Durability and Efficiency of Recycled Multilayer Plastic Covering in the Production of Greenhouse-grown Tomatoes

M.A. Kasrawi[1], N. Khraishi[2], and Y. Tabaza[2]

Additional index words. physical properties, *Lycopersicon esculentum*, virgin monolayer plastic, pollution

Summary. A greenhouse experiment was conducted over two growing seasons to study the physical and mechanical properties of a recycled multilayer plastic cover and its effect on the production of greenhouse-grown tomatoes. Two experimental greenhouses were constructed, one covered with recycled multilayer film and the other with conventional virgin monolayer film. The air temperature under both covers was similar; the soil temperature in the recycled multilayer house was a few degrees lower in the afternoon hours to midnight than in the virgin monolayer house. The recycled multilayer film retained its strength and elasticity over a useful service life of 7 months (one growing season), after which severe degradation occurred as manifested by a 50% loss of elongation at break. During the useful lifetime of the film, haziness, light scattering, and light transmission of the recycled film was similar to the conventional film. The thermal analysis of the recycled film revealed a low stability against thermo-oxidative degradation and the infrared analysis indicated the presence of a measurable amount of degradation products, mainly carbonyl groups, in the recycled film in comparison with conventional film. During the useful lifetime of recycled film, yield components of the tomato crop were identical to the conventional film in both growing seasons. In conclusion, waste plastic recycling offers an attractive solution to nuisance environmental problems. However, the useful lifetime of recycled films needs to be improved.

In the past 2 decades, expansion of high-value horticultural crops production has been associated with an increase in the use of plastic. Plastic greenhouses and high tunnels now cover ≈200,000 ha, worldwide (Wittwer, 1993). Plastic houses in Jordan occupied >1170 ha in 1992. The use of protected agriculture in Jordan has resulted in the accumulation of ≈5800 tons of waste plastic films per year (Ali et al., 1990). Disposal of these waste plastics has been accomplished by burning or dumping in landfills. As environmental concerns about plastic disposal continue to grow, more pressure is applied by various groups to develop alternative safe disposal technologies (Ennis, 1987). Although the current plastic revolution has increased productivity and improved quality of horticultural crops, problems of plastic disposal (Brown and Splittstoesser, 1991) and the high cost of plastic films may limit the use of plastic. Recycling of plastics could be a possible approach to reducing "plastic pollution," alleviating disposal problems (Glenn, 1990; Leaversuch, 1991) and offering plastic at lower prices (Khraishi, 1993).

The quality of a greenhouse cover has a major influence on crop production. Strength, consistency, durability, manufacturing quality, transmission of solar radiation, haziness, and energy conservation should be considered in selecting greenhouse covers. The objectives here were to measure the physical and mechanical properties of a recycled multilayer plastic film and to study the effects of recycled multilayer plastic film cover on the production of greenhouse-grown tomatoes.

Materials and methods

Discarded greenhouse films were collected from the center of the Jordan Valley and treated via sequential steps until regenerated granules were obtained using the facilities of the Plastics Research Laboratory of the Royal Scientific Society (RSS), Amman, Jordan. The recycling steps included collection, coarse size reduction, washing, drying, fine size reduction, and pelletizing to regenerated pellets. The multilayered covers then were coextruded from the regenerated pellets by an Egyptian company. The monolayer film was composed of low-density polyethylene (LDPE) and the recycled multilayer film was composed of LDPE, linear low-density polyethylene (LLDPE), ultraviolet stabilizer, and the waste plastic material. More details on the composition and manufacturing of recycled multilayer film were reported in Khraishi (1993). The recycled multilayer film was 15% thinner than the conventional virgin monolayer film.

