Evaluation of Table Grape Storage in Boxes with Sulfur Dioxide-releasing Pads with Either an Internal Plastic Liner or External Wrap

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ADDITIONAL INDEX WORDS. *Vitis vinifera*, decay, fruit quality, SO₂, *Botrytis cinerea*

SUMMARY. Two main methods are in use for packing table grapes (*Vitis vinifera*) for refrigerated storage and transport. One is to pack the grapes with a sulfur dioxide (SO₂) generator pad inside a box with a perforated plastic liner and then to cool them. The other is to place the SO₂ pad on the grapes, cool the pallet, and wrap it with low-density polyethylene film, leaving the bottom of the pallet open. These two methods were compared for their efficiency in maintaining grape quality and preventing decay for periods ranging from 33 to 117 days. The experiments included 'Redglobe' and 'Zainy' grapes packaged in plastic boxes and 'Thompson Seedless' grapes packaged in cardboard boxes. The quality of the grapes in the trials with plastic boxes was either similar in both packaging methods or better in the wrapped pallet than the liner method. The pedicels, and sometimes the rachis, showed more desiccation in the liners than in the wrapped pallets. Prevention of decay was also better with the wrapped pallets than for storage in liners. However, in the experiment with cardboard boxes, the externally wrapped boxes contained lower levels of SO₂, probably because of absorption of SO₂ by the cardboard, and the grapes developed more decay and rachis desiccation than in liners inside the cardboard boxes. The method of wrapping grapes after cooling them can have significant advantages over the liner method because of the faster cooling of the grapes and the use of less plastic-based, nonrecyclable materials.

Table grapes are a nonclimacteric fruit with a low rate of physiological activity (Peynaud and Ribereau-Gayon, 1971) but are subject to serious water loss and decay during postharvest handling (Nelson, 1985). Gray mold caused by the fungus *Botrytis cinerea* and rachis browning as a result of desiccation are the two main factors that reduce table grape postharvest quality (Nelson, 1985). The means for preventing decay during storage is the use of sulfur dioxide (SO₂), which was first tried in 1925 (Winkler and Jacob, 1925). In subsequent years, a SO₂-releasing pad was developed that consists of sodium metabisulfite grains enclosed in paper–plastic pockets inside a pad. Since the late 1960s a two-stage or dual-release (DR) SO₂ generator consisting of formulations that allow quick release plus slow release of the gas have been widely used for table grape storage and transport (Nelson and Ahmedullah, 1976). The DR pad contains sodium metabisulfite enclosed between paper sheets of differing permeability. Moisture within the package of grapes is absorbed by the pads and reacts with the sulfite, releasing SO₂. The quick-release part of the pad gives a flush of SO₂, which peaks after ≈24 h and then diminishes in ≈1 week. The slow-release part of the pad emits a low concentration of SO₂ over a long period. Laminated pads are a further development in which the salt is impregnated between polymers.

Of interest is how the generator pads behave in different packaging systems. In South Africa, it has been shown that a SO₂ concentration around the grapes of 10 to 20 ppm is safe and effective (Laszlo et al., 1981). It was found that concentrations of less than 7 ppm in the fruit did not control decay if the storage temperature fluctuated above 0 °C and that concentrations higher than 20 ppm could injure the grapes by bleaching. Therefore, an SO₂ concentration of 7 to 10 ppm was recommended for long-term storage of grapes (Laszlo et al., 1981).

There are two main concepts in use for packing grapes for extended storage: packing with a SO₂ generator pad and fumigation of cold storage chambers with SO₂. In the United States during static cold storage, the grapes are subjected to an initial fumigation with SO₂ during forced-air cooling and then given weekly fumigations during storage. Packaging with SO₂ pads is used for both exporting and static storage in other countries (Lichter et al., 2006). One method of packaging is to pack the grapes with an SO₂ generator inside a perforated liner in a box. The liner limits moisture loss from the rachis and berries, and the perforations prevent the humidity from causing water condensation on the grapes. However, this method slows the rapid cooling of the grapes after harvest. A second method is to pack the grapes in a box with an SO₂ generator pad, arrange the boxes on a pallet, rapidly cool the grapes to 4 °C or below, and after they have been in the cold for 1 d, to wrap the pallet with linear low-density polyethylene (LLDPE) on all

Units

To convert U.S. to SI, multiply by	U.S. unit	SI unit	To convert SI to U.S., multiply by
29.5735	fl oz	mL	0.0338
2.54	inch(es)	cm	0.3937
25.4	inch(es)	mm	0.0394
6.4516	inch²	cm²	0.1550
0.4536	lb	kg	2.2046
1	micron	μm	1
28.3495	oz	g	0.0353
28,350	oz	mg	3.5274×10^{-5}
1	ppm	mg·L⁻¹	1
1	ppm	μL·L⁻¹	1
(°F – 32) ÷ 1.8	°F	°C	(1.8 × °C) + 32

sides and the top, leaving the bottom of the pallet unwrapped. This wrapping process is mechanized and allows for rapid cooling of the grapes. There is greater free air space inside the resulting large package.

The SO₂ generator pads were developed for use in liners inside boxes. The two methods of packing were compared for grape quality during sea shipment and storage for a period of 3 weeks and were found to be comparable (Ben-Arie et al., 1984). However, in recent years, late-season grapes such as 'Redglobe', harvested in September, are being stored for longer periods. In these cases, it is important to find the best method of packaging that will minimize water loss while preventing the decay that would occur if the SO_2 level was too low or the SO_2 damage that would occur if it was too high. The purpose of the present study, therefore, was to compare two methods of packaging table grapes destined for storage: boxes with perforated liners and palletized boxes wrapped with LLDPE. In addition, in some trials, the dual-release SO_2 pad was compared with a laminated pad. The kinetics of SO_2 concentration in the atmosphere around the grapes were monitored, and the quality of the grapes after storage and holding for 3 d at 20 °C was examined. The SO_2 generators used were commercially available dual-release and laminated pads. Three grape cultivars were examined, 'Redglobe', 'Thompson Seedless', and 'Zainy', and the storage periods in different experiments ranged from 33 to 117 d.

