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Evaluation of a Refrigerated Barge-on-ship System and Loading Patterns for Postharvest Quality of Exported Texas Grapefruit[1]

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Abstract. **The performance of a prototype refrigerated barge-on-ship system and arrival condition of grapefruit were evaluated. No differences were observed between boxes stacked in register or stacked on pallets except significantly more bruising in palletized fruit. Weight loss of the fruit was minimal. Pulp temperatures in both register and pallet stacks reached the optimum transit temperature of 10°C within 72 hours after the refrigeration system began operating. Humidity levels remained constant at 95% once optimum pulp temperatures were reached. Quality of the grapefruit was considered excellent upon arrival. No significant differences in arrival quality of the fruit, except bruising, could be found between shipping the fruit on pallets or stacking in register.**

A substantial portion of the Texas grapefruit production-2,400,000 boxes (1 box = 24.7 liters or 7/10 bushel) and 160,000 boxes of oranges were exported to European markets during the 1977-78 season (5). Prospects for continued export of grapefruit and oranges are excellent for consumer demand for Texas citrus has been established (4). Markets have been established that require a continual supply of fruit from October through April. Ocean transport companies are interested in the Texas citrus market since volume, combined with a long marketing season, makes export commitments practical. Most of the citrus exported during the 1977-78 season was shipped as break-bulk cargo (requiring loading and unloading of the ship by manual handling of individual shipping containers) although some was containerized. Both systems have worked satisfactorily, but with some limitations.

Shipping citrus as break-bulk cargo generally requires a consignment of 100,000 to 150,000 boxes of fruit. This is often in excess of market demand for a single shipment of Texas grapefruit. Shipping citrus break-bulk is also relatively expensive, for it requires individual handling of the boxes throughout the marketing system at both ports. Containerized shipments allow for smaller shipments (1,000 boxes/container) but shipping fees are becoming prohibitive. In addition, refrigerated container vans are not available in any large quantities for Texas citrus because they are used primarily to transport commodities that return higher revenues per van container (2).

In a new system (1) barges specially designed for perishable fruits and vegetables are carried on a large ship for transoceanic shipment. A prototype refrigerated barge capable of transporting intermediate size loads of perishable products (20,000 boxes) was developed and made available for experimental purposes. The barge system would allow for a uniform, balanced movement of fruit to European markets and help maintain a stable price structure.

The performance of the prototype barge and the condition of grapefruit shipped in it were evaluated in a trial shipment to Rotterdam. The objectives of the study were as follow: 1) to measure the time required to reduce fruit pulp temperatures from ambient to optimum transit temperatures; 2) to determine if the barge's refrigeration system could maintain optimum fruit pulp temperature during an extended voyage; 3) to determine humidity levels inside the cargo area during the initial cooling period and during transit; 4) to determine the relative concentrations of O_2, CO_2, and C_2H_4 during transit; and 5) to evaluate product quality at destination. Measures of these characteristics were compared in boxes of fruit stacked in register (one box placed directly on top of another) and on conventional pallets.

Methods and Materials

Description of system. The refrigerated barge system of transporting citrus was performed as follows. The citrus was packaged in 7/10-bushel corrugated fiberboard boxes, palletized (7 boxes high, 6 boxes/layer) at a packinghouse in the Rio Grande Valley of Texas and trucked to the Port of Houston, where about 19,300 boxes of grapefruit were loaded into the refrigerated barge. The boxes were stowed in the barge in palletized units or handled individually and stowed in a register pattern. Boxes in zones 1, 2, and 3 were stowed in a register pattern on a deck pallet (Fig. 1). In zone 4, the original pallets were replaced at the loading dock by hardwood pallets. The original pallets had broken in transit to Houston. The loaded barge was towed to and loaded aboard the transporting ship after a 3-day refrigeration period.