The experiment was carried out on a calcareous sandy loam soil at the Jordan Univ. Experimental Station in the Jordan Valley during the 1991–92 and 1992–93 growing seasons. Two 50 × 9-m greenhouses were used. One house was covered with the recycled multilayer film (recycled material), whereas the other house used virgin monolayer conventional film. The tomato cultivar Claudia RAF was used. Identical soil preparation was made in each greenhouse and the soil was fumigated with methyl bromide. In each greenhouse, eight raised beds were formed, each 20 cm high, 60 cm wide, and 100 cm from center to center. Drip irrigation and black plastic mulch were applied to the raised beds. Each greenhouse was divided into nine equal plots (replications). Each plot consisted of eight, 5-m-long raised beds. The inside environment of the houses was monitored with nine thermocouples at 120 cm above the soil (one in each plot) along each greenhouse. A 10th thermocouple was inserted 25 cm deep in the soil at the middle of each greenhouse. All thermocouples were connected to a computer system, model Data-10-Ging (3530 Orion),

Table 1. *Average monthly temperature and day length in the Jordan Valley during 1991–92 and 1992–93.*

Month	Average monthly temperature (C) 1991–92	1992–93	Average day length (h)
October	28.6	25.6	11.4
November	23.5	20.9	10.5
December	18.8	14.5	10.2
January	14.4	12.6	10.3
February	15.8	13.6	11.1
March	19.2	17.5	12.0
April	24.1	24.0	13.0
May	27.3	26.7	13.6

[1]*Department of Plant Production, University of Jordan, Amman, Jordan.*

[2]*Royal Scientific Society, Amman, Jordan.*

The cost of publishing this paper was defrayed in part by the payment of page charges. Under postal regulations, this paper therefore must be hereby marked advertisement *solely to indicate this fact.*

to measure and record temperature continuously in both greenhouses and for each growing season. Outside temperature and average day length during the experiment are reported in Table 1.

Five-week-old tomato seedlings were planted in the raised beds the first week of November in both 1991 and 1992. Plants were set 40 cm apart at the center of each raised bed. Plants were trained vertically to one stem by removal of axillary shoots as they appeared. Cultural practices, irrigation, fertilization, and spraying for insects and diseases followed standard commercial procedures. Fruits were harvested at the red-ripe stage. Numbers and weights of fruits were recorded for each plot. A paired comparison test was used for comparing yields.

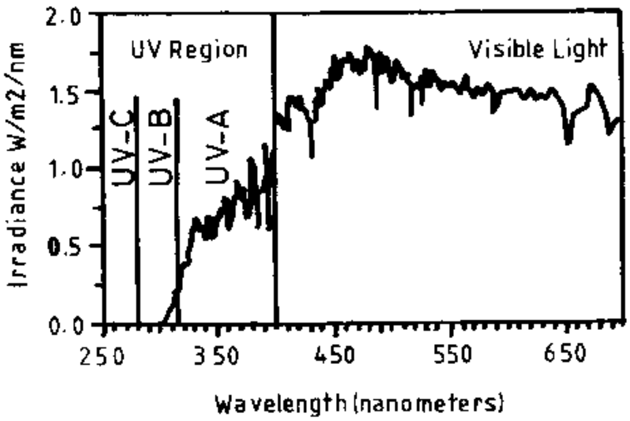

Fig. 1. *The sunlight spectrum.*

One sample(30 × 30 cm) of each monolayer and multilayer films were extracted monthly from Nov. 1991 to June 1992 from the east side of each greenhouse for laboratory testing. The sampled sections were replaced and the greenhouses were repaired promptly. Each sample was used for five readings. The properties of the extruded films were inspected before and after exposure to outdoor weathering. The facilities of both Royal Scientific Society (Amman, Jordan) and McGill Univ. (Quebec, Canada) were used. The following selective tests were conducted:

1) Melt flow index according to ASTM D 1238 using a Frank plastometer at 190C and 5 kg (Charkraborty and Scott, 1977).

2) Tear-resistance using Schenk Trebel universal testing machine at a speed of 50 mm·min^{-1} according to ASTM D-1004. This method tests the resistance of the film to crack propagation (Cordonnier, 1987).

3) Tensile properties using Schenk Trebel universal testing machine at a speed of 250 mm·min^{-1}. A 50 % loss of elongation was the criterion of failure or end of service life of the cover (Khraishi and Al-Robaidi, 1991).

4) Haziness and light transmission using a spherical haze meter according to ASTM D-1003 (Amin et al., 1975).

5) Thermal properties (melting point, heat of fusion, and onset of oxidation) using Mettler DSC 30 calorimeter at a heating rate of 10C / min (Charkraborty and Scott, 1977).

6) Spectroscopic detection of degradation products by infrared analysis using the Michelson 100 FTIR spectrophotometer (Amin et al., 1975).

