AIR TRANSPORT OF CALIFORNIA STRAWBERRIES

Factors Affecting Market Quality in Summer Shipments—1965

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SUMMARY

Strawberries shipped by air from growing areas in California to wholesale markets in the Eastern United States were in transit for an average of 17.8 hours. Of this time, about 34 percent was spent in the air; 45 percent, at airports; and 21 percent, in trucks going to and from airports.

The average ambient temperature during transit was 67° F. Strawberry temperatures averaged 50° for precooled lots and 65° for noncooled lots. Transit temperatures of precooled fruit shipped in open pallet loads averaged 54°; in pallet loads covered by a fiberboard sleeve, 51°; and in pallet loads having a polyethylene liner inside the sleeve, 45°. Noncooled fruit had average transit temperatures of 62° in the open pallet, 67° in the sleeved pallet, and 68° in the pallet with both sleeve and liner.

Dry ice was effective in building up CO_2 atmospheres only when used with a polyethylene liner inside the sleeve. The CO_2 escaped so quickly when only the fiberboard sleeves were used that the concentrations did not become high enough to control decay.

Decay losses were smallest in precooled fruit that had been shipped with dry ice on pallets covered by a polyethylene liner and a fiberboard sleeve. However, when the temperature of the berries was kept below 40° F., there was little further benefit from high CO_2 atmospheres. In higher transit temperatures, the modified atmosphere partially compensated for the lack of refrigeration.

Pallet covers should provide insulation, moisture resistance, mechanical strength, and an effective gas barrier. Handling practices that reduce the rapid loss of refrigeration from precooled fruit early in the transit period are needed. Storing strawberries in refrigerated rooms at the originating airport would help to reduce fruit temperatures through the entire transit period.

BACKGROUND

Air shipments of strawberries from California to eastern and midwestern markets have almost doubled in volume during each of the past 3 years. Carlot equivalents (1,400 flats) shipped out of State by air increased from 316 in 1963 to 746 in 1964 and to 1,105 in 1965. Carload equivalents shipped by rail decreased from 3,333 to 924 during this period. Air shipments of strawberries have increased because of an uncertain supply of good surface shipping equipment, an increase in available jet freighters, and comparatively attractive airfreight rates. Within 3 years the airlines are expected to have 80 percent more jet freighters than they had in 1965 (*1*);[1] consequently shipments of perishables by air are likely to increase.

Handling practices for strawberries shipped by air have varied greatly, and little research has been conducted to determine how these practices affect fruit quality. The objectives of this test were to relate spoilage and market quality to each of the following factors:

1. Time, temperature, and handling procedures in each portion of the transit period;

2. Precooling the fruit before shipment;

3. Use of dry ice to modify the atmosphere in transit; and

4. Use of various types of pallet covers to retain the modified atmosphere produced by the dry ice and also to provide physical protection for the berries.

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[1] Italic numbers in parentheses refer to Literature Cited, p. 12.

METHODS

A list of air shipping tests made in 1965 is given in table 1. All tests originated in Watsonville or Salinas, Calif., where strawberries were received from the fields for palletizing and precooling.

Test packages were selected at the receiving dock to insure that all berries used to test each variable were as uniform as possible in respect to origin, quality, size, and maturity. Test flats of berries were placed in the top and middle layers of each pallet load of fruit tested.

Transit Temperatures

Recording thermometers were fastened inside empty berry flats, and a flat with a thermometer in it was paired with each test package of fruit to provide temperature records. Temperatures in the top and middle layers of each pallet were recorded. In most tests that were accompanied, thermocouples also were placed at these or additional locations in the pallet, and temperatures were read on a potentiometer at intervals during handling and transit. Temperature data shown in the results are from accompanied tests.

Dry Ice

Dry ice (about 10 pounds) was wrapped in heavy paper and placed in an empty strawberry flat. An additional empty flat was always set below the one containing dry ice, and paper or fiberboard was used in the latter to help insulate the berries in surrounding flats from the dry ice. The paired flats (with dry ice and insulation) were set in the top two layers of certain pallet loads just before shipment.

Gas Sampling

When dry ice was used in the pallet, a gas sampling tube was inserted into the pallet load to allow the measurement of carbon dioxide and oxygen concentrations at intervals in transit. Atmosphere composition was determined with an Orsat-type analyzer. In unaccompanied tests an atmosphere analysis was made at the airport before departure and also on arrival at the destination airport. In accompanied tests additional analyses were made in the plane and at transfer or stopover points.

Precooling

Precooled and non-precooled fruit were compared in most test shipments. Tests that were not precooled were shipped on the day of harvest. Tests that were precooled were usually held overnight in the precooling room and were shipped the following morning. Two tests were required to make a com-

TABLE 1.—*Strawberry air shipping tests made in 1965*

Test No.	Date	Carrier and flight No.[1]	Shipping origin in California [2]	Stops or transfers enroute	Destination	Accompanied
1	June 16	TWA 570	Watsonville	Los Angeles, St. Louis	Philadelphia	No.
3	July 21	UAL 994	Salinas	Chicago	New York	No.
4	Aug. 4	UAL 994, UAL 982	Watsonville	Chicago	Philadelphia	No.
5	Aug. 10	TWA 570	Watsonville	Los Angeles, St. Louis	Philadelphia	Yes.
6	Aug. 11	UAL 994, UAL 982	Watsonville	Chicago	Philadelphia	Yes.
7	Aug. 18	AAL 834	Watsonville	Chicago	New York	Yes.
8	Aug. 18	UAL 994	Watsonville	Chicago	New York	Yes.
9	Aug. 24	FTL 232	Watsonville	Chicago	Newark	Yes.
10	Aug. 25	UAL 994	Watsonville	Chicago	New York	Yes.
11	Sept. 7	TWA 570	Watsonville	Los Angeles, St. Louis	Philadelphia	No.
12	Sept. 8	UAL 994, UAL 882	Watsonville	Chicago	Philadelphia	No.
14	Sept. 14	AAL 842, AAL 830	Watsonville	Los Angeles, New York	Boston	Yes.
15	Sept. 14	UAL 992	Watsonville	--	Chicago	No.
16	Sept. 15	UAL 994	Watsonville	--	Chicago	Yes.
17	Sept. 21	UAL 992, UAL 986	Watsonville	Chicago	Detroit	Yes.
18	Sept. 22	AAL 830	Watsonville	Chicago	Detroit	Yes.
19	Oct. 5	FTL 232	Watsonville	Chicago	New York	No.
20	Oct. 6	UAL 994	Watsonville	Chicago	New York	No.

