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EFFECT OF SOLID AND GASEOUS CARBON DIOXIDE UPON TRANSIT DISEASES OF CERTAIN FRUITS AND VEGETABLES

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INTRODUCTION

The effect of abnormal atmospheres on the growth of fungi and on the keeping quality of fruit and vegetables has been a matter of discussion for more than a century, and beneficial effects from different types of gas storage have often been reported. The present studies were undertaken not so much with the idea of developing a method of storage as with the hope of finding at least a partial remedy for the spoilage that results from the warm condition of fruit and vegetable products during the first hours after loading for shipment.

[1] The writers wish to acknowledge their indebtedness to Neil E. Stevens for cooperation in the strawberry and dewberry shipments, and to D. F. Fisher and his associates for cooperation in the shipments in which blower precooling was used. They also wish to express their appreciation of the kind cooperation of growers, and of representatives of the various transportation companies concerned.

It seemed possible that a limited use of solid carbon dioxide might be of value in this connection, both because of its refrigerating effect and because of the inhibiting action of the carbon dioxide gas produced. To determine the practicability of this method of food preservation required detailed information concerning the various effects of the gas upon different fruits and vegetables under various conditions.

Since, in preliminary experiments, it was found that the peach and the strawberry were particularly susceptible to injury from carbon dioxide gas, they have been given special consideration. This bulletin reports the results of four years' experimental work on peaches and strawberries, three years' work on dewberries, and tests on other fruits and on vegetables.

REVIEW OF LITERATURE

In 1821 Bérard (*3*)[2] reported that most fruits can be preserved for a certain period by picking a few days before they are ripe and storing in an atmosphere free from oxygen. Peaches, plums, and apricots were held in good condition for 20 to 30 days, and pears and apples for 3 months; but when these periods were exceeded, the fruit failed to ripen upon removal to normal air. Bérard's paper was considered of sufficient importance to be awarded a prize by the French Academy of Sciences, but apparently his new method of food preservation was not put into practical use.

In 1895 Lopriore (*20*) showed that the germination of the spores of *Mucor mucedo* was delayed by the presence of 10 per cent of carbon dioxide in the atmosphere, and that pure carbon dioxide, though producing total inhibition, did not kill the spores even after an exposure of three months.

In 1907 Fulton (*12*) reported experiments in which strawberries were stored in packages and containers having various degrees of tightness. A moderately tight package retarded mold to some extent and was of material value in retaining the bright color and attractive appearance of the fruit, but packages that were sufficiently tight to allow the carbon dioxide of the storage air to reach a concentration of 7 to 10 per cent in a period of six days caused the fruit to develop a bad flavor.

In 1911 Gore and Fairchild (*13*) investigated customs already established in Japan and discovered that the astringency of Japanese persimmons could be removed by three to five days' storage in an atmosphere of carbon dioxide.

In 1913 Hill (*16*) reviewed the literature on gas storage of fruits, raised the question of the effect of holding fruit in a tight refrigerator car without change of air, and pointed out the need of better means of preserving fruit in transit. He reported experiments showing that storage in oxygen-free air results in the spoilage of the flavor and quality of the fruit. Apples stored in hydrogen or nitrogen began to lose their normal color after four or five days. Peaches held in hydrogen, nitrogen, or carbon dioxide for seven days acquired a bad flavor, which was intensified by longer storage. The rate of softening of peaches was greatly decreased by carbon dioxide and to

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[2] Italic numbers in parentheses refer to Literature Cited, p. 58.

a considerable extent by hydrogen and nitrogen. Ripe Concord and Catawba grapes respired as rapidly in hydrogen or in nitrogen as in air, and during the first 36 hours of storage this was also true of ripe Duke cherries; but the respiratory activity of green peaches was immediately depressed by storage in either hydrogen or nitrogen.

Bartholomew (*2*) discovered that black-heart of potatoes is caused by a deficiency of oxygen resulting from poor aeration.

Shear, Stevens, and Rudolph (*30*) found that cranberries held in nearly pure carbon dioxide were spoiled by the end of three days, the spoilage becoming evident in a loss of color, in a softening of the flesh, and in the development of a bitter flavor.

Brooks and Cooley (*5*) and Brooks, Cooley, and Fisher (*7, 8*) found that high percentages of carbon dioxide for a short period or low percentages for a long period delayed the ripening of apples and served as a partial preventive of apple scald, but that there was danger of injuring the flavor of the fruit. Apples were held in pure carbon dioxide for two to six days at 15° C. with no evident injury, but when the period of exposure was extended the fruit developed an alcoholic and nauseating flavor, often followed by a browning and softening of the flesh. Apples were held at 2.5° in an atmosphere containing 2 to 3 per cent carbon dioxide for 20 weeks without injury, and in one instance in 14 per cent carbon dioxide at 15° for several weeks without injury; but attempts to use higher percentages of carbon dioxide over a prolonged period resulted in serious damage to the fruit.

Kidd and West and their associates of the Food Investigation Board of England made an extensive study of the effects of carbon dioxide upon fruit. In the report of the board for 1919 (*14, Rpt. 1919, pp. 17–18*) it was stated that strawberries could be kept in excellent condition for three to four weeks at 1° to 2° C. either in an atmosphere of oxygen or in one containing reduced amounts of oxygen and moderate amounts of carbon dioxide. Under both of these conditions the growth of fungi was markedly inhibited. In 1920 (*14, Rpt. 1920*) an experiment was reported in which the storage life of apples was doubled by holding in gas storage with an average concentration of 14 per cent carbon dioxide and about 8 per cent oxygen.

In a special report of the board in 1923 (*18*) it was pointed out that the losses in oversea shipments from soft scald of apples and brown-heart of apples are due to the poor ventilation in the hold of the ship with the accompanying increase in carbon dioxide and decrease in oxygen. The lowest concentration of carbon dioxide associated experimentally with the occurrence of brown-heart was 13.6 per cent. In a special report in 1927 (*19*), gas storage was shown to give its optimum results at a temperature of about 46.5° F. At that temperature, storage in atmospheres containing 12 per cent of carbon dioxide and 9 per cent of oxygen practically doubled the storage life of apples and was approximately equivalent to air storage at 34°. It was found that gas storage (10 per cent carbon dioxide and 11 per cent oxygen) owed its effectiveness as much to the reduction in the quantity of oxygen as to the increase in carbon dioxide.

These investigators considered that 10 per cent of carbon dioxide might be excessive at temperatures below 42° F., and 11 per cent or less of oxygen dangerous at temperatures above 65°. Diminishing the oxygen or increasing the carbon dioxide concentration in an atmosphere was found to decrease the respiratory activity in proportion to the effect upon the rate of ripening or aging of the apples. Within the temperature range of susceptibility, they found that the onset of low temperature internal breakdown was accelerated by increasing the concentration of carbon dioxide in the storage air above 5 per cent or by reducing the concentration of oxygen below the normal 21 per cent.

Brown (*9*) found that within very wide limits variation of oxygen pressure had little effect on the germination and growth of fruit-rot organisms, whereas carbon dioxide retarded both germination and growth. The lower the temperature the weaker the nutrient, and, to a less degree, the greater the density at which the spores were sown the more marked became this retarding action. He considered that the greater retardation at lower temperatures could be explained partly on the basis of the greater solubility of carbon dioxide at these temperatures. A concentration of carbon dioxide as great as 20 per cent at ordinary temperatures was found less effective in controlling fungal growth than was a drop in temperature of 10° C. without carbon dioxide. He found that carbon dioxide is always a retarding factor in fungal growth except in cases where alkaline staling takes place, and then it acts as a remedy, making the growth greater where the gas is present.

Experiments were reported in which *Botrytis cinerea*, *Monilia cinerea*, *Rhizopus nigricans*, *Penicillium glaucum*, and other fungi were tested in atmospheres containing different percentages of carbon dioxide. Of the above fungi, *B. cinerea* was inhibited most by the action of the gas and *P. glaucum* least. When inoculated into apples and held at a temperature of either 5° or 15° C., Botrytis was almost completely inhibited by 20 per cent carbon dioxide and greatly checked by 10 per cent. *M. cinerea* was also greatly inhibited, but not so much as Botrytis, while *P. glaucum* was very little affected even by 20 per cent of carbon dioxide.

Bergman (*4*) found that in unventilated cars of strawberries the carbon dioxide did not exceed 2.5 per cent, and he considered this amount not injurious.

