In conclusion, individually quick frozen (IQF) is a suitable method for freezing sugar apple. The green color of sugar apple continued to decrease during 12 months of frozen storage. The phenolic compounds, namely (+)-catechin, chlorogenic acid, eugenol and gallic acid also continued to decrease as a result of increased activity of the polyphenol oxidase (PPO). The discoloration of sugar apple fruit was a combined result of the oxidation of phenolic compounds and the degradation of the chlorophyll. Vacuum packaging was an effective method for inhibiting the PPO activity by removal of oxygen from the packaged fruit and, therefore, vacuum-packaged fruit were capable of retaining better color than the non-vacuum packaged fruit.

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ENZYME-PEELED CITRUS IN MODIFIED-ATMOSPHERE PACKAGING COMPARED WITH WHOLE FRUIT

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Abstract. **Peeled oranges and grapefruit had about the same respiration rate as whole fruit. Using packaging film having O_2 permeance of 6600 ml/m²day, bags of peeled fruit had headspace O_2 and CO_2 concentrations similar to the levels found in the interior gas of fruit coated with candelilla wax. With porous film having permeance of 37,000 ml/m²day the headspace gas concentrations were similar in composition to interior gases of uncoated fruit. Ethanol increased at a much faster rate for peeled fruit than for whole fruit. After 5 weeks storage the peeled fruit had yeast populations of about 1×10^6 cfu/g and appeared inedible.**

Citrus sections prepared by aseptic slicing have been shown to have good stability for about 12 days with respect to color, pH and sugar content, although vitamin C decreased by about 22% and the product lost its characteristic citrus flavor (Rocha et al., 1996).

A similar product developed in our laboratory consists of citrus sections whose peeling has been loosened by vacuum infusion of pectinases (Bruemmer, 1981; Baker and Bruemmer, 1988). Enzyme-peeled citrus is being produced commercially (Baker and Grohmann, 1995), although more information is needed on its storage properties. For example, some leakage of liquid occurs from stored sections, although this was reduced by application of a coating (Baker and Hagenmaier, 1997).

It would seem that gas concentrations might be as important for storage of enzyme-peeled citrus sections in modified atmosphere packaging as they are for storage of whole fruit. Whole citrus fruit has been shown to develop ethanolic off-flavor when stored under conditions of reduced O_2 and elevated CO_2 (Ke and Kader, 1990). Similarly, seal-wrapped whole citrus fruit sometimes develops off-flavor when stored under conditions that cause O_2 depletion or CO_2 build-up (Miller and Risse, 1988).

The present study aims to examine the storage stability of enzyme-peeled citrus in modified atmosphere packaging, from the point of view of how its storage relates to whole citrus fruit.

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Materials and Methods

Valencia oranges [*Citrus sinensis* (L.) Osbeck cv. Valencia] and Marsh grapefruit (*Citrus paradisi* Macf.) were harvested from groves near Winter Haven, FL. Fresh citrus fruit was cleaned on rotary brushes with detergent (Fruitcleaner 395, FMC, Lakeland, FL) with 530 ppm NaOCl. The flavedo was scored and the fruit submerged in a 750 ppm solution of Pectinex Ultra SP-L (Novo Enzymes, Danbury, CT). The submerged fruit was subjected to a reduced pressure of 61 Torr for 2 minutes and held at that pressure without further pumping for 2 minutes, after which the vacuum was slowly released. After 45 minutes, the fruit was removed from the enzyme solution, peeled by hand, submerged for 1 min. in water with 530 ppm NaOCl, rinsed with tap water after 5 minutes, drained a minimum of 15 minutes, and sealed in plastic bags with an impulse sealer (TEW Electric Heating Equip. Co). Each bag contained two peeled grapefruit or three oranges, with mean bag size of 17 × 18 cm inside dimensions. The number of micropores (approximately 50 mm in diameter) per bag for the P-Plus film (Printpack, Prescott Valley, AZ) was estimated from the pattern of holes on a roll of the film from which the bags were formed (Table 1). Oxygen permeance of film was determined with an Oxtran 100 (MOCON, Minneapolis, MN).

Whole fruit were coated with shellac (17.9% crystal shellac [Mantrose-Haeuser Co., Attleboro, MA], 1.1% morpholine, 0.2% NH_3, 0.1% NaOH and 0.5% polysorbate 60), with wax (20.4% candelilla wax No. 75 [Strahl & Pitsch, W. Babylon, NY], 1.6% oleic acid, 1.6% morpholine and 0.2% KOH) or not coated.