[1] TWA = Trans World Airlines, UAL = United Airlines, AAL = American Airlines, and FTL = Flying Tiger Line. These are regularly scheduled flights using cargo planes.

[2] All flights originated at San Francisco International Airport.

plete replication. In a few tests, berries were cooled rapidly in a "forced air" cooler (*4*), which permitted the shipping of precooled and non-precooled berries on the same day.

Pallet Covers

Pallet covers were placed over the berries after they had been precooled and just before they were shipped from the precooling plant. Three types of pallet loads usually were compared in transit: (1) An "open" pallet, in which the flats were exposed except for a vented fiberboard sheet placed over the top layer of fruit; (2) a pallet in which the top and sides of the load of berries were enclosed by a fiberboard sleeve and cap; and (3) a pallet covered by a sleeve and cap as in (2), but with the additional protection of a 4-mil polyethylene liner placed between the berries and the sleeve and stapled to the bottom of the wooden pallet. The floor of the pallet also was covered by fiberboard and polyethylene.

Handling in Transit

After leaving shipping points, the strawberries were handled by conventional commercial procedures. They were hauled in refrigerated trucks to the San Francisco International Airport where, in most tests, the strawberry pallets were set on airline master pallets, each of which accommodated six strawberry pallets. The berries were held in place on the master pallets by a cargo net (fig. 1) or were covered by an aluminum or fiberglass canopy, or "igloo" (fig. 2). Once the master pallets were made up, they were set in a storage area to await loading on the plane. In a few tests, the airline handled the strawberry pallets singly, rather than assembling them on a master pallet.

On loading, test pallets usually were set in a forward position in the cargo compartment in order that they be accessible for temperature and atmosphere readings in transit (fig. 3). Thermocouple wires and gas sampling tubes were passed through a safety net at the front of the cargo compartment into the vestibule between the cargo compartment and the pilots' cabin. This made it possible to obtain data in the vestibule by attaching instruments to the lines.

At terminal airports, the strawberry pallets were removed from master pallets and were transferred to refrigerated trucks that hauled them to the wholesale market (fig. 4). In most markets, the pallet loads of strawberries were moved directly from the trucks to the wholesaler's cold room, but in the New York market, the pallet loads were disassembled in the truck and the paired flats were placed on a hand cart and rolled to the cold room. Test packages of strawberries usually were removed from the pallets at the wholesale market and taken by automobile to the U.S. Department of Agriculture's Market Pathology Laboratory for detailed examination.

FIGURE 1.—Strawberries assembled on a master pallet covered by a cargo net being loaded aboard airfreighter.

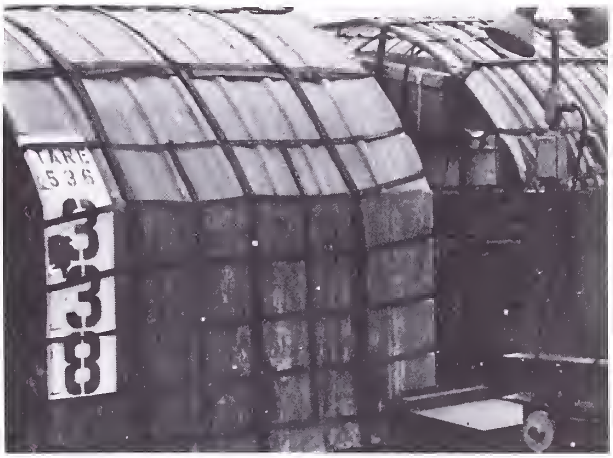

FIGURE 2.—Strawberries on master pallets covered by a fiberglass canopy, or "igloo," ready for loading on airfreighter.

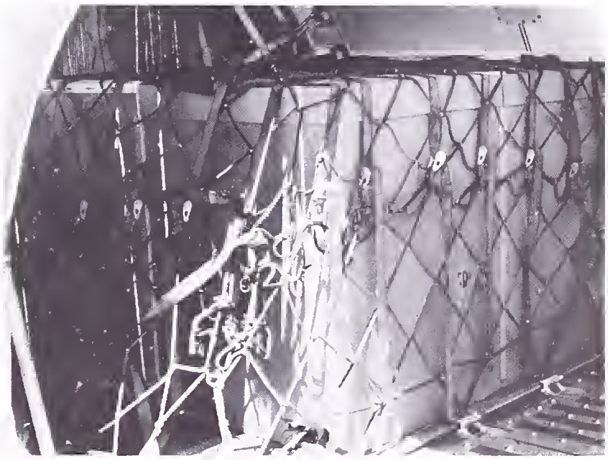

FIGURE 3.—Strawberries assembled on a master pallet, which is set in a forward position in cargo compartment and secured to floor of airfreighter.

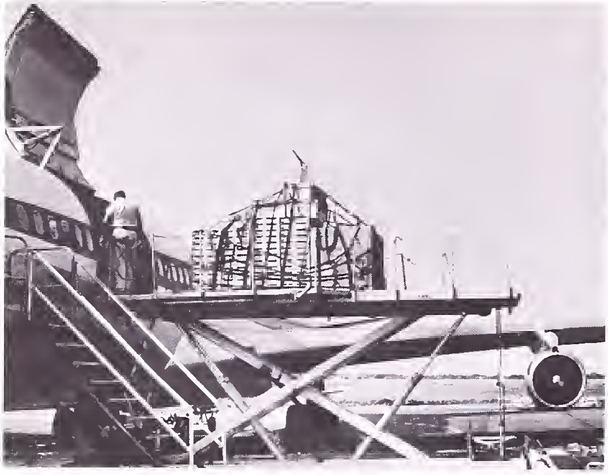

FIGURE 4.—Test pallets of strawberries being unloaded from airfreighter in Philadelphia, Pa.

