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EVALUATION OF OZONE GAS PENETRATION THROUGH CITRUS COMMERCIAL PACKAGES AND CONTROL OF GREEN AND BLUE MOLDS SPORULATION DURING COLD STORAGE

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Introduction

In recent work we reported the ability of gaseous ozone continuously released at low doses (0.3 or 1 ppm, v/v) to inhibit the sporulation of several important postharvest pathogens of table grapes, stone fruit, and citrus fruit (Palou et al., 2001a, 2001b, 2002). Sporulation of *Penicillium digitatum* and *P. italicum* on cold-stored oranges or lemons was suppressed without injuring the fruit. In those trials, however, exposure of the fruit to the gas was unimpeded and we did not evaluate the effectiveness of ozone applied to commercially-packed citrus fruit.

The objectives of this work were to test the ability of ozone gas to penetrate into different commercial citrus fruit packages and to evaluate the effectiveness of the gas in controlling sporulation on commercially-packed citrus fruit.

Materials and methods

Fruit inoculation. Lane late navel oranges (*Citrus sinensis* (L.) Osbeck) from commercial orchards in the San Joaquin Valley (California) were used in the experiments before any commercial postharvest treatments were applied. *P. digitatum* and *P. italicum* were grown on PDA in petri dishes at 25ºC for 7 to 10 days. Spores were rubbed from the agar surface and a high-density spore suspension (approximately 10^6 spores ml^{-1}) was prepared. Oranges were inoculated 1-cm deep into the flesh in the equator of two opposite faces with a plastic syringe with a 20-mm needle. Approximately 0.25 ml of the spore suspension was applied at each inoculation point.

Fruit packaging. The following types of packages were prepared separately with fruit inoculated with each pathogen. See Table 1 for characteristics of each package.

1) Carton (naked): standard corrugated fiberboard citrus cartons with vents were filled with 60-70 oranges. Inoculated fruit were placed in the four corners and at the center of the carton at both the bottom and top levels of the carton. Ten inoculated oranges per carton were used. Cartons were stored with the lids on.

2) RPC (naked): returnable plastic boxes were filled with approximately 50 oranges. Inoculated fruit were placed in the four corners and at the center of the box at both the bottom and top levels of the box. Ten inoculated oranges per box were used.

3) RPC (bagged): 5 lb polyethylene bags with small vents were filled with oranges, 4 were inoculated and 10 were not inoculated. Eight bags were placed in each RPC.

4) Master carton (bagged): polyethylene bags were filled with inoculated and non-inoculated oranges as previously described and placed in master cartons. Ten bags were placed in each carton. Cartons were stored with the lids on.

Six packages of each type were prepared with fruit inoculated with *P. digitatum* and six with fruit inoculated with *P. italicum*. Master cartons were only prepared with fruit inoculated with *P. italicum*. For each pathogen, three of these six packages (replicates) were randomly stacked on one pallet and the other three on another pallet. Packed fruit was held at 55 ± 2ºF for 24 h before ozone exposure.

Table 1. Characteristics of the different packages used in the experiments.

Package	Dimensions (inches) (long x wide x tall)	Volume (in^3)	Lid	Box vented area (%)
Carton	17.3 x 11.9 x 11.7	2,408.7	Yes	2.6
RPC	23.5 x 15.5 x 10.1	3,678.9	No	35.9
Master carton	19.5 x 13 x 14.5	3,675.7	Yes	2.9
Plastic bag	21 x 10.5	–	–	0.7

Continuous exposure to gaseous ozone. A water-cooled corona discharge ozone generator (Model Genesis CD-25G, Del Industries, San Luis Obispo, CA) was installed in an adjacent non-ozonated room and set to produce 2.5 g h^{-1} ozone. The gas was continuously released to a 23,940 ft^3 cold storage room with a constant temperature of 55 ± 2ºF (12.8 ± 1ºC) through a 0.2-inch diameter Teflon tube anchored to the wall of the room. The room was aerated through 105 ceiling cones (with a 6 inch outlet) spaced 5 ft from each other. About 24 h after inoculation and packaging, the pallet containing one half of the packed fruit was stored in this room for 13 days. The pallet containing the other half of the packed fruit was stored at the same temperature and for the same time in an identical non-ozonated room (air atmosphere, control room).

