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CG&TFL Research Report

Development of Design Criteria for a 5-down Box

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INTRODUCTION

The California table grape industry is being requested to pack a significant volume of fruit in a new box with a 16” x 24” (5-down) or a 16” x 12” (10-down) footprint. Grower/shippers are using returnable plastic boxes (RPC), expanded polystyrene foam boxes (EPS), and corrugated fiberboard boxes to satisfy this demand. This new design is typically a shallow box. Limited commercial experience with the 5-down box indicates that it may work well for bagged grapes. Vent design for forced-air cooling is complicated by the fact that palletized boxes are cross-stacked with this footprint and some designs do not have vent patterns that align when boxes are cross stacked. Moisture loss may vary between different designs because of vent area differences and the fact that plastic does not absorb water, while corrugated does. Finally box design, especially one with a large base, may influence vibration characteristics of the package and result in differing levels of damage protection from highway transport vibration damage.

PROJECT GOALS

This project compared the warm up of grapes in the field after packing, forced air cooling time, weight loss in initial cooling and storage, and vibration damage of several commercial implementations of the new 5-down and 10-down sized boxes for table grapes.

PROCEDURE

Description of boxes

Grapes were packed in industry standard corrugated fiberboard boxes with outside base dimensions of approximately 16 x 20 inches or in standard expanded polystyrene foam boxes (EPS) nominal outside dimensions of 16 x 20 inches or 13 x 20 inches. They are stacked either 6 or 7 boxes per layer up to 13 boxes high on 48 x 40 in pallets. The experimental 5-down boxes, with nominal outside dimensions of 16 x 24 inches, are designed to be packed with 19 pounds of grapes and are placed 5 boxes per layer on a 48 x 40 inch pallet. The 10-down boxes, with nominal outside dimensions of 12 x 16 inches, are designed for 11 pounds of bagged grapes and are placed 10 boxes per layer on a pallet. The fruit packed in CHEP or IFCO RPCs had an excelsior pad in the bottom of the box with an attached piece of paper that wrapped around the inside of the box so that the top of the fruit was covered. The sides of the paper were ventilated for air circulation. The RPC boxes had large amounts of ventilation area on the side and end panels. Corrugated fiberboard boxes did not have pads and had much lower levels of venting. The vents did not always align between cross-stacked boxes. The EPS boxes also were packed without a pad. Additional details of the boxes are given in Table 1.

Table 1. Description of boxes used in tests.

Box Type	Outside Dimensions (in)	Tare Weight (lb)	Inside Volume (in^3)	Package Density (in^3/lb)	Side vent area (%)	End vent area (%)
Control:						
Fiberboard	19 3/4 x 16 x 5	1.9	1,382	73	6.1	4.2
EPS	19 7/8 X 15 7/8 X 6 5/8	1.1	1,386	73	1.4	2.5
5-down:						
Fiberboard	23 3/4 X 15 1/2 X 4 3/4	1.8	1,493	79	6.7	8.5
EPS	23 7/8 X 15 7/8 X 5 7/8	1.1	1,463	77	3.6	3.6
CHEP RPC	23 1/2 X 15 3/4 X 5	3.7	1,501	79	18.2	8.1
IFCO RPC	23 5/8 X 15 3/4 X 6	2.6	1,571	83	19.9	28
10-down:						
Fiberboard	15 1/2 x 11 3/4 x 5 1/2	1	782	70	2.1	5.3
EPS	15 1/4 x 11 7/8 x 7	0.6	755	69	2.4	1.3
IFCO RPC	15 1/2 x 11 1/2 x 6	1.7	797	72	2.1	1.9

Fruit warm up in the field

Superior Seedless grapes and Thompson Seedless grapes were packed in two separate tests in four different box styles. Two RPC box designs with a 5-down footprint were each packed with 19 pounds bagged of fruit. Six-down, standard corrugated fiberboard boxes and 6-down EPS boxes were also packed with 19 pounds of grapes. One side of the bags was vented and the other side was slitted. The tops of the bags were folded over and tucked when packed, but not closed. Each box of fruit was weighed after packing. Tare weights of the empty boxes were also recorded. The four boxes were column stacked at the edge of the field. Thermocouples were placed in a grape in the center of the top and bottom boxes, and in a grape in the side of the second box from the top.