Berries were examined on arrival and at the end of 1 and 2 days' exposure to a temperature of 60° F. The berries were examined individually for decay, bruises, and other defects.

Analysis of Data

Data on temperature, atmosphere, and decay were averaged from readings taken on several similar flights. The combined data from several flights provided a more representative result on which to base conclusions than would separate data from an individual flight.

Values for the percent decay were converted to logarithms and treated statistically by analysis of variance. Precooling versus no precooling was treated as whole plots, pallet covers as split plots, and positions within the pallet as split-split plots. The different examinations were analyzed separately. Duncan's Multiple Range test was used to test possible differences among means within a factor. Some of the intended replications were incomplete and were, therefore, omitted from the analysis of variance. Five complete replications were obtained from 10 tests.

The data were further analyzed by correlating the transformed decay values with the average temperatures recorded at the initial airport, at intermediate points, and at the destination airport. This portion of the transit period was used for analysis because the most complete and reliable temperature data were obtained during this time.

RESULTS

Time in Transit

The average total transit time of strawberries from the shipping point to their arrival at the wholesale market was 17.8 hours (fig. 5). Of this total time, berries spent 5.9 hours, or 33.3 percent, on the plane; 8.2 hours, or 45.2 percent, at airports; and 3.8 hours, or 21.5 percent, in trucks being hauled to and from airports.

The transit time at airports was divided as follows: 3.3 hours at San Francisco International Airport; 2.9 hours at transfer points; and 2.0 hours at destination airports.

The transit time of berries on trucks was divided as follows: 2.6 hours from shipping point to the San Francisco International Airport, a distance of about 94 miles; 1.2 hours from the destination airport to the wholesaler.

Two-thirds of the total strawberry transit time occurred on the ground and only one-third in the air.

Temperatures in Transit

Ambient Temperatures

Ambient temperatures varied for individual shipments, but the averages are typical of the environment during August and September (fig. 6). Ambient temperatures averaged near or above 60° F. more than three-fourths of the transit time because the berries were not under refrigeration except when they were in trucks while being hauled to and from airports. Most stopovers and destination of test shipments occurred at night or early in the morning when environmental temperatures were relatively low. However, temperatures over 80° were measured at terminal airports in a few test shipments that were picked up near midday.

Fruit temperatures in precooled and noncooled lots.

Precooled fruit stayed 10° to 17° F. cooler than noncooled fruit most of the time it was in transit (fig. 6). The temperature of precooled fruit was 37° at the beginning and rose rapidly early in transit; for the remainder of the trip it rose at a less rapid rate and climbed to a final average high of 56°. Noncooled fruit remained in the 65° to 70° range the entire time it was in transit.

Although the berries were hauled in a refrigerated truck to the airport, the temperature of the fruit

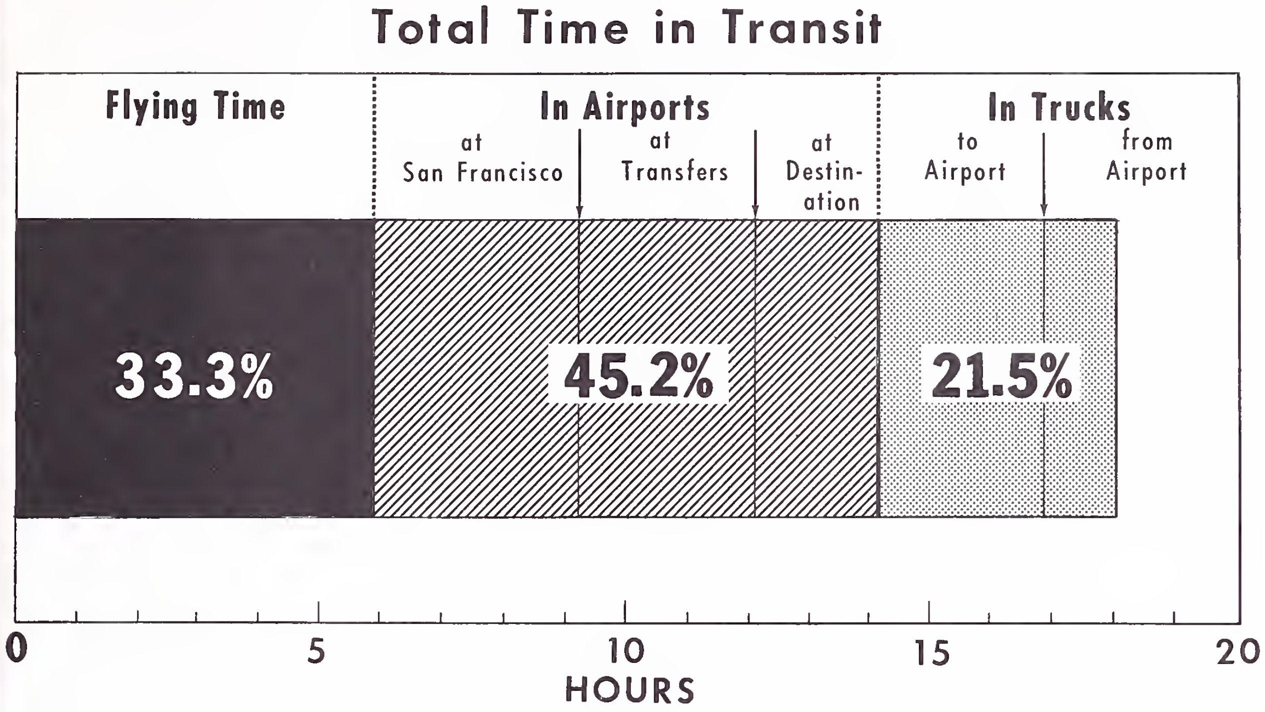

FIGURE 5.—Proportion of transit time for stated phases of shipping California strawberries by air.

