impair this balance One incidence of the growth of such toxins in shredded cabbage led to a study of the Food and Drug Administration of the United States of America demonstrating that the toxin could be developed if a high enough inoculum and temperature were present for enough time (see Brody 1991)

Refrigerated MAP slows the growth of the spoilage flora most of which are mesophiles and grow best at temperatures between 20 and 40°C, and reduces their competitive capacity Psychrophylic pathogens like *Yersinia enterocolitica Listeria monocytogenes Aeromonas hydrophilia* and *Clostridium botulinum* which are able to grow at temperatures as low as 3 to 5°C, may then get a chance to proliferate (Hintlian and Hotchkiss 1986 Palumbo 1987) If inappropriate temperatures are used even mesophylic pathogens such as *Staphylococcus aureus Bacillus cereus Salmonella* spp and *Vibrio parahaemolyticus* may develop rapidly especially on meat fish or dairy products (Brody 1988 Genigeorgis 1985 Hintlian and Hotchkiss 1986 Palumbo 1987)

L'absence d $O_2$ cree des conditions favorables aux micro organismes anaerobies, dont certains pathogenes En outre, en interdisant toute vie microbienne aerobie la concurrence exercee sur les anaerobies se trouve estompee leur offrant alors des conditions presque ideales lorsque la temperature depasse 4°C qu il y a presence de spores et que l operation dure assez long temps

Il est encore possible de supprimer les aerobies par un traitement a chaleur moyenne, c est a-dire par une pasteurisation qui couplee avec un taux d $O_2$ bas peut creer un milieu ideal pour la croissance des anaerobies la chaleur reste l'unique defense contre leur croissance et la formation de toxines

La variante MAP s accompagnant d'un traitement a moyenne chaleur, meme si elle est hautement efficace du point de vue de la retention de la qualite peut donc comporter des risques dans une perspective de secu rite microbiologique La situation s aggrave quand les regles d'hygiene de base et de controle ne sont pas res pectees La forte contamination de legumes frais par pathogenes anaerobies dans des chantiers de 'qua trieme gamme sans discipline sanitaire constituerait un exemple denonçant l abus de stress microbiologique aux produits de quatrieme gamme et illustrerait le besoin d'integrer de multiples disciplines pour atteindre les resultats souhaites Il y a en definitive de bonnes raisons pour essayer de maintenir un certain niveau de $O_2$ autour de la denree emballee Des travaux recents sur les mate riaux d'emballage visent precisement a surmonter le pro bleme de la carence en $O_2$ (Cameron 1989, 1993)

Une note apaisante toutefois il faut souligner l'ab sence quasi absolue d'empoisonnements par fruits et legumes conditionnes MAP au cours de la periode courte il est vrai ou ce procede a ete applique Il conviendrait enfin d'etudier les effets du conditionnement MAP sur les micro organismes qui sont antagonistes aux micro organismes pathogenes

## MAP - APPLICATION AUX FRUITS ET LEGUMES

Geeson (1988), Zagory *et al* (1988) Kader *et al* (1989) Prince (1989) ainsi que Gorris et Peppelenbos (1992) ont passe en revue le conditionnement MAP des fruits et legumes Ben Yehoshua (1991) a de son cote fait le point sur l'enrobage hermetique

Les films plastiques les plus communement utilises pour les fruits et legumes sont PEbd, PEbd lineaire, PEhd et PVC On a experimente ces derniers temps divers films destines a minimiser l'anaerobiose respira toire et les risques d ordre microbiologique (voir Brody 1991)

En depit des multiples avantages de l enrobage her metique son adoption a ete assez lente dans les pays ou l on doit passer par la mecanisation des operations La technique n a donc pas atteint tout son potentiel d ap plication Le manque de machines a haut rendement mais d un coût raisonnable et le prix du film sont probablement les raisons majeures qui freinent son application a grande echelle En Chine et au Japon en revanche ou l enrobage sous film plastique est realise a la main la technique a ete rapidement adoptee En fait le Professeur Huang Bangyan de l Academie des Sciences Guangzhou, a declare que l enrobage her metique est devenu une technique usuelle pour la conser vation des agrumes en Chine reduisant les pertes apres recolte et revelant une bonne efficacite economique (communication personnelle) Kawada et Kitagawa (1988) ont rendu compte de l utilisation actuelle des films plastiques dans la conservation des agrumes et autres fruits au Japon Ils ont soutenu que le film plastique est l un des outils les plus puissants et economiques pour

An absence of $O_2$ creates conditions for the growth of anaerobic micro organisms some of which may be pathogenic Furthermore, by supressing aerobic microbial growth, competition for anaerobes is diminished, leaving almost ideal conditions for anaerobes when the temperature is above 4°C, if the spores are present, and if enough time is allowed

Aerobes may also be suppressed by mild heat, i e pasteurization or heat filling, which coupled with low oxygen, can create an ideal anaerobic growth environment with only temperature as the barrier to prevent vegetation, growth and toxin formation

Thus, a variant of MAP with mild heat – which is highly beneficial from a quality retention perspective – can create a condition of potential hazard – a subject of concern from a microbiological safety perspective The situation is aggravated when the basic rules of sanitation and control are violated Contamination of fresh vegetables with large loads of pathogenic anaerobes in unsanitary minimal processing operations would be an example of applying undue microbiological stress to minimally processed produce – another instance of the need to integrate multiple related disciplines to achieve the desired benefits Thus good reason exists to attempt to maintain some level of $O_2$ in proximity to the packaged food Recent packaging material developments are directed towards overcoming the problem of $O_2$ starvation (Cameron 1989 1993)

However, as a soothing remark one must point out to the almost absence of reported poisoning by fruits and vegetables in MAP throughout the recent period in which MAP is already in use The effects of MAP on these micro organisms that are antagonistic to the pathogenic micro organisms should be studied

## MAP APPLICATION FOR FRUITS AND VEGETABLES

MAP of fruits and vegetable was well reviewed by Geeson (1988), Zagory *et al* (1988), Kader *et al* (1989) Prince (1989) and Gorris and Peppelenbos (1992) A special subject of seal-packaging was summarized by Ben-Yehoshua (1991)

Most common plastics films utilized for fruits and vegetables are LDPE linear LDPE HDPE and PVC Recently various new films were used to minimise respiratory anaerobiosis and potential microbiological hazards (see Brody 1991)

Despite many advantages of seal-packaging adoption of this technique has been rather slow in countries dependent on machinery to apply it, and the technique has not yet reached its full potential Possibly the lack of available fast and reasonably-priced equipment as well as the cost of the film are the main reasons limiting the commercial adoption of seal packaging However in China and Japan where the film packaging is applied by hand this technique has been adopted rapidly In fact Professor Huang Bangyan from the Chinese Academy of Science Guangzhou reported that seal-packaging has become a common new technique for citrus fruit storage in China and its application has reduced the postharvest losses and resulted in good economic effectiveness (personal communication) Kawada and Kitagawa (1988) reviewed the current use of plastics film in the storage of citrus and other fruits in Japan They maintained that plastics film is one of the most powerful and economical tools to minimize the weight loss and when several factors are refined it can prolong the life

minimiser les pertes de poids et pour lorsque l'on affine plusieurs facteurs allonger la duree de vie grace a l effet d'atmosphere contrôlee Ces dernieres annees l emploi des films plastiques dans l emballage des denrees ali mentaires a connu une forte expansion en raison non seulement des vifs progres dans la conception des films et la technologie de l'emballage mais aussi des evolu tions dans la commercialisation

On trouve sur les rayons des supermarches nombre de fruits et legumes sous enrobage plastique herme- tique Pourtant, dans bien des cas, cet enrobage est rea lise juste avant la presentation et non pas au moment souhaitable, juste apres la recolte Le conditionnement MAP presente un grand interêt pour les pays en deve loppement, car les operations peuvent y etre effectuees manuellement, sans les coûts qu impliquerait l'emploi de machines nouvelles En outre le manque d'entrepots frigorifiques adaptes accentue dans ces pays l'interet d'une telle technique

On a recemment conditionne sous MAP, de façon her metique, toute une gamme de produits pommes (Geeson et Smith 1989) asperge (Aharoni *et al* 1990) poivron (Rodov *et al*), myrtilles (Beaudry *et al* 1992, Cameron *et al* 1993), brocoli (Aharoni *et al* 1985), petits fruits (Kader *et al* 1989), concombre (Ben Yehoshua *et al* 1978), auber gines (Temkin-Gorodeiski *et al* 1990) herbes condimen taires (Aharoni *et al* 1989), goyaves (Combrink *et al* 1990) kiwis (Ben Arie et Sonego 1985), laitues (Ben-Yehoshua *et al* 1967), mangues (Rodov *et al*) champignons (Burton *et al* 1987) melons brodes (Lester et Bruton 1986) poires (Geeson *et al* 1991) kakis (Ben-Arie et Zutkhi 1992 Pesis *et al* 1986) fraises (voir Kader *et al* 1989) tomates (Shirazi et Cameron 1992), ainsi que d'autres denrees (voir la monographie de Kader *et al* 1989)

Il semble que la mise sous emballage plastique her metique sans contrôle complexe des concentrations ambiantes reste l'application commerciale majeure du MAP Il est toutefois permis de penser que l'avenir appor tera une maitrise plus elaboree de $O_2$ et $CO_2$

On a conditionne avec succes sous film co-extrude EVA/PEbd de la laitue lavee evidee, paree et prede

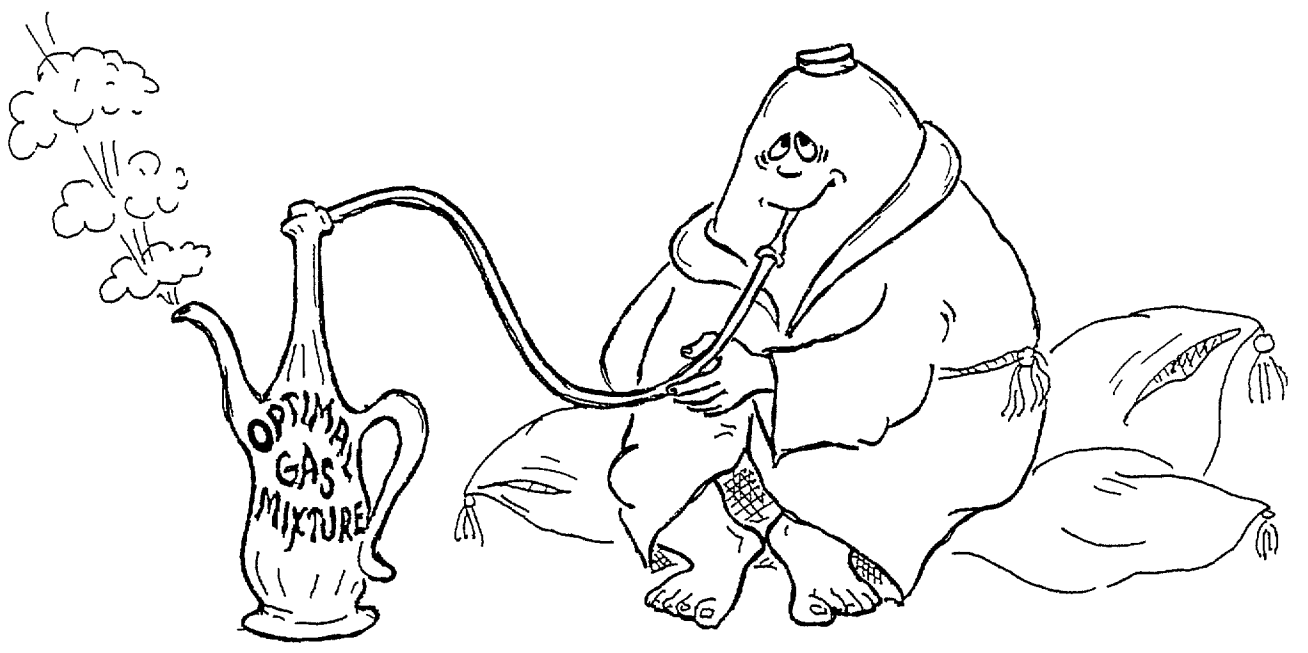
by the controlled atmosphere effect In recent years the use of plastics film in produce packaging has increased greatly This is due mainly to the rapid development of new films and packaging technology together with changes in produce marketing

Sealed produce is usually available on the shelves of supermarkets for many fruits and vegetables However this sealing was applied in many cases just before its display in the supermarket but not at the desirable location just after harvest MAP has great advantages in developing countries due to the fact the operation there is carried out manually which saves a large cost of new machinery Additionally the need there for such technique is much greater because of the lack of adequate refrigerated storage

Recently, more items were sealed in MAP such as apples (Geeson and Smith 1989), asparagus (Aharoni *et al* 1990) bell pepper (Rodov *et al*) blueberries (Beaudry *et al* 1992, Cameron *et al* 1993), brocoli (Aharoni *et al* 1985) bush berries (Kader *et al* 1989) cucumbers (Ben Yehoshua *et al*, 1978) aubergines (Temkin Gorodeiski *et al* 1990) fresh herbs (Aharoni *et al* 1989), guava (Combrink *et al* 1990) kiwifruit (Ben Arie and Sonego 1985) lettuce (Ben Yehoshua *et al* 1967) mangoes (Rodov *et al*) mushrooms (Burton *et al* 1987), muskmelons (Lester and Bruton 1986), pear (Geeson *et al* 1991), persimmon (Ben Arie and Zutkhi 1992 Pesis *et al* 1986), strawberries (see Kader *et al* 1989), tomatoes (Shirazi and Cameron 1992) and other commodities (Kader *et al* 1989)

It appears that sealing produce in plastics film without the intricate controls of its ambient concentrations are still the major commercial application of MAP It is expected that the future may bring more intricate controls of $O_2$ and $CO_2$ into practice

Cleaned and cored, trimmed and precut lettuce were successfully packaged by using co extruded




*Dessins de Victor Rodov*

*Sketches by Victor Rodov*

dernier faisant l'objet d'une couverture mediatique importante Une charge minerale inorganique et inerte telle que carbonate de calcium pulverise ou talc est melangee au polymere Cette charge encapsulee en particules tenues par le polymere, lui confere toutes sortes de proprietes, comme la rigidite

## EFFETS DES PERFORATIONS

Les films perfores permettent au conditionnement MAP d'atteindre la saturation en $H_2O$ avec des teneurs faiblement modifiees en $O_2$ $CO_2$ et $C_2H_4$ (Geeson 1989, Ben-Yehoshua 1995) On peut expliquer le phenomene par le nombre de molecules impliquees dans les echanges gazeux du poivron Un kg de poivrons degage 79 x $10^{20}$ molecules de $H_2O$ et 3 0 x $10^{20}$ molecules de $CO_2$, tandis qu'il consomme 3,0 x $10^{20}$ molecules de $O_2$ par heure, a 17°C et 85 p cent HR Pour chaque molecule de $O_2$ ou de $CO_2$, 26 molecules de $H_2O$ sont donc disponibles pour l echange En outre l'acces de ces molecules aux pores est similaire et les poids moleculaires de ces gaz qui determine leur degre relatif de mouvement, sont relativement proches En consequence bien que la majorite des molecules qui s echappent sont $H_2O$ le grand nombre de molecules $H_2O$ disponibles permet a la HR ambiante d être pratiquement saturee Les pores empechent cependant des changements marques dans les concentrations de $O_2$ et $CO_2$, tout en permettant l echange des molecules $O_2$ et $CO_2$ disponibles en nombre relativement limite

Les bons resultats de l emballage hermetique doivent beaucoup a la perforation reduction des pertes d'eau et allegement du stress hydrique mais sans les effets nocifs de l'anaerobiose, tels qu'odeurs, fermentations ou degats du $CO_2$ La perforation a d'ailleurs permis de realiser le conditionnement hermetique de mangues 'Tommy Atkins' et 'Keitt' avec les avantages du procede mais sans inhibition de la maturation comme c'est le cas pour les fruits enrobes sous film non perfore (Rodov *et al*) La technique d'emballage sous film microperfore a egalement fait ses preuves pour retarder la deterioration de plusieurs denrees par exemple en freinant la decoloration des panais laves ou en ameliorant la retention du sucre chez le mais doux (Geeson *et al* 1988) La perforation permet d ailleurs d'appliquer le conditionnement MAP a des denrees a forte respiration comme les champignons (Bruton *et al* 1987) ainsi qu a des denrees qui sont sensibles meme a des changements minimes des concentrations en $O_2$, $CO_2$ et $C_2H_4$

## MODELISATION DE L'EMBALLAGE

Afin de reduire le temps necessaire a la mise au point d'un emballage il est evidemment tres souhaitable de faire appel a un modele mathematique substituant a la methode par approches ("Pack an Pray") une recherche previsionnelle programmee dans le but de definir le film plastique le mieux adapte a telle denree Des modeles mathematiques fondes sur les caracteristiques des films requis pour etablir ou maintenir des concentrations internes optimales seraient d un grand secours pour maximiser la duree de vie des produits perissables Ils seraient particulierement utiles aux fabricants et aux utilisateurs pour evaluer et definir des priorites dans le choix le developpement et la synthese des films d'emballage Plusieurs modeles de ce type ont fait recemment l'objet de publications (Cameron *et al* 1989 Emond *et al* 1991, Mannapperuma *et al* 1989, Lee *et al* 1991) modeles fondes sur les travaux anterieurs de chercheurs cites par les auteurs

with the latter receiving major media coverage In this type of material the plastics polymer is admixed with an inert inorganic mineral such as crushed calcium carbonate or talc The mineral fill is encapsulated in discrete particulates by the polymer and imparts a variety of properties such as stiffness

