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Some Physiological Effects of Delaying Deterioration of Citrus Fruits by Individual Seal Packaging in High Density Polyethylene Film[1]

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Abstract. **Seal-packaging of individual fruits of 'Shamouti' and 'Valencia' oranges (*Citrus sinensis* L. Osbeck), grapefruit (*C. paradisi* Macf cv. Marsh) and lemons (*C. limon* Burm. f. cv. Eureka) with a film of high-density polyethylene (0.01 mm) markedly delayed their deterioration as measured by peel shrinkage, softening, deformation and loss of flavor. This film was applied to fruit that had received conventional treatments of disinfection with sodium orthophenylphenate and waxing. Sealed fruit maintained their fresh appearance more than twice as long as conventionally handled fruit. Weight loss of fruit was reduced about five-fold. Sealed fruit at 20° were firmer and lost less weight than non-sealed fruit at the lowest optimal temperature. Sealing various citrus fruits in high density polyethylene reduced both their respiratory activity and ethylene production. CO_2 and O_2 content in the internal atmosphere of the sealed and control fruit were similar but ethylene content was lower in the sealed fruit.**

Delaying the deterioration of citrus fruit is of prime importance because most of it is sold several weeks after being picked or even after being stored for several months. Primarily as a result of transpiration, the fruit loses its fresh appearance, becoming shrunken, soft and deformed (4). Ben-Yehoshua reported (2) that an a aqueous suspension of plastic polymers was effective as a skin coating for various fruits and vegetables to reduce transpiration. A suspension of high-density polyethylene (HDPE), called "Tag," delayed fruit deterioration better than waxes (3, 4). Similar results were obtained with an orchard spray of polyethylene in Florida (11). Ben-Yehosua (4) showed that Tag inhibited transpiration without affecting fruit flavor. Badran et al. (1) suggested that packaging in low-density polyethylene would extend the shelf life of many fruits. Working with citrus, Grierson (12) found fruit packed in low density polyethylene bags had more fruit decay than the control mainly because of water condensation within the bags. Daun et al. (10) suggested the use of polyvinyl chloride film for packaging fruit.

In 1973, A. Cohen and D. Nahir reported[2,3] that wrapping lemons in high-density polyethylene film reduced weight loss and slowed softening. Ben-Yehoshua et al. (7) reported very favorable results when various citrus fruits were wrapped, but not sealed, in 0.015 mm HDPE film. This wrap extended the storage life of both oranges and grapefruits far longer than the HDPE suspension. However, the HDPE wrap enhanced stem-end rot and, in particular, the internal decay caused by *Alternaria citri.* Seal-packaging with HDPE film, combined with various treatments of the film or of the fruit with fungicides and other materials, helped overcome this problem (4, 7). Nahir and Ben-Yehoshua (15) developed a special machine (patent pending) that automatically seals the fruit for this purpose.

Carried out over a period of 5 years, the work will be described in a series of articles (5). The present paper deals with the major physiological effects of this new packaging method.

Materials and Methods

The following citrus fruits were used in these studies: 'Shamouti' and 'Valencia' orange; 'Marsh' grapefruit; and 'Eureka' lemon. The fruit was obtained directly from orchards, or from packing plants. Samples of fruit of uniform size and appearance, originating in one orchard, were subjected to the different treatments at random. At first, the samples were of the size required for the statistical analysis, that is, 20 individual fruit per treatment for examinations of firmness or weight loss, and 10 to 20 crates (each containing 50-150 fruits) per treatment for studies of decay. Subsequently, thousands of fruits were sealed with HDPE on a semi-commercial scale, and tested for the regular export shipment as well as for long-term storage extending over ten months to facilitate the supply of fruit all year round.

Since this new packaging markedly improved the keeping quality of the fruit, experiments were performed to see if the need for refrigeration could be reduced. Accordingly, storage tests were carried our at several temperatures (described below). All fruits received the conventional treatment consisting of washing, disinfection in sodium orthophenylphenate (SOPP), rinsing, drying, and coating the fruit with one of several wax-type materials, most of which contained some polyethylene (3) as well as 4000 ppm of thiabendazole. Controls consisted either of fruit treated as described above, or fruit wrapped in thin paper, either plain or impregnated with diphenyl, routine in citrus fruit export.