Barge refrigeration system. The barge has 2 complete and independent cooling and heating systems, one on each end of the barge. Each system is designed to refrigerate half of the lower and upper decks (Fig. 1). Eight cooling evaporators, for both systems, totaling 64 tons of refrigeration deliver air at the rate of 679, 456 liters/min (24,000 ft^3/min). Power is supplied to operate the refrigeration system by an automatic 100 kw diesel generator on the barge deck. The ship provides the necessary power once the barge is on board the carrying vessel. Heaters in the duct system assure proper temperatures of the cargo when interior temperatures drop below the desired interior thermostat setting. Exhaust blowers expel gasses given off by the cargo. The thermostat was set at 10°C for air temperatures in all zones. The refrigeration system provides for a

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Table 1. Timetable for harvest and shipment of grapefruit. March 17 to April 14, 1978.

March 17 – 18	Fruit harvested
March 20	Fruit packed
March 20 – 21	Boxes of fruit transported to Houston, Texas, in open truck
March 22 – 23	Boxes of fruit loaded aboard barge
March 23	Barge refrigeration turned on 15:00 hr, 10°C
March 26	Barge loaded aboard ship
March 28	Ship sailed from Houston
April 13	Ship arrived in Rotterdam (10:00 hr) Barge unloaded from ship Boxes of fruit unloaded from barge (21:15 hr)
April 14	Boxes of fruit cleared by customs transported to USDA European Market Research Center, stored at 10°C
April 20	Grapefruit evaluated, stored at 10°C
April 27	Grapefruit evaluated, discarded

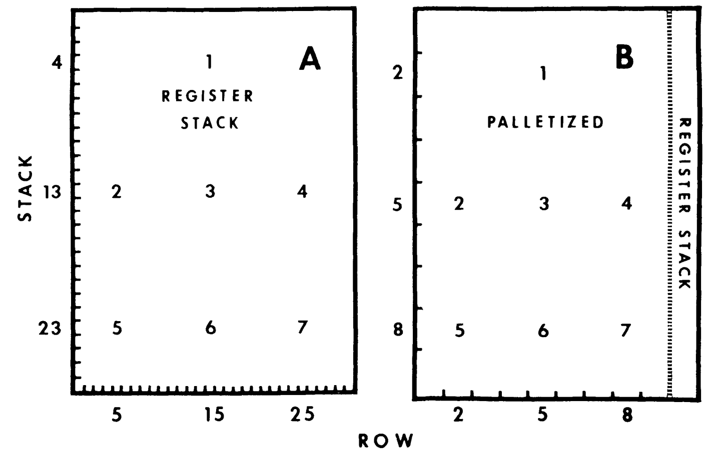

Fig. 2A and B. Schematic of zones 3 and 4, A and B, respectively, showing locations of thermistors within each zone. Layer 1 contains the bottom and layer 7 the top boxes. Location 1 – automatic only, layers 1 and 4. Locations 2, 4 and 6 – automatic, layers 1 and 4; and manual, layers 1, 4 and 6. Location 3 – automatic, layers 1, 4, and 6; and manual, layers 1, 4, and 6. Locations 5 and 7 – manual only, layers 1, 4, and 6.

temperature split of about ± 2°. Engineering details have been published (1).

Description of test fruit and instrumentation. Fruit quality was determined at the packinghouse and again at the destination. Fruit was weighed and evaluated for decay, bruising and pitting. Postharvest decay control consisted of 100 ppm benomyl [methyl 1-(butyl-carbamoyl)-2-benzimidazolecarbamate] in the wax and 2 sheets of biphenyl-impregnated paper (2.4 g biphenyl/paper) among layers of fruit in each box. At the packinghouse, thermistor probes were inserted into the middle of fruit in designated boxes to record pulp temperature. These boxes of fruit were placed in unitized pallets as they were being assembled, and the units were marked for future placement aboard the barge. Discharge and return air and fruit temperature data were obtained during the entire voyage automatically at 6-hr intervals with a Grant Magnetic Tape Recorder, Model CRW, and manually at 12-hr intervals with a digital temperature recorder. Location of thermistors are shown in Fig. 2-A and 2-B. Humidity was recorded by Friez hygrothermographs secured to a return air opening.