## PERFORATIONS EFFECTS

Perforated films enable MAP that allows the build up of $H_2O$-saturation with only a slight change in $O_2$ $CO_2$ and $C_2H_4$ (Geeson 1989 Ben Yehoshua 1995) These facts may be explained by considering the number of relevant molecules in gas exchanges of bell-pepper fruit One kg of pepper evolves 79 x $10^{20}$ molecules of $H_2O$ and 3 0 x $10^{20}$ molecules of $CO_2$, and consumes 3 0 x $10^{20}$ molecules of $O_2$ per hour at 17°C and 85 p cent HR Thus, for each molecule of $CO_2$ or $O_2$, 26 molecules of $H_2O$ are available for exhange Furthermore the access of each one of these molecules to the pores is similar and the molecular weight of these gases which determines their relative rate of movement is also relatively similar Consequently, although most of the molecules moving out are those of water, the large number of water molecules available for movement still allows the build up of the ambient RH to almost complete saturation However these pores are able to allow the relative small number of $O_2$ and $CO_2$ available for movement to be exhanged so that the pores prevent marked changes in the concentrations of $O_2$ and $CO_2$

Perforation allows many of the good results of the sealing in reduction of water loss and alleviation of water stress without the possible deleterious effects of anaerobiosis such as off-flavours fermentation or $CO_2$ damage Furthermore, perforation of polyolefin film enabled achieving some of the advantages of seal-packaging of 'Tommy Atkins' and Keitt' mango fruits without inhibiting the ripening process that occurs in sealed fruit that was not perforated as shown by Rodov *et al* Micro-perforated packaging techniques have also proved effective in retarding deterioration in several other crops e g discolouration of washed parships, and improving sugar retention in sweetcorn (Geeson *et al* 1988) Additionally perforation enables MAP to be used for highly respiring produce such as mushrooms (Bruton *et al* 1987) Perforation may also allow MAP to be used for produce that is sensitive even for small changes in concentrations of $O_2$, $CO_2$ and $C_2H_4$

## PACKAGING MODELLING

In order to reduce the time in developing a package, the use of a packaging parameter prediction i e mathematical model, is highly desirable Such a model may substitute the method of «Pack and Pray» with a planned and programmed research attempting to match the best film to the commodity Mathematical models based on the characteritics of films needed to generate or maintain optimum internal concentrations of metabolic gases would help greatly to maximise storage life of perishable produce Such information would be valuable to manufacturers and users of films by helping them to assess and establish priorities in the selection, development, and synthesis of packaging materials Recently several models of this system were discussed by far in the literature (Cameron *et al* 1989, Emond *et al* 1991 Mannapperuma *et al* 1989, Lee *et al* 1991) All these models are based on early work of several researchs who are cited by these authors



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Le premier pas dans la modelisation d un systeme d emballage consiste a trouver des equations mathematiques capables de decrire assez fidelement les processus de respiration et de permeation La plupart des modeles considerent la permeabilite du film aux gaz comme un phenomene physique obeissant a la Loi de Fick le taux des echanges de matieres entre les atmospheres interne et externe est proportionnel a la difference de concentration entre les deux compartiments

Mannapperuma *et al* (1988) ont propose un modele pour le conditionnement MAP en conditions d'equilibre Ils ont montre que dans ce cas existe une relation lineaire entre les concentrations $O_2$ et $CO_2$, qui est soumise a un coefficient respiratoire constant

Lee *et al* (1991) ont ete les premiers a considerer la respiration comme un phenomene biochimique en termes de cinetique des enzymes Supposant que le $CO_2$ joue un role d'inhibition de la reaction enzymatique, ils ont utilise l'equation du mecanisme d'inhibition (sans concurrence), le taux de reaction (r) etant alors

The first basic step in modelling the packaging system is to find mathematical equations which could adequately describe the processes of respiration and permeation The package permeability to the gases is treated in most models as a physical process which obeys Fick's Law i e the rate of material exchange between the internal and external atmospheres is proportional to the concentration difference in these two compartments

Mannapperuma *et al* (1988) developed a model for MAP in equilibrium conditions and showed that in this case there is a linear relation between oxygen and $CO_2$ concentrations subject to a constant respiratory quotient

Lee *et al* (1991) were the first who in MAP modelling treated respiration as a biochemical phenomenom in terms of enzyme kinetics They assumed that $CO_2$ plays a role of inhibitor of the enzymatic reaction and used the equation for uncompetitive inhibition mechanism In this case, the rate of reaction (r) is equal to

$$r = V_m C_1 / [K_M + C_1 (1 + C_2/K_i)]$$

ou $C_1$ est la concentration du substrat ($O_2$ en l'occurrence, s'agissant de respiration),

$V_m$ et $K_M$ sont des parametres de la cinetique classique de Michaelis-Menten $V_m$ etant le taux maximal de reaction enzymatique et $K_M$ la constante de Michaelis,

$C_2$ est la concentration de l inhibiteur ($CO_2$, dans le cas de respiration) et K est la constante d'equilibre entre le complexe enzyme - substrat - inhibiteur et l inhibiteur libre

Combinant cette equation avec la Loi de Fick pour la permeation de $O_2$ et $CO_2$ ils ont obtenu une serie d'equations differentielles, representant le modele mathematique pour le systeme en atmosphere modifiee A partir des valeurs des parametres $V_m$, $K_M$ et K, obtenus par voie experimentale, ils ont ensuite procede au calcul numerique des equations

Cameron *et al* (1993), utiliserent une simple equation de Michaelis Menten sans inhibition ($K_i = 0$) mais greferent une dependance exponentielle sur les parametres $V_m$ et $K_M$, afin de suivre les concentrations $O_2$ et $CO_2$ en fonction de la temperature Leur but etait de prevoir les conditions donnant naissance a une atmosphere anaerobie dans l'emballage

Fishman Rodov et Ben Yehoshua (1995, 1996) ont explore un modele dynamique fonde a la fois sur la Loi de Fick et l'equation de Michaelis Menten Selon les previsions du modele pour la plupart des films plastiques l evolution du $CO_2$, dans le temps ne conduit pas de façon reguliere vers l'etat stable, mais passe par un maximum avant de redescendre a son equilibre (effet de depassement) L'experimentation a confirme ce phenomene Ce pic peut derouter les scientifiques dans leur recherche des conditions d equilibre, ce qui est indispensable dans les travaux de modelisation C'est pourquoi, dans toute etude MAP sur les conditions d'equilibre, il convient d'avoir a l'esprit que le systeme MAP peut traverser une longue periode transitoire et que la concentration en $CO_2$, excede pour un temps son niveau d'equilibre L'ecart entre la concentration de $CO_2$ maximale et l'equilibre depend des parametres numeriques du systeme On a montre que les previsions de ce modele au regard de $O_2$ et $CO_2$ s averaient correctes

where $C_1$ is the substrate concentration (which is $O_2$ concentration in the case of respiration)

$V_m$ and $K_M$ are parameters of the classical Michaelis-Menten kinetics $V_m$ being the maximal rate of enzymatic reaction and $K_M$ the Michaelis constant,

$C_2$ is the inhibitor concentration ($CO_2$ concentration in the case of respiration) and K is the constant of equilibrium between the enzyme-substrate inhibitor complex and free inhibitor

Combining this equation with Fick s Law for $O_2$ and $CO_2$ permeation, they obtained a set of differential equations which represents the mathematical model for the modified atmosphere system They estimated parameters of this model ($V_m$ $K_M$ and $K_i$) from experimental data and then performed numerical calculation of the equations

Cameron *et al* (1993) used a simple Michaelis Menten equation with no inhibition ($K = 0$) and introduced exponential dependence into parameters $V_m$ and $K_M$ to study $O_2$ ans $CO_2$ concentration in MAP as functions of temperature They were trying to predict the conditions in which an anaerobic atmosphere would exist in the package

Fishman, Rodov and Ben-Yehoshua (1995-1996) investigated a dynamic model for MAP based on Fick's law and the Michaelis Menten equation According to the model prediction the $CO_2$ time course for most plastics films does not reach a steady state smoothly but undergoes a maximum and then declines to its equilibrium (the overshooting effect) This phenomenon was confirmed experimentally This maximum may mislead researchers searching for the equilibrium conditions which is necessary in model studies Accordingly, in a MAP study of the equilibrium conditions, consideration should be given to this fact that for considerable time the MAP system may be in the transient period and the $CO_2$ concentration temporarily exceeds that of the equilibrium The increment between maximum and equilibrium state of $CO_2$ concentrations depends on the numerical parameters of the system The predictions of this model regarding $O_2$ and $CO_2$ were found to be correct



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Ce modele, conçu pour verifier les effets de la perforation sur les concentrations de $O_2$ $CO_2$ et $H_2O$ a demontre que dans un plateau contenant 4 poivrons avec une perforation de 0,25 mm, la HR etait pratiquement a saturation tandis que les concentrations de $O_2$ et $CO_2$ restaient proches de celles de l'air

Their model was designed to check effects of perforation on the concentrations of $O_2$, $CO_2$ and $H_2O$ The model showed that in a tray holding 4 pepper fruit with a hole of 0 25 mm the RH was nearly saturated but the concentrations of $O_2$ et $CO_2$ were close to that in air

## APPEL AUX PRODUCTEURS DE RESINES ET AUX FABRICANTS DE FILMS PLASTIQUE

Le conditionnement en atmosphere modifiee (MAP) est une technique promise a une forte expansion, notamment dans le secteur des fruits et legumes

Son developpement cependant requiert non seulement la poursuite des recherches en physiologie apres recolte, mais aussi une connaissance plus complete des materiaux plastique capables d'assurer une meilleure maitrise des concentrations gazeuses

Si votre gamme de produits comprend des matieres ou des films presentant une haute permeabilite aux gaz, microporeux ou meme 'interactifs", merci de vous mettre en rapport avec

## AN APPEAL TO RESIN PRODUCERS AND MANUFACTURERS OF PLASTICS FILMS

The modified atmosphere packaging (MAP), of fruit and vegetables particularly, is a technique which appears to have considerable potential

The development however depends not only on continuing research in post harvest physiology but requires also a more complete understanding of plastics materials which can provide better control of the concentrations of the various gases

If your range of products includes materials or films with a high gas permeability, microporous or even interactive' please send information to

Prof Shimshon Ben-Yehoshua
VOLCANI CENTER
PO Box 6 Bet Dagan 50250 Israel

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# MODIFIED-ATMOSPHERE PACKAGING OF FRUITS AND VEGETABLES REDUCING CONDENSATION OF WATER IN BELL PEPPERS AND MANGOES

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## Abstract

A dynamic model of gas and water vapor exchange in a package containing fresh fruit and vegetables was developed on the basis of Michaelis-Menten equation in combination with Fick's diffusion law A computer simulation was used to evaluate package specifications which would provide best conditions for storage of a given commodity Model predictions were confirmed by measured observations Perforating the film affected greatly $O_2$ and $CO_2$ concentrations and water condensation but not the in-package relative humidity Bell peppers packaged in perforated film lost less weight during storage and maintained higher quality than fruit stored in open carton boxes, and at the same time demonstrated lower decay level than peppers kept in non-perforated package Perforating the film negated ripening inhibition that prevailed in mango in non-perforated packages Perforated packages retained most of the advantages of the modified atmosphere Non-perforated film of the polyamide type had similar effect to perforated polyolefin film Water condensation on the fruit and on the container wall was practically prevented

## Introduction

The keeping quality of fruits and vegetables is affected by temperature, and by concentrations of oxygen, carbon dioxide and water vapor in the surrounding atmosphere (Kader *et al*, 1989) The technique of modified-atmosphere packaging (MAP) is steadily becoming more important as an additional tool to prolong the storage life of perishable commodities (Ben-Yehoshua *et al*, 1985, Ben-Yehoshua *et al* 1994, Gorris and Peppelenbos, 1992, Cameron *et al* 1995)

Experiments undertaken with bell pepper and mango fruits showed that packaging bell pepper in non-perforated plastic film may promote decay when water droplets condensed inside the package (Ben-Yehoshua *et al*, 1994) In mango, seal-packaging inhibited ripening In both cases perforation appeared to present a possible solution to these difficulties Consequently, we evaluated the effects of perforation in modified atmosphere packaging and performed a theoretical analysis of the gas exchange dynamics introducing a new model which also considers the water vapor in a perforated and non-perforated MA package (Fishman *et al*, 1995, 1996) This work established the potential of perforated plastic packaging in extending the life and reducing spoilage of mango and pepper fruits The beneficial effects of perforation on water condensation and decay were evaluated

## Perforation effects on dynamics of $O_2$ and $H_2O$ concentrations

As stated previously, a specific problem appeared with mangoes, when the altered in-package atmosphere was shown to impair ripening The use of perforated films was recommended for mango fruit and was successfully tested under certain experimental conditions (Rodov *et al*, 1994, 1995, Yantarasri *et al*, 1995, Fishman *et al*, 1996) A model which included consideration of the film perforation was developed to help calculate $O_2$ concentration and RH

in a perforated-film MA package aiming at the optimization of MAP conditions for mango fruit (Fishman *et al*, 1996)

Respiration and transpiration of mangoes were studied in independent experiments to estimate the parameters included in the model The results of theoretical predictions were validated by comparison with experiments on MA packages of mango Due to space limitations, only a few highlights regarding the data can be presented here

Figure 1 shows the dramatic effects of perforation on the in-package oxygen concentration Four holes of 2 mm diameter changed the steady state concentration of $O_2$ from 1% (0 1 non-dimensional) for the non-perforated to 19% (0 19) for the perforated film

Completely different results were found for relative humidity (RH) The time variation of RH during the same period, shown in Figure 2, demonstrated good correspondence between predicted and observed steady-state RH levels and showed practically no difference between the atmospheres inside perforated and non-perforated packages, which were both water saturated The visible lag in the experimental approach to the steady-state RH (Figure 2), as compared with the model prediction, was related to the time necessary to reach equilibrium between the in-package atmosphere and the near-sensor environment

These results show that perforations affect the in-package dynamics and steady-state concentration of oxygen much more than those of water vapor (Fishman *et al*, 1996) The holes as compared with the film present a new route with a better ability to transmit oxygen than water The relative contribution of permeation through film and holes for the creation of MA in packages was estimated for oxygen and for water vapor Under the conditions of our experiments, the oxygen transmission ability of the LDPE film-package containing four holes of 2 mm diameter is 131 times greater than that of the film for the same package with an area of 0 03 $m^2$ and thickness of $2x10^{5}$ m but, without holes The water vapor transmission ability of these four holes containing package was three times of that of the film of non-perforated package Thus, the effect of holes is more pronounced in improving the transmission of $O_2$ than in that of water vapor

**Model predictions for perforated film**

Changing the number of perforations per package is equivalent to changing the transmission capability of the film, while alteration of the relative humidity in the ambient atmosphere means changing the driving force for water vapor permeation through the film

The relative humidity changes as predicted by the model for packages with four levels of perforation N = 0, 4, 20 and 40 holes per package, are shown in Figure 3 (Fishman *et al*, 1996) Three ambient atmosphere RH levels ($H_A$, non-dimensional) were studied for each perforation level 0 8 (upper curve), 0 7 (middle curve) and 0 6 (lower curve) The transient periods for these combinations of parameters were very short and varied negligibly As can be expected, lowering of $H_A$ reduced the predicted in-package RH because of the increased RH gradient across the packaging film Increase in the number of perforations, N, makes the package RH more sensitive to the ambient RH and accordingly, the differences between the steady-state in-package RH values corresponding to different $H_A$ increased with increasing perforation level (Figure 3) It should be noted that even at the lowest ambient RH ($H_A$ = 0 6) and highest perforation level (N = 40) studied, the in-package humidity was predicted to be as high as 0 93 Indeed, our measurements confirmed these predictions This prediction of the perforation effect was repeated also in other conditions

The model simultaneously describes the dynamics of oxygen and water vapor concentrations in perforated MA packages Both predicted and observed data showed that perforation allows

to combine elevated in-package RH, similar to that of a non-perforated package with high oxygen concentration, that of the ambient atmosphere This makes it possible to minimize fruit weight loss while maintaining the gas concentrations required for the normal ripening of packaged mangoes The model predicts the effects of the ambient humidity and of package parameters, such as perforation area, film surface, fruit amount, etc on in-package $O_2$ concentration and RH and on fruit weight loss It may serve as an effective tool for optimization of MA packages It is worth noting that the model was evaluated for mango fruits, but the calculations for in-package RH would be valid for other commodities, subject to insertion of the appropriate transpiration coefficients

**Reducing in-package water condensation and *Botrytis* decay by perforation of the plastic film in MA packages**

Perforation was observed to reduce the condensation of water droplets in MA packages In order to characterize the condensation quantitatively, all the water droplets on both fruit and film were absorbed on filter paper and weighed Fig 4 represents the relation between the extent of package perforation and the amount of condensed water in mango packages

The importance of the reduction of the condensation was demonstrated with pepper fruit Four red peppers were placed in a tray package of 40μ thick LDPE film and stored at 8°C and 90±2% RH The in-package atmosphere after achieving steady state was 4 9% $CO_2$ and 4 8-5 0% $O_2$ These conditions fit the recommendations for bell pepper storage in controlled atmosphere (CA) Unfortunately, despite the successful achievement of the recommended CA specifications, the fruit in these packages had a high incidence of decay - above 30%, which was caused mainly by *Botrytis cinerea* This decay was probably related to the large amounts of water droplets which condensed on both the film and the fruit Thus, optimal $O_2$ and $CO_2$ are not in themselves sufficient to provide adequate conditions for MAP of peppers Accordingly, effects of perforation and hygroscopic materials on decay incidence in these packages were investigated