The ozone concentration in the room and inside some of the packages on the pallet was continuously monitored by a 6-channel UV absorption ozone analyzer (Model 450 Nema, API Inc., San Diego, CA) with a minimum detection limit of 0.001 ppm. Air from the sampling points in the ozonated room was pumped through 0.15 inch internal diameter tubes to the analyzer, which was located in the adjacent room near the generator. The sampling points are specified in Table 2.

Sporulation assessment. Green and blue mold sporulation on Lane late navel oranges packed and stored in both ozonated and control rooms were recorded for each inoculated fruit after 13 days of storage at 55ºF. A sporulation index was used where numbers 0, 0.5, 1, 2, 3, 4, and 5, respectively, indicated soft lesion but no spores or mycelium present, mycelium but no spores present, < 5%, 6 to 30%, 31 to 60%, 61 to 90%, and > 91% of the fruit surface covered with spores.

Statistical analysis. Scores in the sporulation index were considered as a quantitative variable. Each value in the data set was transformed to the square root of the value plus 0.5. An analysis of variance was applied to the transformed data and means were separated by Fisher's Protected Least Significant Difference test (LSD, $P = 0.05$).

Results and discussion

Average levels of the ozone concentration for the entire storage period are given for each sample point (Table 2) and type of package (Table 3). Ozone penetration in each type of package, calculated as a percentage of the ozone concentration in the room ambient, is also presented (Table 3).

Table 2. Average ozone levels for the entire storage period at the different sampling points.

Analyzer channel	Sampling point	Position in the pallet	Ozone levels (ppm, v/v)
Channel 1	Inside a plastic bag in a RPC box	Middle	0.12
Channel 2	Inside a RPC box (naked fruit)	Middle	0.59
Channel 3	Inside a carton (naked fruit)	Middle	0.03
Channel 4	Inside a plastic bag in a Master carton	Middle	0.07
Channel 5	Inside a carton (naked fruit)	Top	0.11
Channel 6	In the room ambient	–	0.72

A comparison between ozone concentrations inside the different packages indicated that the gas penetrated more easily into RPC boxes than into cartons or Master cartons. Nevertheless, ozone concentration in RPC boxes was significantly higher in the spaces surrounding the naked fruit than inside plastic bags (Table 3).

Table 3. Average ozone levels and percentage of ozone penetration (based on the average level in the room) for the entire storage period inside the different types of packages.

Packaging system	Ozone levels (ppm, v/v)	Ozone penetration (%)
Carton (naked)	0.07	9.7
RPC (naked)	0.59	81.9
RPC (bagged)	0.12	16.7
Master (bagged)	0.07	9.7

Ozone penetration was related to the vented area of each package (Table 1), indicating that the gas was not able to go through corrugated fiberboard carton or polyethylene bags. Ozone penetration was acceptable only in RPC boxes with naked fruit (82%, Table 3). On the other hand, the position of the box on the pallet also influenced the ozone concentration; ozone levels inside a mid-placed carton were in general lower than inside a top-placed carton (channel 3 vs. channel 5, Table 2).

Sporulation of both *P. digitatum* and *P. italicum* was significantly inhibited by ozone exposure on oranges packed naked in RPC boxes, but it was not on oranges packed following the other packaging methods (Fig. 1). According to the percentages of ozone penetration inside the packages (Table 3), this result confirmed the need for good penetration and full contact to the decayed area on the fruit for ozone gas to be effective in controlling sporulation.

Conclusions

- Gaseous ozone continuously generated in a cold storage room at rates ranging 0.5 to 1 ppm (v/v) effectively penetrated and controlled sporulation of both *P. digitatum* and *P. italicum* on oranges packed naked in RPC boxes.

