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Transporting Perishable Commodities: The Economic Impact of Separating Ethylene-Generating From Ethylene-Sensitive Produce

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ABSTRACT

The purpose of this paper is to predict the changes in shelf-life due to ethylene management during the transportation of lettuce from Arizona to Georgia. The economic effect of transportation management techniques to separate ethylene generating commodities from ethylene sensitive commodities to increase shelf-life is determined. A shelflife model is specified and related to the price at which the lettuce is sold.

I. INTRODUCTION

Transportation plays a significant role in the marketing of fresh produce since most fruits and vegetables are grown a considerable distance from the major consuming areas (Ashby). Fresh fruits and vegetables from Florida or California are for sale in New York stores within a few days of harvest, giving consumers a wide choice of fresh products (Harvey). Since transporting represents one-half or more of the packer-to-retailer time period in the distribution process, the level of transportation services is an important determinant in the final quality of perishable commodities. Postharvest quality losses increase the cost of distribution, reduce quantity, increase consumer prices, and in some cases, reduce the nutritional quality of foods. Consequently, management techniques to maintain the quality of perishable commodities during transportation directly affect the performance of the food system.

Two areas of management are important in controlling quality loss during transportation: the control of temperature (Jordan et al.) and the level of ethylene gas in a truck. In the postharvest physiology of most horticultural crops, ethylene plays an important role, often deleterious, increasing the rate of senescence and reducing shelflife; and sometimes beneficial, improving the quality of the product by faster and more uniform ripening prior to retail distribution (Kader et al. 1985). Some fruits and vegetables produce high concentrations of ethylene while others produce minute amounts. During the transportation of fresh fruits and vegetables, several types of produce are stored together, and under these conditions, ethylene given off by one commodity can adversely affect another.

The physiological principles of ethylene are well known (Morgan; Morris et al.; Yang; Kader, 1985). Consequently, when transporting fresh fruits and vegetables, shippers have been careful to avoid putting high ethylene generating products in the same load as products that are ethylene sensitive. However, current economic pressures are forcing some shippers to mix loads that include both types of commodities. For example, apples naturally are ethylene generators and lettuce is ethylene sensitive. Transporting these commodities together can lead to the browning of the lettuce and a loss of shelflife. While these principles are well known, the economic impact of separating the two kinds of produce has received little attention.

By separating various commodities with respect to ethylene, transportation costs increase due to: (1) higher loading costs; (2) more shipments to the same location; and (3) less than full loads. These and other economic costs must be weighed against the economic effects of shipping ethylene generating and sensitive products together. The question is, will the loss of shelf-life and quality damage be significant enough to offset the increased transportation costs?

II. SCOPE AND APPROACH

The purpose of this study is to predict changes in shelf-life due to ethylene management during the shipping and marketing of lettuce from Arizona to Georgia. The economic impact of ethylene management is evaluated by:

1. Sampling and grading 36 boxes of lettuce from a full truck load arriving in Atlanta from Arizona.
2. Storing twelve boxes with no ethylene treatment, 12 with low levels of ethylene, and 12 with high levels of ethylene. The lettuce was further divided by high and low storage temperature.
3. Grading the lettuce in each group for visual quality deterioration at days three, six, and eight.
4. Using the grading evaluation for each level of ethylene treatment and storage temperature in a lettuce degradation model to estimate expected shelf-life.[1]
5. Analyzing the differences in shelf-life between the three levels of ethylene treatment and estimating the difference in loss attributable to the presence of ethylene.
6. Estimating the gross and net returns due to differences in shelf-life and comparing those to savings in transportation costs.

Thirty-six cartons of lettuce (24 heads per carton), all from the same truck load shipped from Arizona, were purchased on the day of arrival at the Atlanta (GA) Terminal Market in April, 1986. These cartons were loaded into an air-conditioned van and transported 50 km to the evaluation laboratory. Cartons were numbered sequentially as they were transferred to an environmental storage room (5°C, 65% RH). Grading was performed on all heads of lettuce, one box at a time, using the evaluation scales described by Kader et al. (1973).

Cartons were distributed evenly in three environmental storage rooms (5°C, 65% RH) on the basis of a preselected number pattern. One room contained no measurable ethylene (< 0.5 ppm), a second contained low levels of ethylene (3-7 ppm) and a third, higher levels (10-15 ppm). Ethylene was generated with a Tomato Ripening Generator (Catalytic Generators Inc., Norfolk, VA). Each morning the generator was turned on for 2.5 minutes in the low level room and 5 minutes in the high room, resulting in approximately 10 and 20 ppm respectively initially and dissipating to approximately 1 and 5 ppm within 24 hours.