Perforation significantly reduced the extent of *Botrytis* decay in bell-peppers (Figure 5) Use of perforated polyolefin film with 8 holes 0 4 mm in diameter/inch$^2$ (1 24 holes cm$^2$) reduced the amount of water condensation on both the film and the fruit in a package holding 4 peppers This resulted in 5% *Botrytis* decay as compared with 35% observed in the similar package sealed with non-perforated LPDE film It is interesting to note that perforation in these experiments did not reduce *Alternaria alternata* decay (data are not given) Addition of 10g of hygroscopic materials such as NaCl or the Stocksorb polymer in a sealed sachet of spun bonded Tyvec effectively reduced both the condensation and decay caused by *Botrytis cinerea*, similar to perforation These treatments also reduced the RH in the package from ≥ 99% to 92-95% and extended the life of pepper Previously, Shirazi and Cameron had shown that NaCl addition extended the life of tomato fruit The loss of weight of the fruit kept in perforated packages or in non-perforated packages with hygroscopic insertions, was still markedly lower than that in non-sealed packages

**Effect of different types of plastics.**

Bell peppers were packed in cardboard cartons lined with different types of films The type of film affected the rate of weight loss, the most effective in slowing weight loss was the non perforated polyolefin type film, Cryovac MR The same type of film but perforated with 8 holes inch$^2$ Cryovac SM60M increased the rate of weight loss in comparison with the non-perforated Cryovac MR but still effective in reducing weight loss when compared with the control, non lined carton Another type of non perforated film made of polyamide affected the

fruit in a similar way to the perforated polyolefin type film Cryovac SM60M All three types of film used for lining the cartons had similar thickness (Figure 6)

The highest disease incidence caused by *Botrytis cinerea* was found in the carton lined with non perforated polyolefin film Cryovac MR This type of package also had high level of water condensation 0 346gr per 2 fruit and 2 99 gr on the inner top of the lined carton The carton with the perforated film had the lowest decay level and only 0 013 gr of water condensed per 2 fruit and 0 014gr/carton The carton lined with the polyamide film had slightly higher but not significantly different decay incidence than in the perforated film Condensation of water was 0 025 gr/2 fruit and 0 033 on the inner top of the carton In the control non-lined carton the water condensed amounted to 0 016gr/2 fruit and 0 008gr in the carton

## Discussion

### Perforated MAP

The effects of perforation on MAP was evaluated both theoretically with our model (Fishman *et al*, 1995, 1996) and experimentally with mango and pepper fruits The major effect was that perforation of the film negated the inhibition of the ripening process that occurred in mango sealed in non-perforated packages Also, in our experiments, decay in perforated packages was significantly lower than in non-sealed control mango fruit Similar results were obtained also with several citrus fruit (data not given)

Perforated packaging achieves many of the good results of non-perforated packaging in reduction of weight loss and shrivelling without the deleterious off-flavors, fermentation or $CO_2$ damage and without the condensation of water droplets that enhanced decay that occurs in non-perforated non-shrunk bell pepper and mango packages (Rodov *et al*, 1994, 1995, Yantarasri *et al* 1995, Fishman *et al*, 1995, 1996)

### MAP and water condensation

Packaging that reduces desiccation may encourage water condensation, which in turn, encourages pathogen development This problem is difficult to solve, but good practice can minimize the damage and a balance should be achieved that would prevent excessive water loss and excessive condensation Perforation, or the introduction of a sachet containing hygroscopic materials may help achieve such a balance Shrink seal-packaging is also very effective in reducing both weight loss and condensation The adherence of the film to the fruit peel, the inherent perforation present in shrunk films as well as the selection of the proper plastic film all contribute to the virtual absence of condensation from the shrunk-sealed fruit (Ben-Yehoshua, 1985, 1994, Patterson 1993)

## Conclusions

MAP provides a useful tool for extending life and reducing spoilage of perishable agricultural produce This developing technology appears to be of relatively low cost and to require much less investment compared with cooling or CA Furthermore, it has the great advantage of being environmentally friendly utilizing mainly the control of $O_2$, $CO_2$ water and ethylene without exogenous chemicals High decay levels caused by *Botrytis* was found in packages with relatively high water condensation

## Acknowledgment

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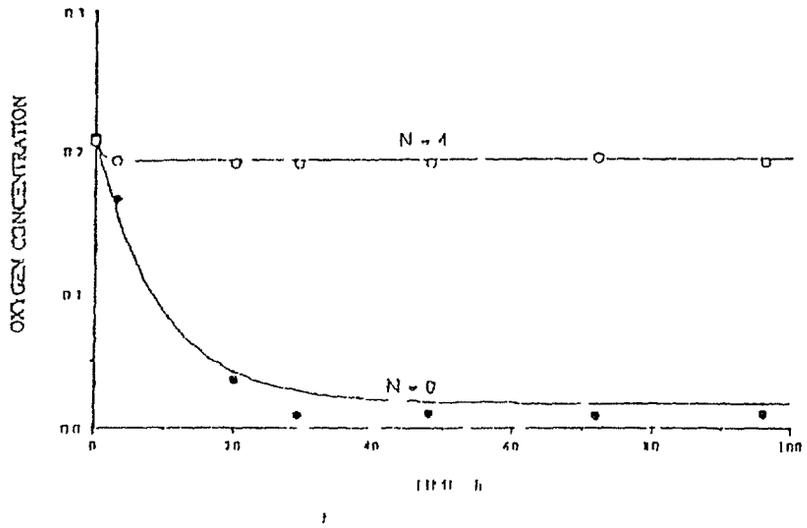


**Figure 1** Effect of perforation on time course of oxygen concentration in a plastic package containing two mangoes at 20C N- number of pores (2 mm diameter) Circles represent observations, curves - predictions

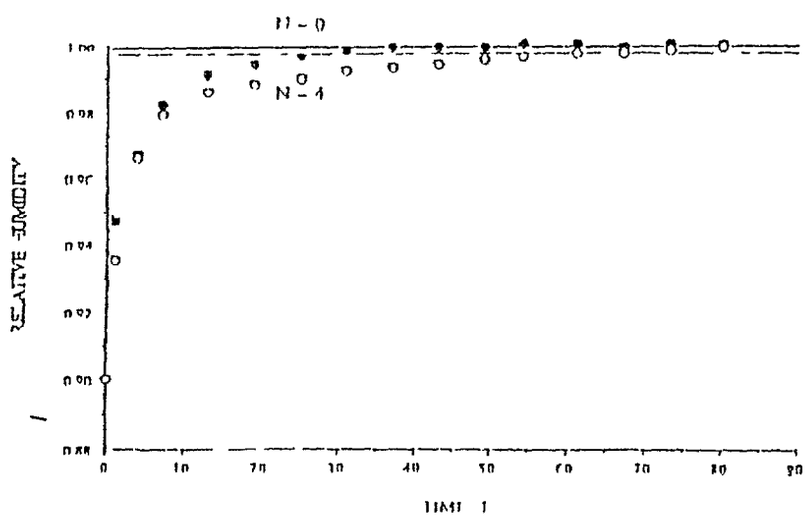


**Figure 2** Effect of perforation on relative humidity in a plastic package containing two mangoes at 20C N- number of pores (2 mm in diameter) Circles represent observations, lines - predicted steady state levels

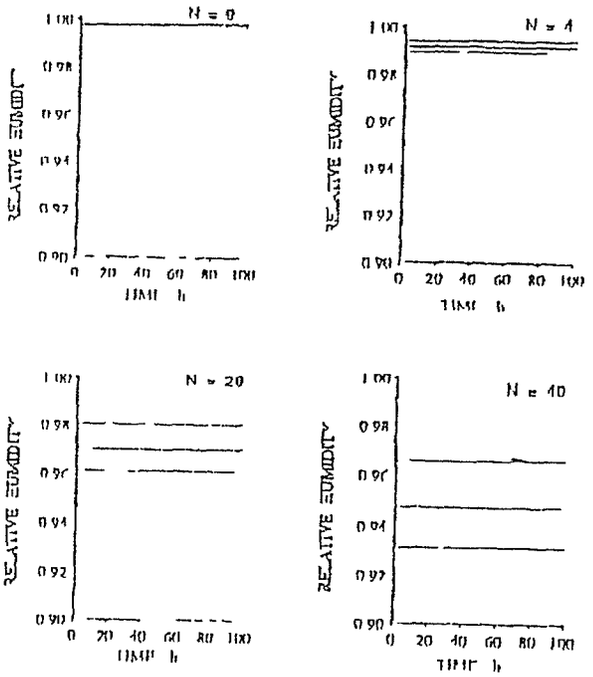


**Figure 3** Effect of perforation on change of relative humidity with time MA packages with four levels of perforation N=0, 4, 20 and 40 Three values of relative humidity in the ambient atmosphere ($H_A$) were considered 0 8 (top curve), 0 7 (middle curve) and 0 6 (bottom curve) Predictions are for 20C

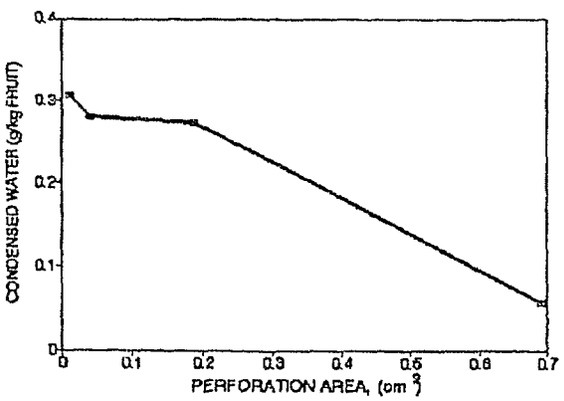


**Figure 4** Effect of perforation level on water condensation inside 40μ-thick LDPE packages containing two 'Tommy Atkins' mangoes

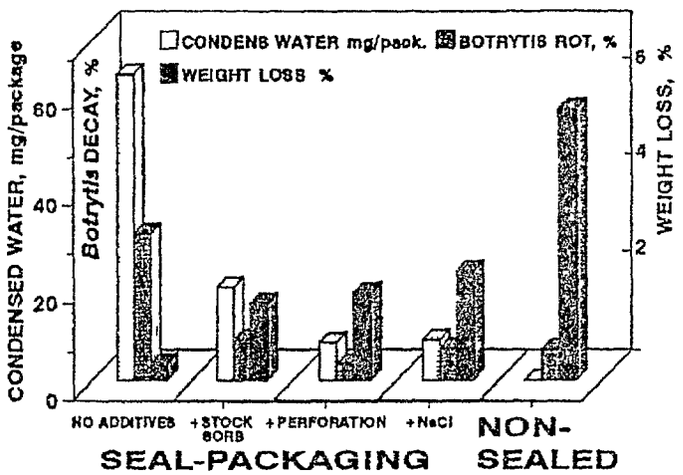


**Figure 5.** Effect of perforation and hygroscopic additives on in-package water condensation, weight loss and Botrytis decay of seal-packaged bell-pepper at 20C

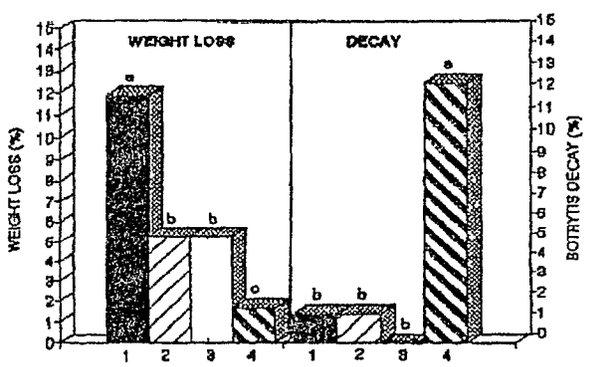


**Figure 6** Effect of film type and perforation on weight loss and decay incidence of Bell peppers after 3 weeks in storage at 8C + 1 week at 17C 1= Control, 2 = carton lined with non-perforated polyamid film 3=carton lined with perforated polyolefin film Cryovac SM60M 4=carton lined with non-perforated polyolefin film Cryovac MR. within each parameter, a different letter indicates a significant difference (p=0 05) by the Duncan's Multiple Range Test.

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# Mathematical Model for Perforation Effect on Oxygen and Water Vapor Dynamics in Modified-Atmosphere Packages

SVETLANA FISHMAN, V RODOV, and S BEN-YEHOSHUA

## ABSTRACT

A mathematical model was developed o study the influence of film perforations on $O_2$ concentration and relative humidity in the atmosphere in a package containing fresh fruits The model included equations de scribing fruit respiration and transpiration as well as permeation of ox ygen and water vapor through the perforated film Closed system experiments with mango fruit revealed a linear dependence of respiration rate on O concentration The model allowed analytical computation of the time course of in package O concentration and relative humidity and the results were in good agreement with experimentally measured values Perforations had a much more pronounced effect on O concen tration than on relative humidity The model enabled practical predic tions for designing modified atmosphere packaging

Key Words modified atmosphere fruit packaging perforation in pack-age humidity mango

## INTRODUCTION

PACKAGING OF FRUITS and vegetables in plastic films is common for prolonging the postharvest life of fresh produce High relative humidity (RH) in the atmosphere surrounding fruit di minishes dehydration and preserves freshness (Ben-Yehoshua, 1987 Ben-Yehoshua et al 1994) Low O and elevated CO concentrations in the modified atmosphere (MA) of the package reduce the respiration rate and hence improve storage life Fruits have different tolerance limits to low $O_2$ and elevated CO levels Excessive in-package humidity may stimulate microbial pathogen development Therefore, the ranges of $O_2$, $CO_2$ and water vapor levels must be chosen for each produce and the MA packaging must be designed to provide optimal storage conditions A specific problem appeared for example with mangoes (Shapiro et al 1989), when the altered in-package atmosphere was shown to impair their ripening mechanisms The optimal MA package should provide a desirable (not too low) oxygen concentration to ensure the ripening of mango fruit and, at the same time, should maintain in-package humidity high enough to minimize weight loss The use of perforated films was recommended for mango fruit by Shapiro et al (1989) and later was tested under experimental conditions (Rodov et al 1994 Yantarasri et al, 1994) Optimal conditions for mango packaging could be determined with the aid of a model which would include consideration of the film perforation

Investigation of gas exchange through perforated plastic was undertaken by Emond et al (1991), who measured gas transport through the perforations and developed descriptive empirical equations based on the measurements Permeabilities were measured on boxes made of perforated plastic of relatively deep thicknesses and wide perforation sizes Empirical equations were included in a computer program to simulate various per forated packagings Results were applied to fit conditions for broccoli storage Shirazi and Cameron (1992) indicated that optimization of moisture content in the MA package must be done in parallel with optimization of the O and CO levels

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A model for calculation of O and CO concentrations in a non perforated package containing fresh fruits was developed and applied to bell pepper (Fishman et al 1995) The model based on two processes (fruit respiration and gas permeation through a homogeneous film) was analyzed theoretically It revealed a maximum as an intrinsic characteristic of the $CO_2$ evolution curve Then the system was simulated numerically Model predictions were compared with results of experiments with red bell pepper fruit for validation

The main objective of our work was to develop a model to calculate the O concentration and RH in a perforated film MA package It was aimed at optimization of storage conditions for mango fruit The model comprised a theoretical analysis of gas permeation through a perforated film Respiration and transpiration of mangoes were studied in independent experiments to estimate parameters in the model Theoretical predictions were validated by comparison with experiments on simulated MA packages of mango

## MATERIALS & METHODS

MATURE GREEN MANGOES cv Keitt grown in the Jordan Valley (Israel) were obtained from a packing house on the day of harvest The fruit did not receive any postharvest treatment except washing

### Closed-system experiments

A closed system was used to estimate the kinetics of oxygen uptake by mango fruit Fruits of known weight and volume were placed in 750 mL chambers practically impermeable for gases Each chamber comprised a 0 5 mm thick polyethylene terephthalate polyester (PET) cylinder tightly mounted on top of a massive rubber stopper (Fig 1) One fruit was placed in each chamber To prevent gas leakage the union of plastic cylinder to stopper was lubricated with silicone gel The gas tightness of each system was tested in preliminary experiments To eliminate the effect of $CO_2$ on respiratory activity of the fruit calcium hydroxide was placed in the chamber as a CO absorber Sealed bags of gas permeable spun bonded polyethylene (Tyvek Du Pont Co Geneva Switzerland) containing 10g of Ca(OH) were mounted in the tops of the chambers without direct contact with the fruit

Each chamber had three openings One was tightly plugged with a rubber septum about 1 cm thick through which 5 mL gas samples were extracted using a gastight 20 mL glass syringe with a 0 5 × 16 mm needle A plastic tube with inner diameter 1 mm was installed in the rubber stopper (Fig 1) in order to collect gas samples from the central part of the chamber The second opening was connected through a Luer joint with a gastight 35 mL plastic syringe to prevent the development of negative pressure in the system as a result of regular sampling to ensure accurate pressure maintenance and to prevent leakage during sam pling After each sampling the syringe plunger was lowered by 5 mL to compensate for the reduction of gas volume in the system then the plunger was fixed with a splint The homogeneity of the atmosphere within the chamber and the syringe was maintained by pumping air with a syringe plunger The third opening was connected to a water mano meter via a rubber tube The partial vacuum formed in the chamber with Ca(OH) as a result of CO absorption was compensated before each sampling by injecting nitrogen to equilibrium pressure between the chamber and its surroundings Fruit were kept in the chamber for 15–25 hr until oxygen depletion

Oxygen and carbon dioxide concentrations in the samples from the closed system were determined on a Packard 7500 gas chromatograph with thermal conductivity detector and CTR I packed column using he