The high-density polyethylene (HDPE) film was applied with a plastic heating unit made by Swery Inc., Israel, and later with a specially designed sealing machine (15), with similar results. The HDPE, supplied by Mitsui Petrochemicals, Japan, or Hoechst, Germany, had a specific density of 0.955. The HDPE was extruded to make a sleeve or bag, which was then

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[3]Cohen, A. & D. Nahir. 1973 Wrapping of Lemons in High Density Polyethylene Paper (in Hebrew). Internal report of the Institute of Agricultural Engineering, The Volcani Center, Bet Dagan, Israel.

sealed over the individual fruit so that the air space within the package was around 50% of the fruit's volume. However, the sealing machine (15) incorporated a hot-air tunnel that caused the HDPE film to adhere to the fruit, leaving no air space at all. This heat-shrinking operation had little or no effect on the fruit tested.

CO_2 evolution, ethylene production and endogenous levels of CO_2, O_2 and ethylene were measured by the methods described in previous reports (3, 4, 5). The sealed fruits were handled the same way as the non-sealed ones. Ethylene and CO_2 production were investigated by enclosing both sealed and non-sealed fruits in closed jars for a limited time. It was previously established that such a brief exposure does not affect the rate of CO_2 or ethylene production (6). Fruit firmness was examined by hand or with a compression tester developed in our laboratory and modeled after Hamson's Cornell Pressure Tester (13). The method is based on the response of the fruit to pressure exerted on its longitudinal axis. The pressure was 5kg on grapefruit and 3kg on 'Shamouti' orange. The first reading obtained 30 sec after placing the weight gave the full deformation in mm. Then, the weight was removed and the size of the fruit partially restored. This residual deformation was also scored 30 sec after removal of the weight when the reading was about constant. The firmer the fruit, the lower were both the first reading of full deformation and the second of residual deformation. These readings were found to give an objective and operational measure of firmness of citrus fruit.

Taste determinations were carried out by means of the triangle test (14).

The temperature of the fruit itself was measured by inserting thermocouples into the peel of the fruit.

Development of overripe coloration of 'Marsh' grapefruit and 'Eureka' lemon was measured visually.

To measure the relative water loss of peel and segments of grapefruit, the fruit was peeled after 2 months storage at 20°C and both organs were dried at 80° until a constant weight was achieved.

Results

Effect of weight loss. Seal-packaging of fruit in 0.010 mm HDPE film markedly reduced the loss of weight in 'Shamouti' oranges (Tables 1, 2). One or even 2 dippings in Tag suspension reduced the loss in weight by no more than 18% and 22%, respectively, while the reduction of weight loss in oranges seal-packaged in HDPE was 90%. About the same reduction was obtained with other citrus fruits seal-packaged with HDPE and stored under normal conditions for shipping or storing citrus fruit such as temperatures between 10° and 30°C. Fig. 1 shows these effects for 'Eureka' lemons. Sealed fruit kept at 50% relative humidity (RH) for 2 weeks at 20° lost less weight (1.3%) than non-sealed fruit kept at 90% RH (7.3%), probably because of saturated humidity and no air circulation inside the seal-package.

The major source of weight loss of grapefruit stored for 2 months at 20°C is water from the peel rather than from the pulp. No difference was found in the amount of water (91%) in the segments of both sealed and non-sealed fruit. In the peel, however, fruit wrapped in paper contained 74% water, while fruit sealed in HDPE had 83%.

Effect on appearance. An important consequence of seal-packaging with HDPE film is its effect on fruit appearance (Table 2). The fruit tested maintained its fresh appearance for many months even under storage conditions of 20°C and 65% RH, or under packing plant conditions without cooling or ventilation. In the sealed fruit shrinkage was virtually prevented, being hardly noticeable after months of storage even under room conditions, while the non-sealed fruit appeared dry and brittle (Fig. 2). Even more impressive were 'Eureka' lemons that were kept for 10 months at 14° and 90% RH followed by 2 months of shelf-life at 20° and 50% RH: they looked fresh, showing no shrinkage at all, whereas the non-sealed fruit shrank after 2-4 months at 14°, subsequently turning brittle even at that temperature.

Seal-packaging grapefruit had another desirable effect of considerably inhibiting the deformation to which that fruit is particularly subject (Table 3). One month after picking, 50%

Table 1. Effect of seal-packaging with high density polyethylene (HDPE) on weight loss and firmness of 'Shamouti' oranges stored at 20°C and 60-75% RH.