Respiration rates were determined from measurement of CO_2 concentration from flow-through chambers at 5°C one week after peeling or coating. Rates for non-packaged peeled citrus were measured simultaneously for all treatments, with 3 samples taken per treatment.

Headspace O_2 and CO_2 concentrations for the bagged sections are reported for only one storage time per treatment (19 days) as preliminary results indicated these achieved steady-state values within one week (data not shown). The interior gas concentrations of whole fruit were measured after 7 days storage, it being well known that steady-state concentrations are achieved within hours (Hasegawa and Iba, 1980). Gas samples for O_2 and CO_2 analysis were taken by syringe, within 2 minutes of their removal from refrigeration, from packages or from whole fruit submerged in water, simultaneously checking the packages for leaks. The gas samples (250 µl) were applied via a loop injector to a Hewlett Packard 5890 (Avondale, PA) gas chromatograph fitted with a CTR-1 column (6 ft long, ¼" and ⅛" diameter, outer and inner columns, respectively, Alltech, Deerfield, IL). Column flow rate was 70 ml/min. Temperatures were 40°C and 120°C, respectively, for the column and thermal conductivity detector. Standard O_2 and CO_2 gas mixtures were used for calibration. Ethanol content of juice was determined by direct injection of 5 µl juice with 1000 ppm n-propanol as internal standard. The gas chromatograph was used with a FFAP column (50 m × 0.32mm, Hewlett Packard) and flame ionization detector. Column flow was 4ml/min, and column temperature was 55°C for injection, increased thereafter 3°C/min.

For microbial analysis, samples (100 g) were mixed with 100 ml peptone dilution water and agitated 90 s in a paddle blender (Masticator, IUL, Barcelona, Spain). Four appropriate dilutions were plated out. Plate count agar (Difco, Detroit, MI) was incubated at 35°C for 2 days to determine mesophilic population. Potato dextrose agar (Difco), acidified to pH 3.5, was incubated at 25°C for 3 days to determine yeasts and molds. Populations were expressed in colony forming units per gram of product (cfu/g).

The reported mean values of cfu/g, headspace gases and ethanol are mean values from five bags of fruit per sample. The mean values for bag permeance are based on three bags per manufacturer. The cfu/g values were first converted to logarithms for statistical calculations, using Statistix software (Analytical Software, Tallahassee, FL). The Tukey test was used to determine significant differences between means.

Table 1. Description of the films and bags used.

Type	Film permeance (ml/m^2day)[z]		Micro-pores[y] (no./bag)
	O_2	CO_2	
B540	5	unknown	0
LDX5073	2800	9400	0
LDX4475	6600	20000	0
P-Plus 2400[b]	37000	unknown	18

[z]Film permeance values from the manufacturers (Cryovac, Duncan, SC for B540 and the LDX films; Printpack (Prescott Valley, AZ) for the P-Plus 2400. The value for the LDX films is for 23°C, and that for B540 is for 5°C.
[y]Samples of this film without micropores had O_2 permeance of only 3,200 ml/m^2day at 30°C, and therefore over 90% of the apparent O_2 permeance is diffusion through the micropores.

Results and Discussion

The respiration rates of peeled grapefruit and oranges at 5°C were not significantly different ($\alpha = 0.05$) from that of whole fruit after one week of storage, presumably long enough for the fruit to recover from being handled (Table 2). Similar results were also obtained for whole and peeled 'Hamlin' oranges. Ben-Yehoshua et al. (1979) had proposed that most of citrus respiration occurs in the peel, so it was expected that peeled fruit would have lower respiration than whole fruit. Even so, it was recently reported that respiration rates of citrus fruit were not markedly changed even when the fruit was sliced (Rocha et al., 1996). Respiration rates of whole fruit were virtually the same with different coatings at 5°C (Table 2), but were not measured at higher temperatures, where these would be expected to be more influenced by the type of coating applied.

Peeled grapefruit packaged in LDX4475 film and stored for 19 days at 5°C had mean mesophilic population of 1300 cfu/g (83% yeasts), compared with 290 cfu/g (93% yeasts) for non-packaged peeled fruit on day one (data not shown).

Table 2. Respiration rates at 5°C for non-packaged 'Marsh' grapefruit and 'Valencia' oranges after one week of storage at this temperature, as determined in a flow-through system.