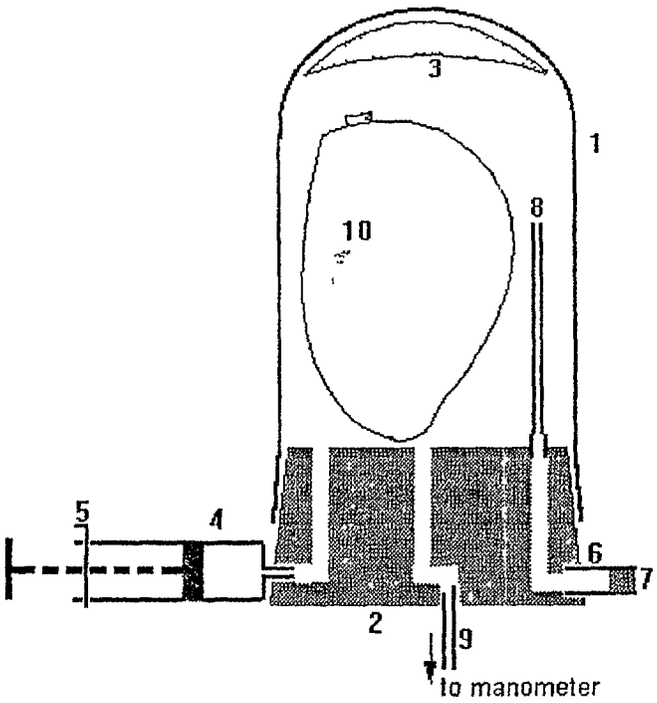


Fig 1—**Scheme of closed system** The components of the apparatus are shown separated from one another in order to clarify the figure 1—plastic cylinder 2—rubber stopper 3—$CO_2$ absorber 4—syringe (pressure compensator) 5—splint 6—sampling port 7—rubber septum 8—plastic tube 9—connection to manometer 10—fruit

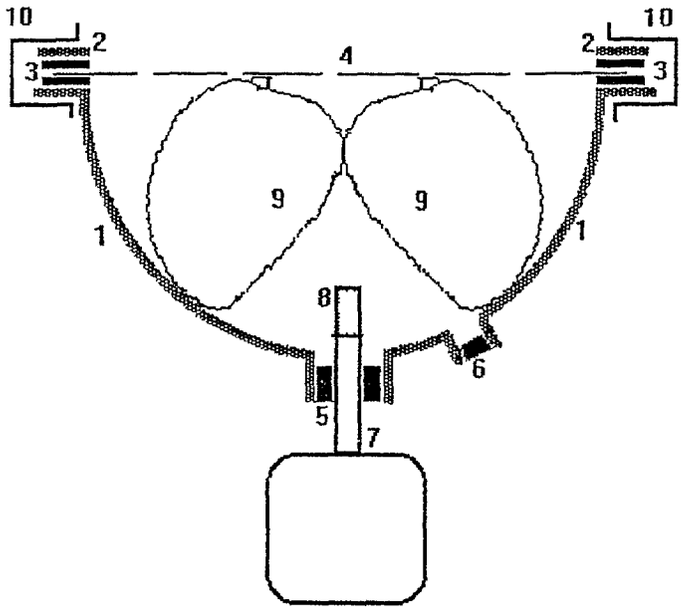


Fig 2—**Scheme of package simulation** 1—chamber 2—rigid plastic ring 3—two rubber rings 4—LDPE film (with or without perforations) 5—rubber gasket 6—rubber septum 7—temperature and humidity probe 8—sintered metal filter 9—fruit 10—double clips

lium as carrier gas Resistance of the fruit surface to water vapor permeation was calculated from measurements of fruit weight losses (Ben Yehoshua et al 1985)

### MA package imitation

In order to check model predictions experimentally the modified atmosphere package was simulated (Fig 2) A dome shaped chamber 1 6L in volume with the open side 20 cm in diameter made of 4 mm thick rigid polycarbonate plastic with flat 1 5 cm rim simulated the MA package The walls of the chamber were practically gas impermeable A low density polyethylene (LDPE) film 20μ thick was stretched over the open side of the chamber between two rubber rings of 1 5 cm width clamped against the rim by a rigid plastic ring of the same dimension The rings were lubricated with silicone gel to ensure gas tightness and the system was fastened with double clips The experiment involved two chambers one covered with nonperforated LDPE film the other covered with the film with four holes each 2 mm in diameter The film was perforated before stretching over the chamber by means of sharpened steel tubes

Combined temperature and humidity probes (model I 100 Rotronic Zurich Switzerland) were inserted into the bottom of each chamber through a tight gasket The sensors were protected against condensed water by sintered metal filters with 8 micron pore size as recommended by the manufacturer (Rotronic 1987) for work under high RH conditions Each chamber had an opening tightly plugged with a rubber septum about 1 cm thick through which 5 mL gas samples were withdrawn by a gas tight syringe for analysis by gas chromatography

Two mature green mangoes of known weight and volume were placed in each chamber which was closed as described The chambers were kept in a storage room at 20°C and RH 90 ± 1% Oxygen and carbon dioxide concentrations in the package simulations were measured daily The temperature and humidity values inside each chamber and in the ambient atmosphere of the storage room were recorded every 6 hr with a data logger (Picologger YM Electronics Ramat Gan Israel)

Statistical analysis of data was performed on a Macintosh computer using JMP (SAS Institute Inc 1989) software The base units of the International System of Units SI (see Downs 1988) were used throughout the study except for the unit of time It was much more convenient to express time in hours because the main processes under consideration had characteristic times on the order of hours The main dynamic variables oxygen concentration and RH were expressed on a relative (non dimensional) basis to simplify the equations (Banks and Cleland 1993)

### Model development and parameterization

Two main processes contribute to change in the amount (Q) of a gas inside a package containing fresh fruit physiological activity (respiration resulting in oxygen consumption and transpiration emitting water vapor) with a total rate f and permeation of gases through the packaging film with a rate F

$$dQ/dt = f + F \quad (1)$$

The amount of gas is usually represented by the product of its partial concentration (denoted as C for oxygen concentration and as $C_w$ for water vapor) and the free volume within the package V which was formerly called the headspace

$$Q = VC \quad (2)$$

The level of water vapor is usually represented by relative humidity (RH) defined as $H = p/p_{sat}$ where p is the partial pressure of water vapor and $p_{sat}$ is the saturation vapor pressure (the partial pressure exerted by the water vapor in equilibrium with pure water) According to the Ideal Gas Law the concentration of water vapor $C_w$ is equal to p/RT where R is the gas constant and T is the absolute temperature (°K) Thus $C_w$ may be approximated as $C_w = H\,p_{sat}/RT = \alpha H$ where $\alpha = p_{sat}/RT$ is the water vapor concentration under saturation vapor pressure which depends on temperature For 20°C in non dimensional units $\alpha = 0\ 023$ (L/L) Dimension of $C_w$ is the same as that of $\alpha$ $C_w$ does not participate in the following calculations being substituted by $\alpha H$ In equation of water vapor balance $\alpha$ can be shortened leaving H as the main variable

To perform the calculations necessitates estimation of parameters involved in the mathematical description of the system Parameterization is described below in parallel with the mathematical description of the processes under consideration as an integral part of the model development

### Gas transfer through a polymeric film with macroscopic perforations

The total permeation flow through a macroscopically homogeneous film is defined as flux J the gas quantity which crosses a unit of film area multiplied by the film area S $F = J\,S$ If the film is perforated the perforations represent an alternative route for gas transport which is



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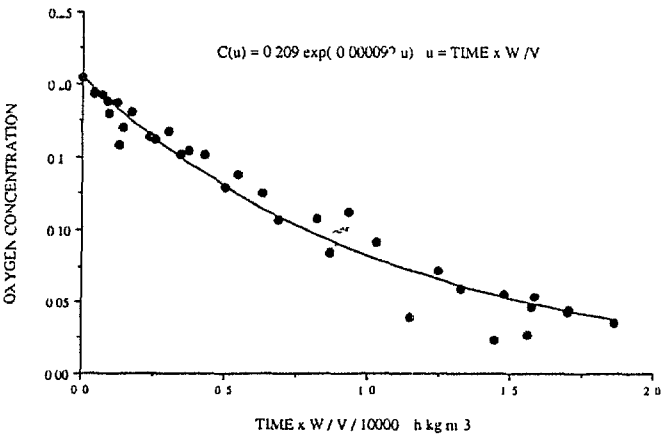


**Fig 3—Study of respiration parameter μ (Eq 10)** The curve represents $O_2$ concentration as a function $C(u) = 0.209 \exp(-\mu u)$ with $u = t\,W/V$ (h kg $m^{-3}$) and coefficient $\mu = 9.2 \times 10^{-5}$ ($m^3$ $kg^{-1}$ $hr^{-1}$) determined by means of a curve fitting procedure using experimental data (black points)

in parallel to the barrier formed by the plastic material In this case the total flow is

$$F = JS + J_h S_h \quad (3)$$

where $S_h$ is the total area of the holes and $J_h$ is the flux of a gas through unit area of the hole A similar equation states for the water vapor flow $F_w$

The steady-state diffusion flux of a gas through a non perforated film obeys the following equation (Cussler 1984)

$$J = -P\,(C - C_A)/L \quad (4)$$

where C and $C_A$ are concentrations of gas inside the package and in the ambient atmosphere respectively P is the permeability coefficient of the film to the gas and L is film thickness

Macroscopic perforations in polymeric films have diameters of the order of $10^{-4}$m or greater whereas the mean free path of gas molecules at atmospheric pressure is much less being about (1 to 2) × $10^{-7}$m (Kesting and Fritzsche 1993) Therefore transport through the perforation may be treated as macroscopic diffusion in a cylindrical pathway filled with air Diffusive flux in this case obeys Fick s law

$$J_t = -D\,(C - C_A)/L_t \quad (5)$$

with diffusion coefficient of the gas in air D replacing the permeability coefficient P of Eq (4) The diffusive pass length is denoted here as $L_h$ Its evaluation is a complicated diffusion problem If the distance between perforations is much greater than their radius estimation of $L_t$ may be approximated by the model employed by Meidner and Mansfield (1968) and Nobel (1974) for computation of the stomatal resistance According to this approximation $L_t$ equals the length L of the cylindrical pore enlarged by the hole radius $R_h$ i e

$$L_h = L + R_h \quad (6)$$

We examined some additional models (unpublished results) with different symmetry for this diffusion problem and obtained similar results in all cases considered Therefore Eq (6) w is used in subsequent computations

Taking into account Eq (3) to (6) the total flux through plastic film of area S with N perforations of radius $R_h$ (with total area $S_t = \pi R_t N$) may be represented as

$$F = (C_A - C)\,[SP/L + S_h\,D/(L + R_h)] \quad (7)$$

The water vapor flux through the perforated film is represented in a similar way with αH replacing the concentration

$$F_w = \alpha\,(H_A - H)\,[SP_w/L + S_h\,D_w/(L + R_h)] \quad (8)$$

where $H_A$ is relative humidity in the ambient atmosphere and $D_w$ is the diffusion coefficient of water vapor in air

Parameters P and $P_w$ were found from the LDPE film specifications and checked in our laboratories (Fishman et al 1995) The diffusion coefficients in air D and $D_w$ are known from published data

### Respiration

Changes in gas amount due to fruit respiration are represented by respiration rate r(C) which is defined as volume of O consumed per unit weight of fruit in unit time Multiplication of r(C) by the fruit weight W gives the respiration contribution to changes in gas amount in the headspace V The term f in Eq (1) is given by

$$f = -r(C)\,W \quad (9)$$

Equations of Michaelis Menten type have been applied (Lee et al 1991 Cameron et al 1994 Fishman et al 1995) to describe the respiration rate as a function of concentration in MA package

To estimate the respiration parameters for mango fruit experiments were performed in a closed system according to the scheme applied to bell pepper (Fishman et al 1995) A statistical analysis of the observed $O_2$ depletion with mango fruit showed that Michaelis Menten parameters were strongly correlated and had broad confidence limits This usually indicates a model has redundant parameters, i e a simpler model with reduced number of parameters would fit the observed data as well (Garfinkel and Fegley 1984) Therefore the rectangular hyperbola was approximated by a linear model with one parameter

$$r(C) = \mu\,C \quad (10)$$

The linear dependence of mango respiration rate on $O_2$ concentration has also been reported by Yantarasri et al (1995) who worked with cv Nam Dork Mai In terms of enzyme kinetics this dependence indicated a low affinity of enzyme for substrate as compared with the affinity of cytochrome oxidase for oxygen Forward (1965) and others (Chevillotte 1973 Tucker and Laties 1985 Joles et al 1994 Cameron et al 1995) considered possible explanations of an apparently low affinity observed previously in lemon apple and avocado Equation (10) was used in our current study with parameter μ fitted for mangoes Combining Eq (1) (2) (9) and (10) subject to F = 0, results in the linear differential equation for the closed system

$$dC/dt = -\mu\,(W/V)\,C \quad (11)$$

which has a solution

$$C(t) = C_0 \exp(-\mu\,Wt/V) \quad (12)$$

where $C_0$ is the initial O concentration It is convenient to represent observed data as a function $C(u) = C_0 \exp(-\mu u)$ where $u = (W/V)\,t$ The use of the normalized variable u instead of time enabled us to perform a joint statistical analysis of observations on fruit with different weights and volumes The parameter μ was found to be (0 918 ± 0 033) × $10^{-4}$ $m^3$ $kg^{-1}$ $h^{-1}$ from statistical curve fitting The time course of the O concentrations measured in the closed system (Fig 3 circles) was compared to the fitted curve C(u) based on the estimated parameter μ

### Transpiration

A transpiration flow $f_w$ replaces the flow f in Eq (1) in the case of water vapor It is the amount of water vapor which passes away from total fruit surface per unit of time Denoting the water vapor efflux from unit of fruit surface area per unit of time as $\phi_w$ and the fruit area as s the total flow $f_w$ is calculated as

$$f_w = \phi_w\,s \quad (13)$$

As pointed out by Burg and Burg (1965) gas diffusion from plant tissue should behave according to Fick s law Ben Yehoshua et al (1985) used Fick s law to describe the flux of water vapor through unit area of fruit surface in their study of citrus fruit resistance to water vapor transport Hence $\phi_w$ is proportional to the difference between RH of fruit internal atmosphere and RH of the MA in the package

$$\phi_W = \rho\,\alpha\,(H_f - H) \quad (14)$$

where $H_f$ is relative humidity of fruit internal atmosphere and ρ is the permeance of fruit surface to water vapor (definition given by Donhowe and Fennema 1994) The inverse value σ = 1/ρ is the resistance of the fruit surface to water vapor transport often used for describing water vapor flux The relative humidity of fruit internal atmosphere was considered as a first approximation to be 1 0 (or 100%) This parameter depends on solute content of the fruit and is slightly less than 1 0 (Patterson et al 1993)

Transpiration resistance of mango fruit was estimated according to the method described by Ben Yehoshua et al (1985) using weight losses observed in 16 mangoes in the open air The mean resistance over 16 observations was 29 2s cm $^{-1}$ with standard deviation 4 5s cm $^{-1}$ The

Table 1—Parameters and constants of the sy tem

| Symbol | Description | Value | Dimensions |
|---|---|---|---|
| $C_A$ | oxygen concentration in ambient atmosphere | 0 209 | non dimensional |
| D | diffusion coefficient of oxygen in air | 0 073 | $m^2$ $hr^{-1}$ |
| $D_W$ | diffusion coefficient of water va por in air | 0 09 | $m^2$ $hr^{-1}$ |
| $H_A$ | relative humidity in ambient at mosphere | 0 9 | non dimensional |
| $H_f$ | relative humidity of fruit internal atmosphere | 1 0 | non dimensional |
| L | thickness of film | $2\times10^{-5}$ | m |
| N | number of pores | 0 or 4 | non dimensional |
| P | oxygen permeability coefficient of film | $4\ 6\times10^{-9}$ | $m^2$ $hr^{-1}$ |
| $P_W$ | water vapor permeability coefficient of film | $3\ 5\times10^{-7}$ | $m^2$ $hr^{-1}$ |
| $R_h$ | radius of pores | 0 001 | m |
| S | area of the plastic film | 0 03 | $m^2$ |
| s | area of the fruit surface | 0 045 | $m^2$ |
| V | headspace (free volume within the package) | $7\ 8\times10^{-4}$ | $m^3$ |
| $W_0$ | initial weight of fruits in a pack age | 0 8125 | kg |
| $\mu$ | coefficient of respiration rate | $9\ 2\times10^{-5}$ | $m^3$ $kg^{-1}$ $hr^{-1}$ |
| $\rho$ | permeance of fruit surface to water vapor | 1 233 | m $hr^{-1}$ |
| $\alpha$ | water vapor concentration under saturated atmosphere at T=293°K | 0 023 | non dimensional |

mean value of resistance was about one third of the transpiration resistance of citrus fruits (106s cm $^{-1}$) found by Ben Yehoshua et al (1985)

### Equations for gas exchange in MA steady state and transient solution

Inserting Eq (2) (7) (9) and (10) into Eq (1) gives the equation describing dynamics of oxygen in the MA

$$dC/dt = -\mu\ CW/V + (C_A - C)\ [SP/L + S_h\ D/(L + R_h)]/V \quad (15)$$

Combining Eq (2) (8) (13) and (14) with Eq (1) lead to equation describing dynamics of water vapor in the MA

$$dH/dt = s\ \rho\ (H_f - H)/V - (H - H_A)[SP_W/L + S_h\ D_W/(L + R_h)]/V \quad (16)$$

The steady state solutions of Eqs (15) and (16) (denoted by super script *) are obtained by equaling the rate to zero

$$C^* = C_A\ [SP/L + S_h\ D/(L + R_h)]/[\mu\ W + SP/L + S_h\ D/(L + R_h)] \quad (17)$$

$$H^* = \{s\ \rho\ H_f + [S\ P_W/L + S_h\ D_W/(L + R_h)]\ H_A\}/[s\ \rho + S\ P_W/L + S_h\ D_W/(L + R_h)] \quad (18)$$