By purging lengths of Tygon tubing positioned in the center of each zone of the barge above the cargo, we obtained gas samples for analysis. These samples were analyzed with a Bendix Unico 400 – Kitagawa gas analyzer and appropriate Bendix Gastec analyzer tubes. Measurements of O_2, CO_2, and C_2H_4 concentrations were made every other day.

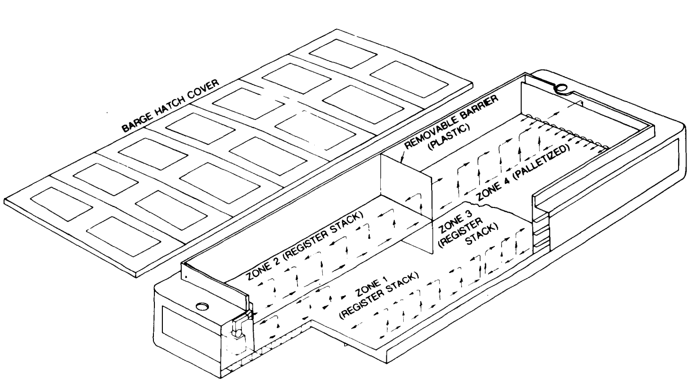

Fig. 1. Schematic of the refrigerated barge showing cargo zones, box stacking patterns and airflow through the individual zones.

Weight loss of the grapefruit was determined by weighing the fruit in 40 test boxes at the packinghouse and then again immediately after discharge of the cargo at Rotterdam. Test boxes held in refrigerated storage rooms at Weslaco, Texas, were also weighed and inspected at the time of the barge's arrival and subsequent opening and inspection in Rotterdam.

Moisture contents of the cartons themselves were measured with a Delmhorst Moisture Detector, Model RC-1C. Moisture readings from each of 40 randomly selected boxes were recorded at the packinghouse and at Rotterdam. Moisture measurements were obtained from both the cover and bottom sections of each box. Three readings were taken on the inside of the cover from the end, side, and top panels and 3 on the body section from the outside bottom, end, and side panels.

Eighty boxes of fruit were taken at random from the packing line. Forty contained fruit with thermistor probes, 10 for each of the barge zones, and were unitized as previously described. These 40 boxes were examined after the voyage and after a 14-day holding period at the USDA Laboratory in Rotterdam. The other 40 boxes were taken from the packing plant to the USDA Laboratory at Weslaco and held at 10°C until the barge was unloaded in Rotterdam. The fruit was then examined for condition and returned to storage for another 14-day period at 10°. At the end of 7 and 14 days the fruits were examined for decay, chilling injury, bruising and other types of damage. Decay organisms were identified.

Results and Discussion

The *Doctor Lykes* docked in Rotterdam at 10:00 hr on April 13, 1978. The ship had been loaded so that the test barge could be discharged first. The barge was then towed to another harbor where the boxes of fruit were discharged. Immediately after removal of the top hatch covers, the Grant automatic temperature recorders were recovered. Preslung pallets were removed first to allow working space for unloading the dock pallets. The 2 vertical straps and 1 horizontal strap on each unitized pallet were generally loose. Most of the pallets were either broken or damaged. Boxes loaded in the tight register pattern showed no box damage or failure. Discharge of the barge was completed at 21:15 hr on April 13. Moisture content of the boxes, and weight measurements of the fruit were made of the experimental boxes within minutes after removal from the barge. The experimental boxes were

Table 2. Mean percentage moisture of 40 boxes at origin and destination.