Magness and Diehl (*21*) reported that atmospheres containing carbon dioxide in concentrations of 5, 10, 20, and 50 per cent, respectively, with 20 per cent of oxygen, markedly inhibited the softening rate of apples, the retardation in rate of softening varying with the carbon-dioxide concentration. Concentrations of 5 and 10 per cent of carbon dioxide had no appreciable effect upon the flavor of apples. In concentrations of 20 per cent of carbon dioxide, however, there was a slight flavor of fermentation, and fruit held in concentrations of 50 per cent of carbon dioxide was entirely inedible. The experiments were made at 71.5° F. and were continued for a period of from 10 to 11 days.

Stevens and Hawkins (*31*) suggested the possibility that the accumulation of carbon dioxide in the center of a tightly packed car of strawberries might be sufficient to reduce the rot development.

Thomas (*32*) found the percentage of carbon dioxide in the storage air to be a controlling factor in the production of alcohol and acetaldehyde by apples.

Durrell (*10*) reported that concentrations of from 1 to 5 per cent of carbon dioxide stimulated the spores of *Basisporium gallarum* to profuse germination, whereas control cultures failed to germinate.

Fellows (*11*) found that a variation in the carbon dioxide content of the atmosphere between 0.9 and 18 per cent did not greatly affect the growth of *Ophiobolus graminis*. In liquid medium, growth diminished gradually as the oxygen concentration decreased; on solid medium, marked diminution in growth did not occur until the oxygen was below 6 per cent.

Howe (*17*) found that a continuous flow of carbon dioxide into spore suspensions of *Ustilago levis* increased the percentage of germination, apparently as a result of favorable changes in the hydrogen-ion concentration.

Platz, Durrell, and Howe (*26*) reported that atmospheres containing 15 per cent of carbon dioxide were optimum for the germination of chlamydospores of *Ustilago zeae*. They attributed the stimulating effect of the carbon dioxide to the increase in acidity that it produced in the culture medium.

Rippel and Bortels (*27*) found that spores of *Aspergillus niger* germinated very poorly in an atmosphere free from carbon dioxide.

Overholser (*25*) found that the storage life of Fuerte avocados could be considerably extended by holding them in an atmosphere having only 4 to 5 per cent of oxygen and not over 4 or 5 per cent of carbon dioxide. Exposure to an atmosphere containing 20 to 25 per cent of carbon dioxide did not result in objectionable flavors, but prevented normal softening of the flesh even after removal from the experimental conditions.

In another publication, Overholser (*24*) reported that the astringency of Japanese persimmons could be removed by exposure to an atmosphere of carbon dioxide for 12 to 24 hours.

Barker (*1*) found oranges less liable than apples to injury from high concentrations of carbon dioxide. Pronounced injury resulted after five weeks' storage in 25 to 40 per cent carbon dioxide at 34° F., but not at 45° and 55°.

Onslow and Barker (*23*) reported that the alcohol content of oranges severely injured by storage in an atmosphere of high carbon dioxide and low oxygen concentration is significantly higher than that of control oranges.

Thornton (*33*) has shown that the life of cut flowers, especially roses, can be prolonged by holding them in an atmosphere containing a relatively high percentage of carbon dioxide. For a 12-hour period, concentrations of 60 to 80 per cent of carbon dioxide were found desirable, and for a 24-hour period, concentrations of 30 to 50 per cent. In a later publication Thornton (*34*) reports the tolerance of various fruits and vegetables to carbon dioxide.

The effect of carbon dioxide upon bacteria has been investigated from many angles, the results varying widely with the species tested. The literature extends over a period of 50 years and recently has been fully reviewed by Valley (*35*).

PURPOSE OF THE INVESTIGATION

It is evident from the results cited that increases in the carbon dioxide content of the storage air may have a marked effect upon both fruit and fungi and that this effect will vary with the temperature and also with the organism. Despite the well-established fact that carbon dioxide has a definite inhibiting action upon certain parasitic organisms and also upon the ripening of certain fruits, the investigators who have made the most thorough study of the subject apparently have not felt justified in recommending gas storage for general use, because of the danger of injuring the fruit.

The present studies have been made with the particular purpose of determining the effect of short-period gas storage, such as might be used in car-lot shipments, as a possible substitute for precooling.

METHODS AND APPARATUS

Experiments were carried out at constant temperatures with a constant percentage of carbon dioxide, and also in "pony" refrigerators and in standard refrigerator cars where both the temperature and the percentage of carbon dioxide were continually dropping during a considerable part of the period of the experiment.

EXPERIMENTS AT CONSTANT TEMPERATURES

The constant-temperature experiments were carried out in a series of six refrigerator boxes, each having a capacity of about 1 cubic yard. A different temperature was maintained in each box, thus making it possible to test fruit of the same lot under six different conditions of temperature.

The fruit and the cultures of fungi that were used as controls were held in moist chambers having a capacity of about 1 gallon. Those that were subjected to carbon dioxide were held in wide-mouthed 9-quart bottles. The usual glass stoppers for these bottles were replaced by 2-hole metal stoppers sealed in position with plasticine.

A constant percentage of carbon dioxide was maintained in the test chambers by means of continuous renewal of the storage air. The desired atmosphere was made up outside the storage container and passed rapidly into it until the percentage of carbon dioxide in the exit air had become practically constant. The movement was then slowed down but kept practically continuous throughout the experiment. From 75 to 115 quarts of the gas mixture were passed through each container in a period of 24 hours.

The storage bottles for the prepared atmosphere were outside the refrigerator boxes, and the air from them was passed through coils of copper tubing within the boxes before entering the containers that held the fruit and cultures. This arrangement brought the temperature of the entering air down to approximately that of the refrigerator box before it passed into the container holding the test material.

The prepared atmospheres were always made by mixing carbon dioxide with laboratory air. When the carbon dioxide content of normal air was increased to 10 per cent, the oxygen content was therefore reduced from 21 per cent to 18.9 per cent, and with 25 per cent carbon dioxide added the oxygen was reduced from 21 per cent to 15.75 per cent.

Carbon dioxide determinations were made either by the absorption method or by means of an electrical carbon dioxide indicator.

The desired percentages of carbon dioxide were usually maintained within 1 per cent, but where one-fourth or more of the atmosphere was composed of carbon dioxide the results of the experiment were not discarded if short-period variations of 2 or 3 per cent were found.

EXPERIMENTS IN PONY REFRIGERATORS

Except where otherwise stated, the pony-refrigerator experiments were made in 80-quart pony refrigerators of the type used in Florida strawberry shipments. These refrigerators have two ice pans, one across the top and a vertical one beneath which divides the berries into two separate stacks, each 4 baskets high, 2 baskets wide, and 5 baskets long. Solid carbon dioxide was used as a supplementary refrigerant and as a source of carbon dioxide gas. It was always placed in the top pan and usually on top of a layer of ice. In later experiments it was placed in the four corners of the top pan and partly separated from the pan and from the ice by means of broken berry baskets or similar material.

Complete temperature records were obtained by means of recording thermometers. These were placed in the bottom of the berry baskets and peach carriers and the fruit poured in over them. The results of the recording thermometers were checked by taking the temperature of the fruit at the close of the experiment and in some instances by placing resistance thermometers beside the recording ones during the experiment; the results were usually in close agreement. During the periods of rapid cooling the temperatures as reported probably more closely represent those of the outside tissue of the fruit than either the air temperature or the temperatures in the center of the individual fruits.

Samples of the atmospheres within the refrigerators were obtained by means of copper tubes that passed through the drainage outlet and extended up through the central ice pan and over into the mass of fruit. Carbon dioxide determinations were made as described under constant temperatures (p. 6).

EXPERIMENTS IN STANDARD REFRIGERATOR CARS

In the refrigerator-car experiments, solid carbon dioxide was used as a supplementary refrigerant, as with the pony-refrigerator tests. The cars were iced in the usual manner, and the solid carbon dioxide was placed in the main body of the car on top of the load of fruit, as described in the legends of Figures 8 to 11, 22 to 26, and 29 to 33, inclusive.

Recording thermometers were packed in the baskets and carriers, as described above for the pony refrigerators. They were always placed in the top baskets or carriers of the top crates and in the bottom baskets or carriers of the bottom crates.

