The distribution of the glucose/fructose ratio is shown in Figure 2. The range for ± 3 standard deviations is 0.764 to 1.07. Therefore only the single sample at 0.72 falls outside of this range. This sample contained 2.9% fructose, 2.1% glucose, and only 1.2% sucrose (which is very low for sucrose). This sample is probably an outlier. The sample with a ratio of 1.15 will be explained next.

Sugar added grapefruit juice. In order to improve consumer acceptance, sugar is sometimes added to GFJ which is high in acid, low in sugars and high in bitter compounds. This process is perfectly legal providing the words "sugar added" appears on the label. One such sample was inadvertently included in this study. It was easily distinguished from the other 148 samples. In Figure 1 this sample is the extreme outlier (>6σ) shown at 4.8% fructose. The added sugar also disturbed the natural glucose/fructose ratio. This sample had a ratio of 1.15 which was greater than 4 standard deviations from the mean. As shown in Fig. 3 the sample with added sugars produced a very high total sugar value. Total sugars were 10.9% which was greater than four standard deviations from the mean of the other 148 grapefruit juices.

Sucrose concentrations and percent sucrose. Sucrose concentrations were highly variable ranging from a low of 0.2% to a high of 5.3%. As shown in Table 1 the average sucrose concentration was 2.7% (w/w). The standard deviation was 0.554, which is fairly high. Even though there was a relatively tight distribution around the mean (138 out of 148 samples were within ±2σ) there were a few high and several very low values. Since GFJ is reasonably acidic, pH approximately 3.5, low sucrose values could be explained if one considers the possibility of acid hydrolysis of the sucrose into glucose and fructose. High sucrose values are harder to explain. Two samples containing 4.5 and 5.3% sucrose, had concentrations greater than 3 standard deviations from the mean (4.40%).

Sucrose comprises a considerably smaller portion of the total sugars in grapefruit juice as compared to the normal 50% in orange juice. Since sucrose concentrations were highly variable, the percentage of sucrose was also highly variable with values ranging from 2.7 to 56.4%. Low percentages of sucrose may be explained in the same manner as low sucrose concentrations. Of the 2 previous samples which contained abnormally high sucrose concentrations only one also had an abnormally high (>3σ) percent sucrose and must therefore be considered an outlier.

Total sugars. As shown in Fig. 3, total sugars were distributed over a wide range of values. Total sugars (glucose + fructose + sucrose) ranged from 4.9 to 9.5%. The value at 10.9% was due to the "sugar add" sample and was therefore expected to be high. Average total sugars was 7.47% with a standard deviation of 0.782. Of the 148 GFJ's only one was outside the limit of ± 3σ (5.12-9.82%). The glucose/fructose ratio and percent sucrose for this sample was very normal (0.941 and 32.6%); however, as might be expected the concentrations of both fructose and glucose were low (1.7 and 1.6%, respectively). Therefore this sample is probably an outlier.

Conclusion

Glucose, fructose, and sucrose concentration profiles have now been established for Florida canned grapefruit juice. Fortunately the vast majority of Florida product meets European sugar standards for grapefruit juice. It was also interesting to note that "sugar added" grapefruit juice is readily distinguished from the normal grapefruit juice sugar profile.

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THE COSTS AND BENEFITS OF TRANSPORTING 72°BRIX ORANGE CONCENTRATE

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Additional index words. Florida, Brazil, ship(s), tankers, bulk shipment, citrus, energy savings, fuel savings.

Florida Agricultural Experiment Station Journal Series No. 6995. The authors wish to acknowledge the assistance of Kathryn C. Davis and members of the citrus industry.

Abstract. **Bulk citrus concentrate is customarily shipped in 62 to 65°Brix concentrations. It now appears technically feasible to increase the concentration level to 72°Brix. In this paper, the economic impacts on transportation costs of going to 72°Brix are examined. The impacts on the costs of transporting concentrate to various destinations are calculated as well as the expected change in Florida's total transport bill for bulk concentrate. Changes in the relative costs of transporting concentrate to a major U.S. market from Florida and Brazil are estimated. These estimates are made for 4 scenarios which differ regarding adoption of 72°Brix. The effects of changing fuel costs on the relative costs of transporting concentrate from Florida and Brazil are examined. Florida has an advantage over Brazil in the amount of fuel required to deliver bulk concentrate. This is about a $417 storage/delivery cost advantage per truckload. The new 72°Brix technology**

should be evaluated in order to expand and maintain this edge.