Materials and methods

EXPERIMENTAL SETUP. Grapes were obtained from various farms on the day of harvest, during the commercial harvest season. They were cleaned of damaged or decayed berries and packed into plastic boxes containing 5 or 9 kg grapes. The internal dimensions of the 5-kg boxes were 40.5 cm long × 34.5 cm wide × 16.5 cm high with a grid 25 cm wide × 20 cm long containing a total of 605 cm² of ventilated area in the bottom and 384 cm² in the sides. The internal dimensions of the 9-kg boxes were 52 cm long × 34 cm wide × 18 cm high with an array of six squares containing a total of 606 cm² of ventilated area in the bottom and 1130 cm² in the

Table 1. Types of sulfur dioxide generator pads used in this study evaluating packaging grapes with either an internal box liner or wrapping pallets externally.[z]

Trade name	Dimensions [width × length (cm)][x]	Material[y]	Pad type[v]	Blisters (no.)[w]	Fast release[u] (%)	Active ingredient (%)[t]	Sodium metabisulfite content (g)[s]	Maximum storage time[r] (weeks)	Color[q]	Manufacturer
Osku-Vid Max-2 LV8	26 × 46	Paper	DR	32	11	97.5	7	7	Purple	Osku, Santiago, Chile
Osku-Vid	25.5 × 35	Laminated	DR	None	NS	60	12	NS[p]	Green	Osku, Santiago, Chile
Fresca	30 × 46	Paper	DR	30	15	97	7	9	Blue	Quimetal Industries, Santiago, Chile
Matesa Grape Guard	33 × 46	Paper	DR	40	12	98	7	12	Green	Empack, Santiago, Chile
Vinguard	26 × 35	Laminated	DR	None	NS	17	3	10	Picture of grapes	Vinguard Ltd., Stellenbosch, South Africa

[z]Data were collected from specifications on the generator pads or from brochures supplied by the manufacturers.
[y]The primary material from which the generator pad is made.
[x]1 cm = 0.3937 inch.
[w]Number of blisters or sachets containing the a.i.
[v]DR = dual-release generator pad containing a part of the a.i. with a fast-release formulation and the remainder in slow-release formulation.
[u]The fraction of fast release formulation in each pad.
[t]Active ingredient of the chemicals embedded in the generator pads.
[s]Sodium metabisulfite content as specified on the sulfur dioxide generator pads; 1 g = 0.0353 oz.
[r]Maximal recommended storage time in weeks as specified by the manufacturers.
[q]Color of the print on the generator pad.
[p]NS = not specified.

sides. Two methods of packaging were used in this study: 1) bunches were placed in boxes with 30-μm high-density polypropylene liners having 0.2% ventilation (holes of 6-mm diameter spaced every 12 cm) with an SO_2 generator pad on top of the bunches; and 2) a unit of three or four stacked plastic boxes of grape bunches, termed a "mini-pallet" (MP), with each box containing a SO_2 generator pad. The MP boxes were passively cooled by placing them into a storage room at 0 °C, 91% relative humidity (RH), so that the temperature of the berries was below 3 °C before the boxes were wrapped the next day. They were wrapped by winding a 50-cm wide, 30-μm film of LLDPE around the MP. In each turn, the film was raised by half its width to create a double spiral overlap. Before wrapping, the top of the MP was covered with a high-density polyethylene sheet, slightly larger than the surface of the box, placed on top. The bottom of the MP was left unwrapped and was raised off the floor by placing it on an empty plastic box. As well as two types of packaging, two different types of SO_2 generator pads were used: 1) a DR pad made of paper layers; and 2) a laminated pad (LM) with a plastic coating. Thus, comparisons were made among two pads in a liner (designated LM liner and DR liner) and two pads in the "mini-pallet" (designated LM-MP and DR-MP). The SO_2-generating pads and laminates were obtained from the following manufacturers: Fresca (Quimetal, Santiago, Chile), Matesa (Empack, Santiago, Chile), Osku-VID (Osku, Santiago, Chile), and Vinguard (Vinguard Ltd, Stellenbosch, South Africa). The specifications of the various pads are given in Table 1. There were three or four replicates for each treatment. In some experiments, RH was determined inside the MP and liners; the RH values in both methods were in the range of 96% to 98% as determined with a Hygrolog (Rotronic AG, Bassersdorf, Switzerland) instrument placed in the boxes.

Three experiments were conducted in different seasons with 'Redglobe' grapes. In addition, one experiment with 'Thompson Seedless' grapes used cardboard boxes, not plastic boxes. The cardboard
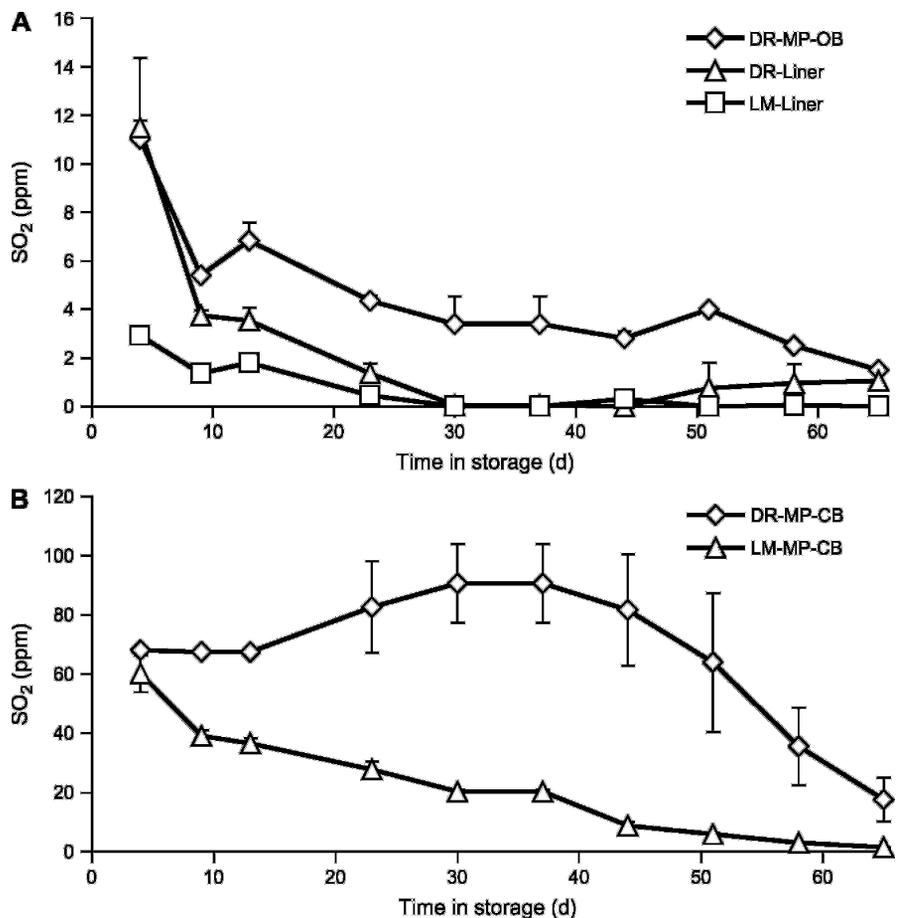