7) Absorption of short UV radiation using a Varian DSM-100 / 200 UV-VIS spectrometer. This test determines the screening or filtering efficiency of the film (Cordonnier, 1987).

The films also were exposed to

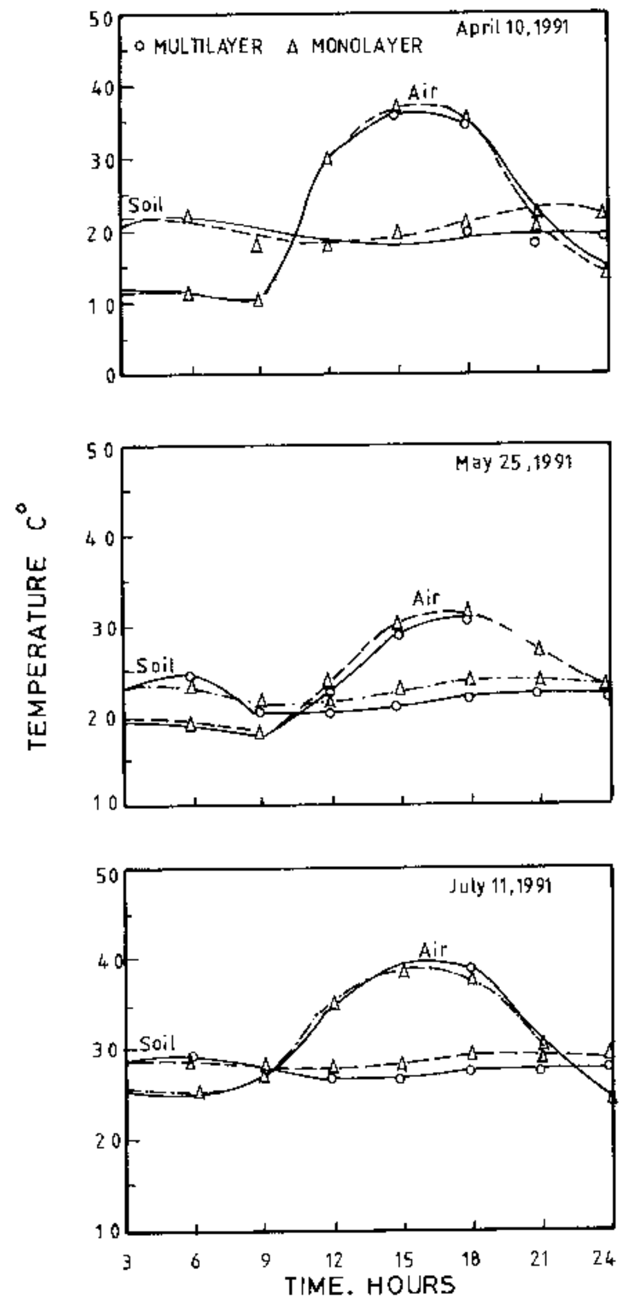

Fig. 2. *Temperatures in greenhouses covered with virgin monolayer and recycled multilayer film.*

ultraviolet radiation from a fluorescent lamp type A in a Q-U-V artificial weathering chamber. The weathering cycle was 12 h of conduction and 12 h of radiation. The spectral distribution in the ultraviolet region of the UVA lamp compared to natural sunlight is shown in Fig 1.

Results and discussion

Temperatures inside the experimental greenhouses were recorded over 24 h for the two growing seasons. Representative samples are shown in Fig. 2. Soil temperature in the recycled multilayer house was a few degrees lower in the afternoon hours to midnight than in the virgin monolayer house, whereas the air temperatures in both houses were very similar. The afternoon cooling suggests that the multilayered cover has a higher permeability to infrared radiation, which could be attributed in part to the 15% lower thickness of the multilayer film.

A 50% loss of elongation is commonly used as the failure criterion of films on the end of the service life of the film. The multilayer cover retained its tensile properties over the first part of the growing season, after which a significant and rapid deterioration in tensile strength was observed (Fig. 3). The monolayer virgin covers showed no variation in the tensile properties over the two growing seasons. The inferior tensile strength of the recycled multilayer film was compromised by an improved elongation at break over the first growing season due to the optimization of the polymer blend of the bottom layer (Fig. 4). The apparent initial insensitivity to UV radiation is a net effect of competing degradation processes. The photodegradation process in a polymer may involve any or all of the following reactions: Chain-breaking, resulting in low molecular weight products; cross-linking, resulting in brittle products; and formation of low-molecular-weight oxidation products that could be washed away (Mukhopadhyay and Banerjee, 1987). The sharp loss of elongation is a final consequence of those series of processes involved in the photochemical degradation. (Khraishi and Al-Robaidi, 1991).