Samples of the atmosphere within the car were obtained by means of tubes of copper and rubber extending from various points in the load out through the upper opening of the bunker to the top of the car. Air was drawn out through these tubes by means of an air pump until the percentage of carbon dioxide became constant, and samples were then taken for record analyses. Analyses were made as described under constant temperatures.

STRAWBERRY EXPERIMENTS

In the strawberry experiments special attention was given to the firmness and flavor of the fruit and to the rate of development of the rots.

The firmness of the fruit was determined by pressure tests, made after methods similar to those reported by Magness and Taylor (*22*). The berry was placed on the platform of a dial cigar scale, and the rounded end of an indelible pencil (7 mm in diameter) was brought steadily down upon it and the pressure increased until the berry was punctured. The pressure was read in ounces as registered on the scale at the time of puncturing.

The question of determining whether the flavor of the berries was normal at the close of an experiment was found to be a most difficult matter. A conclusion was reached by having two or more persons test the flavor without knowing the previous treatment. Individuals would sometimes disagree as to whether the treated or control lots had the more desirable taste; but whenever it was evident that the flavor had been changed by exposure to carbon dioxide, it was considered advisable to set this down to the discredit of the treatment, even though some individuals might find nothing objectionable in the change.

The first effect resulting from the carbon dioxide treatments was a slight loss of aroma. With more prolonged or severe treatment, this was followed by a still greater loss of flavor and finally by the development of an odor of fermentation and by other definitely objectionable qualities. The more highly aromatic, highly flavored varieties seemed to show the effect of the carbon dioxide treatment sooner than did those having less aroma.

Practically all the rots that developed without inoculation were due to either Rhizopus or Botrytis, so the inoculation experiments were confined to these two organisms.[3] Rhizopus has been found to cause more decay on strawberries in transit than all other rot organisms combined (*28*). Botrytis probably comes next to Rhizopus as a cause of loss and is of special interest because of the difficulty of controlling it by means of low temperatures.

Botrytis cinerea Auct. and *Rhizopus nigricans* Ehr. were grown on potato-dextrose agar in various concentrations of carbon dioxide and at various temperatures. The agar was poured into Petri plates and allowed to harden. The spores were then pushed into the layer of agar by means of a sterile needle. The depth to which the spores were pushed did not seem to have any effect upon the inhibiting action of the carbon dioxide. The results of the experiments are shown in Table 1.

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[3] The writers are indebted to L. L. Harter for the pure cultures of *Rhizopus nigricans* that were used in their inoculation experiments. The Botrytis cultures used in the inoculation work were obtained from active rots on strawberries and apparently were *B. cinerea*.

TABLE 1.—*Growth of Botrytis cinerea and Rhizopus nigricans on culture media in atmospheres containing various percentages of carbon dioxide*

CO_2 in atmosphere (per cent)	Temperature	Length of treatment [1]	Diameter of colony			
			Botrytis [2]		Rhizopus	
			In CO_2	Control	In CO_2	Control
	° F.	Hours	Mm	Mm	Mm	Mm
10	59	23+164	19	23.2	----	----
10	50	23+164	8.2	10	----	----
10	41	24+163	2.1	2.5	----	----
13	68	22+50	27.5	27.5	----	----
13	59	22+50	20.5	19.5	----	----
13	50	23+49	3.2	4.3	----	----
13	41	23+49	.5	.8	----	----
17	77	22	(25)	(83.5)	----	----
17	68	23	(26.5)	(30)	----	----
17	59	24	(9.5)	(26)	----	----
17	50	46	(23.5)	(33)	----	----
17	41	47	(8)	(21)	----	----
17	32	48	(3.5)	(14)	----	----
19	77	24	(7.3)	(15.4)	----	----
19	62	25	(17)	(19.3)	----	----
19	59	26	(3.2)	(13.7)	----	----
19	50	48	(3.9)	(11.5)	----	----
19	41	48	(2.6)	(8.5)	----	----
19	32	48	(.6)	(3.8)	----	----
23	77	72	2	55	----	----
23	68	72	5	40	40	95
23	59	72	0	30	0	32
23	50	72	0	6	0	2
23	41	100	0	4	----	----
37	77	26	0	5	30	95
37	68	26	0	4	0	12
37	59	50	0	12	0	30
37	50	98	0	13	0	21
46	77	24	0	7.3	----	----
46	68	24	0	2.5	----	----
46	59	22+23	0	5	----	----
46	50	26+45	.6	2.5	----	----

[1] Where two numbers are used, the first shows the hours of exposure to carbon dioxide and the second the additional hours at the given temperature before the record was taken.
[2] Numbers in parentheses show the increase in diameter of colonies that were large enough to be measured before the experiment was started. In all other cases the inoculations were made at the time the experiment was started.

STRAWBERRIES AT CONSTANT TEMPERATURES

Strawberries also were held in various percentages of carbon dioxide at various constant temperatures. From 8 to 15 berries were used under each condition tested. They were selected individually and with great care, in order that those to be compared under different conditions should be as nearly alike as possible in maturity, firmness, size, color, and freedom from injuries. The Rhizopus inoculations were made by pushing the spores into the flesh of the strawberries in the usual manner. Botrytis inoculations that were made in the same way caused no evident development during the period of the experiment, but it was found that by cutting 4-millimeter disks of mycelium and agar from Petri-dish cultures and placing them on the berries a definite rot and a measurable growth of mycelium could be secured. The Botrytis growth measurements, as reported in Table 2, indicate the increase in diameter of these mycelial disks. The pressure tests were made as described on page 8 and the carbon dioxide atmospheres were prepared as described under Methods and Apparatus (p. 6). The results are reported in Table 2.

TABLE 2.—*Effects of different percentages of carbon dioxide on strawberries at various constant temperatures*

Variety	Date	CO_2 in atmosphere	Temperature	Length of CO_2 treatment	Pressure test			Flavor		Development of rots			
										Increase in diameter of Botrytis colony		Infections from Rhizopus inoculations	
					Before CO_2 treatment	After CO_2 treatment	Control	After CO_2 treatment	Control	After CO_2 treatment	Control	After CO_2 treatment	Control
		Per cent	*°F.*	*Hours*	*Ounces*	*Ounces*	*Ounces*			*Mm*	*Mm*	*Per cent*	*Per cent*
U. S. D. A. No. 450	June 3, 1929	10	68	22		7.8	7.3	Slightly flat	Good				
Do	do	10	59	22		7.7	7.6	do	do				
Do	do	10	50	23		7.7	6	Less flavor	do				
Do	do	10	41	24		9.9	7.3	do	do				
Do	do	10	32	25		10.7	6.8	Good	do				
U. S. D. A. No. 25	May 20, 1929	13	68	22		9.5	8.5	do	do				
Do	do	13	59	22		9.3	6.6	do	do				
Do	do	13	50	23		9.4	7.9	do	do				
Do	do	13	41	23		9.5	8.9	do	do				
Missionary and Dunlap	May 22, 1930	17	77	22				do	do				
Do	do	17	68	23				Less aroma	do				
Do	do	17	59	24				do	do				
Do	do	17	50	46				Good	do				
Do	do	17	41	47				do	do				
Do	do	17	32	48				do	do				
Missionary	Mar. 13, 1930	19	77	24				do	do				
Do	do	19	68	25				do	do				
Do	do	19	59	26				do	do				
Do	do	19	50	26				do	do				
Do	do	19	41	26				do	do				
Do	do	19	32	26				do	do				
Do	Mar. 19, 1930	20	77	24				Off	Poor				
Do	do	20	68	26				Fair	do				
Do	do	20	59	27				do	Off				
Do	do	20	50	47				Poor	Fair				
Do	do	20	41	47				Fair	do				
Do	do	20	32	49				Good	Good				
Do	Apr. 9, 1928	23	77	48	9.8	10.1	5.7	do	Poor			0	67
Klondike-Howard 17 (cross)	May 31, 1928	23	77	45	9.3	9.1	4.1	Distinctly off	Good	0	15		
Missionary	Apr. 9, 1928	23	68	48	9.8	9.3	11.6	Good	do			0	65
Klondike-Howard 17 (cross)	May 31, 1928	23	68	45	9.3	9.8	7	Distinctly off	do	0	12		
Heflin	May 25, 1928	23	68	72	8.3			Insipid	do	11	20		
Aroma	May 17, 1929	23	68	22				Less aroma	do				