- The gas was not able to penetrate properly through corrugated fiberboard carton or polyethylene bags. Therefore, it was not able to control sporulation on oranges packed in standard cartons, Master cartons, or plastic bags. Effective control of sporulation relied on actual physical contact between the gas and the decayed area of the fruit.

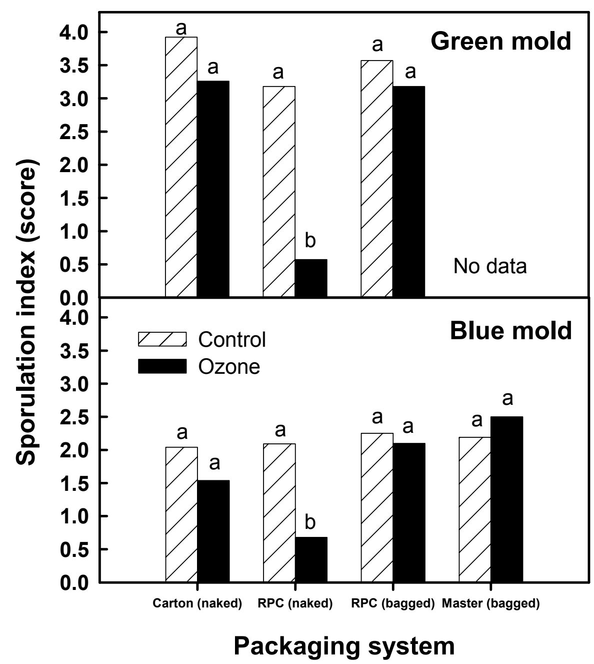

Fig. 1. Sporulation index on Lane late oranges artificially inoculated with *Penicillium digitatum* or *P. italicum*, packed following different packaging systems, and stored at 55ºF for 13 days in an air atmosphere (control) or in an ozonated atmosphere (0.5-1 ppm O_3 v/v). Within packaging systems, columns with the same letter are not significantly different according to Fisher's Protected LSD test ($P < 0.05$) applied after an analysis of variance to the square root transformed data. Non-transformed means are shown.

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TABLE GRAPE COOLING

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The time required to force-air cool grapes is determined by the temperature of the incoming product, the final temperature desired, the temperature of the cooling medium (air), airflow and the box design and inner packaging.

A typical relationship between initial product temperature, cooling medium temperature and cooling time is illustrated in Figure 1. Notice that the product cools rapidly at first and the rate of cooling slows as the product temperature approaches the cooling medium temperature. Since the rate of cooling becomes quite slow as product temperature nears the cooling medium temperature, most operators are satisfied with reducing the temperature 7/8ths of the difference between initial product and cooling medium temperature. This is called the 7/8ths cooling point.

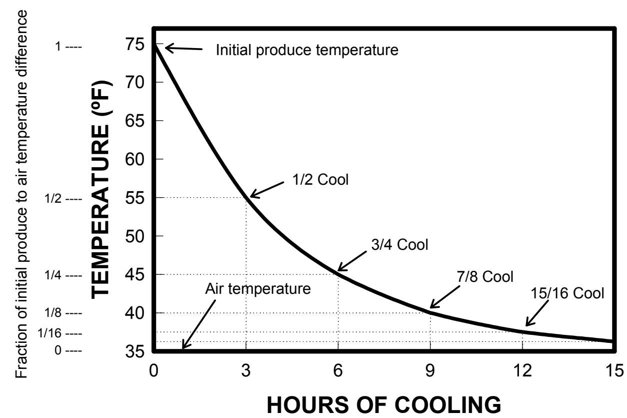

Fig. 1. Typical relationship between initial product temperature, cooling medium temperature and cooling time.