The thickness of the film plays an important role in the determination of the film service life because the light stability decreases significantly with reduced thickness (Cordonnier, 1987). The multilayer film tested was 15% thinner than the traditional monolayer film (Table 2). Agricultural films having an average thickness of 150 µm commonly last for 1 year in the Jordan Valley, whereas films 180 to 200 µm thick last for 2 to 3 years. The tear-resistance of the multilayer film (Fig. 5) was only 2% less than that of the virgin cover over the 7-month weathering period. The inclusion of property modifiers served to improve significantly the impact and tear-strength properties of the recycled waste. The haziness of the multilayer cover showed a similar trend of change with weathering time, but with higher values than those of virgin monolayer cover (Fig. 6). Both films showed discoloration and loss of transparency after 7 months of exposure. However, the multilayer film exhibited a slightly lower light transmission percentage and higher light scatter (Table 3). The lower light transmission in the multilayer film is expected due to the presence of recycled waste with a high gel content. The good scatter diffuses light in such a way that plants receive the light with an even intensity from all directions, allowing for uniform growth.

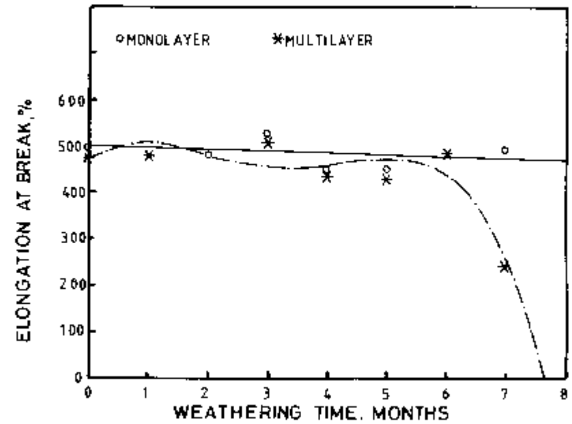

Fig. 4. *Extensibility of weathered virgin monolayer and recycled multilayer greenhouse film.*

Table 2. *Maximum, minimum, and average thickness of recycled multilayer and traditional monolayer plastic films.*

	Thickness (µm)	
Measurement	Multilayer	Monolayer
Minimum	150	138
Maximum	210	176
Average	190	160
No. measurements	94	87

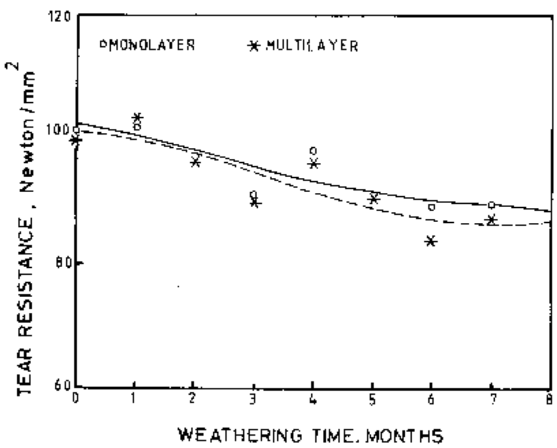

Fig. 5. *Tear resistance of weathered virgin monolayer and recycled multilayer greenhouse film.*

The thermal analysis of the monolayer and multilayer covers showed no variation in the melting point, whereas the heat of fusion of both covers increased to a maximum value after 5 months of exposure and then declined again (Fig. 7).