Increasingly, the 2 major citrus processors, Florida and Brazil, will supply their products to the U.S. market in the form of bulk concentrate (1, 8). This concentrate will be reprocessed into chilled single strength orange juice (COJ) and frozen concentrated orange juice (FCOJ) near points of consumption. There has been a rapid increase in demand for COJ. Gunter et al. (9) project that the retail demand will increase at an annual rate of 5.3% over the next 10 yr. Retail demand for FCOJ is projected to increase by only 2.3% per annum due to consumer demand for convenience and the perception that COJ is closer to fresh squeezed than FCOJ (9). Retail demand for COJ has resulted in increased movements of bulk concentrate from production to consumption areas (Fig. 1). It is advantageous to transport only the concentrated citrus rather than the additional water and packaging materials. Fairchild et al. (6) estimates that transporting bulk concentrate costs one third less than what it costs to transport an equivalent amount of pounds solids as COJ. A citrus grower's organization has adopted the introduction of a high density FCOJ as one of their 5 top priorities (7). There is also an increasing trend for more of this bulk concentrate to enter ocean shipping ports outside Florida (Fig. 2). Bulk citrus concentrate is typically stored and shipped between 62 and 65°Brix. Work by Crandall et al. (4) and Crandall and Graumlich (5) suggests that 72°Brix levels are attainable without sacrificing product quality. It is the objective of this paper to examine some of the implications of going from 65 to 72°Brix. Focus is given to the impact on storage and transport costs associated with movements and relative costs of delivering bulk concentrate to the Northeastern United States from Florida and Brazil. The impact of delivering higher °Brix orange concentrate from Florida and Brazil can have an important effect on their competitive positions and the overall price of citrus products. In addition, the effects of changes in energy costs on the above are addressed.

Materials and Methods

Cost elements. This subsection describes the estimates of various costs and input differences associated with storage at the production site and transport to the consumption area for 65 and 72°Brix bulk concentrate. These values are employed in the subsequent subsection to determine total and relative costs from Florida and Brazil to the Northeast.

The advantage of 72°Brix concentrate is simple and straightforward. With 65°Brix, 35 of every 100 kg is water, while with 72°Brix the amount of water is reduced to 28 kg. Therefore, to store or move a given amount of pounds solids, 20% less water must also be stored or moved. Otherwise stated, with 72°Brix as opposed to 65°Brix, there would be 11% more pounds solids per unit weight. Savings from the higher °Brix level in the movement of product from the production to the consuming areas may be broken down as follows: 1) capital cost savings associated with reduced storage capacity requiremments at the production site; 2) reduced energy requirements for refrigeration at the production site; 3) capital cost savings associated with reduced transport capacity requirements; 4) reduced energy requirements for refrigeration while the product is in transit; and 5) reduced energy, labor, and maintenance costs associated with transporting any given amount of pounds solids. The reprocessor who receives this higher