Incoming grape temperature. Initial grape temperature affects cooling rate and stem quality. However, it is not as important a factor as the temperature of the cooling air media. For example, using Figure 1 the total time needed to cool the grapes to 40ºF (7/8ths cooling) would be increased by 1/3 (3 hours) if the incoming product were of 105ºF rather than 75ºF (30ºF change). On the other hand, reducing the final fruit temperature from 40ºF to 35.5ºF (only a 4.5ºF difference), using a 35ºF air temperature, would also take 3 hours extra cooling time (12 hours total). Thus the difference between final product temperature and the cooling medium generally has a greater effect on cooling time than initial product temperature.

Air temperature. In the example given in Figure 1, when incoming fruit temperature was 75ºF and air temperature was 35ºF, 7/8ths cooling to a product temperature of 40ºF was reached in 9.0 hours. If 32ºF air temperature was used instead, 7/8ths cooling to a product temperature of 37.4ºF would be reached in 8.4 hours. Finally, if 30ºF air temperature was used, 7/8ths cooling to a product temperature 35.6ºF would be reached in 8.0 hours (Table 1).

The rate of cool airflow. Increasing airflow rates decreases cooling times (Table 2). As a rule of thumb, for forced air cooling the airflow rate must be doubled or tripled to reduce cooling times by one half. This rule will not necessarily apply to airflow rates above 2 cfm/lb of produce, but most forced air coolers operate below this level. The price paid for decreased cooling time is greater energy use by the fan (with forced air cooling) and a greater refrigeration capacity requirement.

Box design and inner packaging. The system for packaging the product can increase cooling times if it retards airflow through the box or prevents the air from having direct contact with the product (convection). For forced-air cooling, boxes should have a vent area equal to about 5% of the end area of the boxes. Venting areas less than this will retard airflow through the boxes, increase cooling times, and result in uneven cooling throughout the pallets. Venting greater than 5.0% excessively weakens standard fiberboard boxes.

The use of paper wraps, padding material, cluster bags (Fig. 2), and box liners increases cooling times, requires higher static pressures, and may cause uneven cooling throughout the pallets. Thus, their use should be considered carefully. If these inner packaging materials are used, they should be vented or arranged to allow the cooling medium good access to the produce. The relationship between box venting and inner packaging should be carefully studied. Attempts to improve the Chilean corrugated box have been started (Table 2D). In our preliminary evaluations, we found the 7/8ths cooling times ranged from 11 to 23 hours, and static pressures from 0.7" to 4.4" depending upon airflow. The greatest decrease in cooling time and static pressure was made by reducing inner packaging (paper wraps, etc.).

The use of box liners in California reduces grape water losses, but can increase cooling time and may reduce passive sulfur dioxide penetration to dangerous levels. We are currently trying to find the ideal perforated box liner with a vented area that is a compromise between water loss, cooling time and sulfur dioxide penetration for California grapes that will be exported. In this system, inner packaging is being minimized. In our previous tests, Chilean grapes packed using the California system and shipped to Long Beach, CA arrived in excellent condition (Crisosto *et al*., 1994).

A good illustration of the effect of box liner venting pattern on cooling time has been developed for kiwifruit (Wiley and Crisosto, 1999). For fruit packed using different perforated box liners, static pressure, 7/8ths cooling and water loss varied according to box liner vented area (Table 3). In general, fast cooling occurred when fruit were exposed to high rates of airflow. However, static pressure had to be increased to maintain the same airflow and have uniform cooling when using box liners with less venting.

Prediction of cooling time. In practice, it may not be feasible to accurately predict the cooling time of a lot of produce. During the day produce of varying temperatures will be arriving at the cooler. Varying rates of deliveries often dictate that air coolers be loaded with different quantities of product, which will affect the rate of airflow per box and consequently cooling times. In light of this, cooler operators need to control cooling times on the basis of actual product pulp temperature.

By experience, the manager should determine which box locations tend to cool the slowest and terminate cooling when fruit in these areas have reached the desired temperature. The location of the slowest cooling product is determined by measuring temperatures at many positions for several cooling runs. In general, the warmest product pulp temperature is located at the end of the path of the cooling media through the product. Boxes located on the inside of the corridor of a forced air system will be the slowest to cool. No produce should leave a cooling system until actual product temperature is measured and recorded in a log.