Fig. 1. Sulfur dioxide (SO_2) concentration around 'Redglobe' grapes stored at 0 °C (32.0 °F) in plastic boxes with (A) liners inside (liner) or wrapped on the outside and top with linear low-density polyethylene (LLDPE) film in a "mini-pallet" [MP (three stacked plastic boxes containing grapes)] with the bottom left open (OB); (B) wrapped on the outside and top with LLDPE film and the bottom closed with high-density polyethylene film (CB). SO_2 pads were either a laminate (LM) or a paper-type dual-release pad (DR) manufactured by Osku (Santiago, Chile). SD is indicated (n = 4); 1 ppm = 1 μL·L^{-1}.

boxes measured 37 cm long × 28 cm wide × 12 cm high and they included a total of 88 cm^2 of ventilated area in the bottom and 95 cm^2 in the sides. Another experiment was performed with the local cultivar, 'Zainy', packed in 9-kg plastic boxes with DR pads from three different manufacturers.

SO_2 ANALYSIS. SO_2 levels inside the packages were monitored weekly with an electrochemical sensor fitted with a small pump that operated at a flow rate of 50 mL·min^{-1} to sample air from the package into the instrument (Emproco, Ashkelon, Israel). The instrument was connected to silicon tubes inserted into the center of the middle box of each MP replicate, or 10 cm into the package in each box of the liners, and the connections ensured that air was circulated into the instrument and back to the

package. The SO_2 detection limit of the instrument was 0.1 ppm.

The sulfite content in the berries was determined according to the optimized Monier-Williams distillation method (Association of Official Analytical Chemists International, 2005); 50 berries were sampled from each replicate and frozen for later analysis of sulfite content. After thawing, the berries were homogenized in a blender for 2 min with one intermission. Thirty grams of homogenized sample were weighed into a round-bottomed sample flask connected to a condensation apparatus, and 15 mL of 25% phosphoric acid (H_3PO_4) was added. The "free" SO_2 was released into the apparatus during 15 min with an air stream flowing at 2 mL·min^{-1} that bubbled into a collection flask containing 15 mL of 0.3%

Table 2. Comparison of quality of 'Redglobe' grapes held in storage with two different types of sulfur dioxide (SO_2)-releasing pads and with a polyethylene liner inside the box or with wrapping of three boxes together on the outside.[z]

| Treatment[y] | Rachis desiccation (1–5 scale)[x] | | Pedicel desiccation (1–5 scale)[x] | | SO_2 damage (1–5 scale)[w] | Healthy bunches (%) |
	Storage[v]	Shelf life[v]	Storage	Shelf life	Storage	Shelf life
Control-OB	2.2 ± 0.2 a[u]	2.7 ± 0.1 a	2.6 ± 0.1 a	3.4 ± 0.2 a	1.0 ± 0.0 b	0 b
DR-MP-OB	2.3 ± 0.2 a	2.8 ± 0.4 a	2.5 ± 0.4 a	3.3 ± 0.6 a	1.0 ± 0.0 b	81 ± 21 a
LM-Liner-OB	2.4 ± 0.2 a	2.7 ± 0.1 a	2.9 ± 0.2 a	3.7 ± 0.2 a	1.0 ± 0.0 b	69 ± 17 a
DR-Liner-OB	2.3 ± 0.3 a	2.8 ± 0.3 a	2.7 ± 0.3 a	3.7 ± 0.1 a	1.0 ± 0.0 b	77 ± 38 a
LM-MP-CB	1.8 ± 0.1 b	2.1 ± 0.1 b	1.8 ± 0.2 b	2.3 ± 0.1 b	1.7 ± 1.2 b	100 ± 0 a
DR-MP-CB	1.8 ± 0.0 b	2.3 ± 0.1 b	1.8 ± 0.1 b	2.3 ± 0.1 b	4.3 ± 0.6 a	100 ± 0 a

[z]The storage time was 65 d of storage at 0 °C (32.0 °F) and 3 d at 20 °C (68.0 °F). Quality measurements included rachis and pedicel desiccation, SO_2 damage, and the percentage of bunches with one or no decayed berries at the end of storage and the 3 d of shelf life.
[y]Control was a mini-pallet (MP [a unit of three stacked plastic boxes containing grapes wrapped around the top and sides with 30-μm-thick (30 μm) film of linear low-density polyethylene] without SO_2-generator pads and with the pallet open at the bottom (OB); DR = dual-release SO_2 generator pad; LM = laminated SO_2-generator pad; liner = 30-μm high-density polyethylene bag having 0.2% ventilation [holes 6 mm (0.24 inch) diameter spaced every 12 cm (4.7 inches)] placed inside each box; CB = pallet closed at the bottom.
[x]1 = rachis and pedicels full and green as at harvest; 2 = slight browning; 3 = browning of rachis and pedicels but no shriveling; 4 = browning and some shriveling; 5 = both rachis and pedicels dry and brown. A rating greater than 3 was considered unmarketable.
[w]Rated according to the number of berries per replicate (10 bunches) that suffered bleaching: 1 = no apparent bleaching; 2 = two to five berries; 3 = six to 10 berries; 4 = 11 to 20 berries; 5 = over 20 bleached berries.
[v]Storage was for 65 d at 0 °C and shelf life was 3 d at 20 °C.
[u]Values in columns followed by different letters indicate significant differences according to analysis of variance with the Student-Newman-Keuls test at $P < 0.05$.

hydrogen peroxide (H_2O_2) titrated to pH 7 with 0.01 N sodium hydroxide (NaOH). The solution was supplemented with one drop of the indicator dyes methyl red and methylene blue (100 and 50 mg, respectively) in 100 mL of 50% ethanol solution. "Bound" SO_2 was released from the sample after replacing the H_2O_2 solution and boiling the sample for 15 min. The condensation apparatus was cooled to 10 °C. The samples were titrated with 0.01 N NaOH and the amount of sulfites (in milligrams per liter) in each fraction was calculated by multiplying the titration volume by a factor of 10.6.