A four box column of each box style was placed in the sun, and grape temperature was measured every half hour from about 11 a.m. to 2 p.m. Most grape packing is finished by then. The air temperature rose from about 90^0 F at 11 a.m. to about 108^0 F at 2 p.m. in the first test in Indio, CA, and from 77^o F to 94^o F in the second test at Delano, CA. At the end of the test, each box of fruit was again weighed, and the tare weights of the fiberboard boxes were recorded. The RPC boxes and the EPS boxes do not gain or loose moisture, so it was not necessary to re-weigh them.

Forced-air cooling tests

Two cooling tests were conducted: 1: August 30, 2001 with Thompson Seedless grapes, and 2: September 26, 2001 with Calmeria grapes. The 5-down RPC, EPS, and corrugated fiberboard boxes were packed with 19 pounds of bagged grapes. The 10-down boxes were packed with about 11 pounds of bagged fruit. Enough boxes of each type were packed so that there were five layers of each on a pallet. Temperature data was collected in the three middle layers of boxes. The top and bottom layers of boxes for each type were used as buffer layers. Commercially available six-down fiberboard and EPS boxes packed with 19 pounds of bagged grapes were used as control treatments.

Five “T” type thermocouples were placed in each layer of test fruit. Thermocouple junctions were about 3/8 “ long and the tip of the junction was placed close to the center of a grape. The five thermocouples were connected in parallel to a single lead so that an average temperature was recorded for each layer of boxes. The fruit was allowed to warm slightly after packing, and then all of the test pallets were placed on a single forced-air tunnel. All fruit was cooled to at least 7/8ths of the difference between the beginning fruit temperature and the cooling air temperature. Air pressure in the tunnel was measured during cooling.

Weight loss in initial cooling and storage

The fruit in four replicate boxes for each type of box was weighed before the cooling tests. After cooling, the fruit was placed in a commercial cold storage and weight loss for the fruit in each package type was measured after 14 days.

Vibration test

After the first cooling test, additional boxes of fruit were taken to the Del Monte Research vibration laboratory in Walnut Creek, CA. The Thompson Seedless grapes were placed in cold storage overnight before testing. Four boxes of each type were placed on the vibration table in a single layer and vibrated for 1/2 hour at an average acceleration of 0.73 g-rms using a pattern of frequencies and acceleration to simulate long- distance transport. This test is based on ASTM Standard Practice D4169-94 with an assurance level I. All fruit was then evaluated for the weight of shattered berries in each box.

(In these tests with grapes we did not measure vibration characteristics of the boxes, but we did do this with these same boxes packed with peaches. A ten-box high column of each box type, was tested on August 28th to determine vibration transmissibility and resonance of the box designs. They were placed on the table and vibrated at 0.083 g-rms. The frequency was swept from 2 to 100 Hertz and an acceleration sensor on the top box. This test identifies frequencies, in the range commonly found in transport vehicles, where vibration is amplified as it is transmitted through a stack of boxes. Excessive amplification can lead to fruit damage on top layers of boxes in pallet loads.)

RESULTS

Field heating tests

The two tests indicated that the EPS box had the lowest temperature rise and lowest moisture loss of the four box types, Tables 2 and 3. Temperature rise is directly correlated with heat gain of the fruit (1 Btu is absorbed per lb of fruit heated by 1 °F) and fruit moisture loss represents fruit heat gain that was dissipated in evaporated moisture (1000 Btu are required to evaporate 1 lb of water). Summing the heat gain associated with temperature rise and moisture loss equals the total heat gain of the fruit. By this measure, the EPS box reduced heat gain of the fruit by about half compared with corrugated fiberboard and RPCs.