The rise in heat of fusion of virgin monolayer film, while maintaining its mechanical strength, reflects an increase in the crystallinity of the film due to an ordering process of the low-molecular-weight segments enhanced by the absorbed energy. On the other hand, the change in the heat of fusion

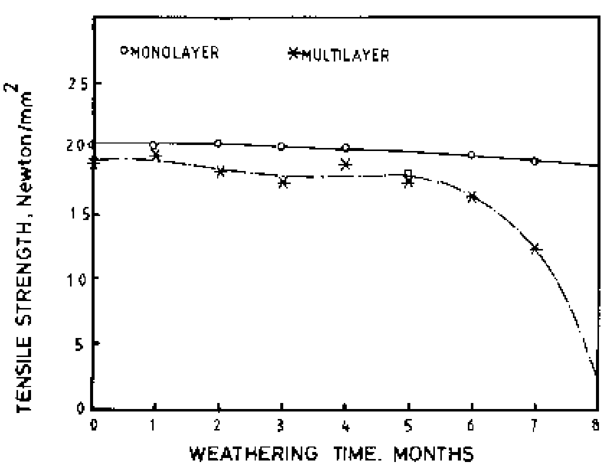

Fig. 3. *Tensile strength of weathered virgin monolayer and recycled multilayer greenhouse film.*

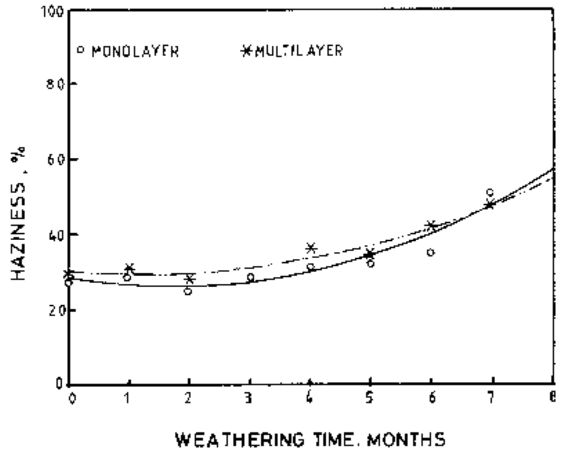

Fig. 6. *Haziness of weathered virgin monolayer and recycled multilayer greenhouse film.*

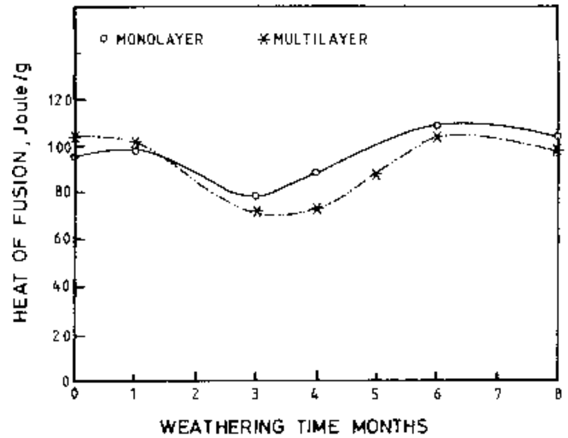

Fig. 7. *Heat of fusion of weathered virgin monolayer and recycled multilayer greenhouse film.*

Table 3. *Percentage of light transmission and scatter of weathered monolayer and multilayer films (1991–92).*

	Natural weathering time (months)							
Variable	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June
	Light transmission (%)							
Monolayer	89.9	88.7	89.9	88.4	88.1	87.6	85.5	84.5
Multilayer	88.4	86.5	85.3	86.3	86.1	85.5	86.4	83.3
Significance (5%)	NS	NS	NS	NS	NS	NS	NS	NS
	Light scatter (%)							
Monolayer	24.5	26.0	22.3	25.6	28.1	28.5	30.5	33.6
Multilayer	26.9	26.4	23.7	26.8	31.2	30.2	36.7	39.8
Significance (5%)	NS	NS	NS	NS	NS	NS	S	S

Table 4. *Effects of recycled multilayer and virgin monolayer plastic covers on early and total fruit yield and average fruit weight of greenhouse-grown tomatoes during 1991–92 and 1992–93.*

	1991-92		1992–93	
Plastic film	Early	Total	Early	Total
	Yield (tons/ha)			
Monolayer	32.8	108.1	26.9	97.0
Multilayer	32.1	110.1	27.6	98.4
Significance[z]	NS	NS	NS	NS
	Average fruit wt (g/fruit)			
Monolayer	183	158	148	138
Multilayer	177	160	151	139
Significance[z]	NS	NS	NS	NS

[z]*Paired comparison test was performed at the 5% level of significance.*

of multilayer film together with the deteriorating properties reflect structural changes due to photodegradation. The photodegradation process of polyethylene involves two competing reactions, namely chain-breaking, resulting in low molecular weight segments, and cross-linking, resulting in an increased molecular weight product. The predominance of either reaction depends on the extent to which the polymer is able to react with oxygen, which is usually present in the amorphous domains of the polymer. Measurements of the melt flow index (MFI) of the multilayer film at a 5-kg load and 190C were 0.18 and 0.02 g·min^{-1} for unweathered film and after 8 months of natural weathering, respectively, and indicated that the dominant reaction is cross-linking (Charkraborty and Scott, 1977).