U. S. D. A. Nos. 450 and 668	May 27, 1929	23	68	22	---	12.8	12	do	do	---	---	---	---
Missionary	Apr. 9, 1928	[2] 23	59	96	9.8	13.2	8.2	Good	do	---	---	0	0
Klondike-Howard 17 (cross)	May 31, 1928	23	59	47	9.3	9.3	9.1	Distinctly off	do	0	8	---	---
Heflin	May 25, 1928	23	59	72	8.3	12.6	7.9	Fair	do	4	14	---	---
Aroma	May 17, 1929	23	59	22	---	---	---	Good	do	---	---	---	---
U. S. D. A. Nos. 450 and 668	May 27, 1929	23	59	22	---	12.5	13.3	do	do	---	---	---	---
Missionary	Apr. 9, 1928	23	50	120	9.8	11.8	8	Slightly off	do	---	---	---	---
Klondike-Howard 17 (cross)	May 31, 1928	23	50	47	9.3	10.5	9.4	Lacking flavor	do	6	7.5	---	---
Heflin	May 25, 1928	23	50	73	8.3	9.2	10.4	Good	do	0	6	---	---
Aroma	May 17, 1929	23	50	26	---	---	---	do	do	---	---	---	---
U. S. D. A. Nos. 450 and 668	May 27, 1929	23	50	23	---	13.4	12.7	do	do	---	---	---	---
Missionary	Apr. 9, 1928	23	41	124	9.8	13	12.7	do	do	---	---	---	---
Klondike-Howard 17 (cross)	May 31, 1928	23	41	92	9.3	12.7	11.4	do [1]	do	0	6.5	---	---
Heflin	May 25, 1928	23	41	100	8.3	13	9.3	Off a trace	do	4	8	---	---
Aroma	May 17, 1929	23	41	26	---	---	---	Good	do	---	---	---	---
U. S. D. A. Nos. 450 and 668	May 27, 1929	23	41	24	---	11.3	10.4	do	do	---	---	---	---
Missionary	Apr. 9, 1928	23	36.5	124	9.8	15.4	11.8	do [1]	do	---	---	---	---
Klondike-Howard 17 (cross)	May 31, 1928	23	36.5	92	9.3	12.5	9.5	do [1]	do	0	7.6	---	---
Heflin	May 25, 1928	23	36.5	100	8.3	13	10.7	Off a trace [1]	do	4	9	---	---
U. S. D. A. Nos. 450 and 668	May 27, 1929	23	32	25	---	14.3	9.7	Good	do	---	---	---	---
Missionary	Apr. 17, 1928	37	77	24	9.8	11.2	7	Fair	Fair	0	3.5	---	---
Do	Apr. 18, 1928	37	77	24	9.7	11.3	10.2	do	do	0	4.5	---	---
Do	Apr. 23, 1928	[3] 37	77	26	12.2	10.5	5.9	Good	Good	0	3.7	---	---
Do	Apr. 17, 1928	37	68	24	9.8	10.1	10.7	Fair	Fair	0	7.5	---	---
Do	Apr. 18, 1928	37	68	24	9.7	10.2	9.3	do	do	0	4	---	---
Do	Apr. 23, 1928	[3] 37	68	26	12.2	10.5	9.2	Good	Good	0	4.5	0	50
Do	Apr. 18, 1928	37	59	48	9.7	11.9	8.4	Fair	Fair	0	9	---	---
Do	Apr. 23, 1928	[3] 37	59	50	12.2	14.5	8.3	Good	Good	0	8	---	---
Do	Apr. 18, 1928	37	50	72	9.7	12.3	11.6	do	do	0	8	---	---
Do	Apr. 23, 1928	[3] 37	50	98	12.2	13.6	14.9	Fair	Fair	0	6	---	---
Do	Apr. 18, 1928	37	41	140	9.7	13	11.3	Good	Good	0	1.5	---	---
Do	Apr. 23, 1928	37	41	100	12.2	13.6	14	Fair [1]	Fair	0	5	---	---
Do	Apr. 18, 1928	37	36.5	140	9.7	11.4	12.3	Slightly off	Good	0	3	---	---
Do	Apr. 23, 1928	37	36.5	100	12.2	15.8	14.8	Good [1]	do	0	3	---	---
Do	Mar. 27, 1928	46	77	24	12.8	12.1	9.9	do	do	---	---	---	---
Do	Apr. 3, 1928	46	77	24	9.1	11.3	4.6	Poor	Fair	0	4	---	---
Do	Mar. 19, 1928	46	68	24	8.6	10.2	9	Good	Good	0	1.1	---	---
Do	Mar. 27, 1928	46	68	24	12.8	11.2	11.2	do	do	---	---	---	---
Do	Apr. 3, 1928	46	68	24	9.1	9	8.3	Slightly off	do	0	4	---	---
Do	Mar. 27, 1928	46	59	48	12.8	12.9	12.3	Good	do	---	---	---	---
Do	Apr. 3, 1928	46	59	27	9.1	11.9	10.2	Slightly off	do	0	2	---	---
Do	Mar. 27, 1928	46	50	53	12.8	12.4	10.7	Good	do	---	---	---	---
Do	Apr. 3, 1928	46	50	51	9.1	10.8	11.8	do	do	0	4	---	---
Do	Mar. 27, 1928	46	41	53	12.8	13.4	13.9	do	do	---	---	---	---
Do	Apr. 3, 1928	46	41	72	9.1	11.3	11.3	do	do	0	1	---	---
Do	do	46	36.5	72	9.1	10.5	9.9	do [1]	do	0	0	---	---
Do	Mar. 19, 1928	[4] 46–23	59	41	8.6	12.3	10.1	do	do	0	1.6	---	---
Do	do	[4] 46–23	50	41	8.6	11.6	11.2	do	do	0	4	---	---
Do	do	[4] 46–23	41	41	8.6	10.8	11.6	do	do	0	2.3	---	---

[1] This jar had no change of atmosphere during the experiment.
[2] During the 15 hours following the first 6 hours, 32 per cent instead of 23 per cent.
[3] During the 15 hours following the first 6 hours, 63 per cent instead of 37 per cent.
[4] 46 per cent for 24 hours followed by 23 per cent for 17 hours.

Table 1 shows that atmospheres containing 10 to 13 per cent of carbon dioxide had little inhibiting effect upon Botrytis grown on culture media, whereas atmospheres with 17 to 19 per cent of carbon dioxide had a checking effect approximately equivalent to that of a drop of 18° F. in temperature. With 23 per cent of carbon dioxide both Botrytis and Rhizopus were almost completely inhibited in most instances both on the culture media and on the fruit. (Tables 1 and 2.) On culture media Botrytis was more completely inhibited than was Rhizopus, whereas on the fruit the reverse condition held. With 37 per cent of carbon dioxide Botrytis was held completely in check at all temperatures, and with one exception this was also true of Rhizopus.

The records on resistance to pressure at the close of the experiment were taken while the fruit was still cool. This, no doubt, accounts for some of the instances in which the pressure was higher at the close of the experiment than at the beginning (*15*). Atmospheres containing 10 to 13 per cent of carbon dioxide did not seem to have any pronounced checking effect upon the softening of the fruit, but those containing 23 per cent or more of carbon dioxide largely, if not entirely, prevented softening at all temperatures. At the higher temperatures there was usually a marked difference in firmness between the treated and the control fruit at the end of the experiment. It was found that this difference was maintained for a considerable time after the removal of the fruit to the same atmospheric conditions.

The small number of berries included in the tests and their wide individual variation made the determination of difference in flavor particularly difficult and the results, perhaps, somewhat unreliable. It will be noted that in the experiments carried out in 1929 and 1930 injury was obtained with lower percentages of carbon dioxide and with shorter treatments than in the experiments of 1928. In some instances this may have been due to the variety of berries, but the writers are convinced that as the work progressed they developed a much more critical sense of taste and that this accounts partly for the inconsistent results. In the experiments of 1928 no injury to flavor was detected after subjecting Missionary berries to atmospheres containing 23 per cent of carbon dioxide for 48 hours at 77° or 68° F., 96 hours at 59°, or 124 hours at 41°; and no injury was detected after exposure to 37 per cent of carbon dioxide for 24 hours at 77° or 68°, 48 hours at 59°, 72 hours at 50°, or 100 hours at 41°. In the experiments of 1930 a reduction in aroma was noted in Missionary and Dunlap berries after exposure to 17 per cent of carbon dioxide at 68° for 23 hours, and in the experiments of 1929 a similar change in U. S. D. A. No. 450 was noted after exposure to 10 per cent of carbon dioxide for 23 to 24 hours at 50° and 41°. The writers believe that the results of 1928 could be duplicated if individuals of average taste discrimination were the judges, but in light of later experiments they are of the opinion that in some instances there may have been a loss of flavor in the 1928 experiments that was not detected at the time the experiments were made.