Treatment	Weight loss during 12 days (%)	Firmness after 28 days: mm full deformation[y]	Firmness after 28 days: Hand-test
Control[z]	4.23 a[w]	6.9 a	Resilient
One dip in Tag[x]	3.45 b	5.9 b	Resilient-firm
Two dips in Tag	3.27 b	5.6 b	Resilient-firm
Sealed in HDPE	0.43 c	3.3 c	Firm

[z]Disinfection with SOPP, waxed with Zivdar.

[y]The higher the value, the more the fruit had softened.

[x]A skin coating for waxing fruit produced by Makhteshim, Be'er Sheva, Israel.

[w]Mean separation in columns by Duncan's multiple range test, 5% level.

Table 2. Effect of seal-packaging with high-density polyethylene on storage life and weight loss of different citrus fruits at 20°C and 85% RH.

Fruit	Mean storage life (months): Sealed	Mean storage life (months): Non-sealed	Weight loss per week (%): Sealed	Weight loss per week (%): Non-sealed
'Eureka' lemons	10	2-3	0.4	3.5
'Marsh' grapefruits	6	2	0.2	1.1
'Valencia' oranges	5	2	0.2	1.0
'Shamouti' oranges	3	1.5	0.3	1.0

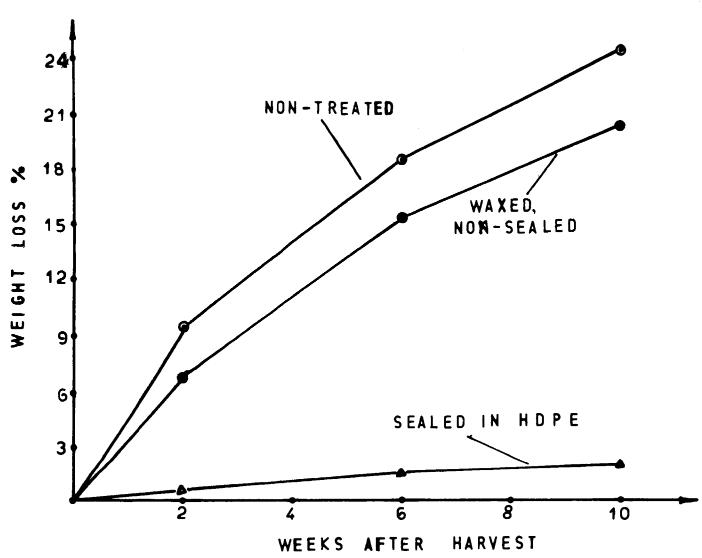

Fig. 1. Effect of seal-packaging with high-density polyethylene (HDPE) on weight loss of 'Eureka' lemons stored for 10 weeks at 20°C.

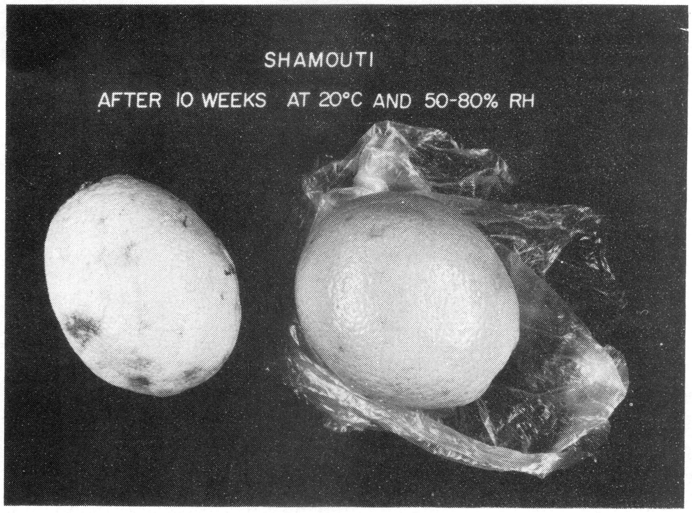

Fig. 2. Effect of seal-packaging with high-density polyethylene (HDPE) on appearance of 'Shamouti' oranges. The sealed fruit is placed over the HDPE film (right); unsealed fruit (left).