Table 2. Temperature rise, weight loss and heat gain of bagged Superior Seedless grapes packed in various boxes and stacked in the direct sun, Coachella June 6, 2001.

Box type and dimensions	Grape temperature increase (°F)	Weight loss (%)	Initial fruit weight per box (lb)	Total fruit heat gain per lb (Btu/lb)
EPS, 12x20	4.0	0.8	18.2	12.0
Corrugated fiberboard, 16x20	4.2	1.6	19.1	20.2
CHEP, 16x24, lid on top box	6.5	1.3	17.8	19.5
IFCO, 16x24, lid on top box	10.4	1.2	18.4	22.4

Air temperature was 91°F to 108.5°F from 11AM to 2 PM, corrugated fiberboard boxes gained 7.3% from moisture.

Table 3. Temperature rise, weight loss, and heat gain of bagged Thompson Seedless grapes packed in 5-down boxes stacked in the direct sun, Delano September 26, 2001.

Box type	Temperature increase (°F)	Weight loss (%)	Initial fruit weight per box (lb)	Total fruit heat gain per lb (Btu/lb)
EPS	6.7	0.5	19.6	11.7
Corrugated fiberboard	12.5	0.6	18.3	18.5
RPC – CHEP, paper liner	17.9	0.8	20.8	27.2
RPC – IFCO, paper liner	19.2	0.8	19.3	25.9

Air temperature was 77° F to 94° F from 11AM to 2 PM.

The total heat gain numbers are valuable because they correlate with the total grape moisture loss, from harvest through the completion of cooling. Other studies we have done show that moisture loss in forced-air cooling is directly related to the incoming temperature of the fruit. The warmer the fruit is at the beginning of cooling, the more moisture it will lose in the cooling process. The total heat gain data account for the moisture loss in the field and the moisture that will be lost in subsequent forced-air cooling.

The EPS boxes reduce heat gain because they completely cover the grapes, unlike the open-topped RPCs. They also protect the fruit from air movement and from heat conduction caused by the warm ambient conditions because they have a percent low vent area and are insulated. EPS boxes do not absorb moisture from the fruit, as do the corrugated fiberboard boxes.

In Delano, for our convenience, the boxes were moved on the back of a flatbed truck from the field to a sunny area next to the cold storage, a distance of about 3 miles. During that move, the temperature of the grapes decreased in all boxes, the result of moisture evaporation from the grapes as air moved across the fruit. The temperature decreased an average of 2.9° F in the fiberboard boxes, 3.2° F in both RPCs, and 4.2° F in the EPS boxes.

Truck capacity

Estimates of truck capacity assumed five-down boxes were packed with the same 19 pounds of grapes that are packed in the standard box. Ten-down boxes were packed with 11 pounds of fruit. Five-down and 10-down EPS boxes fill a truck before reaching a maximum of 44,000 pounds, the load limit that we assumed, Table 4. These boxes caused a nearly a 10 percent reduction in the payload compared with using the standard 6-down EPS boxes. Also, the EPS boxes require the greatest number of pallets to carry the same weight. (This is actually an advantage in the common 53' long refrigerated trailer because it is easier to correctly distribute load weight with the floor area of the truck completely covered.)

The CHEP RPCs weigh significantly more than the standard fiberboard and EPS boxes and their weight reduced the amount of fruit that the truck could carry. The IFCO RPC had the same net fruit weight as the EPS box and the CHEP RPC caused a 4% reduction in fruit weight compared with the EPS standard box and a 10% reduction compared with corrugated fiberboard. The corrugated fiberboard box was the only 10-down box that maximized the net payload. The EPS and IFCO RPC boxes had a reduced payload by approximately 9 and 7 percent, respectively.