The varieties with a relatively high aroma were the most susceptible to injury from carbon dioxide. The Heflin, U. S. D. A. No. 450, and Aroma were more susceptible than were Missionary and Klondike.

Strawberries showed a greater endurance of carbon dioxide treatments at lower temperatures than at higher ones. The differences were fairly consistent with the usual physiological responses to temperature.

STRAWBERRIES IN PONY REFRIGERATORS

The pony-refrigerator experiments were carried out as described under Methods and Apparatus (p. 7) and the inoculations were made as described under Strawberries at Constant Temperatures (p. 9). In addition to the Petri-dish and disk inoculations, berries that were already rotten from Botrytis were placed at various points in the baskets, and at the close of the experiment a record was taken of the number of berries infected by contact with the rotten fruit.

The result of the various pony-refrigerator experiments are shown in Table 3 and in Figures 1 to 7, inclusive.

TABLE 3.—*Condition of strawberries held in pony refrigerators with solid carbon dioxide as a supplementary refrigerant*

Figure reference [1]	Ice		Solid CO_2 used	Pressure test upon removal	Flavor upon removal	Berries frozen	Botrytis rot				Rhizopus on uninoculated berries
	At beginning	At end					Diameter of Petri-dish colonies	Increase in diameter of disks	Average infections from one rotten berry	On uninoculated berries	
	Lbs.	*Lbs.*	*Lbs.*	*Oz.*		*Per cent*	*Mm*	*Mm*	*Number*	*Per cent*	*Per cent*
Fig. 1:											
a	135	0	0	9.1	Good	0	---	8	1.8	11.7	25.4
b	105	15	30	12.5	do	4	---	3	.3	6	10.8
c	90	16	45	12.1	Reduced aroma	16	---	4	.2	3.6	8
d	75	20	60	12.[illegible]	do	29	---	3	.1	2.7	10
Fig. 2:											
a	135	0	0	9.1	Good	0	5.5	---	3.2	24.9	5.4
b	125	0	10	10.2	Very good	0	2.2	---	2.3	24.8	2.8
c	120	1	15	9.9	do	2	0	---	1.7	18.6	3.6
d	110	0	25	10.4	Reduced aroma	6	1	---	1.8	22.8	2.5
Fig. 3:											
a	135	18	0	8.9	Fair	0	---	---	2.5	2	27.2
b	120	32	15	9.4	do	.5	---	---	.5	1.4	34.2
c	110	40	25	8.7	do	2.3	---	---	1.8	1.2	31
d	100	47	35	11.4	do	6.7	---	---	.6	1.2	27.8
Fig. 4:											
a	144	36	0	8.7	Good	0	2	---	1.3	.4	17.6
b	119	42	15	11.1	Reduced aroma	8	0	---	0	.3	12
c	119	23	20	11.9	Off taste	9	0	---	0	.4	9.6
d	110	44	30	13.2	Bad	8	0	---	0	0	8.8
Fig. 5:											
a	183	50	0	8.3	Good	0	27	---	---	2.9	47.7
b	156	67	16	9.6	Reduced aroma	0	11.5	---	---	.5	10.1
c	144	73	18	11	do	0	12	---	---	0	9
Fig. 6:											
a	161	62	0	9.7	Good	0	---	---	---	12	---
b	145	66	15	14.6	do	.5	---	---	---	8.9	---
c	101	67	35	15.3	Off flavor [2]	1	---	---	---	7.6	---
Fig. 7:											
a	163	22	0	7.3	Good	0	5.8	---	---	42.9	---
b	147	23	7	9.6	do	0	3.6	---	---	21.7	---
c	94	37	12	8.6	do	0	3.6	---	---	32.1	---

[1] For data on variety, CO_2, temperature, and length of treatment, see Figs. 1 to 7, inclusive.
[2] After 3 days at 50° F. the objectionable flavor had disappeared.

In most cases two recording thermometers were used in each refrigerator, thus giving opportunity for comparing the temperatures in different parts of the same container. In the control the top layer was sometimes a few degrees warmer than the bottom, especially at the beginning and near the close of the experiment. The middle layers were always warmer than the top layer, and the fruit in the corners was always warmer than that in the center, near the vertical pan.

Where solid carbon dioxide was used, the top layer of fruit was usually as cold as, and sometimes colder than, the bottom layer; and where the solid carbon dioxide was placed in the corners of the top refrigerating pan, the difference in temperature between the fruit in the center and that in the corners was much less than in the control.

When freezing injury resulted from the use of large amounts of solid carbon dioxide it was mostly in the top layer and usually worse in the center than in the corners.

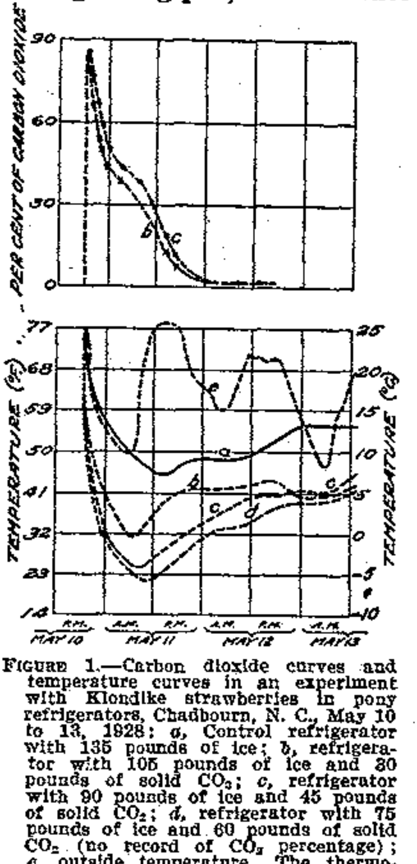

FIGURE 1.—Carbon dioxide curves and temperature curves in an experiment with Klondike strawberries in pony refrigerators, Chadbourn, N. C., May 10 to 13, 1928: *a*, Control refrigerator with 135 pounds of ice; *b*, refrigerator with 105 pounds of ice and 30 pounds of solid CO_2; *c*, refrigerator with 90 pounds of ice and 45 pounds of solid CO_2; *d*, refrigerator with 75 pounds of ice and 60 pounds of solid CO_2 (no record of CO_2 percentage); *e*, outside temperature. The thermographs were in the top layer of baskets

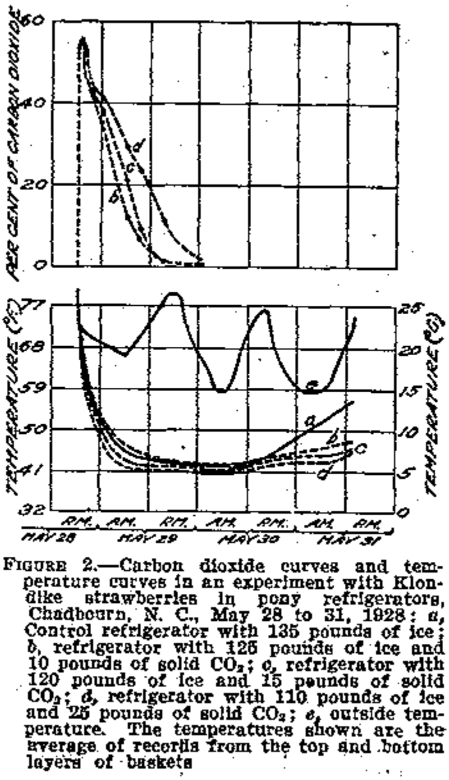

FIGURE 2.—Carbon dioxide curves and temperature curves in an experiment with Klondike strawberries in pony refrigerators, Chadbourn, N. C., May 28 to 31, 1928: *a*, Control refrigerator with 135 pounds of ice; *b*, refrigerator with 125 pounds of ice and 10 pounds of solid CO_2; *c*, refrigerator with 120 pounds of ice and 15 pounds of solid CO_2; *d*, refrigerator with 110 pounds of ice and 25 pounds of solid CO_2; *e*, outside temperature. The temperatures shown are the average of records from the top and bottom layers of baskets

Despite the fact that the use of solid carbon dioxide sometimes resulted in freezing injury, the temperature curves of Figures 1 to 7 do not indicate that it greatly lowered the average temperature in the boxes. However, by the proper placing of the solid carbon dioxide it was found possible to bring about a significant lowering of the temperature in the warmer parts of the refrigerator without causing freezing injury in the colder parts.