QUALITY ANALYSIS OF FRUIT. At each removal from storage, the boxes were transferred to 20 °C, 80% RH for 3 d, after which 10 bunches from each box were examined individually as previously described (Lichter et al., 2005). Each bunch was rated for desiccation, SO_2 damage, and decay. Desiccation and SO_2 damage were assessed on an index rating of 1 to 5. Desiccation ratings were 1 = rachis and pedicels green and full as at harvest; 2 = slight browning; 3 = browning of rachis and pedicels but no shriveling; and 5 = both rachis and pedicels dry and brown. An index rating above 3 for desiccation was considered unmarketable. SO_2 ratings were defined according to the number of berries per replicate that suffered bleaching: 1 = no apparent bleaching; 2 = two to five berries; 3 =

six to 10 berries; 4 = 11 to 20 berries; and 5 = over 20 bleached berries per 10 bunches. Healthy bunches were defined as having only one or no decayed berries, and the percentage of such bunches in each box was determined.

STATISTICAL ANALYSIS. Statistical analysis was routinely conducted with the Instat (ver. 3.06; GraphPad, San Diego, CA) by one-way analysis of variance with the Student-Newman Keuls posttest at $P < 0.05$. Transformation to square root of arcsine

values was applied to the percentages of healthy berries.

Results and discussion

'REDGLOBE'. In the first experiment on 'Redglobe' grapes, Osku DR pads were compared with an Osku LM pad in liners and in MP.

An additional two treatments in this experiment tested LM and DR pads in an MP configuration but with the bottom of the pallet closed (designated CB). There was also a control
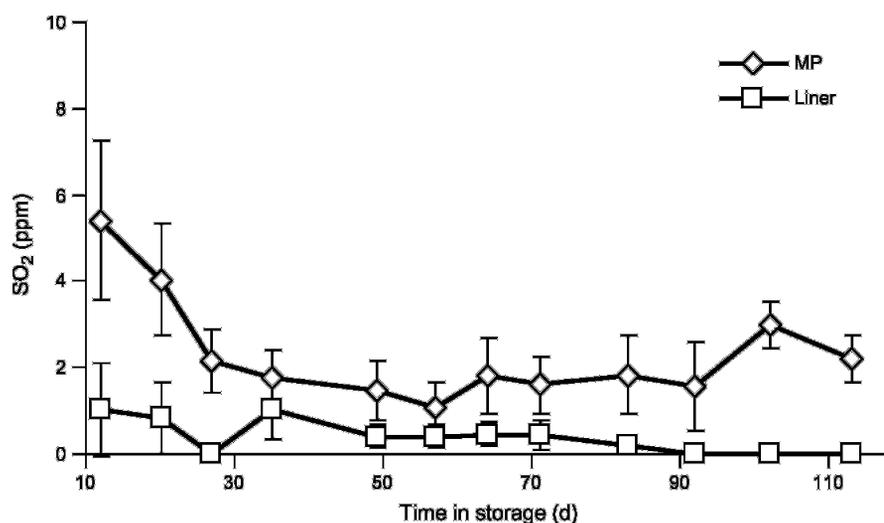

Fig. 2. Sulfur dioxide (SO_2) concentration around 'Redglobe' grapes stored at 0 °C (32.0 °F) in plastic boxes with liners inside (liner) or wrapped on the outside with linear low-density polyethylene in a "mini-pallet" [MP (three stacked plastic boxes containing grapes)]. The SO_2 generator pad was a dual-release type (DR) manufactured by Osku (Santiago, Chile). SD is indicated (n = 4); 1 ppm = 1 μL·L^{-1}.

without any SO_2-generating pad packaged in MP. The results showed that when the bottom of the pallet was closed, the level of SO_2 around the grapes was much higher than with either an MP with an open bottom (MP-OB) or in boxes with liners (Fig. 1). After 4 d, the SO_2 level was above 60 ppm in MP-CB with either DR or LM pads, and this increased to 90 ppm after 30 d with the DR pad, whereas in MP-CB with LM, SO_2 levels decreased to 20 ppm. By 65 d, the SO_2 level in the closed-bottom MP containing a LM pad was below 2 ppm compared with 17 ppm in the same packaging format with DR pads. In contrast, the SO_2 in the MP-OB boxes started at a level of 11.5 ppm after 4 d and reached a level of 1.5 ppm after 65 d with some fluctuations. In liners with LM pads, SO_2 declined to below the detection level after 30 d. With the DR pad in the liners (DR liner), the SO_2 level decreased from 11 ppm to below the detection limit within 30 d in two subsequent measurements, but in three later measurements, levels of 0.8 to 1.1 ppm were recorded.

In this trial, grape quality was inspected after 43 or 65 d. On the first removal from storage, after 43 d, the untreated control contained 4% of healthy bunches compared with 100% in all other treatments. After 65 d in cold storage and 3 d at 20 °C, decay appeared, but there were still 81% of healthy bunches in the MP-OB treatment and 69% in the LM liner treatment (Table 2). The grapes in the MP-CB treatments were 100% healthy but had high levels of SO_2 damage, making them unmarketable. The damage was more extensive in treatments with DR pads than in those with LM. The latter did not differ statistically from the MP-OB or liner treatments without damage. There was no SO_2 damage in either the MP-OB treatments or the liners in this experiment or in the other trials reported here. The rachis and pedicels were less desiccated in the MP-CB treatments than either the MP-OB or the liners. The most desiccation was found in the liners.

In the second experiment with 'Redglobe', the grapes were stored for 117 d with an Osku DR pad (Fig. 2). In the MP treatment, the level of SO_2 was ≈5 ppm after 12 d of storage, and this decreased to 2 ppm

after 27 d, after which it was maintained at 1 to 3 ppm during the next 3 months. The level of SO_2 in liners with the same pad was below 1 ppm and it declined to below the detection limit after 3 months. The total levels of SO_2 residues after shelf life in the MP and liner treatments were 4.5 and 3.4 ppm, respectively. The MP treatment had 69% healthy bunches compared with none in the liner treatment (Table 3). The desiccation of rachis in the liners was significantly worse than in the MP treatment.