The general solution of linear differential Eq (15) and (16) subject to initial conditions of ambient atmosphere i e, $C = C_A$ and $H = H_A$ at $t = 0$ is

$$C = C^* - (C^* - C_A)\ \exp(-t/t^*) \quad (19)$$

$$H = H^* - (H^* - H_A)\ \exp(-t/t_W^*) \quad (20)$$

where $t^*$ and $t_W^*$ are characteristic times for the dynamics of $O_2$ concentration and relative humidity respectively The characteristic time is that required for a dynamic variable to traverse a fraction $1 - \exp(-1) \approx 0\ 63$ of the range from initial to steady state value It is analogous to the lifetime —a parameter used for describing the first order processes of decay in photo- and radio chemistry (Nobel 1974) The characteristic times in Eq (19) and (20) represent the following combinations of parameters

$$t^* = V/[\mu\ W + SP/L + S_h\ D/(L + R_h)] \quad (21)$$

$$t_W^* = V/[s\ \rho + S\ P_W/L + S_h\ D_W/(L + R_h)] \quad (22)$$

Equations (19) and (20) represent solution of Eq (15) and (16) on the assumption that the coefficients of the equations are constant in time For climacteric fruits such as mango the parameters of respiration and transpiration are known to change with time Nevertheless Eq (19) and (20) provide good approximations when the climacteric changes are slower than characteristic times of the system so that the coefficients may be considered as constant within the time required to reach steady state The climacteric related changes of the parameters may become important in long term simulations and will be taken into consideration in a comprehensive computerized model of MA packaging for mango storage based on these analytical developments

## RESULTS

### Model validation

Equations (17) to (22) which describe the time changes and steady state levels of $O_2$ and water vapor in MA packages formed by perforated film as well as the weight loss of the packed fruit represent our theoretical results The mathematical problem was solved analytically for mangoes, but this solution may be applied to other fruits when the Michaelis-Menten equation for respiration rate can be linearized with respect to $O_2$ concentration

The model parameterization was based on experiments performed with mangoes in a closed system and in ambient atmosphere as described Several parameters were measured for the system (Table 1) some of which were physical parameters of the package (weight of fruit headspace within package etc ) others were physiological characteristics of fruit studied from independent experiments

To validate the model its predictions were compared with experiments on mango fruit in simulated MA packages with perforated and non-perforated films For all computations independently estimated parameters were used (Table 1) Calculation of steady-state oxygen concentration from Eq (17) yields $C^* = 0\ 0177$ for non perforated film ($N = 0$ i e $S_h = 0$) and $C^* = 0\ 193$ for perforated film ($N = 4$ i e $S_h = 1\ 257 \times 10^{-5}$ m ), whereas experimental values of steady-state oxygen concentration were 0 01 and 0 19 with nonperforated and perforated films respectively The steady-state relative humidities calculated from Eq (18) were $H^* = 0\ 999$ with $N = 0$ and $H^* = 0\ 997$ with $N = 4$ while observed relative humidity was close to $H^* = 1\ 0$ with both kinds of packaging film

The dynamics of gases in MA is governed by Eq (19) and (20) which depend on characteristic times The characteristic times for oxygen dynamics calculated from Eq (21) were $t^* = 9\ 6$ hr for $N = 0$ and $t^* = 0\ 8$ hr for $N = 4$ For water vapor the values of $t_W^*$ computed from Eq (22) were 0 0139 hr and 0 0137 hr for $N = 0$ and $N = 4$ respectively The characteristic times were much shorter than those of the climacteric changes, which started to be observable in our experiments more than 100 hr after the beginning of the study This justified our assumption of constant parameters The observed (circles) and calculated (curves) time courses of oxygen concentration in MA were compared (Fig 4) for both $N = 0$ and $N = 4$ They demonstrated similar patterns of predicted and observed results

The dynamics of RH during the same period (Fig 5) demonstrated a good correspondence between predicted and observed steady-state RH levels This showed practically no difference between perforated and non-perforated packages (difference under given conditions $\leq 0\ 2\%$ RH) The visible lag in experimental approach to the steady-state RH as compared with model prediction was related to the time required to reach equilibrium between in package atmosphere and the near-sensor environment This time period was greatly increased by the presence of a sintered metal microporous protective filter over the sensor Our observations (not published) showed that removal of the protecting filter reduced the probe reaction time from hours to minutes but greatly affected the longevity of the instrument when it was used at RH close to 100%

Results showed that perforations affected the dynamics and steady-state concentration of oxygen in MA much stronger than those of water vapor In our experimental system the oxygen



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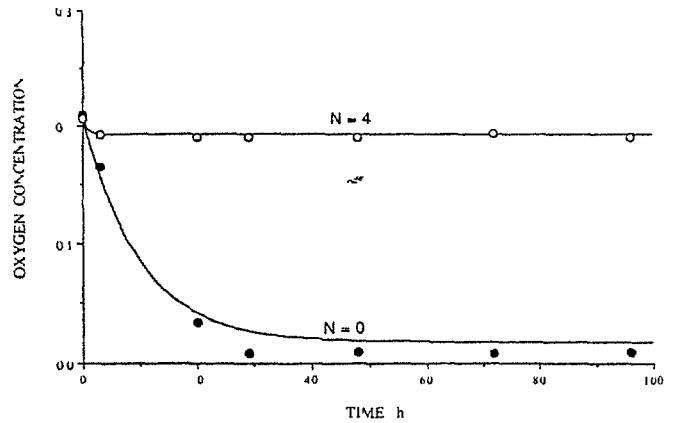


**Fig 4—Model validation** Effect of perforation on change of $O_2$ concentrations in MA packages with time Calculated curves (Eq 19) for the films with (N = 4) and without (N = 0) perforations as compared with experimental data at 20 C (circles)

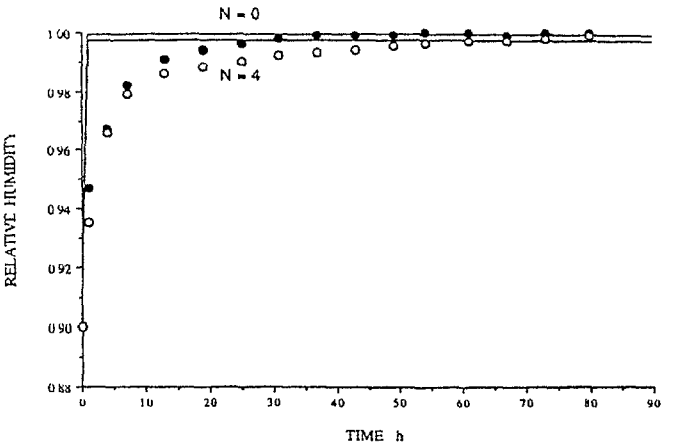


**Fig 5—Model validation** Effect of perforation on change of in package relative humidity with time Model predictions (Eq 20) for the films with (N = 4) and without (N = 0) perforations (curves) compared with experimental data at 20°C (circles)

concentrations in perforated and non perforated packages differed by an order of magnitude while in-package RH levels were practically equal Naturally these quantitative results depend on specific parameters of the system weight of fruits in the package, ambient RH free volume area and thickness of film etc Results would be different with other parameters and may be predicted from Eq (17) to (22)

The contribution of perforations to the creation of MA inside the packages could be estimated from the model by comparison between 4 flow components (a) oxygen flow through the plastic material $F_{[ox]pl} = -SP\Delta[ox]/L$ (b) oxygen flow through the holes $F_{[ox]hl} = -S_hD\Delta[ox]/(L + R_h)$ (c) water vapor flow through the plastic material $F_{[w]pl} = -SP_w\Delta[wv]/L$, and (d) water vapor flow through the holes, $F_{[w]hl} = -SD_w\Delta[wv]/(L + R_h)$ Here $\Delta[ox]$ and $\Delta[wv]$ are gradients of oxygen and water vapor concentrations across the film The relation between oxygen flow through perforated and non perforated film was $(F_{[ox]hl} + F_{[ox]pl})/F_{[ox]pl} \approx 131$, whereas the similar ratio of water vapor flows was $(F_{[wv]hl} + F_{[wv]pl})/F_{[wv]pl} \approx 3$ Thus, under our conditions (parameters in Table 1 $S \gg S_h$), perforations increased by 131 times the total oxygen flow through the packaging film whereas total water vapor flow was increased only by three times This explains the much more pronounced effect of perforations on oxygen concentration than their effect on water vapor concentration

## Model predictions

Changing the number of perforations per package is equivalent to changing the transmission capability of the film Alteration of relative humidity in the ambient atmosphere would then change the driving force for water vapor permeation through the film The relative humidity changes within the package predicted by the model (Eq 20) for films with four levels of perforation, N = 0 4, 20 and 40 are shown in Fig 6 The same three ambient atmosphere RH levels ($H_A$) were studied for each perforation level 0 8 (upper curve) 0 7 (middle curve) and 0 6 (lower curve) The transient periods for these combinations of parameters were very short and varied slightly As expected lowering of $H_A$ reduced the predicted in-package RH because of the increased RH gradient across the packaging film Increasing the number of perforations N makes the package RH more sensitive to the ambient RH and accordingly the differences between the steady state in package RH values corresponding to different $H_A$ rose with increasing perforation level (Fig 6) Note that even at the lowest ambient RH ($H_A$ = 0 6) and highest perforation level (N = 40) studied, the in-package humidity was predicted to be as high as 0 93 Our preliminary measurements confirmed these predictions

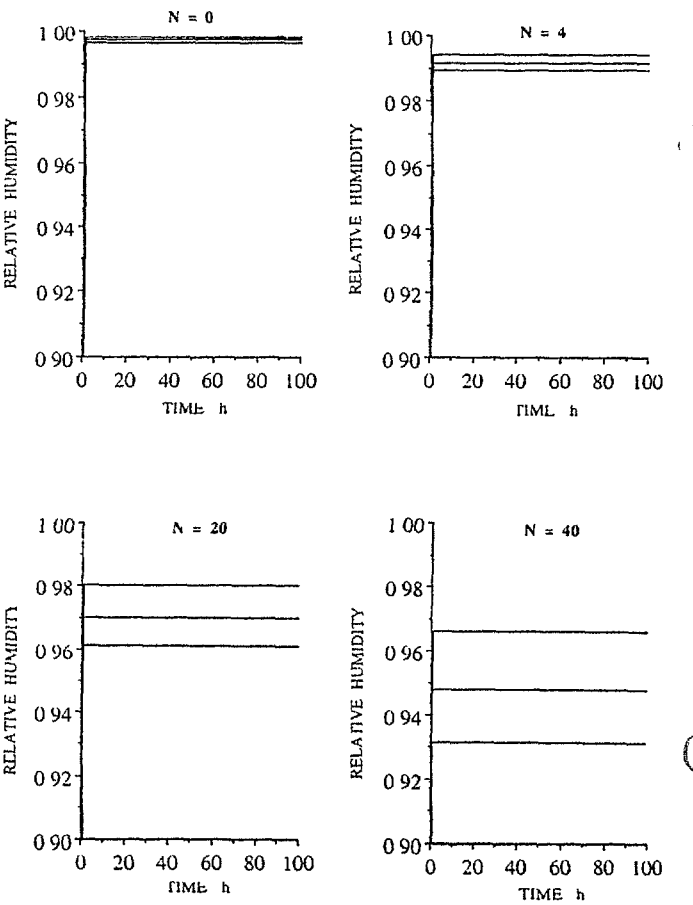


**Fig 6—Model predictions** Effect of perforation on change of relative humidity with time at 20°C (Eq 20) in MA packages with four levels of perforation N = 0 4 20 and 40 Three values of relative humidity in the ambient atmosphere ($H_A$) were considered 0 8 (top curve) 0 7 (middle curve) and 0 6 (bottom curve)

## CONCLUSIONS

OUR PROPOSED MODEL described simultaneously the dynamics of oxygen and water vapor concentrations in perforated and non-perforated MA packages It included equations which characterized fruit respiration and transpiration as well as permeation of oxygen and water through the homogeneous film and through



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the perforations The latter was treated as macroscopic diffusion along cylindrical holes filled with air The equations were solved analytically and their validity was confirmed by comparison of computed O and RH levels with experimental results Predicted and observed data showed O concentrations were affected by package perforations to a much greater extent than relative humidity Thus it is possible to modify in package humidity to minimize fruit weight loss while maintaining gas concentrations for the normal ripening of packaged mangoes The model predicts effects on in package $O_2$ concentration and RH of ambient humidity and package parameters such as perforation area film surface fruit amount etc It may serve for optimization of $O_2$ concentration and RH in MA packages The model was parametrized for mango fruit, but the equations developed here for RH would be valid for other commodities subject to insertion of appropriate transpiration coefficients

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# Dynamics of Carbon Dioxide Concentration in Modified-Atmosphere Packages

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## Abstract

Mathematical analysis of gas dynamics in modified atmosphere packages of fruit and vegetables was performed, to study the time course of carbon dioxide concentration In a package containing fresh produce, $O_2$ concentration declines from its level in ambient atmosphere to a lower steady state value, and $CO_2$ concentration increases from its atmospheric value to a higher steady-state level We found that the increase of $CO_2$ was monotonous only when the packaging material had permeability to $O_2$ higher than or equal to that to $CO_2$ However, most of the existing plastic films have lower permeability to $O_2$ than to $CO_2$ In this case, the $CO_2$ concentration passes through a maximum, exceeding the steady state level (overshooting effect), and approaches the steady state from above This phenomenon has been observed experimentally by several authors In the present work we have demonstrated that this overshooting effect is an intrinsic characteristic of the system This means that the produce kept in a plastic package may spend most of the storage period under conditions of $CO_2$ concentration higher than that estimated from steady-state calculations With a proper choice of the package parameters the overshooting effect may be minimized

## 1 Introduction

Calculation of the gas balance in the atmosphere within a package containing fresh produce is an important step in making decisions concerning the optimal package parameters Numerical solution of equations describing the gas balance must be performed several times with different sets of parameters until the parameters which provide the optimal in package gas content are found The optimization procedure can be more effective and the number of the iterations can be diminished if analytical study of the mathematical model is carried out before the optimization In the present report, an analysis of the time course



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of carbon dioxide concentration in modified atmosphere packages is performed in the framework of a model which has been adopted during recent years by several authors, for various kinds of stored products

The main processes which affect the package atmosphere are the produce respiration and gas permeation through the plastic film Most of the models presented in the literature describe the gas diffusion by Fick's law, which leads to the following equation for the flux through a thin film

$$F_i = P_i A(C_{iA} \quad C_i) / L \qquad (1)$$

where the subscript i is used for a gas specification (i=1 is for $O_2$ and i=2 is for $CO_2$), $F_i$ is the flux of gas i through a film of area A and thickness L, $P_i$ is the coefficient of the film permeability to gas i $C_i$ is the concentration of gas i in the package and $C_{iA}$ is its concentration in the ambient atmosphere From Eq (1) the dynamics of $O_2$ and $CO_2$ concentrations in the package is described as

$$dC_1 /dt = -R_1(C_1,C_2) W /V + P_1A(C_{1A} \quad C_1) /(LV)$$

$$dC_2 /dt = R_2(C_1,C_2) W /V + P_2A(C_{2A} \quad C_2) /(LV) \qquad (2)$$

where W is the weight of fruit, V is the free volume in the package, $R_1(C_1,C_2)$ is the rate of $O_2$ consumption due to produce respiration which in general case may depend both on $O_2$ and on $CO_2$ concentrations $R_2(C_1,C_2)$ is the rate of $CO_2$ evolution which is related to $R_1(C_1,C_2)$ by the respiratory quotient Q

$$Q = R_2(C_1,C_2) / R_1(C_1,C_2) \qquad (3)$$

Q is equal to 1 in many cases but may be different depending on the stoichiometry of the respiration pathways in different products Initial conditions for the differential Eqs (2) are concentrations in ambient atmosphere $C_1(0) = C_{1A}$ and $C_2(0) = C_{2A}$

To describe the fruit respiration rate, $R_1(C_1,C_2)$, various equations have been suggested in the literature For example, a power-exponential equation depending on $O_2$ concentration with three adjustable parameters was used by Beaudry *et al* (1992) for modeling modified-atmosphere packaging of blueberries Lee *et al* (1991) followed by other authors (Ben Yehoshua *et al*, 1994 Cameron *et al* 1994, Joles *et al*, 1994, Renault *et al* 1994 Talasila *et al* 1994) attempted to apply the Michaelis Menten equation to simulate fruit respiration in the package

In our previous study, with mature red peppers of the Ma'or cultivar (Fishman *et al* 1995) we found that the rate of $O_2$ consumption could be fitted to the Michaelis Menten rate equation with noncompetitive inhibition by accumulated $CO_2$



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$$R_1(C_1,C_2) = v_m C_1 / (K_M + C_1 + K_I C_1 C_2) \quad (4)$$

where $v_m$ is the maximal rate of the reaction $K_M$ is the Michaelis constant, and $K_I$ is the equilibrium constant for formation of an enzyme-substrate inhibitor complex The respiratory quotient for red pepper was found to be close to 1 We showed analytically that in the case when Q = 1, the time course of $CO_2$ concentra tion may pass through a maximum, independently of the form of the respiration equation, if $P_2 > P_1$ (which is the case for low-density polyethylene (LDPE) packaging film) The experiment performed for model validation revealed the predicted maximum on the $C_2$ (t) curve