The most significant differences in temperature came at the close of the experiments in cases where the outside temperature was high or the storage period prolonged. In such cases the temperature of the control rose earlier and more rapidly than that of the refrigerator containing solid carbon dioxide. A reason for this is found in the amount of ice left in the different boxes at the close of the experiments, as shown in the third column of Table 3. The carbon dioxide gas apparently had an insulating or blanketing effect that tended to check the action of the refrigerants, thus limiting the initial rate of cooling but extending the possible period of refrigeration.

The carbon dioxide content of the air in the control refrigerator was tested at various times and usually found to be 1 to 1½ per cent.

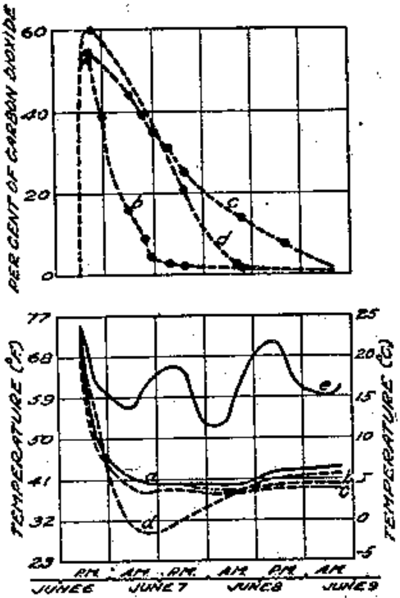

FIGURE 3.—Carbon dioxide curves and temperature curves in an experiment with strawberries from United States Department of Agriculture breeding plots at Glenn Dale, Md., in pony refrigerators, June 6 to 9, 1928. The records were made on crosses Nos. 122 and 197: *a*, Control refrigerator with 135 pounds of ice; *b*, refrigerator with 120 pounds of ice and 15 pounds of solid CO_2; *c*, refrigerator with 110 pounds of ice and 25 pounds of solid CO_2; *d*, refrigerator with 100 pounds of ice and 35 pounds of solid CO_2; *e*, outside temperature. The thermographs were in the top layer of baskets

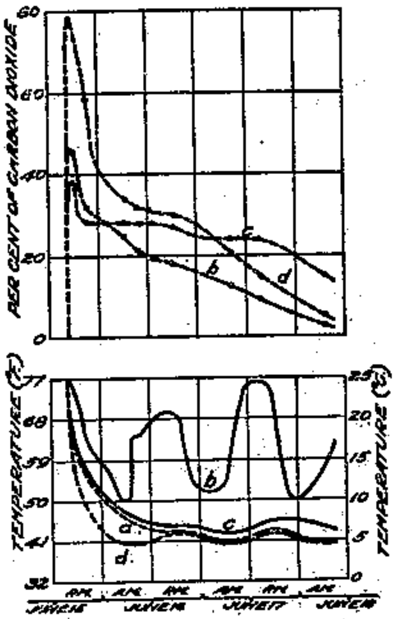

FIGURE 4.—Carbon dioxide curves and temperature curves in an experiment with strawberries from United States Department of Agriculture breeding plots at Glenn Dale, Md., in pony refrigerators, June 15 to 18, 1928: *a*, Control refrigerator with 144 pounds of ice; *b*, refrigerator with 119 pounds of ice and 15 pounds of solid CO_2 (no temperature record); *c*, refrigerator with 119 pounds of ice and 20 pounds of solid CO_2; *d*, refrigerator with 110 pounds of ice and 30 pounds of solid CO_2; *e*, outside temperature. The thermographs were in the top layer of baskets.

The percentage of carbon dioxide gas in the refrigerators in which solid carbon dioxide was used is shown in the upper portions of Figures 1 to 7. Little difference was found in the carbon dioxide content of the air in the different parts of the same refrigerator. The records as reported are based on air samples taken from near the center of the refrigerator.

As would be expected, there was a fairly close relationship between the amount of solid carbon dioxide used and the percentage of carbon dioxide gas in the air. There is, however, considerable variation in the character of the curves, as shown in Figures 1 to 7. Part of this variation was due to the fact that the solid carbon dioxide was not always broken up to the same degree of fineness, and also that in a few cases free downward movement of the gas was somewhat checked by the containers in which the solid carbon dioxide was held.

It will be seen that the percentage of carbon dioxide gas mounted rapidly as soon as the refrigerators were closed; a maximum was often reached within half an hour, followed by a rapid drop a few hours later. During the first 6 to 10 hours the carbon dioxide

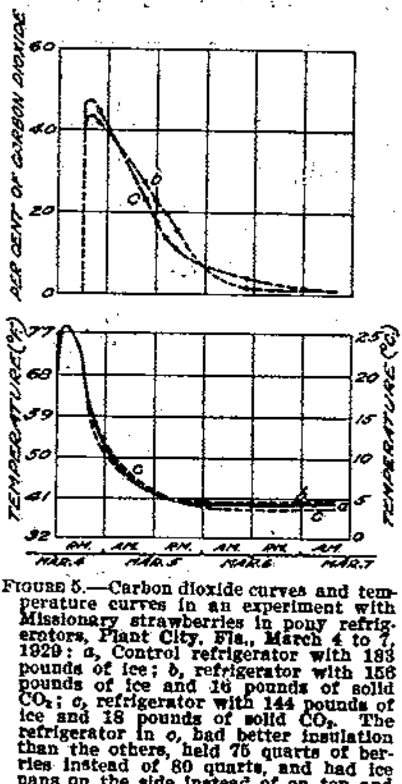

FIGURE 5.—Carbon dioxide curves and temperature curves in an experiment with Missionary strawberries in pony refrigerators, Plant City, Fla., March 4 to 7, 1929: *a*, Control refrigerator with 183 pounds of ice; *b*, refrigerator with 156 pounds of ice and 16 pounds of solid CO_2; *c*, refrigerator with 144 pounds of ice and 18 pounds of solid CO_2. The refrigerator in *c*, had better insulation than the others, held 76 quarts of berries instead of 80 quarts, and had ice pans on the side instead of on top and in the center. On March 4 the maximum outside temperature was 87° F., the minimum 66°; on March 5 the maximum was 74°, the minimum 54°; and on March 6 the maximum was 69° and the minimum 48°. The berries used in the experiment were from the experimental plots of A. N. Brooks

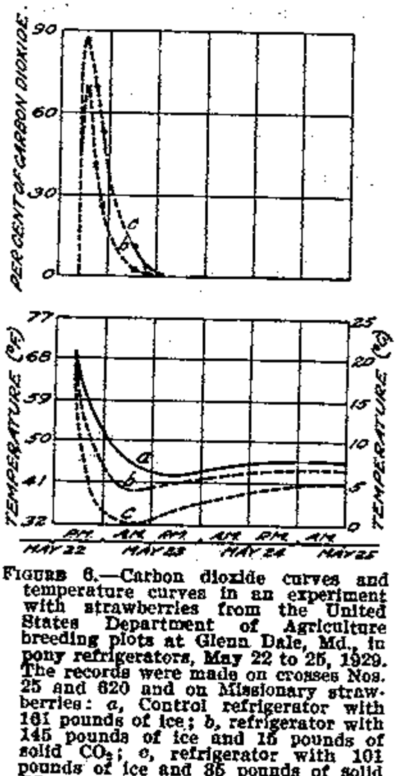

FIGURE 6.—Carbon dioxide curves and temperature curves in an experiment with strawberries from the United States Department of Agriculture breeding plots at Glenn Dale, Md., in pony refrigerators, May 22 to 25, 1929. The records were made on crosses Nos. 25 and 620 and on Missionary strawberries: *a*, Control refrigerator with 161 pounds of ice; *b*, refrigerator with 145 pounds of ice and 15 pounds of solid CO_2; *c*, refrigerator with 101 pounds of ice and 85 pounds of solid CO_2. The refrigerator in *c* had better insulation than the others and lacked the vertical ice pan described for the standard refrigeration. The temperatures shown are the average of records from the top and bottom layers of baskets. On May 22 the maximum outside temperature was 68° F., the minimum 46°; on May 23 the maximum was 75°, the minimum 45°; and on May 24 the maximum was 77°, the minimum 60°

content was usually 40 to 80 per cent, but by the end of 24 hours it had usually dropped below 10 per cent, and often to 1 or 2 per cent.