The 5-down and 10-down corrugated fiberboard boxes allowed the most net fruit per truck compared with the other 5 and 10-down boxes. These boxes also allowed more fruit weight than the standard 6-down box, although not more than the standard EPS box.

Table 4. Truck capacity for standard, 5-down, 10-down boxes. Pallet height was assumed to be 80 – 83 in and load weight limited to approximately 44,000 lb in a 53ft trailer.

Type of box	Tare weight per box (lb)	Number of layers per pallet (number)	Number of boxes per pallet (number)	Number of boxes per truck (number)	Number of pallets per truck (number)	Fruit weight per truck (lb)	Total weight per truck (lb)
6-DOWN							
Fiberboard	2	15	90	2,070	23	39,330	43,470
EPS	1.1	12	72	2,160	30	41,040	43,416
5-DOWN							
Fiberboard	1.8	16	80	2,080	26	39,520	43,264
EPS	1.1	13	65	1,950	30	37,050	39,195
CHEP	3.7	15	75	1,875	25	35,625	42,563
IFCO	2.6	13	65	1,950	30	37,050	42,120
10-DOWN							
Fiberboard	1	14	140	3,640	26	40,040	43,680
EPS	0.6	11	110	3,300	30	36,300	38,280
IFCO	1.7	13	130	3,380	26	37,180	42,926

Forced Air Cooling

The first forced-air cooling test showed no statistically significant differences between the box types in the same box size, except the 10-down RPC cooled faster than the 10-down corrugated fiberboard and EPS boxes, Table 5. The 10-down boxes made of corrugated fiberboard or EPS required more cooling time than the 5-down box of the same material. The RPC and EPS 5-down boxes cooled faster than the standard corrugated fiberboard box.

The second cooling test showed no statistical differences in cooling times between the boxes except that 10 down EPS box had a significantly longer cooling time than the other boxes. Two of the 10-down box treatments had a great deal of variability in cooling time and allowed the statistical test to detect significant differences only if cooling times differed by more than 1 hr. If the 10-down treatments were removed from the analysis, differences of more than about 0.5 hr were significant, but none of the cooling times of the 5 and 6-down boxes differed by more than this time period.

Overall, the cooling tests do not show consistent differences between the various 5-down boxes and the 6-down control boxes. It may be that cooling times are more influenced by factors associated with the bags than with the boxes. For example, boxes had vent areas that ranged up to almost 20%, while the bags had only 1.6% vent area on the side with the punched holes. This is a low vent area, especially considering that the holes can be easily blocked. Bag placement may have caused the longer cooling times of the 10-down boxes. The bags in 10-down boxes were placed almost vertically, causing the vent holes in one bag to be placed against the slit vents of the neighboring bag. This may have effectively blocked a large portion of the vent area of the bags. In the 5 and 6-down boxes, the bags of fruit were laid flat with the hole punched side of the bag facing up, allowing good exposure to the cooling air.

Table 5. Seven-eighths cooling time (in hours) for bag-packed Thompson seedless table grapes. Static pressure across pallets was 0.68 to 0.62 in. of water column.

	Corrugated	Expanded Polystyrene foam	Returnable Plastic (CHEP)	Returnable Plastic (IFCO)
5-down	1.8[a,b]	1.7[a]	1.7[a]	1.3[a]/1.6*[a]
10-down	2.6[c]	2.3[b,c]	--	1.3[a]
Standard (6-down)	2.3[b,c]	1.9[a,b]	--	--