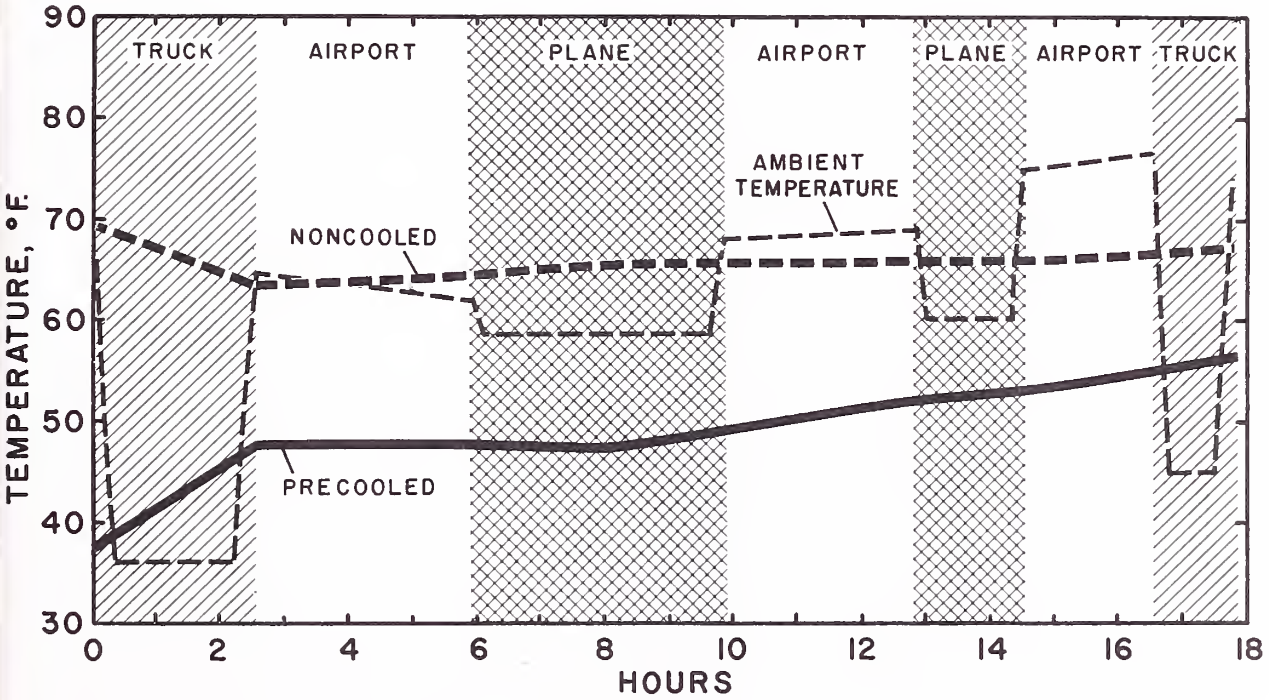

FIGURE 6.—Average transit temperature of California strawberries shipped by air to eastern markets.

increased considerably by the time the first temperature reading was taken at the airport. Some loss of refrigeration occurred while the fruit was moved from the precooler to and on the truck. Additional refrigeration was lost while the fruit was unloaded at the airport and before it was accessible for the first temperature reading at the airport.

Fruit temperatures in relation to type of pallet covers

Precooled fruit warmed most rapidly when shipped on open pallets and least when shipped on pallets covered by a fiberboard sleeve plus a polyethylene liner (fig. 7). At the end of the transit period, precooled fruit shipped on the open pallets had an average temperature of 67° F.; that on pallets protected by a fiberboard sleeve, 54°; and that on pallets protected by a sleeve plus a polyethylene liner, 48°. Thus, the temperature of berries on arrival at the wholesale market differed by almost 20°, depending upon the type of pallet cover that protected them in transit.

Average transit temperature of noncooled fruit was not affected so much by the type of pallet cover as that of precooled fruit (fig. 8). Noncooled fruit shipped on an open pallet had slightly lower temperatures during most of the transit period than fruit protected by pallet covers. Some cooling of fruit on the open pallets occurred in the truck on the way to the airport. However, all noncooled fruit had about the same average temperature on arrival at the wholesalers, regardless of the type of pallet cover used.

Fruit temperatures at tops and centers of pallets

The average temperatures of top- and middle-layer precooled berries differed more than those of noncooled berries (figs. 9 and 10). Middle layers of precooled pallets had temperatures between 40° and 50° F.; top layers were between 50° and 60° most of the transit period. Noncooled fruit in top layers had slightly lower average temperatures than fruit in middle layers, but fruit in both layers remained between 60° and 70° in transit.

The type of pallet cover affected strawberry temperatures in both the top and middle layers of pallet loads. On arrival at destination airport, top-layer temperatures of precooled fruit on open pallet loads averaged 4° F. higher than those on sleeve-covered pallets, and they were 12° higher than those on pallets covered by sleeve and polyethylene liner. Middle-layer temperatures of precooled fruit averaged 10° higher on open pallets than those on sleeve-covered pallets and were 16° higher than those on polyethylene-lined pallets.

The type of pallet cover had only a slight effect on top and middle-layer temperatures of noncooled berries. Temperatures in these layers differed only by a few degrees for a particular type of pallet cover used.