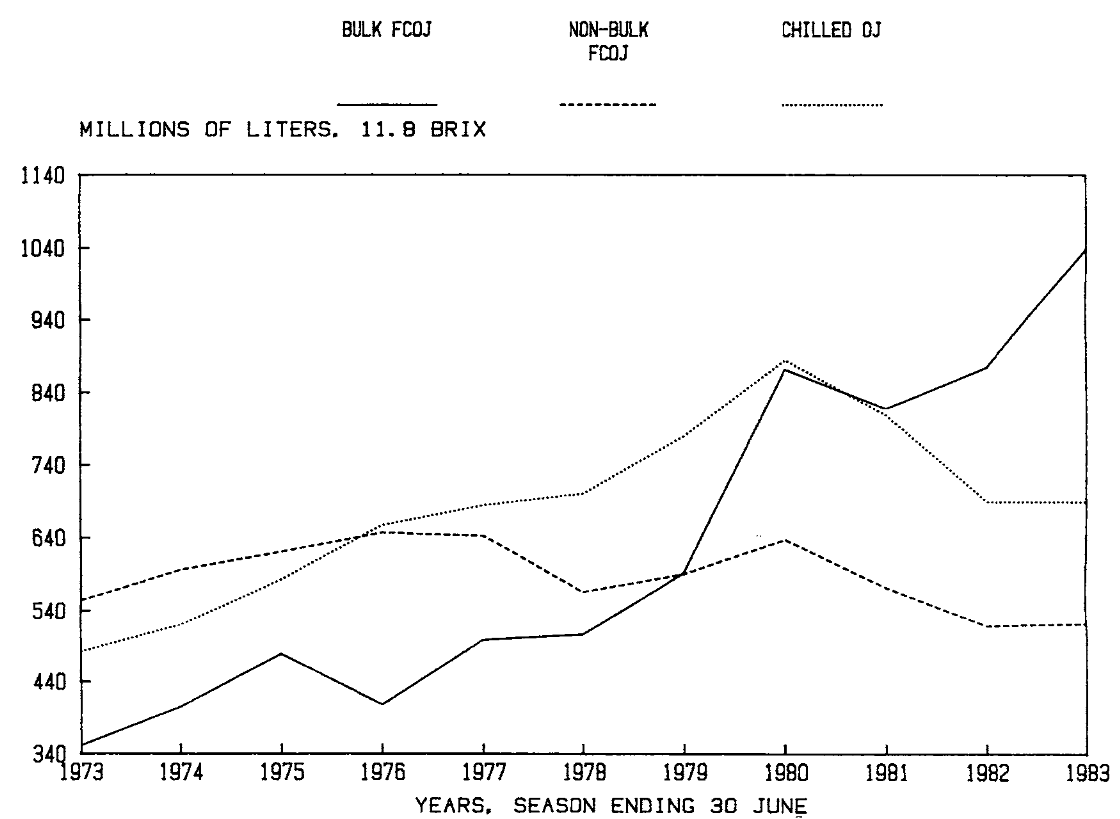

Fig. 1. Florida movement of chilled single strength orange juice, bulk and nonbulk frozen concentrated orange juice.

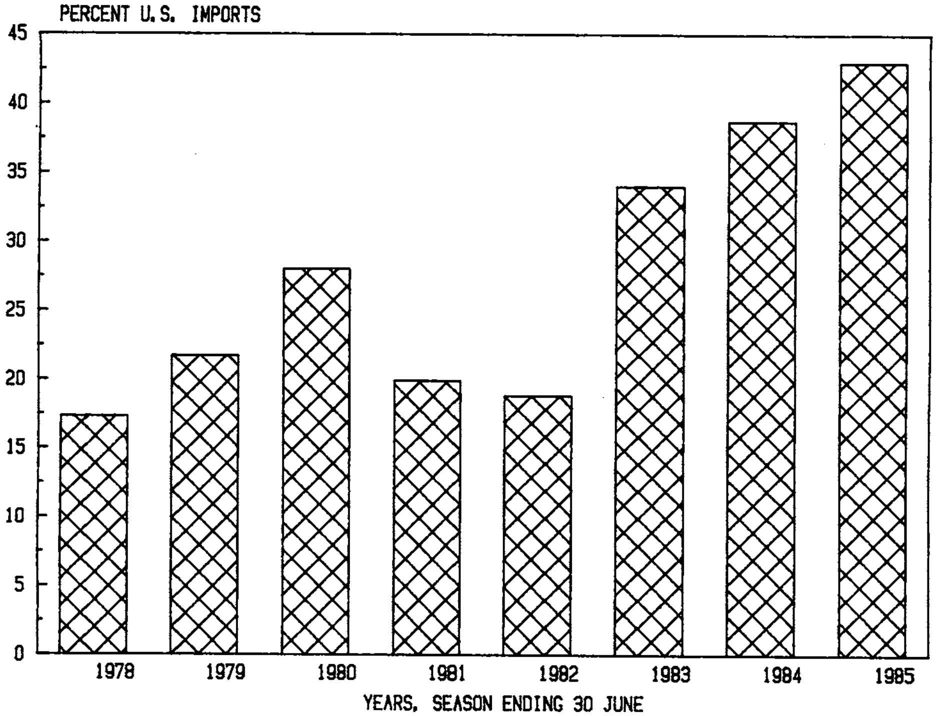

Fig. 2. Percentage of imported frozen concentrated orange juice entering non-Florida ports.

°Brix concentrate would benefit from added storage and reduced energy costs.

Capital costs for different scenarios of concentrate storage have been addressed (16). All capital costs (no. 1 and 3 above) will not be considered because these are sensitive to movement in interest rates, and salvage values and are considered to be durable so reductions in capital costs would not reduce the price of concentrate for several years. For these reasons, these savings are difficult to estimate accurately.

The disadvantages of going with a higher °Brix product and storing at refrigerated temperatures are 1) the concentrate is more viscous; 2) lower juice yields may be needed to reduce the viscosity; and 3) about 2.3% more energy is needed to evaporate 65°Brix to the higher 72°Brix. Evaporators use about 21% of the total plant energy cost (10). There is additional concern that the higher temperature storage will result in an increased rate of formation of off-flavor and browning compounds. These disadvantages have been redressed in several publications (4, 13, 15).

Energy savings—refrigeration. The first aspects we want to address are the energy requirements for ocean shipment of bulk concentrate. Older style ships burned 1-1/2 to 2 metric tons (MT) per day of marine diesel to run electrical generators on board, part of which was used for refrigeration. Modern ships use shaft generator powered compressors. These generators are assumed to be 80% efficient, similar to stationary electrical power generating stations. A 10,000-MT ship will burn about 18 MT per day of fuel (180 centistokes, IFO) under full cargo conditions and about 15.5 MT of fuel per day without the refrigeration load under ballast conditions. This savings of 2.5 MT per day is due to moving less weight and reduced refrigeration requirements. Ocean shippers have told us that these ships maintain the concentrate at −10°C, are filled on a volume not a weight basis, and sail back under ballast (no cargo) conditions after rinsing and pressurizing the tanks with an inert gas.