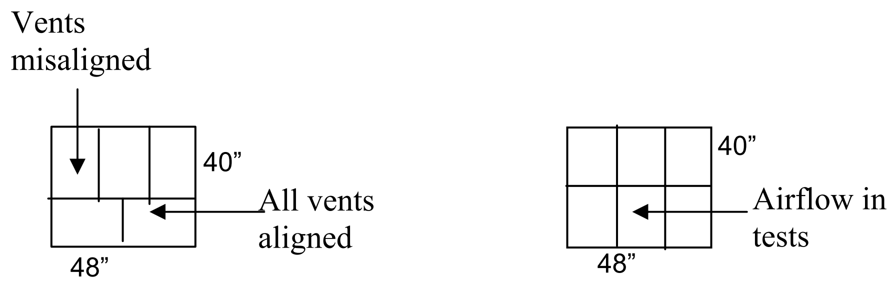
* first data point for IFCO 5-down box is for standard slitted grape bags and the second is for vented ziploc bags oriented so the open top of the bag faces upward.
a,b,c data with the same letter are not significantly different, Duncan's new multiple range test, alpha=0.05.

Table 6. Seven eighths cooling time (in hours) for bag-packed Calmeria table grapes. Static pressure across pallets was 0.40 in of water column.

	Corrugated	Expanded Polystyrene foam	Returnable Plastic
5-down	2.1[a]	2.6[a]	2.0[a] (CHEP)
10-down	2.8[a]	3.7[b]	2.8[a] (IFCO)
Standard (6-down)	2.2[a]	2.6[a]	--

a data with the same letter are not significantly different, Duncan's new multiple range test, alpha=0.05.

In both cooling tests, pallets were arranged on the cooler so that the cooling air flowed parallel to the 48" dimension. This orientation causes all box vents to be aligned in the direction of airflow. The vents in the corrugated 5-down do not align if air flows parallel to the 40” dimension, Figure 1. This orientation could be expected to cause longer cooling times compared with orienting the boxes so air flows parallel to the 48”. Some shallow depth RPCs also have very limited end panel venting and may experience cooling time increase if oriented so that air must flow through cross-stacked boxes.



5-Down pattern   6-Down pattern

Figure 1. Airflow patterns and pallet orientation for cooling tests.

<u>Weight loss in forced-air cooling and two week storage</u>

There were no completely consistent trends in the amount of weight loss between the various treatments in the two tests. In most comparisons, grapes packed in fiberboard boxes lost the most weight and grapes in the EPS boxes lost the least, Tables 7 and 8. Grapes in the RPCs lost intermediate amounts of moisture in forced-air cooling and two week storage.

One test compared grapes packed in slitted bags packed with the tops folded closed with open topped zip bags, Table 7 - two data points for 5-down IFCO RPC. There was no detectable difference in weight loss with the two bags.

Table 7. Percent weight loss in forced-air cooling and two-week storage of bag-packed Thompson seedless table grapes.

	Corrugated	Expanded Polystyrene foam	Returnable Plastic (CHEP)	Returnable Plastic (IFCO)*
5-down	1.2[h,l]	0.6[b,c]	0.80[c,d,e,f]	0.7[c,e]/0.7[c,d]
10-down	1.0[f,g,h]	1.0[f,g]	--	0.4[a]
Standard (6-down)	1.1[g,h,i]	0.4[a,b]	--	--

* first data point for IFCO 5-down box is for standard slitted grape bags and the second is for vented ziploc bags oriented so the open top of the bag faces upward.
[a,b,c] data with the same letter are not significantly different, Duncan's new multiple range test, alpha=0.05.

Table 8. Percent weight loss in forced-air cooling and two-week storage of bag-packed Calmeria table grapes.

	Corrugated	Expanded Polystyrene foam	Returnable Plastic
5-down	0.6[c,d,e]	0.2[a]	0.5[b,c] (CHEP)
10-down	0.5[c,d]	0.3[a,b]	0.5[c,d,e] (IFCO)
Standard (6-down)	0.7[e,f]	0.3[a,b]	--

[a,b,c] data with the same letter are not significantly different, Duncan's new multiple range test, alpha=0.05.