The low and high ethylene levels were chosen to represent the ethylene generated by one and two pallets of apples, loaded in a truck with 850 boxes of lettuce, and transported three days at 50C (Ryalls and Lipton). Apples were chosen for comparison because of their known physiological incompatibility with lettuce. A USDA study concludes that apples are not compatible with lettuce since ethylene production can be high and harmful to lettuce (Lipton and Harvey). The retail price for which the lettuce was sold was obtained from the produce manager at the Terminal Market. Information on related handling of the lettuce was obtained through personal interviews with retail produce managers in the Atlanta area.

III. SHELF-LIFE MODEL

Straight regression lines were fit to the test data and the results for the slopes and intercepts are shown in Table 1. In order to assess the actions of ethylene and storage temperature, the following distribution process was considered:

Phase 1: During transportation from Arizona to Atlanta, the truck temperature is set at 5°C and the ethylene content is at level E (E = control, low or high).[2] With the quality index set at 9.0 in Arizona, the quality index C_1 at arrival in Atlanta is given by equation (1):

$$C_1 = 9.0 + S_1 t_1 \qquad (1)$$

where: t_1 = Days in transit from Arizona to Atlanta;

S_1 = Rate of quality deterioration, i.e., the slope value chosen from Table 1, for the appropriate ethylene level (S_1 is a negative value).

Phase 2: During storage at the retail warehouse and grocery store in Georgia, two storage temperatures are used: low (1°C to 5°C) and high (12°-15°C). Storage is ethylene-free. The shelflife (SL) is then determined by equation (2):

$$SL = \frac{C_2 - C_1}{S_2} = \frac{C_2 - 9.0 - S_1 t_1}{S_2} \qquad (2)$$

where: C_2 = Quality index value when lettuce is at the end of shelflife (SL);

t_1 = Transit time between Arizona and Atlanta;

S_1 = Rate of deterioration during transit (for appropriate ethylene level), and;

S_2 = Rate of deterioration during later storage (for appropriate storage temperature).

For example, for a "low-ethylene" transit of three days and a storage at 5°C, the following equation is obtained:

$$SL = \frac{C_2 - 9.0 - (-0.381)*3}{-0.475} \qquad (3)$$

Table 1
Slope and Intercept Values From Experimental Data

			Slope	Intercept
During Ethylene	Control		-0.182	8.403
Treatment, Temp. 5°C	Low		-0.381	8.625
(During Transit)	High		-0.509	8.733
	Ethylene Pre-treatment	Storage Temperatures		
	Control	1°-5°C	-0.490	9.296
		12°-15°C	-0.561	9.481
Ethylene-Free Storage	Low	1°-5°C	-0.475	8.960
		12°-15°C	-0.543	9.178
	High	1° 5°C	-0.411	8.403
		12°-15°C	-0.518	8.715

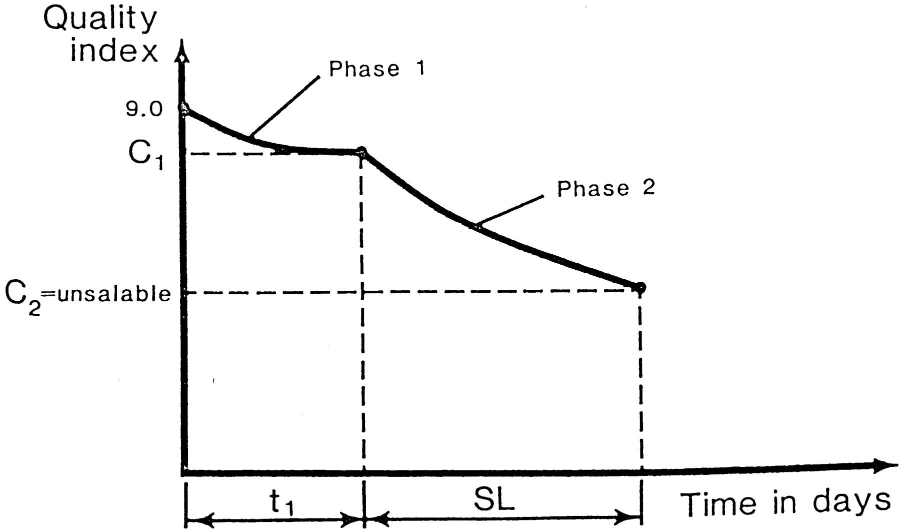

Figure 1. Lettuce quality changes from shipper to grocer.