Table 1 shows the calculated savings from shipping 72°Brix at 4°C vs. 65°Brix at −10°C for a load of 10,000 MT. Assuming an average outside temperature of 27°C, the difference in refrigeration requirements would be about 38% less. About 13% more solids could be moved per shipment.

A summary of refrigeration requirements for 1 MT (2200 lbs.) of orange juice solids at 65 and 72°Brix is presented in Table 2. Refrigeration costs will depend on several factors: product load, density, heat gain, and power conversion efficiencies. The calculated refrigeration load for over-the-road tankers is straightforward. Modern bulk tankers can be thought of as giant, mobile "thermos bottles" which are not surrounded by a vacuum but with 12 to 15 cm of insulation. Tankers are currently loaded at about −10°C and gain only about 1°C per day. These trucks deliver concentrate anywhere in the U.S. within 3 days.

Energy savings—transportation. Energy requirements for ships were made under the assumptions that 10,000 MT of cargo was moved from Santos, Brazil to New York at a speed of 22.2 km per hour consuming 19,000 liters of fuel and 16,000 liters of No. 6 diesel per day. These values were considered representative after discussions with shippers, ships agents, and naval architects and engineers.

Energy requirements for the over-the-road tanker were calculated assuming 21.8 MT cargo (48,000 lb, 80,000 lb gross weight), 2 km per liter of No. 2 diesel and that it always carried a revenue generating load. The first 2 assumptions were made after conferring with carriers and from studies by Boles (2), Buxton (3), and Knorr (14). Other research reported by ICC (11) indicates all types of tankers average about 39% of their highway mileage empty. The final assumption was made to avoid assigning

Table 1. Proposed savings from shipping 10,000 MT (7.4 x 10^6 liters) at 72°Brix and 4°C.

Conditions	Current	Proposed
Concentration, °Brix	65	72
Temperature, °C	−10	4
Temperature difference, °C from 27°C ambient	37	23
Refrigeration savings, %	38	—
Solids, 10^6 kg per shipment	6.3	7.2
Additional solids, %	13	—

Table 2. Summary of cost and input elements for 1 MT of orange juice solids.[z]

Cost element	65°Brix	72°Brix
Refrigeration	−10°C	4°C
Storage, tank farm	0.0922 liter[y]	0.0475 liter
Over-the-road	0	0
On ship	0.0922 liter	0.0475 liter
Transportation	−10°C	4°C
Over the road (No. 2 diesel)	0.0352 liter[x]	0.0319 liter
By ship (No. 6 diesel)	0.0101 liter	0.00913 liter
Nonenergy, noncapital	$/km	
Over-the-road	$0.0205	$0.0185
By ship	$0.000411	$0.000371

[z]Assumptions for Table 2:
1. Refrigeration figures are calculated from those supplied for a tank farm for 10,000 MT of orange juice. This amount of 65°Brix stored at −10°C requires 69.6 MT of refrigeration and 72°Brix stored at 4°C requires 39.6 MT. Units run 23 out of 24 hr.
2. No. 2 diesel is 38,180 kJ/liter. No. 6 diesel is 42,170 kJ/liter
3. Transportation is based on a 10,000-MT shipment from Santos, Brazil to New York. Fuel costs for propulsion for the roundtrip were used.

[y]Liters of No. 6 diesel per day/MT solids.
[x]Liters of diesel per km/MT solids.

Table 3. Times in storage, distances, times in transit, and additional assumptions to determine Florida and Brazil to New York storage and transportation costs.[z]

	Point of origin	
	Florida	Brazil
Storage time at production site (days)	180	180
Time in transit		
Overland	60 hr	7 hr
By sea	–	17.2 days
Distance to New York (km)		
Overland	2011	400
By sea	–	9180
Cost of diesel		
No. 2	$0.303/liter	
No. 6	$0.202/liter	

[z]Assumptions:
1. 6 months storage in each location was used. The trip from Matao to Santos, Brazil is 7 hr by truck which is then backhauled empty. Short-term concentrate storage at the port is not included.
2. Delivery from port to reprocessor is not included.

Table 4. Costs per km to move 1 MT of solids.