The FTIR absorption spectra of the sample films were measured. The photo-oxidation products of polyethylene is expressed commonly as the carbonyl index, which is the ratio of the carbonyl absorbance to an invariant absorbance of the polymer. The measurements indicated that unweathered multilayered films contained initially a measurable amount of carbonyl at the absorption peak of 1740 cm^{-1}, whereas no peaks were observed in the carbonyl region (1700–1785 cm^{-1}) for the virgin monolayer film. The carbonyl groups in the film containing recycled waste are a main light-absorbing species that initiate and catalyse the photochemical decomposition (Amin et al., 1975). The IR spectrum of monolayer films weathered for 6 months and 15 months, respectively, showed that the virgin plastic film had excellent resistance to weathering, as reflected by the unchanged profile. Attempts to identify the complex products of degradation in the recycled multilayer film did not reveal much information, although significant mechanical deterioration (40% loss in elongation) was observed. The multilayer spectrum showed a decrease in absorbances at 728 and 1463 cm^{-1}. The peaks at 1247 and 1378 cm^{-1} also were shifted to 1242 and 1390 cm^{-1} as a result of structural changes.

Comparison of yields of tomatoes grown in a plastic greenhouse covered by recycled multilayer film with that covered by traditional monolayer film is shown in Tables 4 and 5. There were no differences in early and total tomato yield or average fruit weight between the two covers during either the 1991–92 or 1992–93 seasons (Table 4). The same monolayer film was used for both seasons; a new multilayer film was used for each season, indicating that the one-season-old multilayer film was as effective as the one- or two-season-old monolayer film in providing the biological requirements of a tomato crop. Although soil temperatures were slightly lower in the greenhouse covered with recycled film , the yields were not significantly different. The multilayer cover has the potential to provide the biological requirements of a tomato crop for only one growing season (7 months), whereas the traditional monolayer film is effective as a cover for two or more growing seasons.

The results of this research proved that waste recycling offers an attractive solution to nuisance environmental problems. However, subsequent work should be focused on the increase of useful lifetime of the film by controlling the thermo-oxidative degradation.

Literature Cited

Ali, M., A. Qatarneh, and S. Mehyar. 1990. A marketing study of multilayer polyethylene films in Egypt, Jordan,Iraq, Syria and Turkey. Royal Scientific Society, Jordan.

Amin M., G. Scott and L. Tillekeratne. 1975. Mechanism of the photo-initiation process in polyethylene . European Polymer J. 2:85.

Brown, J.E. and W.E. Splittstoesser.1991. Plasticulture. Disposal problems limit its commercial uses. Proc. Natl. Agr.Plastics Congr. 23:35–38.

Charkraborty K. and G.Scott.1977. Effects of the thermal processing on the thermal oxidative and photo-oxidative stabilities of low density polyethylene. European Polymer J. 13:731–737.

Cordonnier, M. 1987. LLDPE and UV aging. Plastics and Rubber Processing and Applic. 8: 23–27.

Ennis, R.S. 1987. Plastigone™ a new, time-controlled, photodegradable, plastic mulch film. Proc. 20th Natl. Agr. Plastics Congr. p. 83–90.

Fontes, M.K. 1973. Controlled environment horticulture in the Arabian Desert at Abu Dhabi. HortScience 8(1):13–16

Glen, J. 1990. Curbside recycling reaches 40 millions. Biocycle 3(7):30–37.

Khraishi, N. 1993. Multilayer polyethylene films (final report). Royal Scientific Society, Amman, Jordan.

Khraishi, N. and A. Al-Robaidi. 1991. Effect of weathering on UV stabilized low density polyethylene film for a multilayer greenhouse cover. Polymer Degradation and Stability 32:105–114.