Box location	Moisture (%)		
	At origin	At destination	
		Register	Pallet
Cover			
Top	10.8	19.4	19.4
End	10.5	18.9	19.3
Side	10.3	19.3	19.1
Body			
Bottom	9.9	17.5	18.7
End	10.4	17.8	17.9
Side	10.6	17.3	17.9

left overnight in the warehouse and were cleared by customs inspectors the following day. After customs clearance on April 14, they were transported to the U. S. Department of Agriculture's European Marketing Research Center for initial fruit inspection. Data from the register stack in zone 3 was representative of all register stacks and were compared to the palletized fruit in zone 4 (Fig. 1). Both zones were refrigerated by the same unit.

Moisture content of cartons at origin and at destination is shown in Table 2. No significant differences in moisture content was observed between boxes stacked in register or stacked on pallets. Box compression measurements showed no evidence of box failure from excessive moisture absorption in either zone.

Mean weights of individual cartons of grapefruit at origin and at destination are shown in Table 3. Grapefruit remaining at Weslaco averaged 5.1% loss in fruit weight while fruit stowed in the barge averaged 3.7% weight loss. Neither value is considered excessive for an experiment of 28 days' length. This difference in weight loss may be attributed to design differences between the two types of refrigeration systems.

Average pulp temperatures for location 6 (Fig. 2A-B) in both zone 3 and 4, respectively, for the first 5 days of the voyage are shown in Fig. 3 and 4. No differences were observed in grapefruit pulp temperatures between the 7 locations. Location 6 was chosen as representative of all locations because it was farthest from the discharge openings and in the middle of the barge. Temperatures of grapefruit pulp had stabilized at $10 \pm 1^{\circ}C$ in all zones by March 28. Minor temperature fluctuations after the 5th day in both zones could be attributed to the shift of power sources from the power generator unit on the barge to shipboard circuits or to power shutoff while in port. Pulp temperatures at the 3 layers in both register and pallet stacks reached the optimum transit temperature of 10° within 72 hr after the refrigeration system began operating. The bottom layers of fruit reached optimum pulp temperature first, within 24 hr in zone 3 and 48 hr in zone 4, because the air flows up from the floor through the cargo. Pulp temperatures of fruit in register-stacked-boxes reached optimum for each layer of boxes 12 to 24 hr before comparable layers in palletized boxes of fruit. The 12° decrease in 24 to 72 hr from initial ambient temperature is better than has been achieved

Table 3. Mean weights of grapefruit at origin and destination.

	Weight of grapefruit (kg)		Loss (%)
	At origin	At destination	
Control[z]	17.6	16.7	5.1
Barge			
Register	17.7	17.1	3.4
Pallets	17.8	17.1	3.9

[z]Forty boxes of control grapefruit were held in storage at $10^{\circ}C$ at Weslaco, Texas, and evaluated on same time schedule as exported fruit.

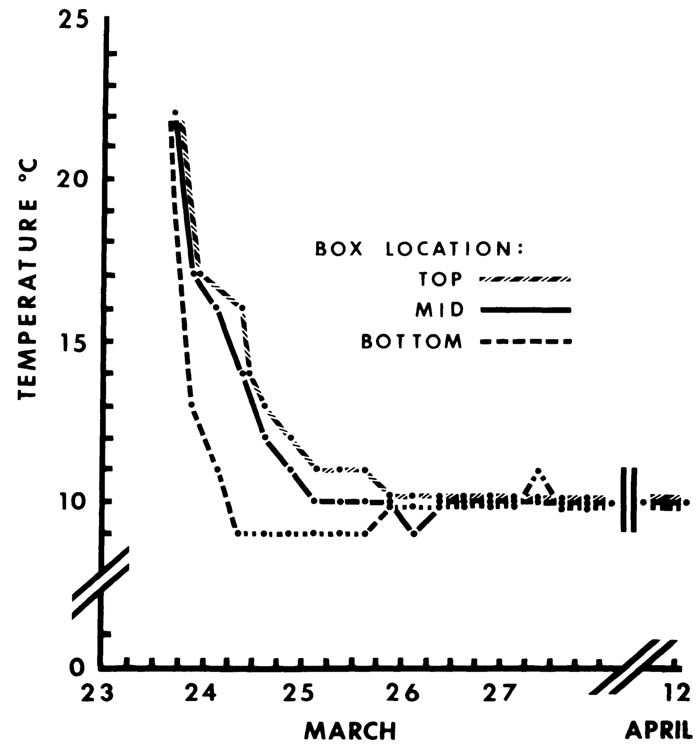

Fig. 3. Average pulp temperatures of grapefruit in zone 3 for the first 5 days of the voyage. Boxes were stacked in a tight register pattern.