Figure 1 represents the decline in quality as the lettuce travels from Arizona to the grocery shelf, as affected by ethylene producing apples as expressed in the above equations.[3]

Interviews with grocery producer managers indicated that lettuce is sold for its full price until it deteriorates to approximately 75 percent of arrival quality. This usually happens after two days of warehouse storage and after it has been displayed for two days at the retail store. Perceived quality at the grocery store is related to leaf discoloration and wilting. Those heads not sold are then reduced to half-price until they deteriorate to 50 percent of arrival quality, at which point the remaining heads are discarded.[4] Under such a system, approximately 80 percent of a load of lettuce is sold at full price, 15 percent at half-price and five percent is discarded. The gross revenue for each load can then be estimated as:

$$GR_i = 0.8H_iP + 0.15H_i\frac{P}{2} = .875H_iP \quad (4)$$

where: GR_i = Gross revenues, load i;
H_i = Total number of lettuce heads in load i;
P = Retail price (cents) per head;

and net returns would be:

$$NR_i = GR_i - \text{shipping cost} \quad (5)$$

If the ethylene produced by the apples shipped in the lettuce load does not significantly reduce shelf-life, the economic loss may be less than the return in lower transportation costs. If however, shelf-life is reduced significantly by only the equivalent of one or two pallets of apples in a full truck load of lettuce, the mixing of ethylene sensitive and ethylene generating commodities will reduce economic returns.

IV. RESULTS

Using the lettuce shelf-life model, Table 2 shows the predicted shelf-life for three levels of ethylene exposure and two storage temperatures. Across all three levels of ethylene treatments, shelflife decreases as storage temperature increases from 1°-5°C to 12°-15°C. For the control sample, with no ethylene added, shelf-life declines less due to temperature increases than in the other two groups. However, in all three groups, the decline in shelf-life due to storage temperature is less than one day. The loss in shelf-life ranges from 6 hours for lettuce in the control group, to 75 percent of quality, to just over 16 hours for lettuce in the high ethylene group to 50 percent of arrival quality. Thus, while the experimental data indicates that shelf-life does decline with higher storage temperature, the decrease will not significantly affect the retailing of lettuce.

Considering the control sample, the data in Table 2 indicates that from the time the lettuce arrived in Atlanta, it is predicted to remain above 75 percent arrival quality, and thus can be sold at full price, for an average of 4.5 days. This conforms to the observation that lettuce is stored two days in a warehouse and from two to three days on the grocery shelf at full price. The model also predicted that the sample lettuce will remain above 50 percent arrival quality for an average of 6.35 days. This too conforms to the observation that lettuce will be reduced to half price after four days from arrival and sold for two to three days before being discarded.

When ethylene is added to the environment during transportation, the model indicated that shelf-life will be reduced below the levels required for the pricing formula observed. At low levels of ethylene, comparable to one pallet of apples in a full truck load of lettuce, shelf-life is reduced to an average of

Table 2

Predicted Shelf-life (days) Until Quality Declines to 75 Percent and 50 Percent.

Level of Ethylene Treatment	Storage Temperature (°C)	75 Percent of Arrival Quality (days)	50 Percent of Arrival Quality (days)
Control	1° - 5°	4.63	6.53
	12° - 15°	4.37	6.16
		Avg = 4.50	Avg = 6.35
Low (3-7 ppm)	1° - 5°	3.83	5.89
	12° - 15°	3.42	5.26
		Avg = 3.63	Avg = 5.58
High (10 - 15 ppm)	1° - 5°	3.24	5.45
	12° - 15°	2.84	4.77
		Avg = 3.04	Avg = 5.11

3.63 days for 75 percent of arrival quality; a decline of about 21 hours from the control group. The shelf-life to 50 percent of arrival quality declines to 5.58 days, or by about 18.5 hours.

As expected, when ethylene levels equivalent to two pallets of apples are mixed with a load of lettuce, the decline in shelf-life is more pronounced. It took the lettuce just over 3 days to decline to 75 percent arrival quality and five days to 50 percent, a reduction of just over 35 and 34 hours, respectively, from the control group.

The data show that at low levels of ethylene treatment, instead of over four days of shelf-life above 75 percent quality, the retailer will face about 3.5 days. Thus, the time to sell the lettuce at full price is reduced from 2.5 days to 1.5 days. At higher levels of ethylene, the time to sell lettuce at full price is reduced from 2.5 days to 1.04 days. The time period to sell at half-price remains about two days at all levels of ethylene treatment. Thus the loss in revenue due to the mixing of the load will be felt in the amount of lettuce that can be sold at full price.

Based on the above results the grocer will not be able to sell 80 percent of the lettuce at full price since the time to do so has been reduced approximately 19 percent at low ethylene levels, and 32 percent at high treatment levels. Assuming that the amount of lettuce sold at full price will be reduced by the percentage decline in shelf life, at low levels of ethylene, only 65 percent of the lettuce will be sold at full price and 54 percent for high ethylene levels. The resulting gross revenue[5] for each level of ethylene are shown in Table 3.