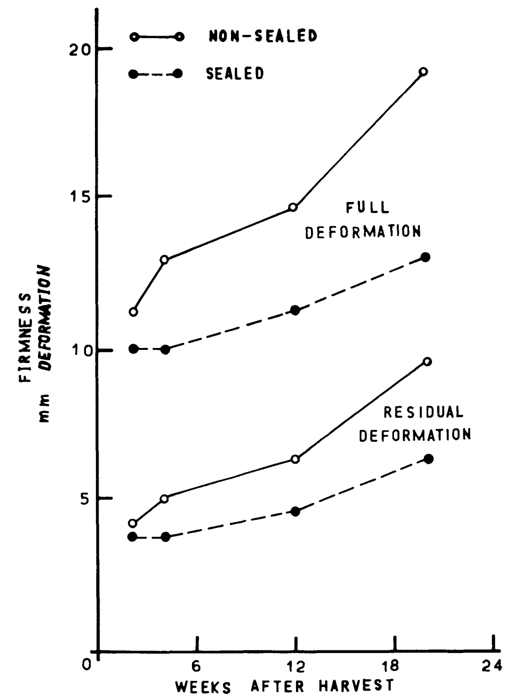

Fig. 3. Effect of seal-packaging with high-density polyethylene (HDPE) on softening rate of 'Marsh' grapefruit stored at 17°C and 50-70% RH as measured by a modified Hamsen pressure tester (13).

of the non-sealed fruits were already deformed but only 16% of the sealed ones and to a much lesser extent.

Effects on flavor. The most significant advantage of HDPE sealing is that the reduction in weight loss is achieved without affecting the fruit flavor. Furthermore, seal-packaging delayed the disappearance of the fresh flavor of the fruits. Thus, after 2 months' storage at 17°C and 90% RH, non-sealed 'Valencia' oranges had developed off-flavors, while the sealed fruit retained its normal flavor much longer. In a triangle test 15 trained testers out of 16 identified the flavor segments of non-sealed 'Valencia' fruit from that of sealed ones. Eleven testers preferred the sealed fruit segments. Seven testers scored the non-sealed fruit segments as having senescent off-flavors. After 4 months all testers identified and preferred the flavor of segments from sealed fruit. These results were significant at P=0.1%. Testing juice yielded similar results but at lower significance of P=5%.

Effects on firmness. All citrus fruit sealed in HDPE remained firm for a much longer period than the non-sealed ones. In comparison with other treatments (Table 1), HDPE markedly inhibited softening in 'Shamouti' fruit. The same effect was found in grapefruit (Fig. 3). Again lemons responded even more remarkably; all sealed fruit remained firm for 10 months at 14°C and 90% RH followed by 2 months of shelf-life at 20° and 50% RH, whereas the non-sealed fruit became soft after 2 to 4 months at 14°.

Table 3. Effect of seal-packaging with high-density polyethylene on deformation of grapefruit kept at 20°C and 85% RH.[z]

Treatment	Weeks in storage	Distribution of fruit (%) No deformation	Light deformation	Heavy deformation
Sealed	4	49.9	34.3	15.8
	8	40.8	40.6	18.6
Non-sealed	4	84.4	15.0	0.6
	8	79.4	20.2	0.4

[z]Effects of seal-packaging were significant in each category of fruit, p = 1%.

Since sealing gave such good results, it was compared with the best known treatment for delaying the deterioration of the fruit, which is cooling at its optimal temperature.

Table 4 shows the effect of HDPE sealing on loss of weight and firmness at 20°C, and also at 10° for grapefruit and at 2° for 'Valencia' oranges, which represent the optimal temperatures for storing these fruits. Sealed fruits at 20° lost less weight and were firmer than fruits handled conventionally and kept at 10° or 2°.

Effects on development of overripe coloration. Another important effect of sealing on fruit senescence was the considerable delay in the development of the advanced undesirable color in 'Marsh' grapefruit and 'Eureka' lemons. After 3 months at 20°C, 41% of the non-sealed fruits had an orange color compared to 17% of the sealed fruit. The effects were more conspicuous with lemons; all the non-sealed fruit developed the over-ripe brownish-yellow color within 2 to 6 months at 14° while the sealed fruit maintained its yellow color for 10 months at 14° with a shelf-life of 2 weeks or longer.

Table 4. Effect of seal-packaging with high-density polyethylene (HDPE) and cooling, on loss in weight and on firmness of citrus fruit stored at 85-90% RH.

Treatment	% weight loss in 2 months 10°C	20°	Firmness hand test after 4 months 10°	20°
			'Marsh' grapefruit	
Non-sealed	2.3 B[z]	4.5 A	Resilient – soft	Soft – very soft
Sealed i n HDPE	0.6 D	1.1 C	Firm	Firm-resilient
			'Valencia' orange	
	(2°)		(2°)	
Non-sealed	2.2 B	4.8 A	Resilient – soft	Soft – very soft
Sealed in HDPE	0.2 D	1.2 C	Firm	Firm

[z]Mean separation by Duncan's multiple range test, 1% level.

