waxed fruit. Ethanol and other anaerobic metabolites accumulate as a consequence of high respiratory activity and restricted oxygen diffusion to the juice sacs. Apparently waxes are more restrictive than polyethylene films to the diffusion of oxygen. Interestingly, the permeability of the polyethylene film used in this study increases almost linearly with increasing temperatures between 6°C and 38°C (Cryovac, personal communication). At 30°C, the permeability of the film is still more than 3 times greater than the rate of oxygen consumption (unpublished data). It is unlikely, therefore, that the film restricted oxygen diffusion into the fruit.

Thus, the primary effect of polyethylene films on citrus fruits appears to be the reduction of moisture loss. There is no evidence that the film used in this study had any effect on the respiration of oranges or grapefruit which resulted in internal quality changes different from those of waxed fruit stored under the same conditions.

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POTENTIAL AND PROBLEMS OF FILM-WRAPPING CITRUS IN FLORIDA[1]

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Additional index words. polyethylene film, decay, weight loss, ethylene dibromide, machinery.

Abstract. **Experimental and commercial storage and shipping tests of film-wrapped citrus fruit were conducted the past 5 seasons. Fruit wrapped in film lost less water than waxed fruit, creating the potential for better arrival condition of export fruit and for extended storage of fruit to prolong the domestic marketing season. Film wrapping may allow 1 to 2 month holding periods with little quality loss at moderate temperatures (21°C) and longer storage at lower temperatures. Unwaxed fruit should be used for film wrapping since the 2 barriers of film plus wax can lead to excessive off-flavor, particularly at temperatures higher than 21°C. Promising prototypes of commercial wrapping machines have been tested in Florida packinghouses, but the integration of this machinery into a typical packinghouse line will require extensive or innovative packing line alterations since unwaxed fruit of specific sizes is required for wrapping. If adequately permeable films are used, cool coloring and fumigation can be accomplished in film-wraps. Handling and decay control methods have often been limiting factors in research and especially in commercial tests. Better handling and fungicide application are needed to insure adequate decay control if film wrapping is to become a commercial practice.**

Plastic film wrapping can extend the shelf life of citrus fruit with the primary effect of reducing weight (water) loss and thereby deformation (1, 2, 5, 9, 11, 12). This report summarizes some previous film wrap work on citrus, presents new data on color changes and fumigation in film wraps, and evaluates problems and potentials for commercial use of film wrapping.

Materials and Methods

Data on weight loss and decay from grapefruit tests (1, 2, 3, 9, 12) over several years were summarized. Commercially harvested fruit were used in most of these tests and were commercially treated with TBZ [2-(4′-thiazolyl) benzimidazole] fungicide or by us with benomyl [(1-butylcarbamoyl)-2-benzimidazole carbamic acid].

'Robinson' tangerines (*Citrus reticulata* Blanco) were

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harvested at minimum color (approx. 25% color break) and sorted into 8 lots of 10 fruit each for weight loss and color measurement. Two circles were marked on each fruit to measure color with a Hunter Color Difference Meter before treatment and after 1 and 3 wk of storage. Sixty additional fruit per lot were included for decay evaluation also. All fruit received a 1000 ppm TBZ nonrecovery spray fungicide treatment before degreening or wrapping in film. Four lots were degreened 48 hr at 30°C with 1 to 5 ppm ethylene. One lot was unwashed and 3 washed. Two of the 3 washed lots were wrapped with plastic film before degreening. The other washed lot was waxed after degreening. The unwashed lot was washed and waxed after degreening. These lots were placed at 21°C after degreening. Four other lots were washed; one was left untreated, one was then waxed, and 2 were wrapped in plastic films. These lots were placed at 15.5°C. In another test, 10 waxed and 10 unwaxed green grapefruit with and without film wraps also were tested for degreening at 15.5°C.