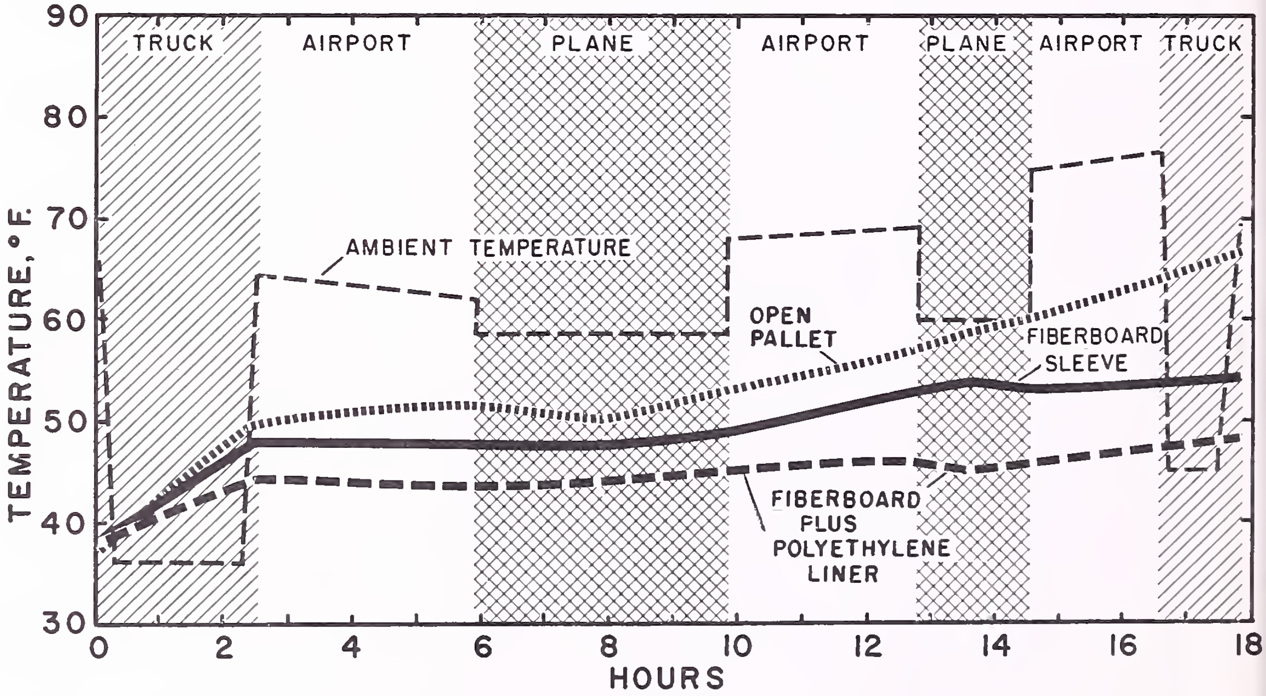

FIGURE 7.—Average transit temperature of precooled California strawberries shipped by air on pallets protected by stated types of covers.

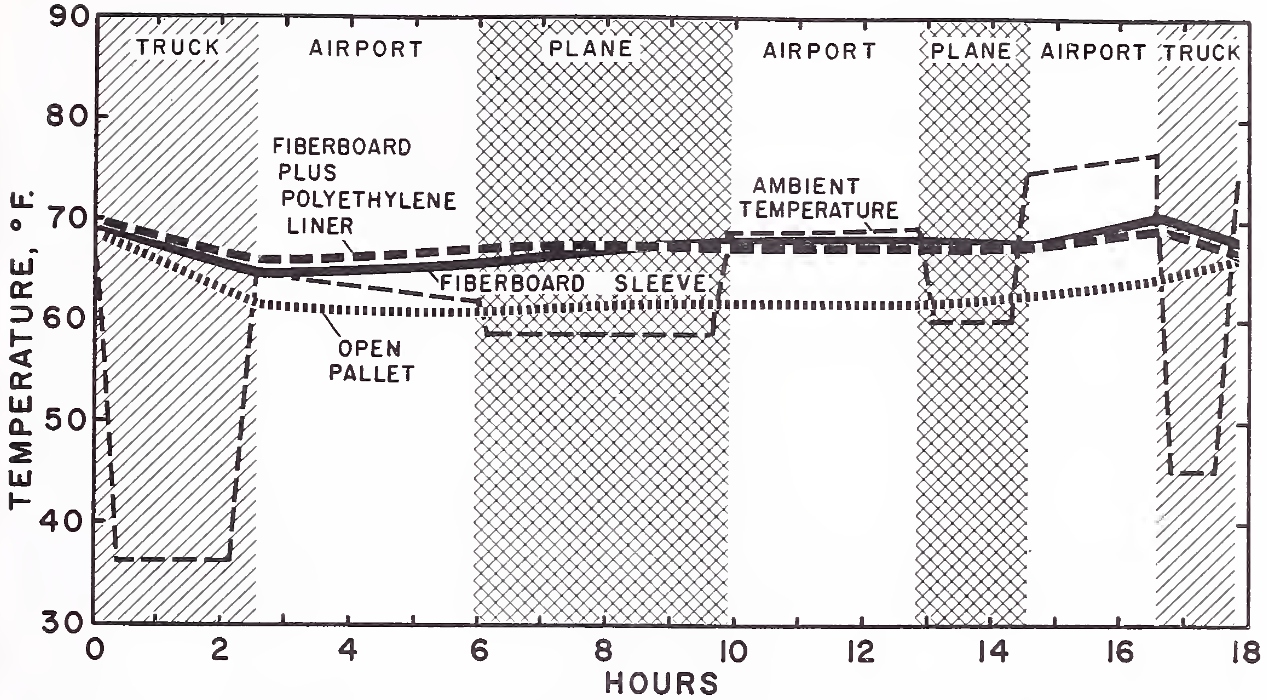

FIGURE 8.—Average transit temperature of noncooled California strawberries shipped by air on pallets protected by stated types of covers.