A maximum allowable concentration of SO_2 residues in table grapes has been set to 10 ppm (U.S. Government Printing Office, 1986). In grapes, the SO_2 is dissolved into the

cytoplasm as sulfite and bisulfite, depending on the pH (Peiser and Yang, 1985). After fumigation of 30 min, sulfite and bisulfate were converted to sulfate in the fruit within 24 h (Peiser and Yang, 1985). Sulfates are natural components of grapes, and their presence has no toxicological or health implications. However, the oxidation capacity of grape berries is limited, and the internal conversion of sulfite to sulfate can be exhausted. In this trial with the longest storage time of 113 d, it was found that SO_2 residue levels were 4.5 and 3.4 ppm for the MP and liner treatments, respectively. Therefore, although the levels of SO_2 around the grapes in the MP packaging method were higher

Table 3. Comparison of 'Redglobe' grape quality stored with a dual-release (DR) sulfur dioxide (SO_2) generator pad in either boxes wrapped with polyethylene from the outside or with a polyethyelene liner inside the boxes.[z]

Treatment[y]	Rachis desiccation (1–5 scale)[x]		Pedicel desiccation (1–5 scale)[x]		Healthy bunches (%)
	Storage[w]	Shelf life[w]	Storage	Shelf life	Shelf life
DR-MP	2.3 ± 0.4b[v]	3.3 ± 0.2 b	2.3 ± 0.4 b	3.4 ± 0.3 b	69 ± 42 a
DR-Liner	3.2 ± 0.3 a	3.8 ± 0.4 a	4.0 ± 0 a	4.5 ± 0.4 a	0 b

[z]Storage was for 117 d at 0 °C (32.0 °F) and 3 d at 20 °C (68.0 °F). Quality measurements included rachis and pedicel desiccation and the percentage of bunches with one or no decayed berries at the end of storage and the 3 d of shelf life.
[y]Treatments were with a DR SO_2 generator pad in either a mini-pallet (MP [a unit of three stacked plastic boxes containing grapes wrapped around the top and sides with 30-μm-thick (30 μm) film of linear low-density polyethylene]) or in a liner (liner), which is a 30-μm high-density polyethylene bag having 0.2% ventilation [holes 6 mm (0.24 inch) diameter spaced every 12 cm (4.7 inches)] placed inside each box.
[x]1 = rachis and pedicels full and green as at harvest; 2 = slight browning; 3 = browning of rachis and pedicels but no shriveling; 4 = browning and some shriveling; 5 = both rachis and pedicels dry and brown. A rating greater than 3 was considered unmarketable.
[w]Storage was for 117 d at 0 °C and shelf life was 3 d at 20 °C.
[v]Values in columns followed by different letters indicate significant differences according to analysis of variance with the Student-Newman-Keuls test at $P < 0.05$.

Table 4. Comparison of quality of 'Redglobe' grapes stored in boxes with an internal polyethylene liner or as three boxes of grapes wrapped on the outside and with either a laminate or dual-release sulfur dioxide (SO_2) generator pad.[z]

Treatment[y]	Rachis desiccation (1–5 scale)[x]	Pedicel desiccation (1–5 scale)[x]	Healthy bunches (%)
Liner	3.2 ± 0.2[w]	4.2 ± 0.4	9 ± 16 c[y]
LM-Liner	2.7 ± 0.2	4.1 ± 0.4	45 ± 10 ab
DR-Liner	2.9 ± 0.2	3.9 ± 0.2	46 ± 50 ab
MP	2.9 ± 0.5	3.9 ± 0.5	29 ± 30 b
LM-MP	2.6 ± 0.4	3.6 ± 0.5	70 ± 14 a
DR-MP	2.9 ± 0.8	3.8 ± 0.5	79 ± 21 a
	NS	NS	

[z]Storage was for 62 d at 0 °C (32.0 °F) and 3 d shelf life at 20 °C (68.0 °F) with quality measured at the end of the 3 d. Quality measurements included rachis and pedicel desiccation and the percentage of bunches with one or no decayed berries at the end of storage and the 3 d of shelf life.
[y]Treatments were with boxes with a liner (liner), which is a 30-μm-thick (30 μm) high-density polyethylene bag having 0.2% ventilation [holes 6-mm (0.24 inch) diameter spaced every 12 cm (4.7 inches)] placed inside each box or with a mini-pallet (MP; a unit of three stacked plastic boxes containing grapes wrapped around the top and sides with 30-μm film of linear low-density polyethylene). In each type of box, there was no sulfur dioxide SO_2 generator pad, a laminated pad (LM), or a dual-release (DR) pad.
[x]1 = rachis and pedicels full and green as at harvest; 2 = slight browning; 3 = browning of rachis and pedicels but no shriveling; 4 = browning and some shriveling; 5 = both rachis and pedicels dry and brown. A rating greater than 3 was considered unmarketable.
[w]Values in columns followed by different letters indicate significant differences according to analysis of variance with the Student-Newman-Keuls test at $P < 0.05$; NS = no significant differences.

than with liners, the residue levels are not expected to exceed the allowable limit.

The third experiment with 'Redglobe' grapes was conducted for 65 d. With Osku DR pads in a MP, the SO_2 level from day 11 to day 40 was 3 to 4 ppm, whereas in boxes with liners, it was 1 to 2.5 ppm. At day 50, the SO_2 level in the MP was 1.8 and that in the liners was 0.6 ppm, whereas at the end of storage, the MP SO_2 level was 0.6 ppm and that in the liners 0.1 ppm. The level of SO_2 from a Vinguard LM pad, either in MP or boxes with liners, fell below the detection limit within the timeframe of measurement (11 to 64 d). Further examination of the properties of this laminate showed that it released SO_2 only in the first week of storage (data not shown). Grape quality was analyzed after 65 d (Table 4). The presence of an LM or a DR pad increased the percentage of healthy bunches in liners from 9% with no pad to 45% or 46%, respectively. In the MP treatment, the proportion of healthy bunches increased from 29% without a pad to 70% or 79% for the LM or DR pads, respectively. There was a tendency for the grapes in the liners to have dryer rachis and pedicels, but the differences between pairs of treatments were usually not significant.

In all three trials, the levels of SO_2 were higher inside the MP packaging than in the liners. There are a number of explanations for the differences in SO_2 release from the same type of SO_2-generating pad in the two different packaging systems. One is that although the MP was open on the bottom, it was still less permeable to SO_2 than the liner, whose surface area contained 0.2% of perforations around the grapes. However, it is also possible that because we began monitoring the SO_2 levels several days after storage was initiated, we might have missed a peak of SO_2 emission from the pads in the liners. The cooling rate of grapes in the liners was slower than that of unwrapped grapes, and in the MP method, they were wrapped only after they had cooled to 4 °C or lower. In previous experiments, it was established that in the experimental storage rooms, it took grapes inside 0.2% perforated liners 44 h to reach 0 °C, whereas those without the liners cooled to 0 °C after 18 h (R. Ben-Arie,

unpublished data). Warm grapes respire more than cold ones and would cause release of SO_2 from the pads at the beginning of the storage period. Most of the measurements of SO_2 were performed after 6 d or more of storage, and these measurements were likely to miss any early SO_2 burst.