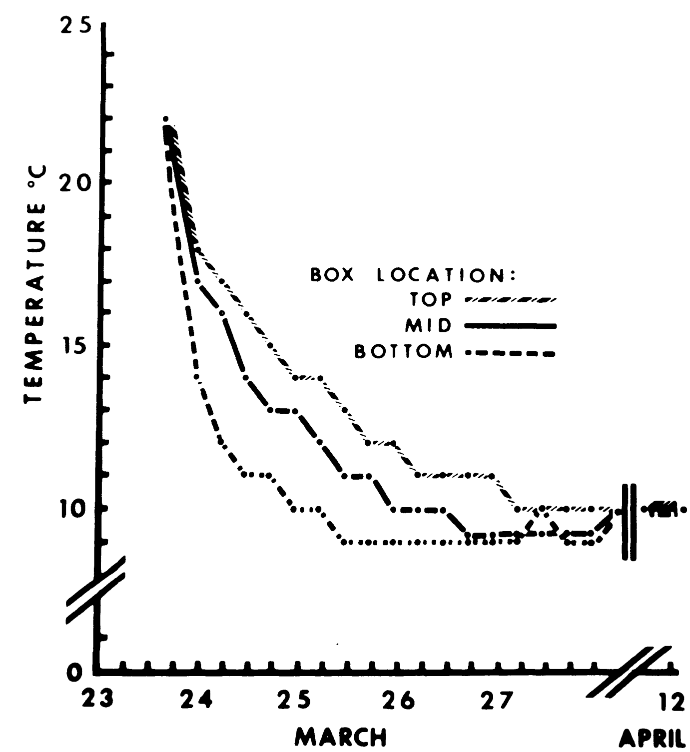

Fig. 4. Average pulp temperatures of grapefruit in zone 4 for the first 5 days of the voyage. Boxes were stacked on conventional hardwood pallents.

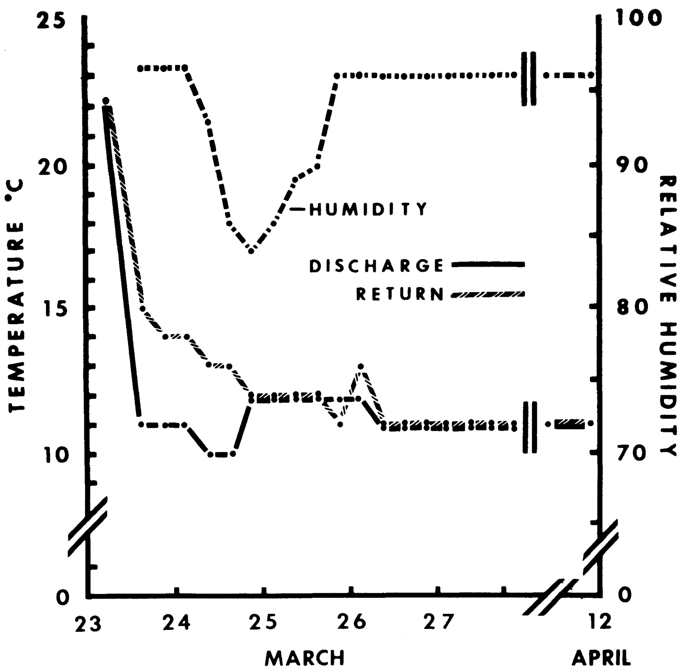

Fig. 5. Relative humidity and discharge and return air temperatures in zone 4 for the first 5 days of the voyage.

in either experimental refrigerated containers or break-bulk (T. H. Camp, unpublished data). A 10° reduction in pulp temperature reduced the rate of respiration of grapefruit by half to a third (3).