Seedless table grapes begin to show shriveled stems, the first sign of moisture loss, at about 2% moisture loss. Above 3% moisture loss the berries are soft. Adding the moisture loss of Thompson Seedless grapes in the field before cooling, Table 3, to the loss in cooling and two-week storage, Table 7, estimates the total moisture loss the fruit between harvest and shipment to market. Grapes in corrugated fiberboard lose 1.8% and in RPCs they lose 1.6% compared with only 1.1% in the EPS boxes. The half percent reduction in weight loss is important because the fruit will be subject to additional moisture loss in transport and in wholesale and retail marketing. The reduced moisture loss caused by EPS boxes may be the difference in the consumer not being able to see shriveled stems and soft berries at retail display.

Vibration Tests

The tests of columns of boxes filled with peaches showed that the RPC (CHEP) boxes with bottom pads and corrugated boxes had similar resonant frequencies and transmissibility (ratio of top box acceleration to table acceleration), Table 9. This implies that boxes of this size and made from either material will produce similar levels of acceleration of fruit in the topmost boxes. These boxes are the most subject to damaging levels of vibration in highway transport. However fruit damage may be different in the boxes due to differing interior surfaces.

Table 9. Vibration characteristics of corrugated and RPC fruit boxes filled with peaches.

Box	Resonant frequency	Transmissibility at resonance
5-down corrugated (FBA)	9.0	10.5
5-down RPC (CHEP)	10.5	10.0
10-down corrugated (FBA)	11.0	10.0
10-down RPC (CHEP)	11.0	10.0
8-down Bliss - control	10.5	12.0

The vibration tests, designed to simulate bruising to fruit in top boxes on pallets over steel spring suspended axles in a refrigerated trailer, showed that grapes packed only in 5-down corrugated boxes had higher levels of shatter, Table 10. The amount of shattered berries was not significantly different for grapes packed in regular vented bags as it was in ziploc bags, Table 11.

Table 10. Thompson seedless grape shatter as percent weight loss after vibration.

	Corrugated fiberboard	Expanded Polystyrene foam	Returnable Plastic (CHEP)	Returnable Plastic (IFCO)
5-down	11.2[b]	5.2[a]	3.8[a]	--
10-down	5.3[a]	6.7[a]	--	3.3[a]
Standard (6-down)	5.8[a]	6.5[a]	--	--

Nonvibrated fiberboard control had 4.6[a] shattered berries.
[a] data with the same letter are not significantly different, Duncan's new multiple range test, alpha=0.05

Table 11. Thompson seedless grape shatter and weight loss – two bag types.

Type of bag	Shatter

	(%)
Slitted	3.6
Zip bag	3.3

Testing with other fruits has shown that vibration bruising can be minimized by shipping it in air ride suspended trailers and by never loading damage susceptible fruit on the rear of a steel spring suspended truck. All of the RPC boxes had aspen fiber bottom pads and paper side-wall liners. Testing with other fruits has shown that vibration bruising can be minimized by shipping it in air ride suspended trailers and by never loading damage susceptible fruit on the rear of a steel spring suspended truck.

CONCLUSIONS

1. When exposed to direct sunlight, EPS boxes reduced table grape heat gain by one half compared to corrugated fiberboard boxes and RPCs.
2. The 5-down CHEP and IFCO RPCs and the EPS box resulted in a lower net fruit weight per truck compared with corrugated fiberboard. The EPS boxes required more pallet loads to carry the maximum weight.
3. There were no consistent cooling time differences between the various types of 5-down boxes and the standard 6-down boxes when packed with bagged grapes. All tests were conducted with air flowing parallel to the 48” pallet dimension. Tests could detect significant differences only if cooling times differed by more than about one half hour in a 2 hour cooling time.
4. Weight loss in initial cooling and two week storage was generally greatest in corrugated fiberboard, less in RPCs and least in EPS boxes.
5. There was no distinguishable differences grape transport damage between the boxes tested, except that the 5-down corrugated fiberboard box allowed more berry shatter.

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