Method	°Brix	Labor	Maintenance	Total
		dollars		
By ship	65	0.000411	[z]	0.000411
	72	0.000371	[z]	0.000371
Over the road	65	0.0141	0.00635	0.0205
	72	0.0127	0.00573	0.0185

[z]Not available

costs to empty movement. Tankers are cleaned between loads and carry a number of food grade products. Using these assumptions, it is estimated that to move 1 MT of solids, 1 km, 0.0352 liter of No. 2 diesel is required for 65°Brix and 0.0319 liter for 72°Brix or about 11% less fuel.

Times and shipping distances. A summary of times, distances and prices are shown in Table 3 for both Florida and Brazil. Rates were assumed to be 75% of those in the U.S. for the 400 km over-the-road trip from Matao to Santos, Brazil. Over-the-road carriers deliver directly to reprocessors and tankers would have to deliver the concentrate from the port to a reprocessor's plant. This was assumed to be small for the New York area.

In comparing shipping distances, it was found that from Santos, Brazil to Tampa is 9,317 km (5,031 nautical miles) and it takes about 17.4 days (419 hr) sailing time, pilot to pilot. The distance from Santos to New York (Port Elizabeth, NJ) is 9,180 km (4,957 nautical miles) and it takes about 17.2 days (413 hr) sailing time. Therefore, it is actually 6 hr closer to sail to New York than Tampa from Santos, Brazil because ships are about 5,500 km east of Tampa when they start North.

Labor and maintenance. Labor costs for a ship are based on a crew of 25 making a 35 day trip out of 200 work days per year. No overall transportation rate was available and demurrage costs were not included. Estimates of labor and maintenance costs for trucks were derived from discussions with industry representatives and from Boles (2) and Buxton (3). Driver salary and benefits are estimated to be $0.20 per km. Maintenance costs are estimated at $0.09 per km. In recognition of Brazil's lower labor pay scales, labor and maintenance costs were assumed to be 75% of those in the U.S. Results are shown in Table 4 for the costs per km to move 1 MT of solids at 65 and 72°Brix.

Results and Discussion

Total Florida and Brazil to Northeast costs. This subsection describes the methodology for determining total °Brix level-related cost differences for concentrate delivered from Florida and Brazil to the Northeast. As the single largest market, New York City was selected as the point of consumption. The following are examined: 1) Cost differences from each production site related to Brix levels; 2) Cost differences between Florida and Brazil if a) both continue shipping 65°Brix, b) Florida but not Brazil adopts 72°Brix, c) Brazil but not Florida adopts 72°Brix, and d) both adopt 72°Brix; and 3) All of the above under varying energy costs.

Rate/cost estimates. Transportation costs are influenced by several factors, many of which are difficult to quantify or are situation specific. For example, the cost of delivering concentrate to a destination depends in part upon the probability of securing another load from that site (12). Carriers typically offer volume discounts to receivers for commitments of multiple loads. Also, the capital and overhead costs associated with the vehicle must be spread across various movements. The manner in which these costs are partitioned is essentially arbitrary. Even given some method for spreading these costs, the level of cost per movement is not known until the total number and the distances of revenue and nonrevenue generation movements per unit of time are known.

Given these difficulties, a mixed strategy was adopted. Estimates of the fuel costs for stationary storage were assumed to equal the total (short run) costs. Transportation rate levels were solicited from carriers for the Florida to New York movement. Costs for the overland movement in Brazil was assumed to be 75% of the Florida to New York rate adjusted for the difference in distance. Costs for the ocean movement and port-to-plant transfer were set at $109.5/MT-solids, or $0.05/lb. solids (assuming 65°Brix). This rate is below the $0.085/lb. solids estimate made by Gunter et al. (9). However, discussions with industry representatives have led us to believe that the $0.085 estimate was high. These cost/rate elements were employed as benchmarks. It was assumed that these would vary in accordance with differences in the cost/input elements which have thus far been identified. The cost/rate elements employed for the analysis are storage, $0.0187/MT-solids/day; Florida to New York (over-the-road), $115.34/MT-solids; Matao to Santos, Brazil (over-the-road), $34.60/MT-solids; and Santos, Brazil to New York (ocean), $109.56/MT-solids. It should be pointed out that rates can and do vary across carriers and destinations. Therefore, the benchmark levels should be regarded as rough approximations. What is of importance, however, in the analysis is the direction of change in the relative rates as Brix levels or fuel costs are varied.