Penetration of ethylene dibromide (EDB) through film wraps was measured with 4/5 bushel lots of waxed and unwaxed size 32 or 40 washed grapefruit wrapped in various films and compared to a waxed control. In each test, 3 cartons per treatment were randomized in a pallet stack with one carton/treatment in the bottom, middle, and top of the stack. The pallet in each test was placed on a loaded truck trailer and subjected to commercial EDB fumigation. After aeration, the cartons were wrapped in double plastic bags to minimize EDB loss and the fruit were extracted for EDB within 24 hr.

Results

Summarizing previous tests (Table 1), waxed fruit averaged 0.6% initial weight loss per week while wrapped fruit losses were 0.1% per week averaged over several tests. These losses were during storage or transit at 10 to 15.5°C. When these fruit were held for additional time to simulate marketing periods, waxed fruit weight loss increased to 2.3%, but wrapped fruit weight loss only increased to 0.2% per week. Some of these second periods were continuations of lower temperature storage but most were 2 wk periods at 21°C or higher to simulate marketing conditions.

Table 1. Summary of percentage weight loss per week for waxed and film-wrapped grapefruit during several storage tests from 1979 through 1983.

Time period		Weight loss/wk Waxed	Film wrapped
		(%)	(%)
Initial storage	Avg	0.6[z]	0.1[z]
	Range	0.2-1.3	0.03-0.3
Simulated[y] marketing	Avg	2.3[x]	0.2[w]
	Range	0.6-4.9	0.1-0.5

[z]Sixteen tests of from 2 to 11 wk duration at 10°C to 30°C to approximate short storage and delivery to market.
[y]Six tests of from 2 to 9 wk duration.
[x]Ten tests of from 2 to 9 wk duration.
[w]Usually 2 wk at 21°C to simulate marketing, but some data includes continued prolonged storage at 10°C to 15°C.

During the first 6 to 8 wk storage of fruit in these previous tests, decay incidence averaged 9.2 and 6.2% for waxed and film wrapped fruit, respectively (Table 2). Decay increased to 25% by 10 to 12 wk and 41 to 52% for 16 to 20 wk periods. For fruit held 16 to 20 wk, all lots had 26% decay. Differences in decay between waxed and film wrapped fruit were not significant.

Table 2. Summary of percentage decay losses for waxed and film-wrapped grapefruit during several storage tests from 1979 through 1983.

Test time periods (wk)	No. tests		Total decay/test[z] Waxed	Film wrapped
6-8	9	Avg	9.2	6.2
		Range	0-23.3	0-16.7
10-12	6	Avg	24.7	25.5
		Range	6-50	10-48
16-20	3	Avg	52-7	41.0
		Range	38-62	26-59

[z]All fruit received standard 1000 ppm thiabendazole non-recovery sprays of fungicide or 600 ppm benomyl. Penicillium, stem end rot and sour rot were the primary decays observed.

In a 1982 test using (25% color break) 'Robinson' tangerines, weight loss was reduced by film wraps but the weight loss rates were 0.6% of fruit weight per week (Table 3). By 4 wk, decay was severe for degreened fruit held at 21°C and moderate for treatments at 15°C. Most of the fruit in all lots developed decay by the end of 2 months. During the first week at 21°C, degreened fruit in film wraps had less color change than unwashed or washed fruit that were waxed after degreening (Table 3). At 1 wk, degreened treatments at 21°C usually had better color than those at 15°C. By 3 wk, there were differences in color between some treatments but all treatments resulted in satisfactory orange color.

In another test, green grapefruit (*C. paradisi* Macf.) (rated 1) were successfully degreened in 4 wk to yellow (rated 3) in polyethylene (PE) at 15.5°C with no ethylene. By 4 wk, unwaxed and waxed control fruit rated 3.1 and 2.8, respectively and unwaxed film wrapped fruit were rated 2.8 and 3.0. Waxed fruit in film wraps only rated 1.8 to 2.1 or yellow-green.