It is sometimes necessary to estimate the volume of airflow (CFM) through the product (flow rate). Unfortunately, this is not easily done in a commercial cooling situation. In a forced air cooler, the flow rate through a container is estimated by determining the total air volume produced by the cooling fan. The flow through an average box is equal to the total air volume produced by the fan divided by the total number of boxes minus 10% to 20% to account for air leakage.

The air volume produced by the fan is determined by measuring the total negative or positive pressure that is causing air to flow. Fan performance data provided by the manufacturer lists the relationship between static pressure, fan speed and fan airflow.

The airflow rate through the box can be used to estimate the cooling time with the aid of Tables 2A-D. The following equation can be used to calculate the time required to cool a box of product to a specific temperature:

$$T = 1.107\ V\ \mathrm{Log}\ \frac{S-M}{F-M}$$

where

T = time (minutes) to cool to temperature F
V = 7/8ths cooling time (minutes)
S – temperature (ºF) of the incoming product
F – temperature (ºF) of product when cool (final temperature)
M – temperature (ºF) of cooling air entering box

This equation can be used to estimate total cooling time to any temperature given the 7/8ths cooling time, air temperature and the incoming temperature of the product.

If 7/8ths cooling time (V) cannot be found in Table 1, the following formula can be used to calculate V:

$$V = \frac{0.903\,T}{\log \frac{S-M}{F-M}}$$

where T, S, F, M are measured under actual operating conditions.

In the initial planning of a new cooling facility, it is often desirable to estimate the size of refrigeration system needed for a cooler. As a rule of thumb, the size can be estimated from the following formula:

$$\frac{P \times (T_{initial} - T_{final})}{10{,}000} = \text{refrigeration tonnage}$$

where P = maximum lbs. of product cooled per hour (including weight of containers

$T_{initial}$ = maximum expected temperature of incoming product

T_{final} = temperature of product at the end of the cooling cycle

Actual selection of refrigeration equipment will require a more detailed analysis of other factors such as: peak cooling rates, heat input from walls, lights, and machinery and product respiration. See USDA Handbook 66 for an example of a more detailed calculation. Refrigeration loads for storage rooms (without cooling capability) require an analysis similar to the detailed computations for cooling and there is not a simple rule of thumb calculation.

Final Recommendations

- Keep in mind that cooling is started in the field.
- Pick, pack and haul the grapes to the cold storage as soon as possible.
- If harvested fruit is temporarily stored in the orchard, it should be covered or placed in the shade.

- Rapid cooling should be done as soon as possible after harvest.
- Keep air temperature constant during forced air cooling.
- Keep a data log and control your cooling operation.
- When packaging, align liners and vents.
- Do not over or under fill packages.
- For shed packing operations, if fruit is harvested faster than the packinghouse capacity, fruit should be forced air cooled and held in storage before packing.
- Packing low temperature grapes can cause condensation on the berries. This concentrates dust into spots that look bad. Therefore, do not cool below the dew point or air-condition packing sheds.
- Fruit will rewarm in the packinghouse and will need to be cooled again.
- Use of forced air initial fumigation in combination with cooling is advised.
- Remove the fruit from the precooler as soon as the fruit reaches the desired temperature in the warmest position or just turn the fan off.
- Fruit should be stored at 30 to 32.0ºF pulp temperature throughout its postharvest life.
    - Highest berry freezing point is 28.1ºF.
    - Highest stem freezing point is 28.4ºF.
- Inspect your grapes frequently during storage.
- Determine and record product temperatures during loading.
- Check loading patterns for transportation.
- Keep transit times to an absolute minimum by avoiding unnecessary delays en route.
- If you need to repack grapes in storage, the newly repackaged grapes should be promptly forced-air cooled and fumigated. Forced-air cooling will not only cool the grapes, but it will accelerate the drying of condensation that will exacerbate decay. When decayed berries are removed, workers' hands will spread gray mold to other berries quickly unless fumigation follows promptly.
- Consider redesigning your inner packaging and boxes.