In Table 3 are presented the distances, times in storage, times in transit, and additional assumptions employed to calculate rate/cost levels and differences. The estimated rate/costs to store and deliver 1 MT of pounds solids to New York from Florida and Brazil at 65°Brix is $118.43 and $147.86, respectively, and $105.62 and $132.19, respectively, for 72°Brix (Fig. 3). Currently (with both at 65°Brix), Florida storage/delivery costs are estimated to be 80% of those for Brazil. If Florida transported 72°Brix concentrate and Brazil transported 65°Brix, the Florida costs would drop to 71% of the Brazilian costs. If the reverse occurred, Florida costs would rise to 90% of those for Brazil. In other words, Florida currently enjoys about a $417 storage/delivery cost advantage per truckload of concentrate over Brazil. If Florida went to 72°Brix and Brazil did not, the per truckload cost advantage would increase by $193 to $610. If Brazil adopted 72°Brix and Florida did not, Florida's per truckload advantage would be reduced by about half to $195.

Changing fuel costs. Energy costs are a large component of total storage/transport costs and have displayed considerable volatility in recent years so the effects of fuel cost changes are examined. In terms of the total amount of fuel used for storage/transport, Florida has a marked advantage as is evident in Fig. 4. Note that over 80% of the fuel used to store/move Brazilian concentrate is No. 6 fuel oil for refrigeration and ocean transport, rather than the more expensive No. 2 diesel fuel oil. The effect of the No. 2 to No. 6 fuel oil cost differential can be seen by comparing Fig. 3 and 4. With both production areas shipping 65° Brix concentrate, Florida uses 38% of the fuel as Brazil for equivalent amounts of concentrate, but Florida's costs are 50% of those for Brazil.

Florida's fuel advantage relative to Brazil is reflected by the fact that the Brazil minus Florida cost differentials are directly related to fuel costs (Fig. 5). If both Florida

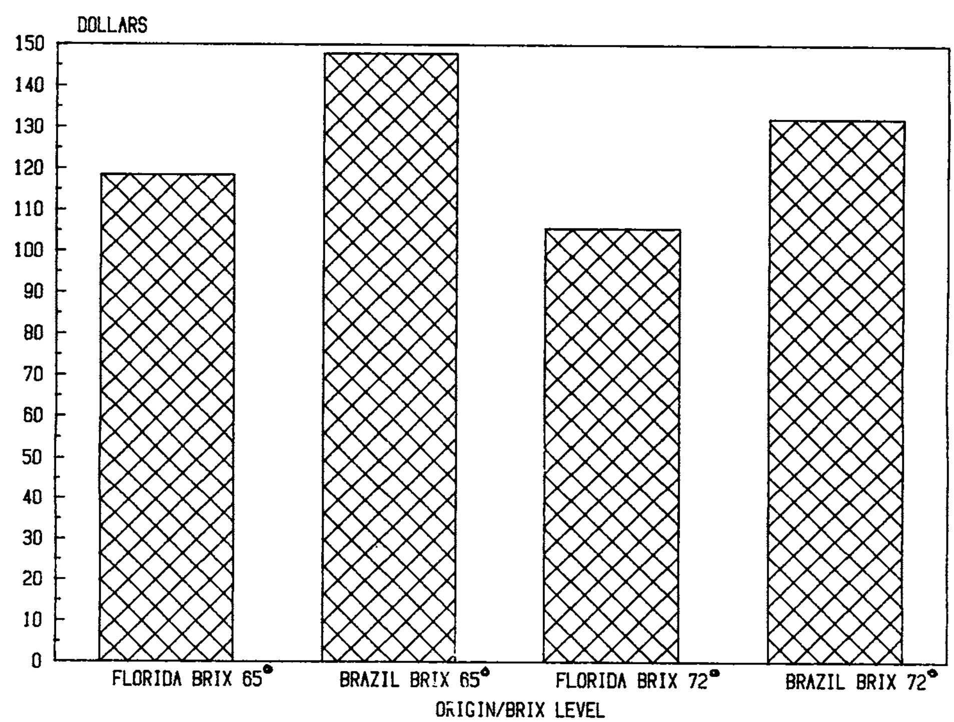

Fig. 3. Current costs to store and move 1 MT pounds solids to New York.