Type of sample	Respiration rate (mg $CO_2 kg^{-1} hr^{-1}$)	
	'Marsh'	'Valencia'
Whole, not coated	3.1	4.2
Whole, shellac coating	3.1	3.7
Whole, candelilla coating	3.4	3.8
Peeled	3.0	4.2
Std. Error	0.3	0.3

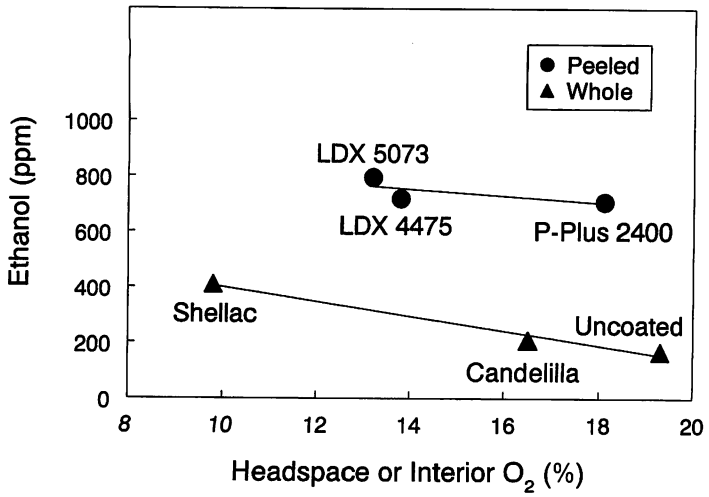

Figure 1. Ethanol content of peeled 'Marsh' grapefruit stored 19 days at 5°C after packaging, compared to whole fruit stored for the same time and temperature.

All samples appeared edible after 19 days, which is one day longer than the shelf life claimed by a Florida producer of enzyme-peeled citrus. Similar microbial populations were observed for grapefruit stored 19 days in other films (B540, LDX5073 and P-Plus2400). For peeled grapefruit stored in all these films the ethanol content after 19 days was 700 to 820 ppm (Fig. 1). Because of the low microbial populations, it seems unlikely but not impossible that the elevated ethanol of peeled fruit was caused by yeast fermentation.

The interior gas composition of fruit with candelilla wax coatings was similar to the headspace gas of peeled fruit packaged in LDX4475 (Table 3). The interior gas of fruit that was not coated had higher O_2 and lower CO_2 concentrations than the most permeable film (Tables 1-2).

Internal O_2 levels depend in part on the type and thickness of coating applied to the fruit. Ethanol content of fresh citrus fruit increases markedly at low values of interior O_2 concentration. Flavor is adversely affected when ethanol content becomes several times that found in fresh fruit (Ahmad and Kahn, 1987; Hagenmaier and Baker, 1993, 1994). High CO_2 is also related to increased production rate of ethanol in citrus (Ke and Kader, 1990).

For whole citrus and also for the peeled citrus in packages, there was a permeable barrier between the fruit pulp and atmosphere air. For the whole fruit the barrier was the peel plus or minus a coating, and for peeled fruit it was the packaging film. This barrier supported a difference in gas concentration between atmospheric air and the air in contact with the pulp, which was the interior gas or the headspace gas in the case of the whole fruit or peeled fruit, respectively.

Table 3. Headspace in bags of peeled grapefruit 19 days after packaging, and interior O_2 and CO_2 of whole fruit 7 days after application of coatings. Storage and measurements were at 5°C.

Fruit	Film or Coating	O_2 (%)[z]	CO_2 (%)
Whole	Not coated	20.5^{a}	1.3^{c}
Peeled	P-Plus 2400 film	18.1^{ab}	4.5^{b}
Whole	Candelilla coating	15.4^{abc}	4.4^{b}
Peeled	LDX4475 film	14.4^{bc}	5.0^{b}
Peeled	LDX5073 film	13.2^{bc}	9.7^{a}
Whole	Shellac coating	10.7^{c}	4.9^{b}

[z]Items in a column with same superscript are not different ($\alpha = 0.05$, Tukey).

Table 4. Properties of peeled citrus packaged in LDX4475 film after storage for 5 weeks at 5°C. Each row is a separate experiment[z].

	Headspace gases (%)				
Type of fruit	CO_2	O_2	Ethanol (ppm)	Log [mesophiles] (cfu/g)	Yeasts as % of mesophiles
'Marsh'	11.0	2.3	2160	5.9	88
'Marsh'	5.8	11.1	1320	6.0	87
'Valencia'	9.5	5.7	2180	6.1	82
'Valencia'	7.3	8.9	2390	5.9	82
Std Error	0.6	0.5	42	0.03	3.2

[z]At zero time the mean ethanol content of peeled fruit was 310 ppm for grapefruit and 700 ppm for oranges; and the mean of log [mesophiles] was 2.8, of which 80% were yeasts.