A study of the respiration of mature green mangoes cv Keitt (Fishman *et al*, 1996a) was undertaken as a step towards developing a model of the effect of perforations on oxygen and water vapor dynamics in modified atmosphere packages Fitting of the observations of $O_2$ depletion to the Michaelis-Menten equation showed a strong correlation among the parameters which indicated that a simpler equation with fewer parameters would fit the observations When $K_M$ is large, a linear equation with only one parameter $\mu$ follows from the Michaelis-Menten rate

$$R_1(C_1,C_2) = \mu C_1 \quad (5)$$

The respiratory quotient for mango was found to be 0 785 at $C_1$ >0 05 A similar respiration equation was also reported by Yantarasri *et al* (1995) for mangoes cv Nam Dork Mai Inserting Eq (5) into system of equations (2) transforms the system (2) into a linear one which can be solved analytically Solutions for oxygen and water vapor concentrations for the cases of perforated and non perforated films were found to be one-exponential curves (Fishman *et al*, 1996a) The time course for $CO_2$ concen tration follows a two-exponential curve which passes through a maximum for certain combination of the system parameters (Fishman *et al*, 1996b) The curve for a non perforated package shows the maximum When the package was perforated the maximum disappeared, because the air-filled holes formed the main pathway across the film for $O_2$ and $CO_2$ gases, since the diffusion coefficient for $O_2$ in air is greater than for $CO_2$, the condition for overshooting, $P_2 > P_1$, was no longer fulfilled

Thus, the presence of a maximum in the time course of $CO_2$ concentration was shown to be an intrinsic characteristic of the packaging system in two important instances (a) no limitations on the form of respiration equation, but with the respiratoty quotient Q, being equal to 1 and (b) with a linear respiratory equation and no restriction on the value of Q In the present communication, a general case is analysed mathematically with



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no restrictions of the form of respiration equation, and no limitations on the respiratory quotient

## 2 General analysis of $CO_2$ concentration dynamics

Equations (2) may be transformed as follows multiply each term of the first equation by Q and substitute $R_2(C_1,C_2)$ in the second equation according to Eq (3)

$$QdC_1/dt = QR_1(C_1,C_2)\,W/V + QP_1A(C_{1A}\ \ C_1)/(LV)$$

$$dC_2/dt = QR_1(C_1,C_2)\,W/V + P_2A(C_{2A} - C_2)/(LV) \qquad (6)$$

Define $p_i = P_iA/(LV)$ for i=1,2 and add the two equations This results in an equation in which the term containing the respiration disappears

$$QdC_1/dt + dC_2/dt = Qp_1(C_{1A}\ \ C_1) + p_2(C_{2A}\ \ C_2) \qquad (7)$$

Reordering the terms in Eq (7) one obtains

$$dC_2/dt + p_2C_2 = p_2C_{2A} + Qp_1C_{1A}\ \ Qp_1C_1 - QdC_1/dt \qquad (8)$$

If the concentration $C_1(t)$ and its derivative $dC_1/dt$ are considered as given functions of time, Eq (8) may be solved as a linear differential equation for the function $C_2(t)$, subject to the initial condition, $C_2(0)=C_{2A}$ The solution is

$$C_2(t) = C_{2A} + Q(p_1/p_2)C_{1A}\ \ Qp_1\exp(-p_2t)\int_0^t \exp(p_2t)C_1(t)dt$$

$$Q\exp(\ p_2t)\int_0^t \exp(p_2t)dC_1(t) \qquad (9)$$

The first integral in Eq (9) may be written in a form similar to that of the second one by means of the rule of integration by parts

$$\int_0^t \exp(p_2t)C_1(t)dt = [\ \exp(p_2t)\ C_1(t) - C_{1A} - \int_0^t \exp(p_2t)dC_1(t)\ ]\ /\ p_2 \qquad (10)$$

Inserting Eq (10) in Eq (9) and combining the similar terms we obtain

$$C_2(t) = C_{2A} + Q(p_1/p_2)C_{1A}\ \ Q(p_1/p_2)C_1(t) + Q[(p_1/p_2)\ \ 1]\exp(\ p_2t)$$

$$\int_0^t \exp(p_2t)dC_1(t) \qquad (11)$$

To analyse the time course of function $C_2(t)$, it is necessary to study the sign of its derivative Differentiation of Eq (11) leads to

$$dC_2(t)/dt = Q\ [\ dC_1(t)/dt + (p_1\ \ p_2)\ \exp(\ p_2t)\int_0^t \exp(p_2t)\ dC_1(t)] \qquad (12)$$



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Function $C_1(t)$ is known to decrease monotonically, i e $dC_1(t)/dt$ is negative and the integral in Eq (12) is also negative Therefore, in the case $p_1 > p_2$ both terms in brackets are negative which results in a positive $dC_2(t)/dt$ at all intervals of time, i e, $C_2(t)$ grows monotonically When $p_1 < p_2$, the second term in the brackets has a sign opposite to that of the first one and the time $t=t^*$ may occur when the absolute values of these two terms are equal, leading to $dC_2(t)/dt = 0$ At this point, the function $C_2(t)$, which started to grow at t=0, passes through a maximum The position of this maximum is defined by

$$dC_1(t^*)/dt = (p_2 \quad p_1) \exp(\ p_2 t^*) \int_0^t \exp(p_2 t)\ [dC_1(t)/dt]dt \quad (13)$$

Introducing a new function, $Y(t) = \exp(p_2 t)\ dC_1(t)/dt$ we have the following equation for the time of maximum

$$Y(t^*) / (p_2 - p_1) = \int_0^{t^*} Y(t)dt \quad (14)$$

To the definite integral in Eq (14) an « intermediate value theorem » may be applied, which states that in the interval of integration [0, t*] a time $t=\tau$ exists at which the function $Y(\tau)$ multiplied by the length of the interval is equal to the integral, i e

$$\int_0^t Y(t)dt = t^*\ Y(\tau) \text{ with } 0<\tau<t^* \quad (15)$$

Combining Eqs (14) and (15) gives

$$t^* = [1/(p_2 \quad p_1)]\ [Y(t^*)/Y(\tau)] \quad (16)$$

It can be seen from Eq (16) that a positive t* does not exist if $p_2 < p_1$ It may be estimated also that when Y(t) is a diminishing function, the position of the maximum is $t^* < 1/(p_2 \quad p_1)$, whereas when it is an increasing function $t^* > 1/(p_2 - p_1)$

Figure 1 compares time course of $CO_2$ concentration calculated with the same set of package parameters but with two different film permeability coefficients curve A was calculated for $P_2 = 2\ 0\times10^{8}\ m^2h^{1}$, and curve B for the incident $P_2 = 0\ 46\times10^{8}\ m^2h^{1}$ In both cases $P_1 = 0\ 46\times10^{8}\ m^2h^{1}$ The first case corresponds to the film of LDPE and it reveals a maximum in the $CO_2$ concentration The curve B represents a hypothetical film with equal permeabilities for $O_2$ and $CO_2$ This may be realised in perforated films, in which case, the maximum vanishes and the increase of $CO_2$ concentration to the steady-state level is monotonic

## 3 Final remarks

The necessity for studying the dynamics of gas concentrations in packages is well recognized and many authors have reported their experimental observations and computer simula-



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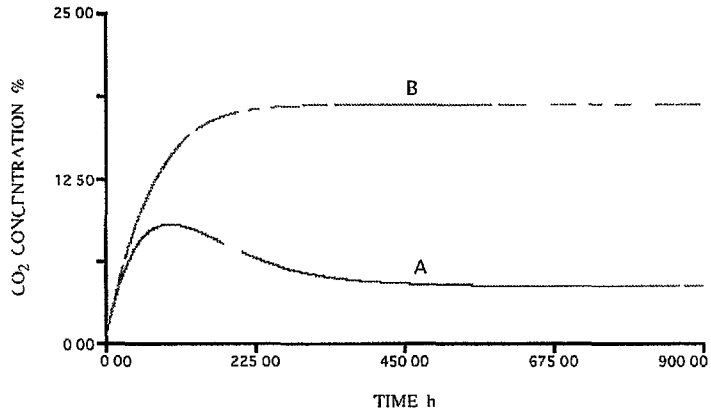


*Figure 1 Time course of $CO_2$ concentration calculated with the same set of package parameters but with two different film permeability coefficients Curve A was calculated for $P_2 = 2\ 0x10^{-8} m^2h^{-1}$ and curve B for $P_2 = 0\ 46x10^{-8} m^2h^{-1}$ In both cases $P_1 = 0\ 46x10^{-8} m^2h^{-1}$ The first case corresponds to the nonperforated film of low density polyethylene (LDPE)*

tions of the gas dynamics of the packagings of different fruits and vegetables To adapt the simulation model for building an expert system to the optimal design of modified-atmosphere packaging, its response to parameter changes must be carefully estimated by detailed numerical sensitivity analysis, as well as by mathematical analysis of the governing equations We performed the mathematical study of $CO_2$ kinetics in modified atmosphere packages and revealed an overshooting effect on the time course of $CO_2$ concentration

An overshooting effect in the curves for $CO_2$ kinetics appeared in the data published by several workers (Tomkins, 1962, Jurin and Karel, 1963, Hayakawa *et al*,1975, Geeson *et al* 1985) The phenomenon was not considered as an intrinsic characteristic of the system, dependent on the package parameters no model simulated this effect before our first attempt to explain this phenomenon and to validate it experimentally for red pepper (Fishman *et al* 1995) and mango (Fishman *et al*, 1996b) In the present study we showed that this effect depends mainly on the difference between film permeability to $CO_2$ and $O_2$ ($P_2>P_1$), but its existence does not depend either on the type of respiration equation, or on the value of respiratory quotient This means that during a prolonged part of the storage time the $CO_2$ concentration may be higher than its steady-state value This fact has to be taken into account in the search for parameters for optimal modified atmosphere packaging, especially for $CO_2$ sensitive commodities

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# POSTHARVEST LIFE OF FRUITS AND VEGETABLES MODEL OF MODIFIED ATMOSPHERE PACKAGES WITH FILM PERFORATIONS

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Abstract

A model was developed to study gas dynamics in a package containing fresh fruit The model calculates the gas balance taking into account the processes of fruit respiration and transpiration as well as the permeation of gases and water vapor through a perforated packaging film Equations are suggested to describe the permeation of gases and water vapor through perforations in the film The model enabled the time course of $O_2$ consumption $CO_2$ evolution and the humidity changes in the modified atmosphere enclosed in the perforated film to be computed analytically when the respiration rate depends linearly on $O_2$ concentration as is the case for instance for mango fruit The weight loss of the fruit in this modified atmosphere was calculated by means of the model The model enables the investigators to evaluate the film specifications and the package parameters which will provide the best conditions for storage of a given commodity

## 1 Introduction

The quality of fruits and vegetables stored in packages is affected by temperature and by the concentrations of $O_2$ $CO_2$ and water vapor The in package atmosphere is usually described as a modified atmosphere (MA) Its composition differs from that of the ambient atmosphere and depends on events happening at the boundaries of the free volume of the package the surface of the enclosed product and that of the packaging material

Reduced $O_2$ and elevated $CO_2$ concentrations in the MA of the package reduce the respiration rate which benefits for the storage of many fruits and vegetables High in package humidity reduces the dehydration of the stored commodities The $O_2$ $CO_2$ and water vapor levels have to be chosen individually for each stored produce and the parameters of MA packaging have to be selected to furnish the optimal storage conditions Among the most important parameters of the packaging are the permeabilities of the plastic film to $O_2$ $CO_2$ and water vapor these may be varied by choosing different materials for the film or by a change of the film thickness The commercially available materials are limited in their range of variation but film perforation provides a tool to extend the possibility for control of the gas exchange in the MA packages

Investigation of gas exchange through perforated plastic was undertaken by Emond *et al* (1991) They performed laboratory experiments to measure the gas transport through the perforations and developed empirical equations based on the observations The measurements were done with perforated plastic boxes of relatively large thicknesses and perforation sizes

A model for calculation of $O_2$ and $CO_2$ concentrations in a package containing fresh fruits was presented in our previous communication and was applied to bell pepper (Fishman *et al* 1995) The main objective of the present work was to extend our model by including a theoretical analysis of gas permeation through a perforated film and to

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calculate the in package gas concentrations and relative humidity (RH) The problem allows analytical solution when the Michaelis Menten equation describing the respiration rate can be linearized as in the case of mango fruit The weight losses of fruits packed with variously perforated films may be compared for various levels of RH outside the package

## 2 Theory

### 2 1 Gas transfer through a polymeric film with macroscopic perforations

The steady state diffusion flux density of gas i through a macroscopically homogeneous film obeys the Fick s law (in the following subscripts i = 1 2 and W will relate the variable to $O_2$ $CO_2$ and water vapor respectively)

$$J_i = P_i (C_i \quad C_{i\,A}) / L \tag{1}$$

where $C_i$ and $C_{i\,A}$ are the gas concentrations in modified and ambient atmosphere respectively $P_i$ is the permeability coefficient of the film to the gas i and L is the film thickness If the film is perforated the perforations represent a barrier for gas transport which is in parallel to the barrier of the plastic material In this case the total flow is

$$F_i = S\,J_i + S_h\,J_{i\,h} \tag{2}$$

where S is the film area $S_h$ is the total area of the holes and $J_{i\,h}$ is the flux of a gas i through unit area of the hole Macroscopic perforations have diameters of order of $10^{-4}$ m or greater whereas the mean free path of gas molecules at atmospheric pressure is much less being in the region of (1 to 2)x$10^{-7}$ m Therefore the transport through the perforation may be treated as macroscopic diffusion along a cylindrical pathway filled with air The diffusive flux in this case also obeys the Fick s law

$$J_{i\,h} = D_i (C_i \quad C_{i\,A}) / L_h \tag{3}$$

The diffusion coefficient of the gas in air $D_i$ replaces here the permeability coefficient in Eq (1) because there is no air-plastic interface on this pathway If the air were perfectly strongly stirred $C_i$ and $C_{i\,A}$ would represent the concentrations at the openings of the hole and the length of the cylindrical pathway $L_h$ would be equal to the thickness of the film L In the real systems unstirred layers of air exist on both sides of the hole This extends the path length by the thickness $L_u$ of the unstirred layers so that

$$L_h = L + L_u \tag{4}$$

If the distance between the perforations is much greater than their radius a model with spherical symmetry may be applied to calculate this diffusion problem and to estimate the thickness of the unstirred layers as described by Meidner and Mansfield (1968) According to this approximation $L_u$ is of order of the hole radius $R_h$

Taking into account Eqs (1) to (4) the total gas flow through the plastic film of area S with N perforations each of radius $R_h$ (i e total perforation area $S_h = N\pi R_h^2$) may be represented as

$$F_i = \quad (C_i \quad C_{i\,A}) [\, S\,P_i / L + S_h\,D_i \,/ (L + R_h) \,] \tag{5}$$



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2 2 Respiration

Equation of the Michaelis-Menten type may be applied to describe the rate of $O_2$ consumption due to fruit respiration in the MA package as described in our previous communications (Fishman *et al*, 1995) as well as adopted by other authors (e g Lee *et al* 1991)

$$r(C_I) = v_m C_I / (K_M + C_I + I) \quad (6)$$

where $v_m$ is the maximal rate of the respiration per unit weight of fruit and $K_M$ is the Michaelis constant The accumulation of $CO_2$ in the system may inhibit the respiration The term I in Eq (6) was introduced to describe the inhibition This effect is negligible for mango fruit and henceforth I=0 is assumed as a first approximation Study of the parameters of Eq (6) from experiments with mangoes reveals a strong correlation between parameters $v_m$ and $K_M$ indicating that only the ratio $\mu = v_m / K_M$ can be obtained from observations The best fit for mangoes was obtained when Eq (6) was linearized giving

$$r(C_I) = \mu C_I \quad (7)$$

Eq (6) may be approximated by Eq (7) when $K_M \gg C_I + I$ In terms of enzyme kinetics the linearization of the Michaelis Menten equation indicates a low affinity of the substrate for the enzyme as compared with the affinity of cytochrome oxidase for oxygen Forward (1965) followed by other authors (Chevillotte 1973 Tucker and Laties 1985) discussed possible explanations of this apparently low affinity which had already been observed in lemon apple and avocado

The ratio between the respiratory $CO_2$ evolution and $O_2$ consumption rates termed the respiratory quotient (RQ) is denoted by q RQ is constant over a wide range of $O_2$ concentrations but rises steeply at low $O_2$ concentrations (for mangoes we found q ≈ constant for $C_I \geq 0\ 05$)

2 3 Transpiration

As pointed out by Burg and Burg (1965) the gas diffusion from plant tissue should behave according to Fick s law Ben-Yehoshua *et al* (1985) adopted the Fick s law to describe the flux of water vapor through unit area of the fruit surface using the difference of relative humidities as a driving force in their study of citrus fruit resistance to water vapor transport

$$t_W(H) = \rho (H_f \quad H) \quad (8)$$

where the parameter $\rho$ is the permeance of the fruit surface to the water vapor (permeability coefficient divided by the barrier thickness) which is inversely related to the resistance $r = 1/\rho$ of the fruit surface to water vapor transport H is the in-package RH and $H_f$ is the RH inside the fruit which usually is very close to unity

The rate of change of fruit weight W due to transpiration is

$$dW/dt = s\rho (H_f - H) P^* / RT \quad (9)$$



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where s is the area of the fruit surface $P^*$ is the saturated vapor pressure R is the gas constant and T is the absolute temperature When fruits are placed in the open air H in Eq (9) has to be replaced with $H_A$ In that case the right-hand side of Eq (9) is constant and its solution represents the weight loss which is linear with time

$$W_0 \quad W = (s\,\rho\, P^*/RT)\,(H_I - H_A)\,t \qquad (10)$$

Observations of weight losses in the open air as a linear function of time enable us to learn the parameter $\rho$ as a factor of the line slope

## 3 Results and discussion

### 3 1 Solution of dynamic equations for MA package

Taking into account Eqs (5) (7) and (8) dynamics of oxygen carbon dioxide and water vapor in the MA package is represented by the following set of differential equations

$$dC_1/dt = \mu W C_1 / V + (C_{1A} - C_1)\,[S P_1 / L + S_h D_1 / (L + R_h)] / V \qquad (11)$$

$$dC_2/dt = q\,\mu W C_1 / V + (C_{2A} \quad C_2)\,[S P_2 / L + S_h D_2 / (L + R_h)] / V \qquad (12)$$

$$dH/dt = s\,\rho\,(H_I - H) / V + (H_A \quad H)\,[S P_W / L + S_h D_W / (L + R_h)] / V \qquad (13)$$