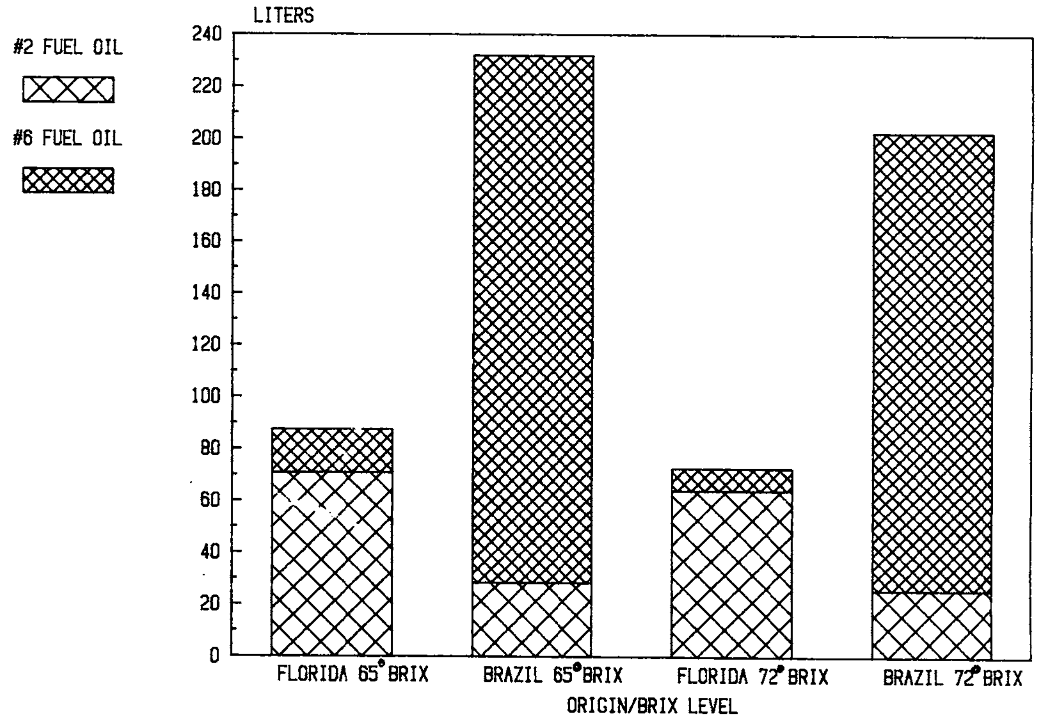

Fig. 4. Fuel required to store and move 1 MT pounds solids to New York.

and Brazil either remain at 65°Brix or both adopt 72°Brix, a 100% rise in fuel costs would result in an increase in the per MT pound solid cost differential of about $25 ($350 per truckload). In other words, if both countries ship the same Brix level, a 100% rise in fuel costs would reduce Florida's storage/transport costs from 80 to 72% of those for Brazil. If Florida adopts 72°Brix and Brazil does not, the impacts of fuel cost increases would be somewhat more favorable to Florida (Fig. 6). A 100% rise in fuel costs would result in an increase in the per MT pound solid cost differential of about $28.50 ($400 per truckload). However, if the reverse were to occur and Brazil alone went to 72°Brix, the advantageous effects of fuel cost increases for Florida would be greatly reduced. A 100% rise in fuel costs would only increase the Brazil minus Florida cost differential by $18.50 per MT of pounds solids ($260 per truckload). In this case, even after the 100% fuel increase, Florida's costs would be a larger proportion of Brazil's 81.5% than they are currently, 80% (Fig. 7).

Summary and Conclusions

In this paper, the effects of using higher °Brix levels on the short-run (noncapital) costs of storage/transport of bulk concentrate to the Northeast from Florida and Brazil have been examined. The savings resulting from higher Brix levels are due to the fact that there are more pounds solids per unit volume or per unit weight and that the product can be stored at higher temperatures.

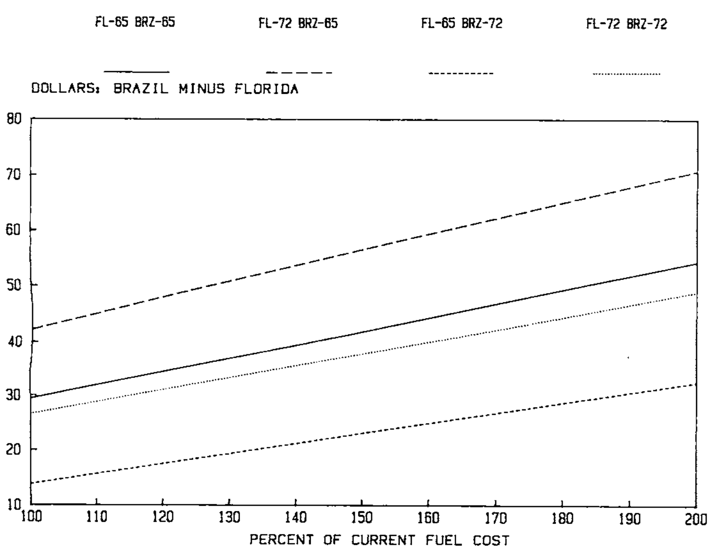

Fig. 5. Difference in costs/rates with 100% change in fuel costs: Brazil minus Florida.