Table 3. Weight loss, decay, and color change of 'Robinson' tangerines.

Treatment	Weight loss-3 wk	Decay 4 wk	Hunter color change[y] a/b 1 wk	3 wk
30 → 21°C[z]	(%)	(%)		
Unwashed	6.1 b	27.0[x]	1.11 ± 0.16	1.20 ± 0.31
Washed	6.7 a	36.7	1.06 ± 0.68	1.30 ± 0.37
Washed + Wrap 1[w]	1.8 d	43.1	0.69 ± 0.24	1.21 ± 0.39
Washed + Wrap 2[w]	2.3 c	76.1	0.71 ± 0.23	1.43 ± 0.22
15°C				
Washed	7.7 a	6.6	0.69 ± 0.14	1.18 ± 0.13
Washed + Wax	6.2 b	6.7	0.61 ± 0.18	1.15 ± 0.20
Washed + Wrap 1	1.5 d	1.5	0.49 ± 0.16	0.99 ± 0.14
Washed + Wrap 2	1.5 d	10.4	0.42 ± 0.14	1.07 ± 0.18

[z]Degreened 48 hr at 30°C and subsequently held at 21°C. Treatments for this group indicate condition before degreening.
[y]Initial a/b color range for all lots = 0.12-0.20 with 20 readings per lot.
[x]Non-replicated 70 fruit samples.
[w]Wrap 1 = polyethylene, 0.75 mil; Wrap 2 = polyethylene + ethyl vinyl acetate, 0.80 mil.

Based on EDB residue levels, fruit in film wraps were successfully fumigated in several different film wraps in 2 tests as long as polypropylene (PP) was not part of the film (Tables 4 and 5). In the second test in which lower residues resulted, all films resulted in lower fruit residues of EDB than the waxed control but only the film with PP drastically reduced EDB residues.

Table 4. Ethylene dibromide (EDB) initial residues following fumigation for whole grapefruit in various film warps (Sept. 29, 1981).

Treatment	EDB residue[z] (ppm)
Waxed	10.3 a
PE-1 0.60 mil[y]	13.3 a
PE-1 0.6 mil + wax	8.3 ab
PE-IR 0.60 mil	9.1 a
(PP + PE) 0.60 mil	3.9 b
(PP + PE) + wax	4.1 b

[z]Fruit placed in double plastic bags after fumigation; extracted within 24 hr; mean separation by Duncan's multiple range test, 1% level.
[y]PP = polypropylene, PE = low density polyethylene, PE-IR = irradiated PE film.

Table 5. Ethylene dibromide (EDB) initial residues following fumigation for whole grapefruit in various film wraps (May 7, 1982).

Treatment	EDB residue[z]
Waxed	4.2 a
PE + EVA 0.50 mil[y]	3.6 b
PE-1 0.60 mil	3.2 b
PE-2 0.75 mil	2.7 c
PP + PE 0.60 mil	1.6 d

[z]Fruit placed in double plastic bags after fumigation and extracted within 24 hr. Mean separation by Duncan's multiple range test, 5% level.
[y]EVA = ethyl vinyl acetate; PE = polyethylene; PP = polypropylene.

Discussion

Appearance and therefore marketability of waxed citrus fruit is reduced when weight loss exceeds 5% (10). This much dehydration results in a soft, old appearing peel and the fruit usually deforms in the shipping container (3, 9, 12). For most of our previous tests (Table 1), waxed grapefruit lost more than 5% of their weight in 7 to 8 wk. This is the time required to ship and market fruit in Japan. Wrapped grapefruit would have required 25 to 50 wk to lose 5% of their weight. This is a longer period than needed for long-term storage.

The rate of weight loss differs between types of citrus for waxed (13) and wrapped fruit (1). Mandarin types have the highest weight loss rates (1, 13) and this is one reason for their short shelf life.