'THOMPSON SEEDLESS'. 'Thompson Seedless' grapes were stored for 45 d in cardboard boxes holding 4 kg grapes rather than in plastic boxes. The average SO_2 levels over the course of 45 d of storage were calculated for each treatment (Table 5). The SO_2 levels in liners containing DR pads differed significantly from those in the other treatments. When the statistical analysis excluded the first time point, determined after 6 d of storage, the differences between DR and LM pads were significant, irrespective of the

Table 5. A comparison of average sulfur dioxide (SO_2) level over the course of 45 d of 0 °C (32.0 °F) storage of 'Thompson Seedless' grapes and quality of the grapes after 45 d at 0 °C and 3 d at 20 °C (68.0 °F) when stored with either a polyethylene bag inside the box or with three boxes wrapped on the outside in polyethylene.[z]

Treatment[y]	SO_2 level (ppm)[x]	Rachis desiccation (1–5 scale)[w]	Pedicel desiccation (1–5 scale)[w]	Healthy bunches (%)
Liner		2.7 ± 0.1 ab	3.2 ± 0.1 ab	0 c
LM-Liner	0.5 ± 0.4 b[v]	2.4 ± 0.1 abc	2.6 ± 0.1 b	87 ± 8 a
DR-Liner	4.7 ± 0.8 a	2.1 ± 0.2 c	2.6 ± 0.0 b	62 ± 10 ab
MP		2.7 ± 0.0 ab	3.1 ± 0.1 ab	0 c
LM-MP	0.4 ± 0.3 b	3.1 ± 0.1 a	3.7 ± 0.2 a	54 ± 12 ab
DR-MP	1.9 ± 0.4 b	2.9 ± 0.2 a	3.6 ± 0.1 ab	28 ± 24 b

[z]SO_2 was determined every week. Quality measurement at the end of storage and shelf life include rachis and pedicel desiccation and the percentage of bunches with no decayed berries.
[y]Treatments were with boxes with a liner (liner), which is 30-μm-thick (30 μm) high-density polyethylene bag having 0.2% ventilation [holes of 6-mm (0.24 inch) diameter spaced every 12 cm (4.7 inches)] placed inside each box or with a mini-pallet (MP; a unit of three stacked plastic boxes containing grapes wrapped around the top and sides with 30-μm film of linear low-density polyethylene). In each type of box, there was no SO_2 generator pad, a laminated pad (LM), or a dual-release (DR) pad.
[x]1 ppm = 1 μL·L^{-1}.
[w]1 = rachis and pedicels full and green as at harvest; 2 = slight browning; 3 = browning of rachis and pedicels but no shriveling; 4 = browning and some shriveling; 5 = both rachis and pedicels dry and brown. A rating greater than 3 was considered unmarketable.
[v]Values in columns followed by different letters indicate significant differences according to analysis of variance with the Student-Newman-Keuls test at $P < 0.05$.
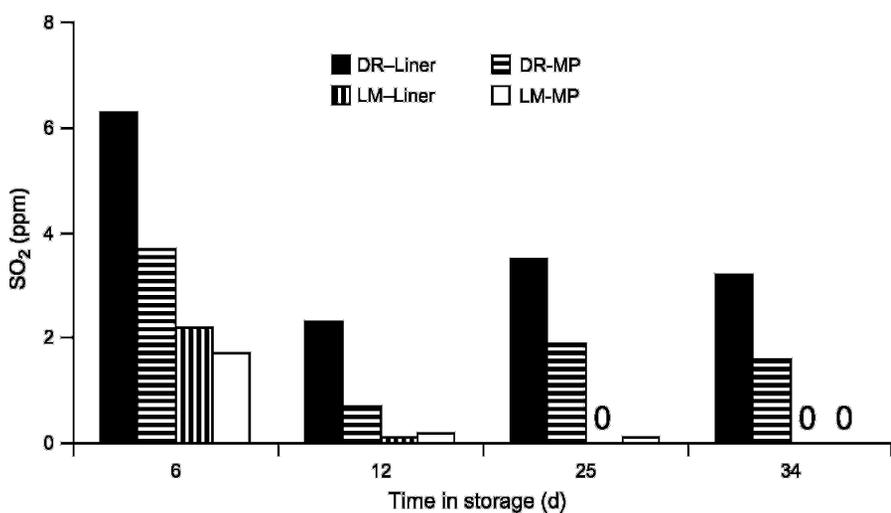

Fig. 3. Sulfur dioxide (SO_2) concentration around 'Thompson Seedless' grapes stored at 0 °C (32.0 °F) in cardboard boxes with liners inside (liner) or wrapped on the outside with linear low-density polyethylene (LLDPE) in a "mini-pallet" [MP (three stacked plastic boxes containing grapes)]. SO_2 pads were either a plastic laminate (LM) manufactured by Vinguard Ltd. (Stellenbosch, South Africa) or a dual-release pad (DR) manufactured by Osku (Santiago, Chile) (n = 3); 1 ppm = 1 μL·L^{-1}.

packaging method (not shown). The SO_2 content in the boxes with liners or in the boxes wrapped in the MP format showed different kinetics from those in the experiments with plastic boxes (Fig. 3 compared with Fig. 1 or 2). For example, after 34 d, the SO_2 level in the MP format was only 1.6 ppm compared with 3.2 ppm measured in the liner. The possible explanation for this situation is that the cardboard absorbed SO_2, whereas the liner separating the grapes and the SO_2 pad from the cardboard prevented this absorption. The first measurement of SO_2 in the MP or liner format with a Vinguard LM pad was ≈2 ppm after 6 d in storage, but in later measurements, SO_2 was not detected. As discussed previously with regard to the third 'Redglobe' experiment, the Vinguard LM pad was found to operate as a fast-release pad so that SO_2 levels exceeded 100 ppm during the first 3 d of storage and declined to very low levels later (data not shown). Table 5 shows the quality of the 'Thompson Seedless' grapes after 45 d of storage at 0 °C and 3 d at 20 °C. As expected, there were no healthy bunches among the control grapes with no SO_2 pad. The best control over decay in this experiment was achieved with the liners and the LM generator pad (87% healthy bunches) followed by liners with Osku DR pads (62% healthy bunches). The MP format gave lower efficacy with 54% and 28% of healthy bunches with the LM pad and the DR pad, respectively. Desiccation indices were high in the MP treatments with both types of pads. Interestingly, there was no apparent difference in the quality of rachis between the liner and the MP controls without SO_2 pads, suggesting that the presence and amount of SO_2 was the major factor that determined the appearance of the rachis. It should be noted also that in this experiment, the rachis were much thicker than normal rachis of 'Thompson Seedless', most likely because of vineyard treatments.