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Table 1. Example of the effect of air temperature on cooling rates of table grapes with an initial temperature of 75ºF at different air temperatures

	7/8ths cooling[z]	
Air temp. (ºF)	Product temp. (ºF)	Time (hours)
35	40.0	9.0
32	37.4	8.4
30	35.6	8.0

[z] Based on Figure 1.

Table 2A. Hours to 7/8ths cool table grapes measured at the slowest cooling position within the pallet for different box types placed three deep and in register. Numbers within parentheses are static pressures measured as inches of water column.

		Hours to 7/8ths cool downstream grapes						
Container type		1½	2	3	4	6	9	12
TKV with no bottom cleat, paper wrap	CFM/lb[z]			2.8[x]	1.6	0.71	0.37	0.25
	Pressure[y]			(>4)[w]	(2-3)	(0.4-0.7)	(0.2)	(0.1)
TKV with ¾" bottom cleat, paper wrap	CFM/lb				2.5	1.3	0.75	0.50
	Pressure				(0.75)	(0.25)	(0.10)	(0.05)
Full telescope 17-1/2" x 11" x 9", 3.7% side area vented	CFM/lb	1.4	1.0	0.62	0.43	0.27	0.17	
	Pressure	(>5)	(2.9)	(1.2)	(0.64)	(0.27)	(0.12)	
Full telescope 17-1/4" x 15" x 6", 5.3% side area vented	CFM/lb	1.4	1.0	0.62	0.43	0.27	0.17	
	Pressure	(3.0)	(1.7)	(0.68)	(0.36)	(0.16)	(0.07)	
Part telescope, CCA tough traveler, 2.7% side area vented	CFM/lb		2.2	1.3	0.9	0.6	0.37	
	Pressure		(>5)	(2.5)	(1.5)	(0.6)	(0.25)	
Part telescope, bliss style, 3.5% side area vented	CFM/lb	1.55	1.15	0.72	0.53	0.34	0.22	
	Pressure	(>4)	(2.6)	(1.1)	(0.55)	(0.23)	(0.09)	
Kool mover, Intl. Paper, 4.1% side area vented	CFM/lb	2.2	1.4	0.80	0.60	0.32	0.22	
	Pressure	(3.5)	(1.6)	(0.6)	(0.32)	(0.11)	(0.05)	

[z] CFM/lb = Cubic feet per minute per pound of fruit.
[y] Static pressure (inches water column) shown is for air path through three tiers of containers stacked in register. For other stacking, multiply static pressure by: 1-tier = 0.05, 2-tiers = 0.3, 4-tiers = 2.3, 6-tiers = 7.0.
[x] Numbers without parentheses are hours needed to reach 7/8ths cooling of the product.
[w] Numbers within parentheses are static pressures measured as inches of water column.

Table 2B. Hours to 7/8ths cool table grapes measured at the slowest cooling position within the pallet for different box types, with and without box liners, and oriented end-to-end or side-to-side with respect to the direction of airflow. Numbers within parentheses are static pressures measured as inches of water column.