A major problem restricting use of the film wraps commercially in Florida is inadequate decay control for long-term storage. Some commercial lots had high decay even within 6 to 8 wk. Wrapped fruit usually did not have more decay than waxed fruit in research tests, but in some commercial tests film wrapped fruit had much greater decay rates than waxed fruit. These high losses appeared to be in situations where the fruit were handled roughly, inadequately treated with fungicides and/or harvested late in the season when fruit are very susceptible to decay. The high humidity under film wraps apparently facilitates decay development, especially if poor handling and inadequate fungicide application have occurred.

Commercial decay losses of 6 to 9% in 6 to 8 wk and 25% in 10 to 12 wk (Table 2) translates into considerable fruit wrapped and then lost before sale. The cost of film-wrapping this non-marketable fruit will raise the cost per marketable fruit one third if 25% of the fruit decay. Special care in harvesting, field and packinghouse handling, and fungicide treatment will be required for film wrapping to have any possibility of being profitable. Using careful handling procedures and adequate fungicide treatment in research tests usually has kept decay losses to less than 10% in long-term storage tests of 2 to 3 months.

Film wrapping provides 3 advantages in relation to decay development. Film wraps help contain and prevent the spread of decays like sour rot. They also reduce soilage of the carton and other fruit by containing decay spores and released juice. This will reduce decay removal costs at the wholesale and retail levels. Recent work (4) showed that wrapping prevented decaying fruit from depleting O_2 levels in cartons containing healthy fruit. The healthy fruit had a better flavor compared to the stale flavor of healthy fruit in boxes of unwrapped fruit that also include decaying fruit.

Film manufacturers are predicting that film wrapping will cost 30 to 40 cents per carton for grapefruit or approximately 1 cent per fruit. Some of this cost could be recovered by eliminating waxing. Waxing plus drying costs approximately 10 to 12 cents per carton (6). Water eliminator rollers plus holding time prior to wrapping provides adequately dry fruit for wrapping.

It is important not to wax fruit that will be film wrapped but fresh fruit packing lines in Florida do not lend themselves to washing and fungicide treatment without waxing. This is particularly difficult because only a few fruit sizes are desired for wrapping. Washed or washed plus waxed fruit do not degreen well at high temperatures. Washing does not appear to prevent color changes during 3 wk of cool coloring at 15°C (Table 3). Film wrapped, waxed fruit will usually develop off-flavors at high temperatures, particularly if harvested late in the season (1, 8). Late season fruit accumulate more ethanol in storage indicating that anaerobic respiration is occurring (7). Waxed or wrapped fruit may be equally susceptible to ethanol build-up and off-flavor development at high temperatures (1, 14). Besides not waxing the fruit, an aid to improving aerobic respiration may be to use films more permeable to O_2 and CO_2 exchange than PE or PE-PP films. Some weight loss control could be sacrificed for more O_2 and CO_2 permeability. Test films have accomplished this balance and prevented off-flavor development in late season harvested fruit (1) but these films may not be easy to use on high speed machines.

In addition to savings obtained by eliminating the waxing process, film wraps could help save on refrigeration requirements for shipment and long-term storage. If decay is adequately controlled, unwaxed fruit in film wraps hold well without weight loss or loss of flavor for several weeks at 21°C and for several months at 15.5°C (1, 3, unpublished data). According to the SeaLand Corp., refrigeration charges for shipping overseas can be more than $2.00 per carton. Reduced weight loss resulting from wrapping also would increase financial returns on fruit shipments to Europe where fruit is purchased by weight.

Regulations for shipping fruit to Japan are very complex and presently film wrapping cannot be done because fumigation is required. Even though EDB fumigation apparently will not be permitted, the Japanese will still fumigate with cyanide (HCN) to protect against importation of scale insects. Our data presented here and in previous tests (2) indicate that fruit can be fumigated through some films. Tests should be conducted to establish if HCN fumigation can be done with film wrapped fruit.