The results of this experiment with cardboard boxes were different from those of the trials of 'Redglobe' and plastic boxes. The trials with plastic boxes showed higher SO_2 levels in the MP than in the liners, but with cardboard boxes, this trend was reversed. It has been recognized that when weekly SO_2 fumigation is used,

like in the United States, instead of SO_2 pads, it is necessary to take into account the absorption of fumigants by packaging materials. It was found, for example, that grapes packed in polystyrene foam boxes absorbed 50% less SO_2 than those packed in wooden boxes (Harvey et al., 1988). In the present trial, the cardboard boxes were in contact with the grapes and the SO_2 pad in the MP packaging, whereas the liner separated the grapes and the SO_2 pad from the cardboard box. Thus, more SO_2 could be absorbed by the cardboard box in the MP than in the liner-

packaging technique. The effect of the cardboard was less significant in the case of the Vinguard LM pad, because it operated by releasing very high amounts of SO_2 in the initial phase of storage.

'Zainy'. To evaluate the differences between the SO_2 generator pads from different manufacturers, three brands of DR pads, Fresca, Matesa, and Osku, were compared in the two packaging methods. The grapes were of the local white, seeded cultivar 'Zainy' packaged in plastic boxes containing 9 kg of grapes, and monitoring of SO_2 was conducted
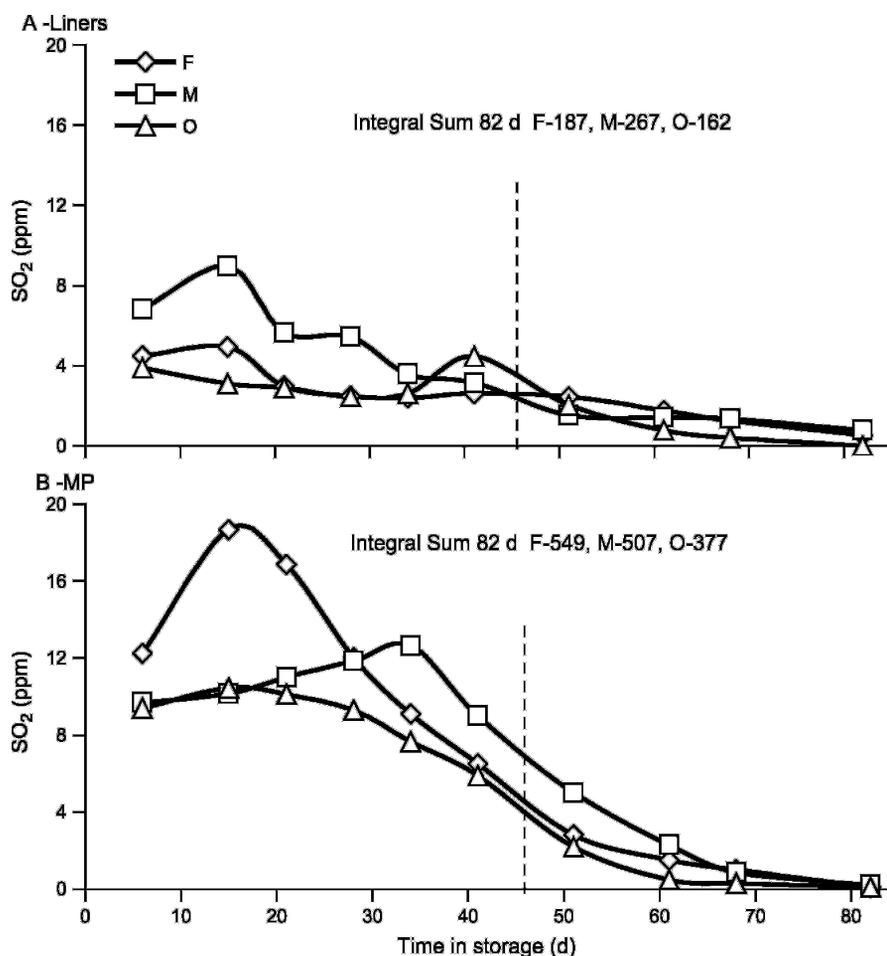

Fig. 4. Sulfur dioxide (SO_2) concentration around 'Zainy' grapes stored at 0 °C (32.0 °F) in plastic boxes with dual-release pads (DR) from three manufacturers: Fresca [F (Quimetal Industries, Santiago, Chile)], Matesa [M (Empack, Santiago, Chile)], and Osku [O (Osku, Santiago, Chile)]. Bunches were placed in liners inside each box (A-Liners) or replicates of three boxes were wrapped on the outside with linear low-density polyethylene in a "mini-pallet" format [MP (three stacked plastic boxes containing grapes)] with the bottom of the MP left open. The broken line indicates up to what time in storage there were significant differences in SO_2 levels measured in liners compared with "mini-pallets." "Integral sum" designates the accumulated amount of SO_2 measured inside each treatment from 6 to 82 d of storage. For example, the number F-187 corresponds to a total of 187 ppm calculated as the integral, which accumulated in the F treatment over the entire period of storage (1 ppm = 1 $\mu L \cdot L^{-1}$).

during 82 d of cold storage (Fig. 4). In the first month of storage, the SO_2 level that accumulated in the liners was usually below 8 ppm, whereas that in the MP was higher than 8 ppm (the measurements began after 8 d of storage). In boxes with liners, the Osku and Fresca pads generated levels between 3 and 5 ppm during the first 3 weeks of storage, after which the levels decreased gradually to 2 ppm after 7 weeks (Fig. 4A). With the Osku pads, levels reached 0 ppm at 82 d, when the other pads still maintained 0.8 ppm of SO_2. The Matesa pads gave higher levels of SO_2 in the liners: 6 ppm after a week of storage, rising to 9 ppm after 2 weeks and then declining. In the MP format, the Fresca pads generated the highest initial levels of SO_2 with a peak of 19 ppm after 2 weeks of storage (Fig. 4B). After 1 month of storage, the SO_2 levels with the Fresca pads declined to levels similar to those with the other two pads. The SO_2 levels measured in all the liners were compared with the values recorded in the MP wrapping method for each time point, and the differences were significant according to the Mann-Whitney two-tailed nonparametric test until 50 d in storage with probability values ranging between 0.0008 and 0.0047.

The quality of 'Zainy' grapes was determined after 33 d of cold storage and 3 d at 20 °C (Table 6). The results show that the quality of the rachis after storage was better in the MP packaging than in the liners. In only one case, the desiccation values were equal in the parallel treatments (rachis desiccation at shelf life with the Osku pad). Decay was low in both types of packages, but the average percentage of healthy bunches in the MP format was 94% compared with 78% in the liner format.