In cases where the carbon dioxide content of the atmosphere had fallen to 25 per cent within 12 hours and to 10 per cent within 24 hours, no injury to the flavor of the fruit could be detected; but in most instances where these percentages were exceeded there was either a loss of flavor or, in the more extreme cases, a definitely disagreeable flavor. In the three instances where 12 pounds or less of solid carbon dioxide was used and in three of the five instances where

15 or 16 pounds was used, the flavor of the fruit was not affected. Rapid cooling seemed to decrease the probability of injury; this is in agreement with the differences in results at various constant temperatures, as shown in Table 2.

Sample lots of fruit, after removal from the various refrigerators, were held for later tests of flavor. In a few instances berries lacking in aroma upon removal regained their normal flavor, but in most instances they failed to do so.

Increasing the carbon dioxide content of the storage air had a very significant effect on the firmness of the fruit. Disregarding the results of the experiments in which the flavor of the berries was affected, the average resistance to pressure at the end of the experiments was 8.7 ounces in the control refrigerators and 11.2 ounces in the refrigerators containing solid carbon dioxide. There was usually a corresponding contrast in the number of extremely soft berries.

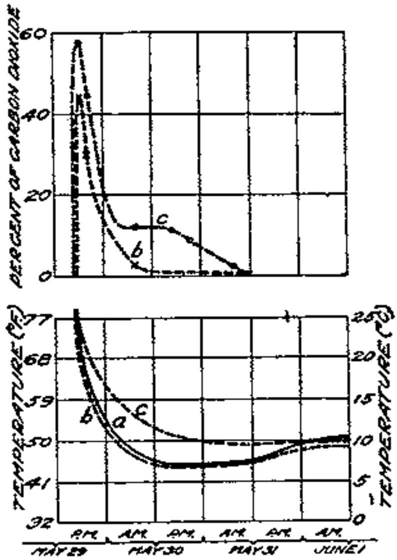

FIGURE 7.—Carbon dioxide curves and temperature curves in an experiment with strawberries from the United States Department of Agriculture breeding plots in Glenn Dale, Md., in pony refrigerators, May 29 to June 1, 1929: *a*, Control refrigerator with 163 pounds of ice; *b*, refrigerator with 147 pounds of ice and 7 pounds of solid CO_2; *c*, refrigerator with 94 pounds of ice and 12 pounds of solid CO_2. The refrigerator in *c* was the same as described under *c* of Figure 6. The temperatures shown are the average of records from the top and bottom layers of baskets. On May 29 the maximum outside temperature was 83° F., the minimum 70°; on May 30 the maximum was 85°, the minimum 67°; and on May 31 the maximum was 92°, the minimum 69°

The effect of the solid carbon dioxide upon the rot organisms was equally significant. Excluding the instances in which the flavor of the fruit was affected, the average growth of the rot organisms was reduced more than 50 per cent in all the inoculation tests; the average growth of the Botrytis rot on the uninoculated fruit was reduced more than 30 per cent, and that of the Rhizopus rot on the uninoculated fruit was reduced more than 50 per cent. Apparently these reductions were largely due to differences in the carbon dioxide of the atmosphere rather than to differences in temperature.

STRAWBERRIES IN REFRIGERATOR CARS

In other experiments solid carbon dioxide was used in car-lot shipments. The method of handling the material is described under Methods and Apparatus (p. 7). The methods of inoculation were the same as those used in the pony-refrigerator experiments (p. 3). A record was included of the rot development on the uninoculated fruit.

The temperature and carbon dioxide records are shown in Figures 8 to 11, inclusive, and the icing records and time and place of shipment are given in the legends to these figures.

The use of solid carbon dioxide tended to lessen the melting of the ice. (Figs. 10 and 11.) Apparently this was due largely to the insulating or blanketing effect of the carbon dioxide gas, since the differences in temperature between the cars were not great enough to cause any decided difference in the melting of ice.

The temperature curves show that the top of the load cooled somewhat more rapidly in the test cars than it did in the controls. In some instances this was true of the bottom center of the cars also, but the bottom next to the bunker was usually as warm in the carbon dioxide car as in the control car. There was thus a slight tendency to equalize the temperatures of the different parts of the load. This may have been at least partly due to the fact that the solid carbon dioxide was placed directly above the load. There is indication in some of the curves that

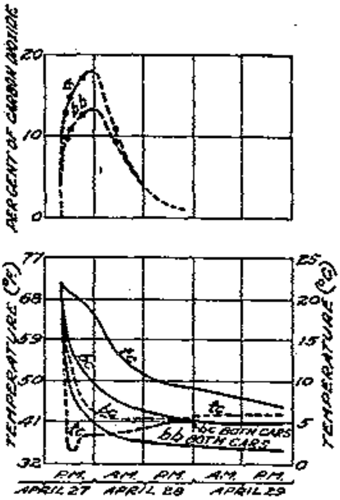

FIGURE 8.—Carbon dioxide curves and temperature curves in an experiment with Klondike strawberries shipped in standard refrigerator cars from Chadbourn, N. C., April 27, 1927. The broken lines give the records for the test car, the solid lines the records for the control car: *tc*, Top center; *tb*, top bunker; *bc*, bottom center; *bb*, bottom bunker. 319 pounds of solid CO_2 was used. It was held in a box in the center of the car about 4 inches above the top of the load. The recording thermometer for the top center of the car was beneath this box

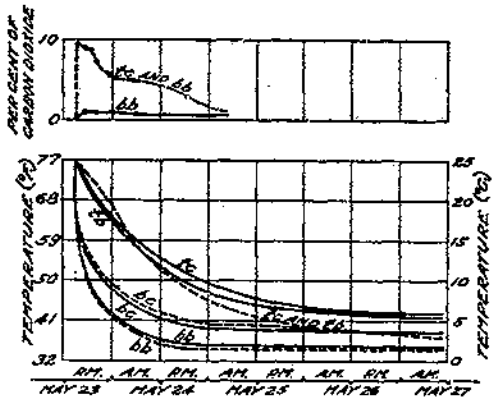

FIGURE 9.—Carbon dioxide curves and temperature curves in an experiment with Heflin strawberries shipped in standard refrigerator cars from Onley, Va., May 23, 1927. The broken lines give the records for the test car, the solid lines the records for the control car; *tc*, Top center; *tb*, top bunker; *bc*, bottom center; *bb*, bottom bunker. 283 pounds of solid CO_2 was used in the test car. It was held about 6 inches above the load in three boxes, one in the center of the car and one in each end at a distance of about 5 feet from the bunker. Care was taken that the thermometers should not be located under the solid CO_2. Each car contained 224 crates of berries

the use of the solid carbon dioxide in the main body of the car sometimes caused the air movement in the bunker to be reversed for short periods, making the current pass upward and out at the top instead of moving downward and out at the bottom.

The carbon dioxide content of the air mounted rapidly in the test car as soon as the car was closed, reaching or nearing its maximum in one or two hours. In the experiment reported in Figure 9 the carbon dioxide remained below 10 per cent; in that shown in Figure 8 it stayed near 15 per cent for several hours and above 10 per cent for about 12 hours; in Figure 11 it reached a maximum of 20 per cent and remained above 10 per cent for about 18 hours; in Figure 10 it reached a maximum of 30 per cent and stood above 10 per cent for 15 to 25 hours, depending on the location in the car.

In the experiments reported in Figures 8 and 10 there was a greater concentration of carbon dioxide in the top center of the car than at other points, but in the experiments of Figures 9 and 11 this does not appear to have been the case.

The percentage of carbon dioxide gas was affected by the tightness of the car as well as by the amount of solid carbon dioxide used. The amounts of solid carbon dioxide reported in the legends for Figures 10 and 11 probably would not be advisable with strawberries loaded in new cars or in cars that had recently been reconditioned.

A number of analyses of the carbon dioxide content of the air in the control cars were made, and it was usually found to be below 1 per cent and never above 1.75 per cent.

The fruit in all the cars was critically tested at destination for anything unusual in taste, but nothing could be detected. In some instances there was a suggestion of less maturity in the fruit of the test car, but this seemed to be a real maturity difference as shown in the firmness of the fruit rather than a definite reduction in aroma as mentioned in the discussion of the pony refrigerator experiments (p. 17).