As expected, the addition of ethylene, even at levels representing only one and two pallets of apples, reduces net revenues by $2,723.40 and $4,720.55, respectively. This loss is a result of the declining shelf-life at which retailers can sell lettuce at full price.

Comparing this loss to savings in apple ship-

Table 3.

Predicted Gross and Net Revenue Based on Shelf-life of Lettuce Given 3 Levels of Ethylene Exposure.

Level of Ethylene Treatment	Gross Revenue*	Net Revenue
Control	$15,886.50	$12,886.50
Low	$13,163.10	$10,164.10
High	$11,165.95	$8,165.95

*Control GR = .8(20,400).89 + 0.15(20,400).89/2 = .875(20,400).89
Low GR = .65(20,400).89 + 0.15(20,400).89/2 = .725(20,400).89
High GR = .54(20,400).89 + 0.15(20,400).89/2 = .615(20,400).89

Table 4.

Total Loss of Mixing 1 and 2 Pallets of Apples in Truck Load of Lettuce.

Level of Ethylene	Loss in NR from Control	Number of Lettuce Loads to Save One Apple Load	Loss	Saving from One Apple Load	Total Loss
Low	$2,723.40	10	$27,230.50	$3,000	$24,230.40
High	$4,720.55	5	$23,602.75	$3,000	$20,602.75

ments, Table 4 shows the total cost of mixing ethylene sensitive with ethylene generating produce. If a shipper loads one pallet of apples with a full lettuce load, it would take approximately 10 shipments to save the $3,000 cost of apple transportation. Over the 10 loads, the net revenue loss in lettuce would be $27,230.40, representing a total loss of $24,230.40. Two pallets of apples would save an apple shipment with every five lettuce loads, but would produce a total loss of $20,602.75.

Given the difference between the loss in lettuce revenue and the saving in transportation costs, it appears that there is no economic rationale for mixing ethylene sensitive and ethylene generating commodities. The economic loss in lettuce quality vastly outweighs any potential gains from mixing loads in this manner.

V. SUMMARY AND CONCLUSION

When shipping perishable commodities, handlers often prefer shipments that consist of multiple commodities. In so doing, shippers should combine only those commodities that are compatible with respect to a number of factors, including physiologically active gases like ethylene. Over the past few years, the number of mixed loads has been increasing and the mixing of ethylene sensitive and ethylene generating commodities has occurred. Shippers have often put just a pallet or two of an ethylene generating commodity in a load of ethylene sensitive produce with the expectation that losses will not outweigh gains in shipping cost savings.

This paper explored the changes in shelf-life due to ethylene management during the shipping and marketing of lettuce from Arizona and Georgia. The lettuce samples were treated with three levels of ethylene representing no ethylene, the equivalent of one pallet of apples in a full lettuce load, and the equivalent of two pallets of apples. The study found that at even these small additions of a ethylene generating commodity into a full load of lettuce produced significant reductions in shelf-life.

The conclusion of this study is that the economic cost in terms of lettuce quality far outweighs the benefit of the savings in transportation services. Effectively, it is not economically feasible to ship any amounts of ethylene generating produce with an ethylene sensitive commodity. The results of this study are limited to the experimental data employed. Further, other factors need to be taken into account to more accurately judge transportation savings of mixed loads. However, the difference between the cost of lettuce quality loss and any expected transportation savings appear too large to change the conclusions of this study. The recommendations on the compatibility of mixed load, based on physiological effects, that suggest to shippers never to mix ethylene generating with ethylene sensitive produce, are correct when also taking into account economic costs and benefits.

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ENDNOTES

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1. The lettuce samples were taken as a truck arrived in Atlanta and the ethylene treatment simulated transit conditions. Consequently, the shelf-life model took into account the lettuce was three-days old (the time it was actually in the truck). This period was treated in the model as if the lettuce has been stored three days before transit. There is nothing in the literature that suggests a life-cycle to lettuce. Thus, the treatment of the actual transit time as storage will not change the results. In fact, lettuce is often stored a few days before shipment. Only top-quality lettuce was used in the sample, with no indication that it had been exposed to any significant levels of ethylene prior to arrival in Atlanta.
2. As noted earlier, the actual transit time of three days was treated as storage in the shelf-life model.
3. A generalized lettuce shelf-life model to be used with any experimental data set, can be found in Jordan et al.
4. In the visual quality scale used to grade lettuce, 75 percent of arrival quality corresponds to a rating of six on the nine point scale, and 50 percent arrival quality is represented by a rating of five.
5. A full truck load is 850 boxes of lettuce, with 24 heads per box, producing 20,400 heads per load. The retail price at which the sample lettuce was sold was $.89 per head. Net revenue is gross revenue minus an average of $3,000 per load shipping cost. The gross revenue calculations from equation 4 are shown under Table 3.