Here V is the free volume in the package Eqs (11) to (13) may be solved analytically to yield $C_1(t)$ $C_2(t)$ and $H(t)$ as functions of time Eqs (11) and (13) contain constant coefficients and could be solved independently Eq (12) is linear in variable $C_2(t)$ but it also contains the time dependent $C_1(t)$ It may be solved after the function $C_1(t)$ has been determined is a solution of Eq (11)

The steady state solutions of Eqs (11) and (13) (denoted by superscript *) are obtained by equalling the time derivatives to zero

$$C_1^* = C_{1A}[S P_1 / L + S_h D_1 / (L + R_h)] / [\mu W + S P_1 / L + S_h D_1 / (L + R_h)] \qquad (14)$$

$$H^* = \{s\,\rho\, H_I + [S P_W / L + S_h D_W / (L + R_h)]\, H_A\} / [s\,\rho + S P_W / L + S_h D_W / (L + R_h)] \qquad (15)$$

The solution of linear differential equations (11) and (13) subject to initial conditions of ambient atmosphere *i e* $C_1 = C_{1A}$ and $H = H_A$ at $t = 0$ is

$$C_1(t) = C_1 \quad (C_1^* \quad C_{1A}) \exp(-t / t_1^*) \qquad (16)$$

$$H(t) = H^* \quad (H^* \quad H_A) \exp(-t / t_W^*) \qquad (17)$$

where $t_1^*$ and $t_W^*$ are characteristic times for the dynamics of oxygen and relative humidity respectively defined as follows



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$$t_1^* = V / [\mu W + S P_1 / L + S_h D_1 / (L + R_h)] \quad (18)$$

$$t_W^* = V / [s \rho + S P_W / L + S_h D_W / (L + R_h)] \quad (19)$$

Eqs (16) and (17) represent solution of Eqs (11) and (13) under the assumption that all coefficients of the equations are constant For climacteric fruits such as mango the parameters of respiration and transpiration are known to change with time but in our observations these climacteric changes were much slower than the characteristic times of the system Thus the coefficients may be considered as constant within the time needed to approach steady-state

The steady-state solution of Eq (12) is obtained when the time derivative equals zero

$$C_2^* = C_{2A} + C_1^* q(C_1^*) \mu W / [S P_2 / L + S_h D_2 / (L + R_h)] \quad (20)$$

Denoting the second characteristic time as the following combination of constants

$$t_2^* = V / [S P_2 / L + S_h D_2 / (L + R_h)] \quad (21)$$

and taking solution (16) into account Eq (12) may be rewritten as

$$dC_2 / dt = (C_2^* - C_2) / t_2^* - (C_1^* - C_{1A}) (q \mu W / V) \exp(t / t_1^*) \quad (22)$$

As stated above $q \approx$ const if $C_1 \geq 0.05$ In this case the solution of Eq (22) subject to initial conditions of ambient atmosphere *i e* $C_2 = C_{2A}$ at t=0 is

$$C_2(t) = C_2^* \quad (C_2^* - C_{2A}) \exp(-t / t_2^*)$$

$$(C_1^* - C_{1A}) q \mu W t_1^* t_2^* [\exp(t / t_1^*) - \exp(-t / t_2^*)] / [V(t_1^* \quad t_2^*)] \quad (23)$$

Eq (23) contains two characteristic times $t_1^*$ and $t_2^*$ which generally results in the appearance of a maximum on the curve $C_2(t)$ under certain combinations of the system parameters The time of the maximum is calculated as

$$t_{max} = [t_1^* t_2^* / (t_1^* - t_2^*)] \ln\{ (t_1^* / t_2^*)$$

$$+ (C_2^* \quad C_{2A}) V (t_1^* \quad t_2^*) / [(C_{1A} C_1^*) q \mu W t_2^{*2}]\} \quad (24)$$

After the in package relative humidity is calculated as a function of time Eq (17) may be used for calculation of weight loss of packaged fruit Inserting Eq (17) into Eq (9) and integrating this differential equation yields

$$W_0 \quad W = (s \rho \quad P^* / RT) [ (H_f - H^*) t + (H^* - H_A)(1 \quad \exp(t / t_W^*)) t_W^*] \quad (25)$$

Eq (25) gives the non-linear time dependence of the weight loss in the package but if the characteristic time $t_W^*$ is much shorter than the time of observation ($t_W^* \ll t$) the non linear term becomes negligible leading to an approximately linear time dependence

3 2 Validation of the model

The model parametrization is based on experiments with mangoes in a closed system and in the ambient atmosphere The estimated parameters are displayed in Table 1

The methods for parameter estimation were described for bell pepper by Fishman *et al* (1995) The value of q in experiments with mango was found to be approximately constant (q=0 785) for $C_1$>0 05 When $C_1$ became less than 0 05 q was observed to rise steeply being about 3 4 at $C_1 \approx 0\ 02$

Table 1 Parameters of the investigated system

| Symbol | Meaning of the parameter | Value | Dimension |
|---|---|---|---|
| q | respiratory quotient for $C_1$>0 04 | 0 785 | non dimensional |
| q | respiratory quotient for $C_1 \approx 0\ 02$ | ≈3 5 | non-dimensional |
| μ | coefficient of respiration rate | 9 2x10 $^{5}$ | $m^3\ kg^{-1}\ h^{-1}$ |
| ρ | permeance of fruit surface to water vapor | 1 233 | $m\ h^{-1}$ |

To validate the theory its predictions were compared with the results of experiments on mango fruits in simulated MA packages with perforated and non perforated films Steady-state oxygen concentrations and RH levels were calculated from Eqs (14) and (15) respectively The calculated and observed values for perforated and non perforated packages are collected in Table 2 where a good agreement can be seen between the theoretical and experimental results Concentrations $C_2^*$ are calculated from Eq (20) which depends on the value of $C_1^*$ Taking into account that with non-perforated film $C_1^* \approx 0\ 02$ the value of 3 5 was used for the parameter q in this case for $C_2^*$ evaluation The computed oxygen concentration for perforated film was $C_1^* \approx 0\ 19$ with the corresponding value of the respiratory quotient q being 0 785

Table 2 Comparison of steady state values of variables in perforated and non perforated packages model predicted vs observed values

| | $S_h = 0\ (m^2)$ | | $S_h = 1\ 257X10^{5}\ (m^2)$ | |
|---|---|---|---|---|
| | predicted | observed | predicted | observed |
| $C_1^*$ | 0 018 | 0 01 | 0 193 | 0 19 |
| $C_2^*$ | 0 15 | 0 14 | 0 016 | 0 017 |
| $H^*$ | 0 999 | 1 0 | 0 997 | 1 0 |

The dynamics of gases in a MA is governed by Eqs (16) (17) and (23) which depend on characteristic times The characteristic times for oxygen dynamics calculated from Eq (18) are $t_1^* = 9\ 6$ h for N = 0 and $t_1^* = 0\ 795$ h for N = 4 Similarly $t_W^*$ computed from Eq (19) are 0 0139 h and 0 0137 h for N = 0 and N = 4 respectively Eqs (21) and (24) predict $t_2^* = 1\ 08$ h and no maximum in the curve of $C_2(t)$ vs t in the case of perforated film In the case of non-perforated film $t_2^* = 26$ h and a maximum is predicted at time $t_{max} = 17\ 8$ h During the characteristic time intervals $C_1(t)$ remains at the level which allows to approximate RQ by the constant q=0 785 Calculating the



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dynamic variables by means of Eqs (16) (17) and (23) at this time interval and comparing the results with observations confirms the validity of the model for studying the transient period Fig 1 compares the observed (points) and calculated (curves) time courses of $O_2$ and $CO_2$ concentrations in MA for both N = 0 and N = 4 showing a good fit of the theoretical equations to the experimental values

Weight losses after 100 h of storage under various conditions were predicted using the model and are shown in Fig 2 Three conditions are compared 1 open atmosphere 2 MA package with perforations and 3 - MA package without perforations Two values of $H_A$ the RH in the ambient atmosphere were chosen for the computations 0 7 and 0 9 All parameters of the system were chosen in accordance with Table 1 Reduction of $H_A$ from 0 9 to 0 7 raises the weight loss nearly threefold A more important result is that the weight loss predicted for the fruit stored in the open air is about 35 40 times greater than that of fruit stored in an MA package with holes whereas the oxygen content in such a package was calculated and measured to be close to that of the free atmosphere

The results show that the perforations affect the dynamics and steady-state concentration of oxygen in MA much more strongly than those of water vapor A qualitative explanation of this phenomenon may be seen by estimating the volumes of $O_2$ consumed hourly by fruit in ambient atmosphere due to respiration and of water vapor evolved hourly due to transpiration The first is $\rho\ C_A\ W = 1\ 56 \times 10^{-5}\ m^3\ h^{-1}$ whereas the second is $a\ p_W\ (H_f - H_A) = 5\ 55 \times 10^{-3}\ m^3\ h^{-1}$ Thus the process of evolution of water vapor in a free atmosphere is about 350 times faster than that of $O_2$ consumption This leads to very quick filling of the free volume of the package with water vapor even if there are small perforations in the packaging film

It may be concluded that the computed variations in the effects of perforation level may serve as a tool in furnishing the MA to supply optimal conditions for storage of given product (together with film material thickness surface area and other package parameters previously discussed as optimization tools) The model is also a tool for prediction of the fruit weight loss under various combinations of the atmospheric humidity and package film perforations

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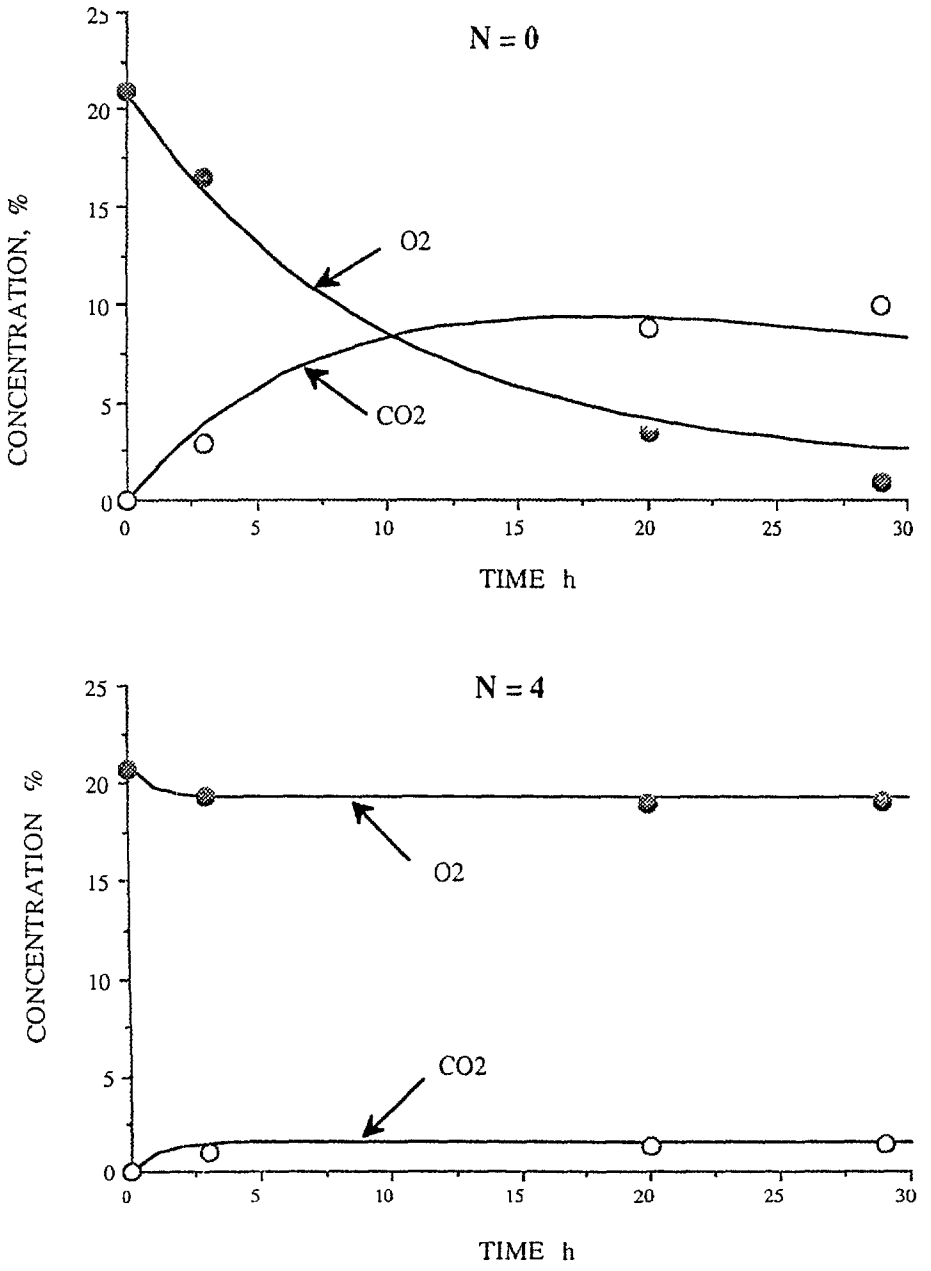


Fig 1 Observed (circles) and calculated (curves) time courses of $O_2$ and $CO_2$ concentrations in MA packaging with (N=4) and without (N=0) perforations



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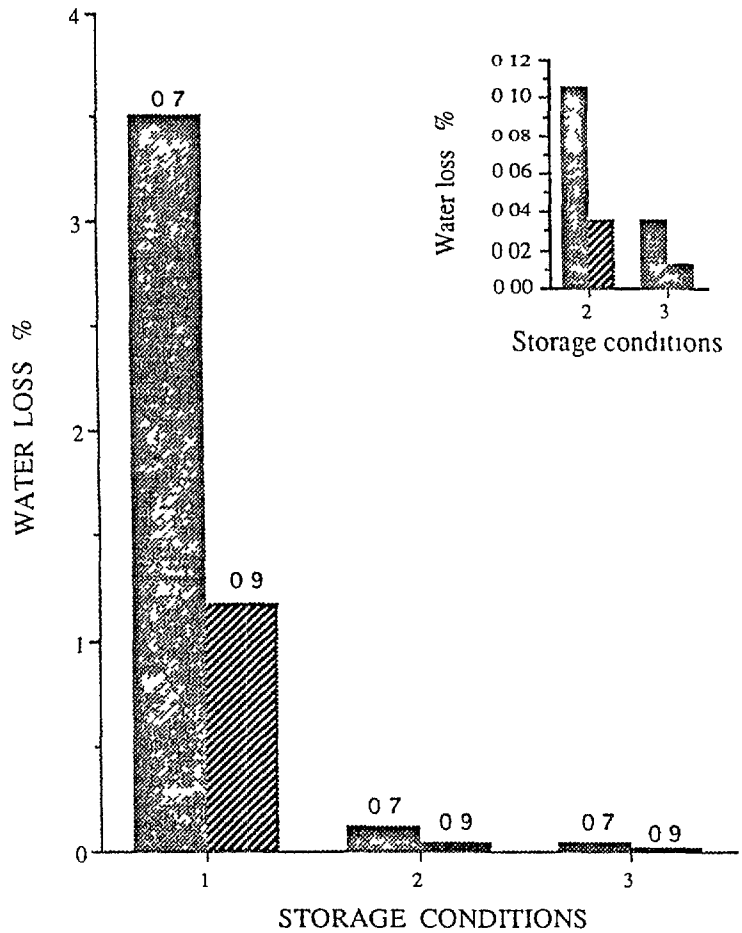


Fig 2 Predicted weight losses of fruit under various conditions 1 open air 2 MA package with perforations and 3 - MA package without perforations Figure over a column is the RH value in the ambient atmosphere The inset shows the cases 2 and 3 on an enlarged scale

# MODIFIED ATMOSPHERE PACKAGING (MAP) OF 'TOMMY ATKINS' MANGO IN PERFORATED FILM

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## Abstract

Packaging 'Tommy Atkins' mango in perforated polyethylene film delayed fruit spoilage and allowed normal ripening together with a weight loss reduction by half and prevention of fruit shrivelling An irreversibly impaired ripening and anaerobic fermentation were observed in the fruit sealed in non-perforated film A series of modified atmosphere packages with different steady-state levels of $O_2$ and $CO_2$ was obtained by varying the perforation area from 1 to 69 sq mm per package containing two fruit In all these perforated packages, the fruit was capable of undergoing ripening-related changes, but their rate differed markedly in accordance with the in-package atmosphere This phenomenon opens a possibility to regulate the ripening rate in accordance with the desired duration of storage and/or transportation period Various ripening parameters differed in sensitivity to modified atmosphere, so that the yellow peel color was reached later than other ripeness traits However, it was still possible to achieve a desirable combination of fruit qualitative characteristics since the phase of over-ripening was consistently delayed in perforated MAP Combination of MAP with effective decay-controlling measures can extend the postharvest life of mango fruit

## 1 Introduction

'Tommy Atkins' is one of the main mango cultivars grown both in Israel and in Costa-Rica The postharvest life span of mango usually does not exceed 2-3 weeks and is limited by physiological deterioration of the fruit related to its overripening, and by pathogens development leading to fruit decay Additionally, desiccation of mango during the prolonged transportation, storage and shelf-life period causes its shrivelling and reduces the market value of the fruit Extending the postharvest life is necessary in order to reach the distant export markets by marine transportation with the fruit of high quality