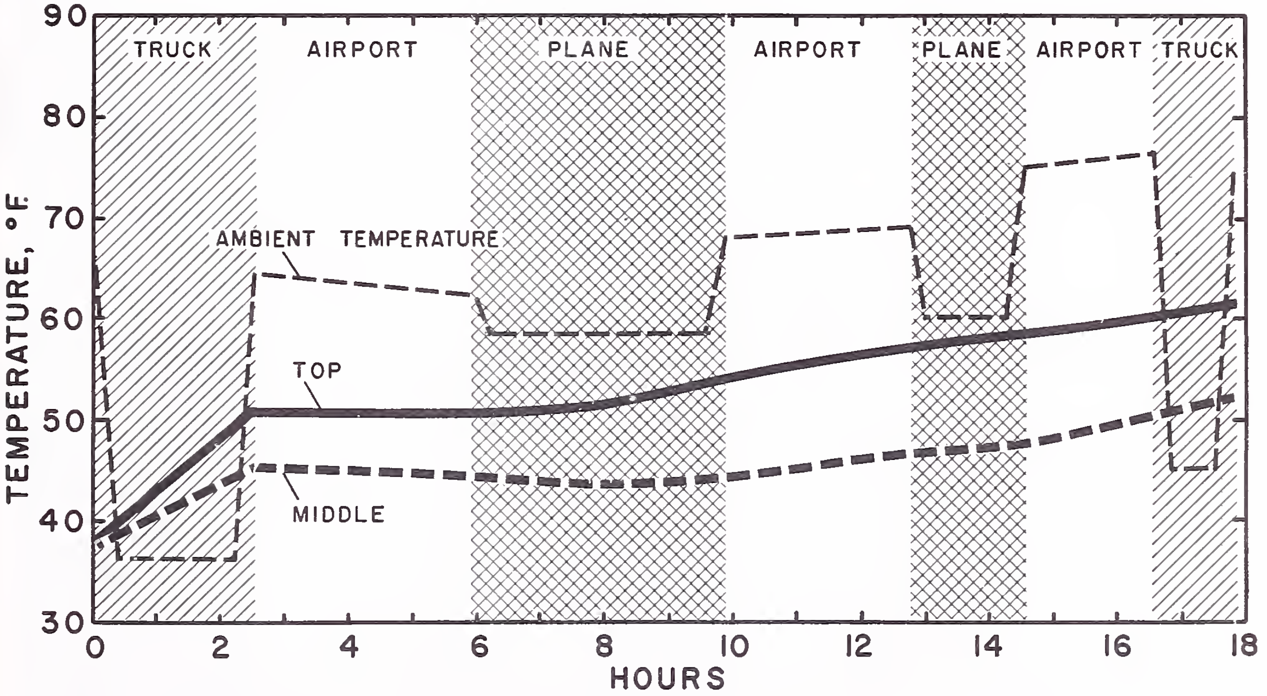

FIGURE 9.—Average transit temperatures of precooled California strawberries in top and middle layers of pallet loads—summer 1965.

Atmospheres in Transit

The type of pallet cover controlled the buildup of carbon dioxide during transit (table 2). With the conventional fiberboard sleeve and dry ice, very low levels of CO_2 accumulated within the pallet loads of berries. Oxygen levels were only slightly affected by the dry ice. A polyethylene liner under the sleeve provided an effective gas barrier and resulted in accumulations of carbon dioxide that were high enough to reduce decay development. With the polyethylene liner, the average carbon dioxide levels of precooled berries at various points in transit ranged from 20.5 percent to 35.5 percent; those of noncooled berries ranged from 29.8 percent to 45.6 percent. Readings at Chicago and at destination were taken shortly after landing and reflect the slight movement of outside air into the pallet because of the increase in atmosphere pressure at ground elevation. Air tended to dilute the CO_2 level within the pallet. Oxygen levels were not low enough in the lined pallets to have significant effects on quality or decay (*3*); consequently, the effects obtained are attributed solely to the increase in CO_2.

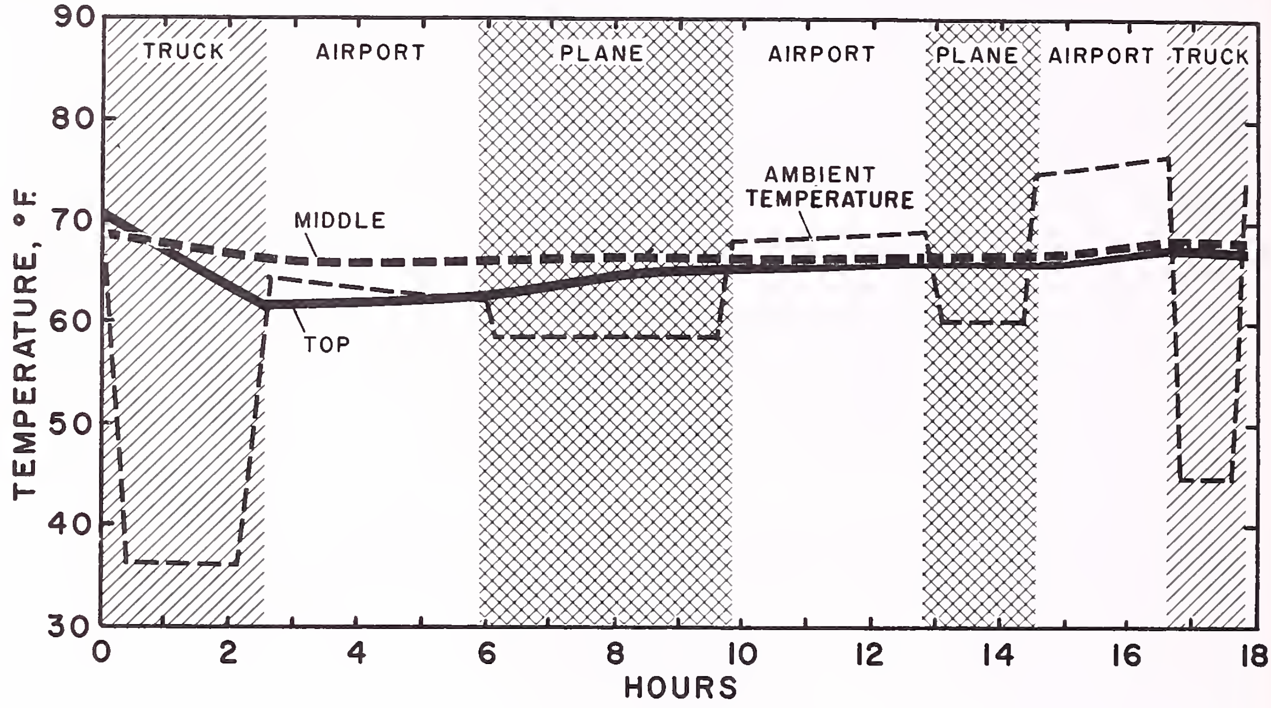

FIGURE 10.—Average transit temperatures of noncooled California strawberries in top and middle layers of pallet loads—summer 1965.