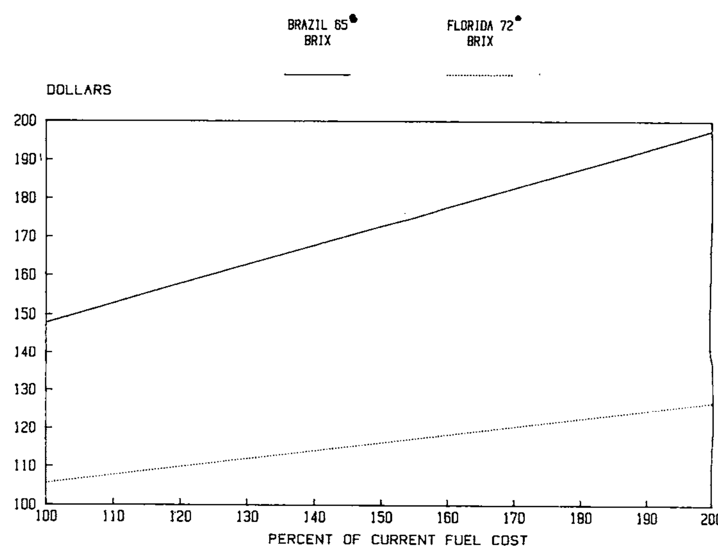

Fig. 6. Change in costs/rate with 100% change in fuel costs: Florida 72 and Brazil 65.

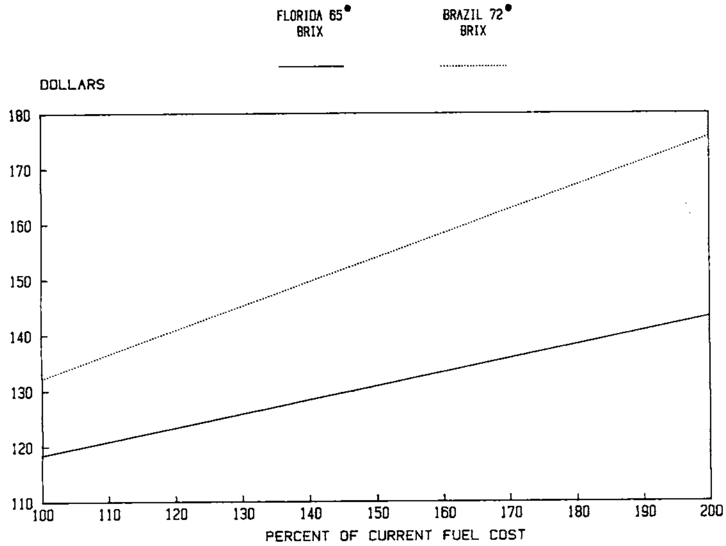

Fig. 7. Change in costs/rates with 100% change in fuel costs: Florida 65 and Brazil 72.

Three major conclusions may be drawn from the analysis. First, in terms of total fuel usage for the storage/transport function, Florida enjoys a marked advantage over Brazil. It is estimated that it requires almost 3 times more fuel to transport a similar amount of Brazilian as Florida concentrate. As most of the fuel used to move Brazilian concentrate is lower cost No. 6 fuel oil, in terms of fuel costs Florida's advantage is reduced to the order of 2 to 1. Second, because of Florida's fuel advantage, increases in fuel costs increase the cost of storing and transporting Brazilian concentrate relative to Florida concentrate. For example, a 100% increase in fuel costs would reduce Florida storage/transport costs from 80 to 72% of those for Brazil.

The third and most important conclusion of the study is that the adoption of higher Brix levels sharply reduces storage/transport fuel requirements. For example, an 11% rise in the concentration level from 65 to 72°Brix would lower the total fuel requirements for Florida concentrate by 17% and lower fuel costs by 15%. An important corollary of this result is that the relative costs of storing and transporting Florida and Brazilian concentrate are sensitive to the Brix levels used by each producer. If Florida but not Brazil adopted 72°Brix, Florida's costs for the storage/transport functions would change from 80 to 71% of Brazil's. However, if only Brazil adopted 72°Brix, Florida's costs for the storage/transport functions would rise from 80 to 90% of Brazil's and the advantages to Florida of fuel cost increases would be greatly reduced.

It is evident from this work that increased Brix levels can play an important role in reducing the energy requirements and the overall costs of storing and transporting citrus concentrate. To the extent that these savings translate into reduced costs to the consumer, total quantities demanded may increase as citrus juices would become more attractively priced relative to other beverages. While important in the long run, from the point of view of the producer, this effect is likely to be of secondary importance in the short run. More crucial is the impact on the relative costs of Brazilian and Florida concentrate delivered to their principal markets. The technology to implement 72°Brix production, storage, and transport will likely be available in the near future. The production area which first adopts this technology will enjoy an improved position relative to its competitor until such time as the competitor implements the higher Brix level. Therefore, both for the long-run benefit of the world citrus industry and the short-run benefit of the Florida citrus industry, it is important for Florida to take the leading role in perfecting and adopting this technology.

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