Table 5. Effect of seal-packaging in high-density polyethylene (HDPE) on rate of production and endogenous content of CO_2 and ethylene in 'Shamouti' oranges stored for three months at 20°C and 85% RH.

Treatment	CO_2 production (ml/kg·hr)	Ethylene production (µl/kg·hr)	Endogenous content	
			CO_2 (%)	Ethylene (ppm)
Non-sealed	10.1 A[z]	0.195 A	3.4 A	0.65 A
Sealed in HDPE	6.0 B	0.029 B	3.7 A	0.13 B

[z]Mean separation by Duncan's multiple range test, 1% level.

Ethylene and CO_2 production and content. Sealing of fruit in HDPE significantly reduced the production of both CO_2 and ethylene (Table 5). However, it had no significant effect on the content of CO_2 or O_2 in 'Marsh' grapefruit (Table 6) or in 'Shamouti' oranges (Table 5). The fruit examined for composition of the atmosphere were late-season 'Shamouti' which exhibits the greatest differences between fruit and air (6). Unlike the effects on CO_2 and O_2 content, the inhibitory effect of the HDPE on ethylene production also affected its endogenous level. Thus, despite the increase in resistance to ethylene diffusion brought about by the film which would raise the level of endogenous ethylene, the ethylene content declined. This greater effect on ethylene content than on the CO_2 content might relate to the greater inhibitory effect of sealing on ethylene production than on CO_2 production. Indeed, in 'Shamouti' oranges, HDPE reduced CO_2 production by about 40% and ethylene production by 75% (Table 3).

The endogenous level of ethylene in non-sealed 'Shamouti' oranges rose during storage (Fig. 4); in HDPE sealed oranges this increase in ethylene content was noticeably diminished, even more markedly as the period of storage increased.

The concentration of CO_2 between the film and the peel of grapefruit stored for 1 month at 20°C was about 0.6%. Though higher than the atmospheric concentration, this level was only about 20% of the endogenous CO_2 content of the fruit itself (Table 4). The O_2 content between the fruit peel and the film was about 19%, while inside the same fruit the content was lower (Table 4). The ethylene concentration inside the bag was 0.01 ppm.

Effects on ripening indices. Sealing with HDPE had no effect on the ripening indices of 'Marsh' grapefruit stored for 8 weeks at 20°C and 85% RH (Table 7), or even on fruit stored for 4 months when the ratio between total soluble solids and acid rose to 7.0.

Sealed 'Shamouti' oranges lost total acidity at a slightly but not significantly slower rate than the non-sealed (Table 7). The effect on total acidity of sealing the 'Shamouti' orange was the same after 8 months' storage at 14°C.

Effects on fruit temperature. Sealed fruit was 1-2°C warmer than non-sealed fruit stored at 20°. No difference in temperature could be detected at 2° storage.

Table 6. Effect of seal-packaging in high-density polyethylene (HDPE) on endogenous CO_2, O_2 and ethylene content in 'Marsh' grapefruit stored for one month at 20°C and 85% RH.

Treatment	CO_2 (%)	O_2 (%)	Ethylene (ppm)
Non-sealed	2.6 A[z]	14.1 A	0.047 A
HDPE-sealed	3.1 A	14.7 A	0.026 B

[z]Mean separation by Duncan's multiple range test, 1% level.

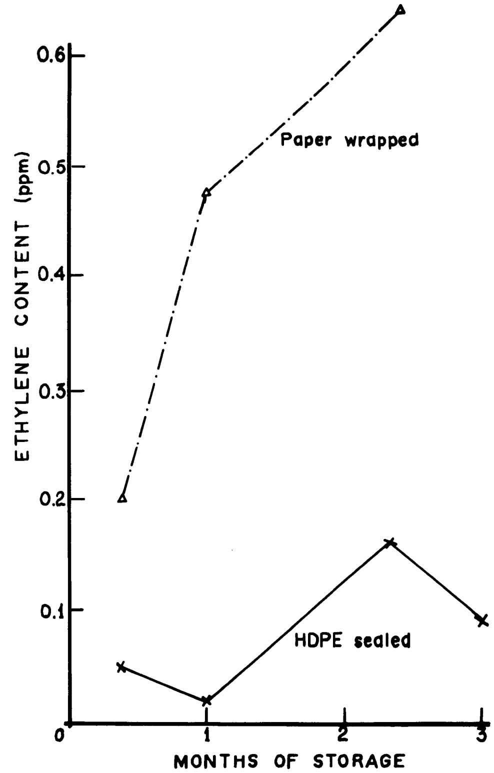

Fig. 4. Effect of seal-packaging with high-density polyethylene (HDPE) on ethylene content of 'Shamouti' oranges stored for up to 3 months at 20°C and 85% RH.