TABLE 2.—*Carbon dioxide and oxygen concentrations in accompanied air shipments of California strawberries in relation to type of pallet cover and other conditions—Summer 1965*

Place	Fiberboard sleeve and polyethylene liner plus dry ice		Fiberboard sleeve plus dry ice	
	CO_2	O_2	CO_2	O_2
	Pct.	*Pct.*	*Pct.*	*Pct.*
Precooled berries:				
San Francisco International Airport	20.5	14.9	1.8	20.1
In transit	31.8	12.3	2.7	19.5
Chicago	29.9	12.6	1.5	19.0
In transit	35.5	--	--	--
Destination	29.8	11.0	2.0	19.0
Noncooled berries:				
San Francisco International Airport	29.8	10.6	2.1	20.6
In transit	43.8	5.5	3.8	19.3
Chicago	39.1	7.0	2.1	20.7
In transit	45.6	6.0	2.0	20.0
Destination	40.4	--	1.0	--

Decay in Relation to Precooling and Type of Pallet Cover

Precooled berries had significantly less decay than noncooled berries after 1 or 2 days' exposure to a temperature of 60° F., but not on arrival at the wholesale market (table 3). Differences in decay of berries on arrival attributed to type of pallet cover were not significant. However, after holding 1 or 2 days at 60°, significantly less decay had developed in berries that were shipped on pallets covered by polyethylene (plus sleeve) than in berries that were shipped on pallets covered only by the sleeve or on pallets that were shipped open. Differences in decay due to type of pallet cover were greatest in noncooled berries. In general, berries in the top layers of the pallets had more decay than those in the middle layers, which is a response to the temperature differences already mentioned (table 4).

The decay data may be related directly to the average temperatures in transit without regard to the reason for the temperature difference. The logarithm of the percent decay in fruit not covered by a polyethylene liner was linearly related to the

Table 3.—*Decay in California strawberries in relation to precooling and type of pallet cover—Summer 1965* [1, 2]

Examination time	Percentage of decay in berries when pallet loads were covered by—			
	Fiberboard sleeve and polyethylene liner plus dry ice	Fiberboard sleeve plus dry ice	Open	Average
	Pct.	*Pct.*	*Pct.*	*Pct.*
On arrival:				
Precooled	8.3 a	9.1 a	10.6 a	9.3 a
Noncooled	8.2 a	9.5 a	8.7 a	8.8 a
Average	8.2 a	9.3 a	9.6 a	
Plus 1 day at 60° F.:				
Precooled	8.2 a	11.1 a	12.3 ab	10.4 a
Noncooled	12.5 ab	23.5 c	21.5 bc	18.5 b
Average	10.1 a	16.1 b	16.2 b	
Plus 2 days at 60° F.:				
Precooled	20.8 a	27.8 ab	28.5 ab	[3] 25.5
Noncooled	27.2 ab	42.7 b	38.0 ab	[3] 35.3
Average	23.8 a	34.4 b	33.0 b	—

[1] Decay was mostly Rhizopus rot.

[2] Geometric means of 5 replications (10 tests): Means (or averages) within a box not followed by the same letter are significantly different at the 5-percent level.

[3] These means are significantly different at the 10-percent level.

Table 4.—*Decay in California strawberries in relation to position on pallet and type of pallet cover—Summer 1965* [1 2]

Examination and position on pallet	Percentage of decay in berries when pallet loads were covered by—			
	Fiberboard sleeve and polyethylene liner plus dry ice	Fiberboard sleeve plus dry ice	Open	Average
	Pct.	*Pct.*	*Pct.*	*Pct.*
On arrival:				
Top layer	8.3 a	10.2 a	10.2 a	10.1 a
Middle layer	8.2 a	8.5 a	7.7 a	8.1 a
Plus 1 day at 60° F.:				
Top layer	8.4 a	18.9 b	18.3 b	14.3 a
Middle layer	12.3 ab	13.8 ab	14.4 ab	13.5 a
Plus 2 days at 60° F.:				
Top layer	23.8 a	40.0 c	39.0 bc	33.3 a
Middle layer	23.8 a	29.6 abc	27.9 ab	27.0 b

[1] Decay was mostly Rhizopus rot.

[2] Geometric means of 5 replications (10 tests): Means (or averages) within a box not followed by the same letter are significantly different at the 5-percent level.

average transit temperature (fig. 11). After 1 day at 60° F., the amount of decay doubled for each 15° increase in transit temperature. After 2 days at 60°, the amount of decay doubled for each 23° increase in transit temperature. When a polyethylene liner was used to maintain a high CO_2 concentration, decay did not increase significantly with increases in temperature. The regression curves also indicate that at 40° or below, high CO_2 concentration had no significant effect on decay. Consequently, the use of CO_2 is of greatest benefit when the temperature is above 40°, which occurs a major part of the time in air shipments.

In a laboratory experiment, berries held for 24 hours at 60° or 37° F. in atmospheres with 20-, 30-, or 40-percent CO_2 had significantly less decay than those held in air, after being held an additional 48 hours in air at 60° (table 5). Differences in decay among berries held in 20-, 30-, or 40-percent CO_2 were not statistically significant, but off-flavors could be detected in fruit exposed to 40-percent CO_2.

The laboratory results, therefore, substantiate the shipping tests in respect to the effectiveness of CO_2 in reducing decay losses. Other laboratory tests made under somewhat different conditions also show the effectiveness of CO_2 (*2*, *7*, *8*, *9*, *10*).

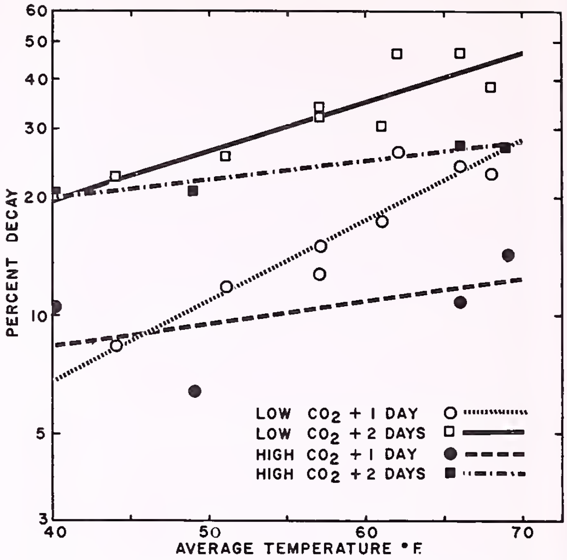

FIGURE 11.—Effect of transit temperature and carbon dioxide (dry ice) on decay of air-shipped California strawberries during marketing. Fruit was held 1 and 2 days at 60° F. after transit. Correlation coefficients after 1 and 2 days were 0.94 and 0.87, respectively. Decay percentages are plotted on a logarithmic scale.