If cold sterilization replaces EDB fumigation for Caribbean fruit fly control and cold sterilization is accomplished during shipment, then weight loss control will be less important because less water loss will occur at low temperature with reasonable humidity maintenance than occurs at higher temperature (14) now used during shipment. After arrival in Japan, weight loss can be very high (2, 3) and film wrapping could still be beneficial for this marketing period and during the curing period before cold treatment. Film wraps may help reduce chilling injury of grapefruit (10) which often occurs at the low temperatures used for cold sterilization.

Experimental machinery for shrink film wrapping of citrus has been tested in Florida the last 3 or 4 yr. The first machine tested was a Shanklin (100 Westford Rd., Ayer, MA 01432) horizontal automatic-fill L sealer. This was modified to run 2 rows of fruit and could run 60 to 80 fruit/min. No further developments have occurred with this machine. Weldotron (1532 S. Washington Ave., Piscataway, NJ 08854) and Cryovac (P. O. Box 464, Duncan, SC 29334) are testing horizontal and vertical form-fill wrapping machines, respectively. These single line machines wrap approximately 60 fruit/min. The Doboy Packaging Machinery Corp. (New Richmond, WI 54017) is testing a fruit wrapping machine in the western U.S.A. and stretch-film fruit wrapping machinery has been tested in Italy. Some horizontal form-fill machines in Japan can wrap small, uniformly shaped objects at the rate of 250 units/min. Faster wrapping rates such as these or multiple line machines will be needed to provide adequate wrapping rates for commercial citrus wrapping.

Some preliminary consumer acceptance evaluation has taken place (DuPont Corp. and Seald Sweet, unpublished). On the negative side, many consumers were concerned about how much more wrapped fruit would cost. On the plus side, consumers in the U.S. and Europe perceive the wrapped fruit to be more sanitary. Little consumer education about the advantages of film wrapped citrus has been done but will be required to promote wrapped fruit. Cryovac recently started an advertising campaign for wrapped citrus.

Major uses for film wrapping in marketing fresh citrus appear to be in export marketing where extended holding times are required and for long-term storage to allow extensive summer sale of grapefruit and oranges. If decay can be controlled, film wrapping would allow early to mid-April harvest of grapefruit for storage, thereby avoiding most seed sprouting and section drying problems (2, 3).

Some gift fruit shippers are interested in film wrapping because of the quality appearance, labeling potential, and containment of decay soilage. Another possible place for film wrap use could be to extend the marketing period of some mandarin varieties until the next variety is mature. For an early variety such as 'Robinson,' this could include cool coloring while storing to avoid degreening. This early harvest procedure would avoid the poor internal quality (section drying) associated with later harvests of most mandarin varieties. All the possible uses of film-wrapping will require better handling and more consistent decay control than presently occurs in the Florida fresh citrus industry.

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DELAYING DETERIORATION OF BROCCOLI AND CUCUMBER USING POLYMERIC FILMS[1]

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Additional index words. Brassica oleraces L. Italica group, *Cucumis sativus,* high-density polyethylene film, weight loss.

Abstract. **The use of polymeric films in produce packaging has recently increased due to the development of new films. Broccoli (*Brassica oleracea* L. Italica group) and cucumber (*Cucumis sativus* L.) were individually seal-packaged in unperforated or perforated polyethylene films of 0.01 or 0.02 mm thickness. Storage temperatures were 1, 7.5, and 15°C for broccoli and 1, 10, and 20°C for cucumber. After 2 wk in storage weight loss of seal-packaged, perforated, and unwrapped broccoli was 1.1, 22.4, and 35.8%, respectively.**

Seal-packaged cucumber stored at 20°C lost 5% of its initial weight after 5 wk in storage, whereas perforated and unwrapped treatments lost up to 85%. Vegetables stored in perforated films maintained their fresh appearance and firmness more than 4 times as long as those which were conventionally handled. Film thickness had no effect on weight loss

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