Leaversuch, R.D. 1991. Chemical recycling brings real versatility to solid-waste management. Modern Plastics 68(7):40–43.

Mukhopadhyay, G. and M. Banerjee 1987. Popular Plastics, July. 15.

Wittwer, S.H. 1993. World-wide use of plastics in horticultural production. HortTechnology 3(1):6–19.

Comparing Objective Quality Attributes of Grapefruit Imported Into Europe

L.A. Risse and A.J. Bongers

Additional index words. *Citrus paradisi* Macf., peel thickness, juice volume, total soluble solids, total acid

Summary. Grapefruit (*Citrus paradisi* Macf.) were sampled biweekly from importers in Rotterdam, the Netherlands, from Oct. 1992 through Sept. 1993. For each sample, fruit size, weight, peel thickness, internal pulp color, juice weight, total soluble solids (TSS), and total acid (TA) were measured. Three grapefruit cultivars—'Marsh' white, 'Ruby Red', and 'Star Ruby'—were sampled from 12 countries of origin. Florida fruit weighed more, had the thinnest peel, the most juice, the lowest TA, and the highest TSS / TA ratio for all three cultivars compared to all other origins, except for 'Ruby Red' grapefruit from California, which had a lower TA and a higher TSS / TA ratio. Turkish 'Ruby Red' and Spanish 'Star Ruby' fruit weighed the least and had the least amount of juice compared to fruit from other origins. Turkish fruit had the highest TA and the lowest TSS / TA ratio for all three cultivars from all origins. Israeli 'Marsh' white and 'Star Ruby' had the highest TSS. Overall, the internal quality characteristics of Florida fruit was high compared to fruit from other origins.

In 1992, imports of fresh grapefruit into the European Economic Community (EEC) totaled 470,000 metric tons from more than 30 countries of origin (Eurostat, 1993). The five leading countries that exported fresh grapefruit to the EEC were the United States, Israel, Cyprus, South Africa, and Argentina, which accounts for ≈80% of the total. The next five countries, in descending order (Turkey, Honduras, Cuba, Uruguay, and Swaziland), exported ≈12% of the total. The United States and Israel accounted for ≈48% of the total imports into the EEC. However, Cuba's export to the EEC is increasing rapidly, as is production in Spain and Turkey. The United States exported ≈98,000 metric tons to the EEC, mostly from Florida, which exported 7.1 million boxes (≈72,000 metric tons), or about 18% of the total imports into the EEC.

U.S. Department of Agriculture, Agricultural Research Service, European Marketing Research Center, Rotterdam, the Netherlands.

Mention of a trademark, proprietary product, or vendor does not constitute a guarantee or warranty of the product by the USDA and does not imply its approval to the exclusion of other products of vendors that may also be available. The cost of publishing this paper was defrayed in part by the payment of page charges. Under postal regulations, this paper therefore must be hereby marked advertisement *solely to indicate this fact.*

External visual quality is very important to most European importers, but internal quality characteristics such as juice volume and sweetness are gaining in importance. Consumers are selecting more products because of better taste and / or flavor and are shifting gradually from only external quality characteristics as the major buying criteria. Palatability of grapefruit depends on the sweetness and a high ratio of TSS / TA (Harding, 1952; Long et al., 1959). In addition to TSS / TA ratio, juice volume is used as a basis for determining maturity and palatability (Harding and Fisher, 1945).

An earlier study was conducted on the variation of three physical and three chemical characteristics related to quality of fresh grapefruit originating from 13 countries and imported into the EEC (Hillebrand et al., 1978). That study indicated that 'Marsh' white grapefruit from Florida had the thinnest peel, highest percent of juice, lowest percent of TA, and highest TSS / TA ratio compared to fruit from most other origins. Another study conducted on only early season (October / November) grapefruit arriving from Florida, Cuba, Mexico, and Honduras into the Rotterdam Fruit Auction showed that Florida fruit compared favorably to fruit from the other origins (Hoogendoorn and Miller, 1986). Most of the grapefruit in that study was 'Ruby Red', and the study was conducted only during a 6-week period in Oct. and Nov. in 1984 and 1985.

The objective of this study was to compare selected physical and chemical characteristics of the grapefruit cul-