Integrating the areas under the SO_2 concentration curves of the three different DR pads in the two types of packaging (Fig. 4) shows that, overall, the DR pads in the MP maintained SO_2 levels between 549 and 377 ppm during the period of storage, whereas in the liners, the amount of SO_2 was between 267 and 162 ppm, not including SO_2 released between days 0 and 6. This indicates SO_2 levels of 5.8 and 2.6 ppm per day in storage for the MP and the liners, respectively. Although it has been thought that a level of 7 ppm SO_2 is necessary to prevent *B. cinerea* development in storage (Laszlo et al., 1981), the present findings indicate that lower levels may be effective. This conclusion does not account for the effect of the fast-release phase, which, as shown for the Vinguard LM pad, made a very significant impact in the control of decay. A trial of fumigation

at a lower SO_2 concentration of 600 ppm (200 ppm three times per week) rather than the commercial method of 2500 ppm once per week led to lower levels of decay development in inoculated berries after 10 weeks at 0 °C (Marois et al., 1986). In another study, individual berries were inoculated with *B. cinerea* and then exposed to a flow-through fumigation system to simulate SO_2 release from the slow-release part of a DR pad (Palou et al., 2002). Both 2 and 3 ppm SO_2 effectively controlled nesting (the spread of decay to healthy berries), although it did not kill the inoculated pathogen. For this, a high level of SO_2 was required at the beginning of storage (Smilanick et al., 1990). For example, a SO_2 dosage that killed 99% of spores was 30 min fumigation with 200 ppm of SO_2 (Smilanick and Henson, 1992). In another study, it was found that decay did not occur in inoculated berries if they were treated with 13 ppm SO_2 for 40 h or with 55 ppm for 15 h (Zutkhi et al., 2001). It is difficult to convert the values used for fumigation to what should be released from a SO_2-generating pad, because in the former case, the grapes are exposed to SO_2 for only a short time and then the SO_2 is removed. In the case of the SO_2-releasing pads, the grapes are exposed continuously to the SO_2, increasing the possibility of cumulative damage to the appearance and the taste of the berries.

The quality of the grapes in the present trials with plastic boxes was either similar with both packaging methods or better with the MP than the liner method. In general, the pedicels (and sometimes the rachis) showed more desiccation in the liners than in the MP (Tables 2, 4, and 6). The percentage of healthy bunches was also greater in the MP than in the liner storage. Desiccation is rated as drying and browning of the rachis and pedicels, which is greatly affected by the humidity around the grapes. Crisosto et al. (1994) found that water loss during postharvest operations can contribute to rachis browning. They found that rachis browning was observed on 'Thompson Seedless' grapes when water loss reached 3%. Packing the grapes in containers with an unperforated liner reduced this water loss and prevented rachis

Table 6. Comparison of quality of 'Zainy' grapes stored in boxes with liners or in boxes wrapped on the other side and with sulfur dioxide (SO_2) generator pads from three different companies.[z]

| Treatment[y] | Rachis desiccation (1–5 scale)[x] | | Pedicel desiccation (1–5 scale)[x] | | Healthy bunches (%) |
	Storage[w]	Shelf life[w]	Storage	Shelf life	
F-Liner	1.9 ± 0.1 ab[v]	2.7 ± 0.0	2.3 ± 0.4	3.6 ± 0.1 a	83.4 ± 10.5 b
M-Liner	2.0 ± 0.0 a	2.6 ± 0.0	2.5 ± 0.3	3.0 ± 0.1 b	83.4 ± 12.5 b
O-Liner	2.1 ± 0.1 a	2.7 ± 0.2	2.6 ± 0.1	3.4 ± 0.1 ab	66.7 ± 13.5 c
F-MP	1.7 ± 0.1 b	2.5 ± 0.1	1.8 ± 0.1	2.5 ± 0.2 b	88.9 ± 9.6 ab
M-MP	1.7 ± 0.1 b	2.5 ± 0.0	1.8 ± 0.2	2.6 ± 0.1 b	100.0 ± 0.0 a
O-MP	1.8 ± 0.1 b	2.7 ± 0.2	2.1 ± 0.4	3.3 ± 0.6 ab	94.4 ± 9.6 ab
		NS		NS	

[z]Storage was for 33 d at 0 °C (32.0 °F) and 3 d at 20 °C (68.0 °F). Quality measurements included rachis and pedicel desiccation and the percentage of bunches with one or no decayed berries at the end of storage and the 3 d of shelf life.
[y]Treatments were with boxes with a liner (liner), which is 30-μm-thick (30 μm) high-density polyethylene bag having 0.2% ventilation [holes 6-mm (0.24 inch) diameter spaced every 12 cm (4.7 inches)] placed inside each box or with a mini-pallet (MP; a unit of three stacked plastic boxes containing grapes wrapped around the top and sides with 30-μm film of linear low density polyethylene). In each type of box, there was a dual-release (DR) SO_2 generator pad from one of three manufacturers: Fresca [F (Quimetal Industries, Santiago, Chile)], Matesa [M (Empack, Santiago, Chile)], or Osku [O (Osku, Santiago, Chile)].
[x]1 = rachis and pedicels full and green as at harvest; 2 = slight browning; 3 = browning of rachis and pedicels but no shriveling; 4 = browning and some shriveling; 5 = both rachis and pedicels dry and brown. A rating greater than 3 was considered unmarketable.
[w]Storage was for 33 d at 0 °C and shelf life was 3 d at 20 °C.
[v]Values in columns followed by different letters indicate significant differences according to analysis of variance with the Student-Newman-Keuls test at $P < 0.05$.

browning during a 10-d shipping period. The same principle applies to the MP format compared with the liners, although the results cannot be directly compared, because in our present trials, a perforated liner was used and the storage was for a longer period.

Conclusion

Although the major method of grape packaging for long-distance shipment worldwide is that of perforated liners, the present study has shown that a packaging method that uses external wrapping of pallets with LLDPE can be as effective as the liner method in preventing grape decay and desiccation. Wrapping is the method of choice for exporting table grapes from Israel, but no extensive comparison of the two methods has been published previously. This method of external wrapping also has the advantage of faster precooling, because there is no barrier such as that presented by a liner. In addition, the use of less packaging material makes external wrapping more economical than the use of an individual liner for each box. The pallet-wrapping method is best when used with recyclable plastic boxes rather than cardboard ones, because there is no SO_2 absorption by the plastic and appreciable absorption by the cardboard. Reusable plastic boxes may also be environmentally better than the cardboard boxes.

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