Both the P-Plus film and the fruit peel have pores that partly account for the permeance. The pores in the P-Plus film were put there for that purpose. The pores in the fruit surface (stomata, lenticels, stem scars, injuries) have been shown to contribute to gas exchange (Hagenmaier and Baker, 1993). By comparison, most of the pores on the fruit surface have only about 10% the diameter of the film micropores (Turrel and Klotz, 1940).

Because the respiration rates of whole and peeled citrus were similar, it seemed that their ethanol production rates might react similarly with respect to changes in composition of the gas in contact with the fruit pulp. For both peeled and whole fruit, the juice ethanol content was indeed highest for the film or coating, which—because of low permeance—gave lowest O_2 content (Fig. 1, Table 1). However, the difference in ethanol contents between peeled and whole fruit were larger than the differences associated with gas concentrations. At storage temperatures higher than the (5°C) used for these experiments, the respiration rates would be higher, and differences in bag permeances would be expected to result in larger differences in ethanol contents.

Peeled oranges and grapefruit in subsequent experiments were stored for a longer time (5 weeks). This extended storage time proved to be too long. The bags became swollen; the headspace gases became quite variable; and the ethanol content and microbial population (about 85% yeasts) had increased considerably (Table 4). In this case, it seems likely that the high ethanol contents observed may have resulted from yeast fermentation. Similar results were obtained for enzyme-peeled oranges and grapefruit stored in B540, LDX5073 and P-Plus2400 films (data not shown). In general, the results indicate that five weeks storage at 5°C exceeded the shelf life of these products.

The increase in ethanol content that occurred during the first 19 days of storage at 5°C suggests that some flavor deterioration may already have occurred by that time. It would seem probable that even more flavor deterioration might occur during storage under normal marketing temperatures, which are frequently above 5°C.

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AN EVALUATION OF GAMMA IRRADIATION FOR PRESERVATION OF CITRUS SALADS IN FLEXIBLE PACKAGING

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Abstract. **Fruit salad was made from melon, pineapple, grapes and enzyme-peeled oranges in acidified sugar syrup, packed in high-barrier film. Addition of preservatives and use of irradiation (mean dosage 0.43 kGy) were optional treatments. Long-term protection from spoilage was achieved with addition of sodium benzoate and potassium sorbate whether or not the product was irradiated. Ethanol content approximately doubled during 6 months' storage at 5°C.**

Chilled citrus sections (or segments) are the unheated, perishable produce preserved in acidified sugar syrup with antimicrobial additives, packed in glass jars and stored under refrigeration. In the 1971-2 citrus season approximately 40,000 M.T. grapefruit and 20,000 M.T. oranges were used to make chilled citrus sections (Rouse and Moore, 1974). However, because the traditional method of making citrus sections was very labor-intensive, their manufacture in the United States was virtually discontinued.

Enzyme technology for making citrus sections drastically reduces the labor requirement and may make it possible to once again manufacture citrus sections in areas with higher labor costs. This new technology was developed in our laboratory (Bruemmer, 1981; Baker and Bruemmer, 1988).

Chilled citrus sections are preserved by a combination of measures. Use of antimicrobial additives, control of acidity and refrigeration, all three together, combine to give this produce a long shelf life. In one study, samples were reported in good condition after storage at 0°C for one year (Rouse and Moore, 1974). A shelf-life of six months was used in about 1980 by a manufacturer of chilled sections stored at 0 to 7°C (Landsman, Bartow Citrus Industries, Inc., personnel communication).

The maximum amount of sodium benzoate allowed as an antimicrobial agent in foods by 21 CFR 184.1021 is 0.1%, benzoic acid equivalent. This is approximately the amount used in the industry (Rouse and Moore, 1974). Chilled citrus sections currently available in Florida supermarkets, packed in glass, contain both potassium sorbate and sodium benzoate.

The acidity of chilled sections depends somewhat on whether the sections are packed with juice or syrup containing sugar and citric acid. Rouse and Moore (1974) observed pH of 3.7 ± 0.1 for orange sections packed in syrup, and pH 3.3 ± 0.1 for grapefruit sections packed in syrup. Specifications used by a manufacturer in the 1980's were pH 3.5 ± 0.2 for orange or grapefruit segments packed in juice, or pH 3.7 ± 0.2 for a mixture of grapefruit, orange and pineapple segments packed in sugar syrup.

Irradiation of whole grapefruit with dosage of 0.08 to 0.9 kGy has been shown not to adversely affect the flavor of ex-

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