Box Liner & Orientation/ Box Type	Airflow (CFM/lb[z]) 0.25	0.50	0.75	1.0	1.5
Without box liners. Boxes oriented side-to-side.					
CHEP Box	8.5[y]	5.4	4.3	3.5	3.8
(23.6" x 15.8" x 5")	(0.13)[x]	(0.49)	(0.83)	(0.95)	(1.36)
Corrugated Box	13.9	4.9	3.3	3.3	2.6
(20" x 16" x 5", 2.9% V.A.)	(0.12)	(0.48)	(0.53)	(0.78)	(1.03)
Foam-1a Box	10.9	4.9	3.4	2.4	2.8
(20" x 16" x 6.5", 3.9% V.A.)	(0.13)	(0.48)	(0.83)	(0.95)	(2.09)
Foam-1b Box		9.6		7.5	7.0
(20" x 12" x 8", 3.9% V.A.)		(0.37)		(1.15)	(1.55)
Foam-2 Box	12.0	7.5		5.0	1.5
(20" x 16" x 6.5", 2.9% V.A.)	(0.09)	(0.30)		(1.07)	(1.50)
IFCO Box	10.2	8.2	6.7	5.6	4.8
(23.6" x 15.8" x 6")	(0.22)	(0.47)	(0.83)	(1.08)	(1.55)
TVK Box	7.7	5.3	4.4	3.7	3.9
(16" x 20" x 5.5")	(0.10)	(0.35)	(0.39)	(0.74)	(1.06)
Without box liners. Boxes oriented end-to-end.					
Foam-1b Box	18.7	15.0		9.3	7.5
(20" x 12" x 8", 3.9% V.A.)	(0.15)	(0.61)		(0.70)	(2.50)
With box liners. Boxes oriented side-to-side.					
CHEP Box	17.0	13.6	14.3	13.8	
(23.6" x 15.8" x 5")	(0.20)	(0.55)	(1.50)	(3.25)	
IFCO Box	14.0	10.5	12.1		
(23.6" x 15.8" x 6")	(0.43)	(1.20)	(3.30)		
With box liners. Boxes oriented end-to-end.					
CHEP Box		8.5		5.0	4.8
(23.6" x 15.8" x 5")		(0.14)		(0.48)	(1.15)
IFCO Box		10.0		7.5	5.5
(23.6" x 15.8" x 6")		(0.13)		(0.37)	(0.94)

[z] CFM/lb = Cubic feet per minute per pound of fruit.
[y] Numbers without parentheses are hours needed to reach 7/8ths cooling of the product.
[x] Numbers within parentheses are static pressures measured as inches of water column.

Table 2C. Hours to 7/8ths cool table grapes measured at the slowest cooling position within the pallet for different types of foam boxes placed three deep and in register. Numbers within parentheses are static pressures measured as inches of water column.

Box type/ Dimensions/ Vented area		Air flow (CFM/lb)[z] 1.5	1.0	0.5	0.25
Fish box	7/8ths cooling (hrs.)	2.8[x]	4.0	6.0	10.0
20” x 11.5” x 7.5”	Static pressure (in w.c.)[y]	(1.8)[w]	(0.7)	(0.22)	(0.07)
3.0% side V.A.					
Shoe box	7/8ths cooling (hrs.)	2.2	2.4	3.0	8.3
20” x 11.5” x 8.75”	Static pressure (in w.c.)	(2.2)	(1.0)	(0.54)	(0.05)
2.9% side V.A.					
Metric box	7/8ths cooling (hrs.)	2.4	3.5	5.2	8.0
20” x 16” x 6.5”	Static pressure (in w.c.)	(1.5)	(1.0)	(0.3)	(0.09)
3.9% side V.A.					

[z] CFM/lb = Cubic feet per minute per pound of fruit.
[y] Static pressure (inches water column) shown is for air path through three tiers of containers stacked in register. For other stacking, multiply static pressure by: 1-tier = 0.05, 2-tiers = 0.3, 4-tiers = 2.3, 6-tiers = 7.0.
[x] Numbers without parentheses are hours needed to reach 7/8ths cooling of the product.
[w] Numbers within parentheses are static pressures measured as inches of water column.

Table 2D. Air flow rates and static pressures required to forced-air cool table grapes in Chilean corrugated boxes.