Discussion

Seal-packaging citrus fruits with a thin film of HDPE more than doubled their life. HDPE inhibited weight loss and softening even more than cooling, which is accepted as the best treatment for extending fruit life. Effects on decay will be discussed in detail in subsequent publications. Ben-Yehoshua (5) reported that in lemons and grapefruits the percentage of decay was lower in sealed fruit than in non-sealed, and in other citrus cultivars in Israel, decay was also controlled by pretreating the fruit or the film itself with the proper fungicide. In addition, pretreatment of the fruit or of the HDPE film with ethylene-releasing agents increased ethylene levels of the micro-atmosphere enough to make each fruit a microdegreening chamber (9).

These effects of HDPE were related to 3 factors:

i) The effective reduction of transpiration rate.

Table 7. Effect of seal-packaging with high-density polyethylene (HDPE) on the ripening indices of citrus fruit stored for 8 weeks at 20°C and 85% RH.

Treatment	Total soluble solids (%)	pH	Acidity (mg/100 cc juice)	TSS/acidity ratio
		'Shamouti' oranges		
Non-sealed	10.8[z]	3.3	1.15	9.4
HDPE-sealed	10.5	3.2	1.41	7.5
		'Marsh' grapefruit		
Non-sealed	10.1	3.3	1.58	6.4
HDPE-sealed	10.0	3.2	1.58	6.3

[z]No significant difference was detected between treatment means.

ii) No deleterious effects on fruit flavor. Seal-packaging with HDPE did not affect the flavor of fruit, whereas fruit sealed in other films, such as low-density polyethylene or polypropylene of the thinnest type available (0.02 mm), resulted in off-flavor, making the fruit unmarketable, particularly when kept at room conditions (unpublished data). HDPE probably has suitable permeation properties allowing restricted but balanced metabolism of the fruit.

iii) Maintenance of fruit in a juvenile stage or delaying senescence, as evidenced by the lower endogenous level of ethylene and by a marked delay in the development of the overripe coloration in grapefruit and lemons. Furthermore, preliminary data (unpublished) also show that the level of endogenous gibberellins is twice as high in the peel of sealed lemons than of non-sealed ones. It is possible that the high level of relative humidity in the microatmosphere of the fruit is responsible for these desirable effects.

The CO_2 and O_2 levels inside the fruit were not changed by the sealing (Tables 3 and 4). The increase in the resistance to diffusion of these gases due to the film was probably counteracted by the inhibition in the respiratory activity, resulting in a new equilibrium at which the level of these gases was not changed. Consequently, the simple hypothesis suggesting that the inhibition of respiration and ethylene production are related to too high CO_2 and/or too low O_2 levels is refuted.

The reduced respiratory activity and ethylene production of the seal-packaged fruit is very interesting. Although it was not observed in every case, it was reproducible enough in all citrus fruits tested. Both of these effects are technologically desirable. It is generally accepted that lowering the respiratory activity is usually related to a slowing down of the rate of deterioration in fruits. In addition, respiration is the major utilizer of the nutrients present in fruit. Indeed, Table 5 shows that the acidity in sealed 'Shamouti' fruit was maintained at slightly higher levels than in non-sealed ones. With grapefruits no difference was observed, probably because measurements were taken only in the pulp, whereas the major metabolism in citrus fruits occurs in the peel. The decrease in endogenous ethylene and in the rate of ethylene production in sealed fruits might be the cause for the reduced respiratory activity (Table 3 and 4). As ethylene is the native hormone that is presumed to catalyze the senescence of plant organs, any reduction in its level would be desirable. An interesting observation is the marked rise in endogenous ethylene occurring in fruit during the season (6), after drying (4) and during storage.

The noticeably higher efficiency of HDPE in reducing transpiration as compared with a skin coating of Tag indicates that Tag does not produce as good a barrier to water vapor diffusion as HDPE film. Even repeated dippings in Tag emulsion did not substantially change the effect on transpiration. Microscopic observation of Tag-coated orange peel showed that dipping in Tag does not produce a continuous film but rather a broken layer of coating (unpublished data). Transpiration probably goes on through the cracks in the coating layer. Not having such cracks, the HDPE film acts as a better barrier to transpiration.

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