Humidity levels remained relatively constant once optimum pulp temperatures were reached (Fig. 5). Humidity dropped sharply to approximately 82% during the first 24 hr, but reached the optimum level (95%) after 72 hr. The drop in humidity correlated with the initial cooling period of the grapefruit as shown by discharge and return air temperatures (Fig. 5). The refrigeration unit was operating constantly during this period.

Quality of the grapefruit upon arrival was considered excellent (Table 4). At destination, 1.9% of the fruit showed decay with a total of 2.6% after 2 weeks of storage. About 90% of the decay was green mold, *Penicillium digitatum* Sacc. and the remaining 10% was sour rot, *Geotrichum candidum* Lk. ex Pers., and stem end rot, *Diplodia natalensis* P. Evans. Only 5% of the fruit were bruised, an amount that is not considered excessive. Bruising was, however, significantly greater for palletized grapefruit. Of the 72 bruised fruit examined, 60 of these were found in palletized boxes from zone 4 that had been repalletized before loading into the barge because of damage to the pallets. Thus, the top layer of boxes on the damaged pallet became the bottom layer on the new pallet, and twice as many fruit were exposed to the overhead pressure from the upper layers. A significantly greater amount of pitting was observed in the control fruit. Control fruit entered storage prior to barge refrigeration. There is a curing effect of time delays on grapefruit that conditions the fruit against chilling injury (i.e. pitting) (W. Grierson, personal communication).

Table 4. Condition of grapefruit on arrival and after 2 weeks of storage.

Treatment	No. of fruit examined	Decay April 14	Decay April 28	Bruising[z] Slight	Bruising[z] Serious	Cuts	Pitting & aging
Control[y]	560	5	1	lb	0	0	53a
Barge	1018	19	7	72	4	1	34
Register	508	9	4	12b	0	0	14b
Pallets	510	10	3	60a	4	1	20b

[z]Bruising:Slight = injury or visible wet breakdown on fruit surface and affecting no more than 1 fruit segment; Serious = affecting more than 1 segment.

[y]Control grapefruit were held in storage at 10°C at Weslaco, Texas, and evaluated on same time schedule as exported fruit. Mean separation in columns by Duncan's multiple range test, 1% level.

No significant changes were observed in either O_2 or CO_2 concentrations. Ethylene, which was not expected because the amount of decay was small, was not detected.

The refrigerated barge system appears to be a satisfactory method of transporting intermediate size cargoes of citrus to export markets. The receivers (wholesalers) of the grapefruit were generally pleased with the fruit upon arrival. The barge system retains many of the better features of both van container and break-bulk methods but with few of the disadvantages. No significant differences in quality of fruit on arrival, except bruising, could be found between shipping the fruit on pallets or stacking in register.

Literature Cited

1. Anon. 1978. The Lykes Seebee system. 36th Annual, Texas Citrus and Vegetable Growers and Shippers Assoc., p. 122, 123, 125.
2. Hinds, Russel H., Jr. 1970. Transporting fresh fruits and vegetables overseas: An interim report. ARS 52-39.
3. Lutz, J. M. and R. E. Hardenburg. 1968. The commercial storage of fruits, vegetables, and florist and nursery stocks. U. S. Dept. Agr., Agr. Handb. 66.
4. Powell, G. R. and T. H. Camp. 1973. Exporting Texas 'Ruby Red' grapefruit. Texas A&M Univ., Texas Agr. Ext. Ser. MP-1080.
5. Texas Dept. of Agr. 1978. Texas citrus market news XXXVII, No. 5. (Oct. 23.) Welsaco, Texas.