The technique of modified-atmosphere (MA) packaging in plastic films is steadily becoming more important as a tool to prolong the storage life of perishable commodities (Ben-Yehoshua et al , 1985, Gorris and Peppelenbos, 1992) Previous experiments on sealing Tommy Atkins mangoes in nonperforated films had shown that altered in-package atmosphere impaired the fruit ripening (Shapiro et al , 1989) and caused the off-flavors (Miller et al , 1986) The use of perforated films was recommended for packaging mango fruit and successfully tested in storage experiments (Rodov et al , 1994, Yantarasri et al , 1994) The development of perforated MA package for Thai mango cultivar Nam Dork Mai has been described recently (Yantarasri et al , 1995)

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The present research was aimed at optimization of perforation level in MA packages of Tommy Atkins mango in order to improve keeping quality of this fruit without decline of its consumer characteristics The work was conducted in 1994 in the Department of Postharvest Science of Fresh Produce (ARO - The Volcani Center, Israel)

## 2 Materials and Metods

Mature-green mangoes of Tommy Atkins cultivar grown in Jordan valley (Israel) were obtained from the packing house at the day of harvest The fruit did not receive any packing-house treatment except washing Within 24 h after reaching the laboratory, the fruit were subjected to hot water dip at 51±1°C for 5 minutes as a disease-controlling measure

The fruit were sealed in packages of 40 μ- thick low-density polyethylene (LDPE) Two fruit of known initial weight were sealed in each package The perforation levels were characterized by total perforation area per package (TPA) which was ranged as follows 0, 1, 4, 19, and 69 sq mm Control fruit were kept in standard mango packages - open cardboard trays

Packaged fruit were stored at 14°C and relative humidity (RH) of 85±3% The storage duration varied from 2 to 4 weeks The storage period was followed by a shelf-life imitation, when the packaged fruit was kept for 4 days at 20°C and RH 85±3% At the end of shelf-life period, the packages were opened and part of the fruit was used for quality analysis If necessary, the rest of the fruit were kept open for one additional week at 20°C to complete ripening

The following parameters were checked in the experiments in-package atmosphere composition (Varian 3300 gas chromatograph), decay incidence, fruit weight loss, shrivelling, firmness (Chatillon penetrometer), percentage of total soluble solids (refractometer), titratable acidity, peel and flesh color (Minolta CR-200 and visual index), taste

## 3 Results

### 3 1 Composition of in-package atmosphere

In non-perforated packages, the oxygen concentration decreased rapidly to the level of 2-3% The anaerobic fermentation process prevailed in fruit at those conditions Accordingly, the atmosphere of non-perforated packages was rich in $CO_2$, ethanol (2,000 to 3,000 ppm) and acetaldehyde (130 to 150 ppm) Even the smallest perforation level tested (1 sq mm/package) practically prevented anaerobiosis In perforated packages, the $O_2$ concentration varied from 10 to about 20% with the increase of total perforation area (TPA) from 1 to 69 sq mm/package Accordingly, the $CO_2$ concentration varied in those packages from 10 to about 1% (Table 1)

At all perforation levels tested, the measured in-package ethylene concentration had a peak after 2 weeks of storage The ethylene peak observed at TPA of 4 sq mm/package (up to 0 045 ppm), was slightly higher than at other perforation levels (about 0 03 ppm) while almost the same ethylene level was registered in the non-perforated packages (0 04 ppm) As a rule, the in-package ethylene level started to increase again during the fourth

week of storage at 14°C (excepting the fruit kept in non-perforated packages), and further increased after transfer from 14°C to 20°C

3 2 Weight loss and shrivelling

Perforated seal-packaging reduced greatly the fruit weigt loss, even at highest perforation level As a rule, the weight loss percentage was directly related to TPA value In non-perforated sealed packages, the weight loss was surprisingly high, possibly, as a result of intensive exudation of liquid from the fruit

Seal-packaging prevented the fruit shrivelling Even when the fruit were taken out from the packages and kept open for an additional week at 20°C, only negligible shrivelling was evident At that period, about 50% of non-sealed control fruit were shrivelled

3 3 Decay

The fruit seal-packaged without perforation had no decay until opening of the package but then rotted rapidly The decay level in fruit stored in perforated packages was consistently lower than that in the non-sealed control For example, after 3 weeks of storage at 14°C and 4 days at 20°C, the decay incidence in perforated packages did not exceed 10-12% as compared to 20% in the control

3 4 Fruit ripening

Softening Keeping mango fruit in non-perforated sealed LDPE packages inhibited their softening, so that the fruit stayed hard even after 4 weeks of storage and 4 days of shelf life The smallest perforation level was sufficient to enable softening similar to that of the control fruit

Total soluble solids (TSS) Similar to fruit softening, the minimal package perforation was enough to enable the normal accumulation of soluble solids in mango fruit during storage In non-perforated sealed packages, this process was completely inhibited and TSS percentage was kept practically at the initial level (Fig 1a)

Titratable acidity The rate of acidity changes depended on perforation level In highly perforated packages (TPA of 69 and 19 sq mm/package), as well as in non-sealed fruit, the titratable acidity declined sharply during the storage period of 2 weeks at 14°C and 4 days at 20°C At that shortest storage period, mangoes seal-packaged with TPA of 4 sq mm/package were more acid than the control (Fig 1b) However, if the cold storage lasted a week longer (3 weeks at 14°C and 4 days at 20°C) the fruit kept at TPA of 4 sq mm/package had by the end of that period the same acidity level as the non-sealed mangoes (Fig 1b) After 4 weeks of storage and 4 days of shelf life, fruit sealed with 1 sq mm of TPA also reached the acceptable acidity value (Table 1) In non-perforated sealed packages, the acidity never approached the level of non-sealed fruit

Taste After 3 weeks of storage at 14°C and 4 days at 20°C, the taste panel preferred the fruit kept in perforated sealed packages over those from the non-packaged control, mainly because it was not overripe The highest taste score was won by the fruit packaged at TPA of 4 sq mm, followed by the fruit kept at TPA values of 19 and 1 sq mm The fruit kept in non-perforated sealed packages was inedible because of extremely strong

alcoholic off-flavor, excessive acidity and firmness The slight off-flavor was sometimes evident also in fruit packaged at TPA of 1 sq mm (Fig 1d)

Flesh color After 2 weeks of storage at 14°C and 4 additional days at 20°C, the non-sealed fruit and the fruit seal-packaged with TPA of 69 sq mm, developed the same intense yellow flesh color This color was reached by the flesh of fruit kept at TPA of 4 and 19 sq mm one week later, and it was enhanced slightly after an additional week of storage TPA lower than 4 sq mm/package, was insufficient to allow full flesh color development The sealing prevented an excessive flesh darkening observed in non-scaled control after prolonged storage as a result of overripening

Peel color Of all ripening-related processes, the peel color change was the most sensitive to the conditions of in-package atmosphere In non-perforated sealed packages, fruit maintained its green color for more than two weeks, and later demonstrated a dark (grayish to dark-brown) discoloration

After 3 weeks at 14°C and 4 days at 20°C, only fruit packaged with TPA of 69 sq mm had turned yellow At least 19 sq mm TPA was required for fruit to reach a yellow peel color after 4 weeks of storage and additional 4 days of shelf life After opening the sealed packages, fruit kept at TPA of 4 sq mm also reached yellow color, while the peel of fruit packaged at TPA of 69 sq mm/package turned yellow-orange However, it still did not reach the color intensity of the control fruit The TPA of 1 $mm^2$/package was not sufficient for complete peel yellowing (Fig 1c)

Direct relationship was observed between the advance of peel color and the in-package oxygen concentration, as well as $O_2/CO_2$ ratio Table 1 summarizes the approximate time necessary for mango fruit to reach "ripeness level" of different qualitative parameters, as effected by in-package oxygen and $CO_2$ concentrations

## 4 Discussion

The advantages of packaging fruits in plastic films, i e reduced weight loss and prevented shrivelling, are well documented for various commodities (Ben-Yehoshua, 1985) including mango (Miller et al, 1983, Shapiro et al, 1989, Sornsrivichai et al, 1989, Gonzales et al, 1990) The main challenge of applying modified atmosphere packaging (MAP) to climacteric fruit, such as mango, is to combine these advantages with desirable ripening rate and good quality of the fruit at marketing stage

As shown above, keeping Tommy Atkins mangoes in sealed non-perforated packages of 40μ-thick LDPE spoiled the commodity because of irreversibly inhibited ripening, anaerobic fermentation, dark discoloration, and rapid decay after opening the packages The $CO_2$ injury was probably a cause of the discoloration as reported earlier by Bender et al (1994) This disorder could be prevented by adding pouches with $CO_2$-absorbing material into the package space (Rodov and Ben-Yehoshua, non-published data) Recently Burdon et al (1996) have proposed that acetaldehyde can retard mango ripening by inhibiting the ethylene biosynthesis through supression of ACC oxydase In our work, the ripening inhibition in non-perforated packages was indeed accompanied by the sharp increase in acetaldehyde and ethanol accumulation, although no complete supression of ethylene production took place Measurement of internal ethylene concentrations in mesocarp tissue and determination of ethylene production rates would be helpful for interpretation of physiological basis of the phenomena observed Altogether, in agreement

with the conclusions of Miller et al (1986) and McCollum et al (1992), the detrimental effects of non-perforated seal-packaging canceled its benefits for Tommy Atkins mango

It should be noted that response of other mango varieties to non-perforated film packaging may be different So, use of non-perforated films improved both the keeping qualities and the consumer characteristics of Keaw Sawoey mangoes traditionally consumed in Thailand at the unripe mature-green stage (Sornsrivichai et al, 1989) Positive results were obtained also with shrink seal-packaging of typically green-colored Keitt mango In contrast to Tommy Atkins variety, the palatability of Keitt mangoes was less affected by the non-perforated film, so that after prolonged storage the panelists consistently preferred the sealed fruit to the non-sealed one because of prevented overripening (Rodov et al, 1994, Yantarasri et al, 1995) The optimal $CO_2$ concentration for controlled-atmosphere (CA) storage of Tommy Atkins mangoes was found to be twice as low as that for the Kent variety (Lizana and Ochagavia, 1996)

Packaging Tommy Atkins mangoes in perforated films did not cause irreversible disorders observed in non-perforated packages, and at the same time markedly alleviated physiological problems limiting the storage life of non-sealed mangoes (overripening, desiccation) Interestingly, in CA experiments the inhibition of chlorophyll breakdown in Tommy Atkins mango was found to be reversible at 25% $CO_2$ + 3% $O_2$, so that the fruit was capable of yellowing after transfer to air, but irreversible at 45% $CO_2$ + 3% $O_2$ (Bender et al, 1994) It is possible that also in our MA experiments the $CO_2$ concentration could determine the character of color changes On the contrary, softening of mangoes in CA conditions was determined by the $O_2$ level rather than by $CO_2$ (Jordan and Smith, 1993)

A series of modified-atmosphere packages with different steady-state $O_2$ and $CO_2$ levels and concomitant rates of ripening-related processes was obtained by varying the perforation area from 1 to 69 sq mm The TPA values between 4 and 19 sq mm/package enabled achievement of full fruit ripening with 1 to 2 weeks delay as compared to non-sealed control This phenomenon opens a possibility to choose a package characteristics in accordance with the desired duration of storage/transportation period, in order to obtain just by the end of this period a fruit which would combine low weight loss, absence of shrivelling with good edible quality Optimizing the characteristis of perforated MA mango package may be based on the newly developed mathematical model (Fishman et al, 1996)

Because of different sensitivity of various fruit quality parameters (such as TSS, acidity, firmness, flesh and peel color) to atmosphere composition, they required different time to reach the full ripeness level in the MA conditions (see Table 1) The change of ground color from green to yellow appeared to be the most sensitive to in-package conditions, so that the yellow peel color was reached later than other ripeness traits This desynchronization of ripening was noted earlier in CA storage (Jordan and Smith, 1993) However, it was still possible to achieve a desirable combination of fruit qualitative characteristics since the phase of overripening was delayed in perforated MAP

In situation when physiological deterioration of the fruit (overripening, desiccation) is alleviated by MA package, pathogen development turns to be a major factor limiting the storage life, especially if the fruit needs longer time to attain the desirable combination of quality characteristics In this view, choice of additional decay-preventing measure is of high importance for application of this technique In our experiments, the combination of perforated plastic package with hot water dip (5 min at 51°C) was not sufficient to

completely prevent the postharvest diseases, although the decay incidence in the perforated packages was lower as compared to non-treated fruit Successful use of plastic packaging with Nam Dork Mai mango in Thailand (Sornsrivichai et al, 1992) was allowed by its combination with hot benomyl applications Combination of new non-fungicide measures to control the postharvest diseases of mango (Prusky et al, 1996) with MA packaging might be an attractive approach for simultaneous improvement of keeping quality and consumer characteristics of the fruit

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Table 1 Effect of in-package atmosphere on the number of weeks* necessary for Tommy Atkins mango to reach ripeness level

| | Steady-state level | | Ripening parameters | | | | |
|---|---|---|---|---|---|---|---|
| TPA, mm²/pac | $O_2$, % (range) | $CO_2$, % (range) | Acidity <0 25% | TSS >13% | Firm <1kG | Flesh color Hue°<85° | Peel color yellow |
| 0 | 2-3 | 25-40 | NR | NR | NR | NR | NR |
| 1 | 9-10 | 11-13 | 4 | 2 | 3 | NR | NR |
| 4 | 16-17 | 4-5 | 3 | 2 | 2 | 3 | 3+1** |
| 19 | 18-20 | 2-3 | 2 | 2 | 2 | 3 | 4 |
| 69 | 19-21 | 0 7-1 | 2 | 2 | 2 | 2 | 3 |
| ∞ (N/seal ) | 20 5-21 | 0 03- 05 | 2 | 2 | 2 | 2 | 2 |

* followed by 4 days at 20°C, NR - never reached

** 1 additional week unpackaged at 20°C

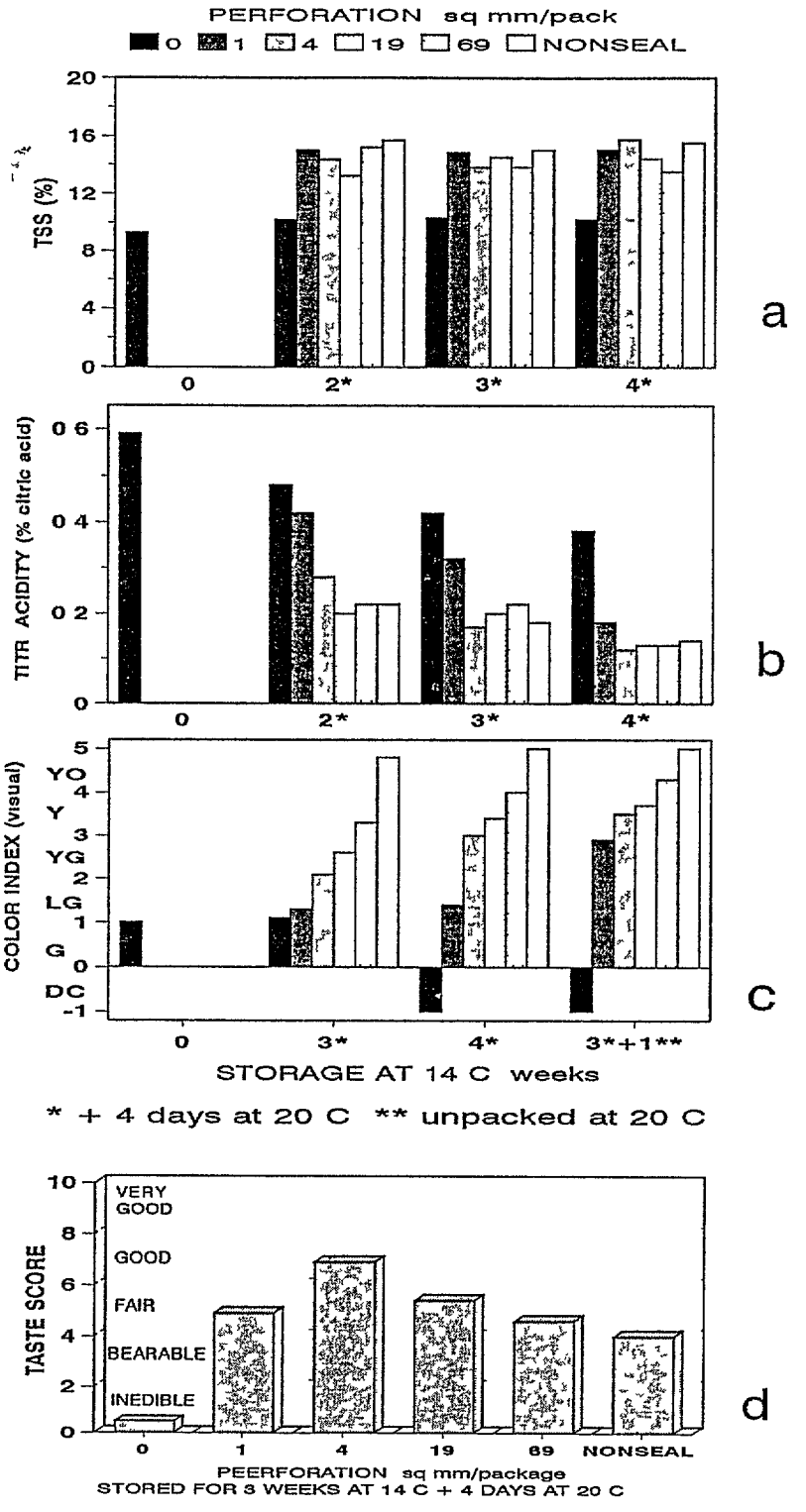


Figure 1 Effect of package perforation and storage duration on the quality of 'Tommy Atkins' mango a - percentage of total soluble solids (TSS), b - titratable acidity, c - peel color (visual scale YO - yellow-orange, Y - yellow, YG - yellow-green, LG - light-green, G - green, DC - discoloration), d - taste score