DISCUSSION AND CONCLUSIONS

Previous work (*5*) has shown that in a 24-hour period about twice as much decay occurs in strawberries held at 55° F. than at 34°, and about four times as much decay occurs at 70° than at 34°. Although the transit time for air shipments is now less than 24 hours, the same temperature-decay relationships prevail. Respiration rates have a similar response to temperature, in that they are about three times as fast at 55° than at 36° (*11*). The respiration rate correlates with physiological aging of the fruit; consequently, keeping the rate low helps to extend market life of the product. Refrigeration of highly perishable commodities cannot be neglected, therefore, even during short transit periods.

TABLE 5.—*Decay in California strawberries held in laboratory 24 hours in modified atmospheres plus an additional 48 hours in air at 60° F.*

Temperature, degrees F.	Percentage of decay in berries held 24 hours in air or indicated CO_2 concentration[1]			
	In air	20-percent CO_2 Concentration	30-percent CO_2 Concentration	40-percent CO_2 Concentration
	Pct.	*Pct.*	*Pct.*	*Pct.*
60	42 a	14 bc	12 bcd	6 e
37	18 b	10 bcde	9 cde	7 de

[1] Averages not followed by the same letter are significantly different. Data are averages of 2 varieties and 3 replications.

The airlines have greatly improved the mechanized handling of airfreight. Palletization has reduced mechanical damage to strawberries and other freight, but no distinction is made in handling between perishables and that of other materials. Although loading or unloading the plane requires only about 30 minutes, 45.2 percent (8.2 hours) of the total transit time was spent at air terminals where ambient temperatures were usually above 60° F., and frequently were above 70°. This is a strong argument for the need of refrigerated holding areas for perishable produce at airports. A limited amount of refrigerated space is available in some terminals, but most perishable shipments receive no protection from high temperature at airports. Some carriers have plans to provide more low-temperature holding rooms.

Ambient temperatures on the plane are necessarily high (near 60° F. average) because freight may include animals. Temperatures will continue to be high in planes until the volume of perishable shipments increases to the point that berries or other commodities requiring low temperature make up entire plane loads.

Precooled strawberries had an average transit temperature of about 50° F., noncooled berries averaged about 65°. The refrigeration provided by precooling is maintained for a longer time by berries in transit if pallet loads are covered by fiberboard pallet covers than when berries are shipped in open pallet loads. The loss of refrigeration was further reduced when a polyethylene liner was placed inside the fiberboard pallet cover.

Less decay developed in precooled fruit than in noncooled fruit in spite of the fact that the time between harvest and arrival at the wholesale market was almost a day longer for the precooled berries. This fact suggests that greater reductions in spoilage could be achieved if berries were rapidly and uniformly precooled and shipped on the day of harvest. A few lots were precooled by the forced-air principle (*4*), but insufficient tests were made to fully evaluate this factor.

Dry ice reduced decay but only when it was used in conjunction with a polyethylene liner that retained the CO_2 gas in effective concentrations (above 20 percent). The use of dry ice with only the fiberboard sleeve as a cover was ineffective, and it did not justify the cost of the ice, the extra handling required, and the cost of the space the ice occupied.

The higher temperatures in top layers of the pallets than in middle layers were correlated, in general, with the higher percentages of decay in the top layers than in the middle layers. Thus, the temperature-decay relationship in shipping tests follows the same pattern shown in laboratory studies.

Precooling the fruit, covering the pallets with polyethylene film, using dry ice, and using a fiberboard sleeve provide the maximum protection for air shipments of strawberries. However, if the berries were properly precooled, and if the refrigeration could be maintained during most of the transit period, dry ice and the polyethylene liner would not be needed to control decay. If the shipper cannot precool his fruit, dry ice and a good CO_2 barrier should be provided. The polyethylene film requires considerable labor to apply, and more developmental work is needed to devise a pallet cover with an effective gas barrier that is economically feasible to use.

Temperature variation within the pallet loads suggests that an insulated cover is needed. At 32° to 41° F., a 1,000-pound pallet of berries produces enough heat in 24 hours to increase the temperature of the pallet load 2° to 3° (*6*). Ten pounds of dry ice absorbs about this same amount of heat in vaporizing and warming to 32°. Most of the warming observed in these tests, therefore, was caused by heat leakage from the outside. A well-insulated pallet cover could reduce the warmup of properly precooled berries to negligible amounts for the entire trip.

At 68° F. the warmup due to respiration could amount to 22° in 24 hours. To absorb this much heat would require 80 pounds of dry ice. Use of this much dry ice would not be practical. Although excessive heating is possible, these tests show that warm fruit can be shipped safely if sufficient dry ice is used to modify the atmosphere with an effective gas barrier. (See fig. 11.)

Physical protection of the pallet loads of berries from rainfall and mechanical damage during handling also is needed in the design of a pallet cover. A pallet cover should, therefore, provide (1) an effective gas barrier, (2) insulation, (3) moisture resistance, and (4) mechanical strength.

The rapid rise in temperature between the time the berries were removed from the precooler and the time the first reading at the airport was taken emphasizes the need for additional effort on the parts of shippers, truckers, and air carriers to maintain the refrigeration achieved during precooling. If the initial rise in temperature could be delayed until the berries are loaded on the plane (an average of 6 hours, or one-third of the time in transit), it is quite likely that final temperatures would be lower and certainly the average temperature for the entire time in transit would remain at lower levels than was shown in the current tests.

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