Box dimensions/ Vented area/ Internal packaging	7/8ths cooling (hours)	Static pressure (in. w.c.)	Air flow (CFM/lb)[z]
19.75” x 11.75” x 6.5”	23.4	0.7	0.5
2.6% V.A.	15.3	2.8	1.0
Clusters paper wrapped	11.0	4.2	1.5
19.75” x 11.75”/11.5” x 6.5”	18.5	0.6	0.5
<1% V.A.	15.0	2.6	1.0
Clusters paper wrapped	11.0	4.4	1.5
19.75” x 11.75”/11.5” x 6.5”	19.7	0.7	0.5
2.8% V.A.	19.6	2.4	1.0
Clusters paper wrapped	11.6	4.4	1.5
19.75” x 11.75”/11.5” x 6.5”	9.6	1.3	1.5
2.8% V.A.			
Naked pack (no paper wraps)			

[z] CFM/lb = Cubic feet per minute per pound of fruit.

Table 3. Effect of box liner vented area on the static pressure and rate of kiwifruit cooling at two different rates of airflow.

Airflow/ Box liner	Static Pressure (in. w.c.)	Hours to 7/8ths cool
0.3 CFM/lb		
0% V.A. (solid)	1.0	23
0.3% V.A.	0.4	22
0.6% V.A.	0.4	12
1.2% V.A.	0.5	9
Naked	0.2	7
0.7 CFM/lb		
0% V.A. (solid)	4.0	21
0.3% V.A.	0.7	14
0.6% V.A.	0.5	9
1.2% V.A.	0.5	6
Naked	0.7	4

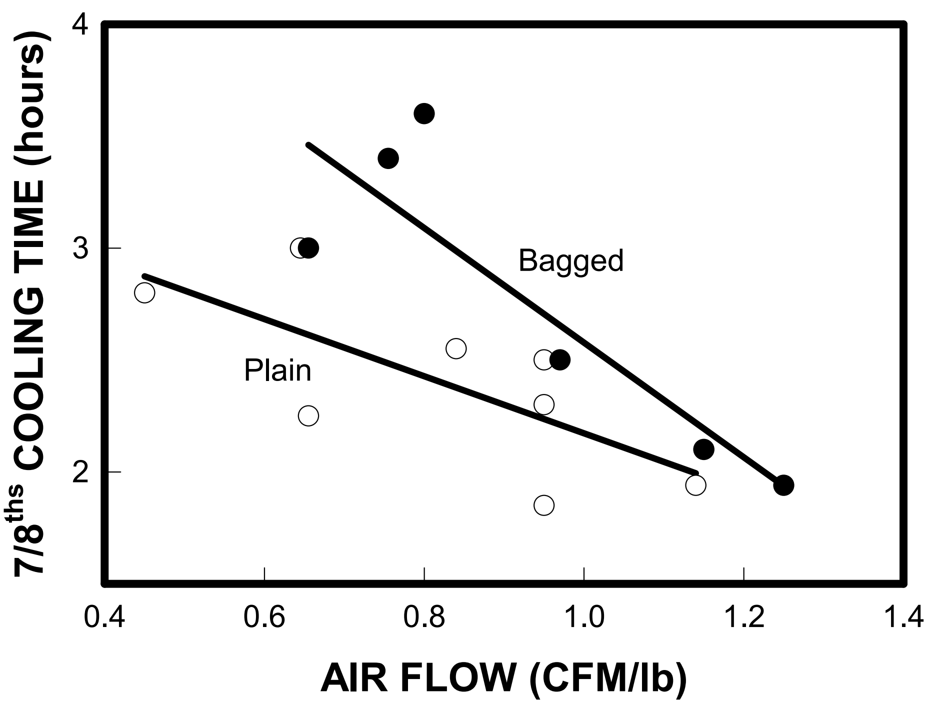

Fig. 2. Relationship between air flow rate and fruit bagging on forced air cooling times based on a laboratory simulation of pallet loads of grapes in various types of boxes.

Fig. 3. Commercial (left) and experimental (right) Chilean corrugated boxes used in cooling tests.

FUTURE EVENTS

Winter Tree Fruit Meeting – December 4, 2002, Dinuba Memorial Hall, Dinuba, CA, 8:00 a.m. until 12:00 noon. *For further information,* please contact Kevin Day, UCCE Tulare County, (559) 685-3309, Ext. 211, krday@ucdavis.edu.

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