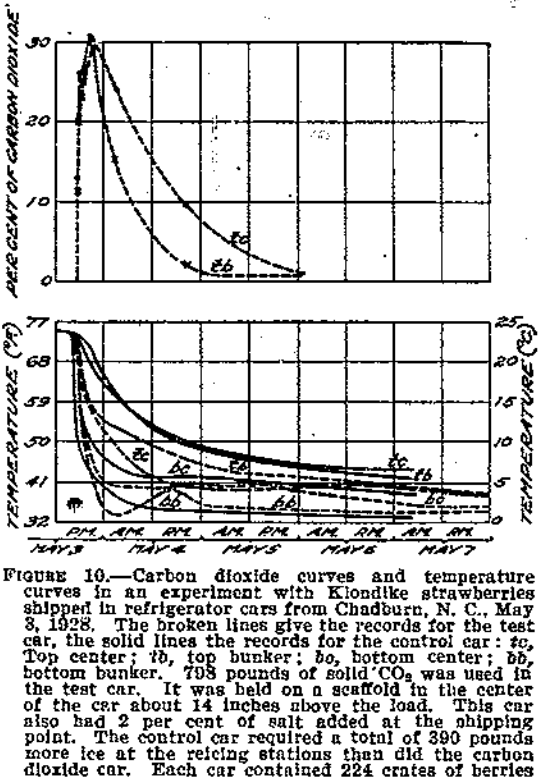

FIGURE 10.—Carbon dioxide curves and temperature curves in an experiment with Klondike strawberries shipped in refrigerator cars from Chadburn, N. C., May 8, 1928. The broken lines give the records for the test car, the solid lines the records for the control car: *tc*, Top center; *tb*, top bunker; *bc*, bottom center; *bb*, bottom bunker. 798 pounds of solid CO_2 was used in the test car. It was held on a scaffold in the center of the car about 14 inches above the load. This car also had 2 per cent of salt added at the shipping point. The control car required a total of 390 pounds more ice at the reicing stations than did the carbon dioxide car. Each car contained 224 crates of berries

For the records on firmness and rots, as shown in Table 4, two or more crates of uniformly graded berries were selected at the shipping point, and the 64 or more baskets from these crates were substituted for other baskets in different parts of the car. At destination these baskets were reassembled for note taking. This arrangement made it possible to obtain a record on comparable lots of berries located in the different parts of the two cars. In the experiments of Figures 8, 10, and 11 the fruit of the test crates at the time of shipping was distinctly riper and softer than was the average for the load. The results, therefore, while comparable, show the condition of the worst of the berries of the regular shipment upon arrival at destination rather than the average condition of the load. In the experiment of Figure 9 the results, as shown in Table 4, give a good picture of the general condition of the fruit in the two cars. In this instance all the fruit was somewhat soft and overripe at the time of loading, and the shipment was on the road practically four days.

TABLE 4.—*Condition of strawberries after shipment in standard refrigerator cars with solid carbon dioxide as a supplementary refrigerant*

Figure reference[1]	Location in car	Flavor upon removal from—		Pressure test upon removal from—		Soft and overripe berries upon removal from—		Botrytis rot						Rhizopus rot in uninoculated berries from—		Total rot in uninoculated berries from—		Remarks
								From disk inoculations on berries from—		Average infections from one rotten berry in—		In uninoculated berries from—						
		Test car	Control car	Test car	Control car	Test car	Control car	Test car	Control car	Test car	Control car	Test car	Control car	Test car	Control car	Test car	Control car	
				Oz.	*Oz.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*No.*	*No.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	
Fig. 8	Top center	Good	Good			15.8	44.8									1.3	26.8	Record taken 12 hours after removal from cars.
	Top bunker	do	do			30.7	18.8									0	64.3	
	Average top of car					23.3	31.8									.6	45.6	
	Bottom center	do	do			25.7	37.9									3.5	16.4	
	Bottom bunker	do	do			12.8	35.6									1.6	19.8	
	Average bottom of car.					19.3	36.8									2.6	18.1	
	Average for car					21.3	34.3									1.6	31.8	
Fig. 9	Top center	do	do	4.6	3.7	34.2	53.6									3.9	20.8	Record taken immediately after opening of cars.
	Top bunker	do	do	3.8	3.4	45.5	38.8									12.2	28.6	
	Average top of car			4.2	3.6	39.9	46.2									8.1	24.7	
	Bottom center	do	do	5	2.8	34.4	28.9									4.2	3.2	
	Bottom bunker	do	do	4.8	3.1	27.5	46.6									2.1	4.6	
	Average bottom of car.			4.9	3	31	37.8									3.2	3.9	
	Average for car			4.6	3.3	35.4	42									5.6	14.3	
Fig. 10	Top center	do	do	12	8.5			20	0	0.5	4.3	5	12.6	22.1	31.2	27.1	43.8	The treated carload was opened 19 hours later than the control. Record taken immediately after opening in each lot.
	Top bunker	do	do	13.1	9.7			0	100	3.1	4.8	12.9	14.9	15.1	22	28	36.9	
	Average top of car			12.6	9.1			10	50	1.8	4.6	9	13.8	18.6	26.6	27.6	40.4	
	Bottom center	do	do	12.7	9.7			20	60	.7	5.3	1.4	17.1	12.3	11.8	13.7	28.9	
	Bottom bunker	do	do	15.5	9.1			20	60	.5	2.8	1.3	11.5	10.4	11.9	11.7	23.4	
	Average bottom of car.			14.1	9.4			20	60	.6	4.1	1.4	14.3	11.4	11.9	12.7	26.2	
	Average for car			13.3	9.3			15	55	1.2	4.3	5.2	14	15	19.2	20.2	33.3	
Fig. 11	Top center	do	do	12.3	11.3					.7	3	.5	3.4	20.5	24.3	21	27.7	Record taken immediately after opening of cars. The top bunker record for the carbon dioxide car was from third layer; that for control car from second layer.
	Top bunker	do	do	12.1	10.7					1.8	2.8	1.1	0	25.4	33.9	26.5	33.9	
	Average top of car			12.2	11					1.3	2.9	.8	1.7	23.0	29.1	23.8	30.8	
	Bottom center	do	do	11.1	11.1					.3	1.5	.4	1.2	14.6	15	15	16.2	
	Bottom bunker	do	do	13.5	9.5					.2	2.7	.2	.4	18.1	18	18.3	18.4	
	Average bottom of car.			12.3	10.3					.3	2.1	.3	.8	16.4	16.5	16.7	17.3	
	Average for car			12.3	10.7					.8	2.5	.6	1.3	19.7	22.8	20.3	24.1	
Average	Top of car			9.7	7.9	31.6	39			1.6	3.8	4.9	7.8	20.8	27.9	15.0	35.4	
	Bottom of car			10.4	7.6	25.2	37.3			.5	3.1	.9	7.6	13.9	14.2	8.8	16.4	
	Entire car			10.1	7.8	28.4	38.2			1	3.4	2.9	7.7	17.4	21	11.9	25.9	

[1] For data on variety, CO_2, temperature, and length of treatment, see Figs. 8 to 11, inclusive.

A study of the total averages in Table 4 shows that while the percentage of Botrytis infection in the inoculated fruit was small it was three and one-half times greater in the control cars than in the test cars. The Botrytis rot in the uninoculated fruit was two and one-half times greater in the control cars than in the test cars, and the Rhizopus rot 20 per cent greater.

The fruit in the test cars showed a resistance to pressure 29 per cent greater than did that in the control cars and had 26 per cent fewer berries that were too soft for satisfactory marketing.

There was less development of Botrytis rot and less softening of the fruit in the top of the test cars than at the bottom bunker of the control cars. The average temperature at the bottom bunker of the control cars was about 13 degrees lower than the average temperature in the top of the same cars, yet the solid carbon dioxide had a greater inhibiting action upon both the growth of Botrytis rot and the softening of the fruit than this 13-degree lowering of temperature. When it is realized that both the solid carbon dioxide and the carbon dioxide gas had almost entirely disappeared by the time the trip was one-third to one-half completed, the efficacy of the treatment is still more emphasized. The difficulty of controlling Botrytis rot by means of low temperatures has been one of the discouraging features in strawberry shipments; the results of the experiments just described give promise of a practical solution.

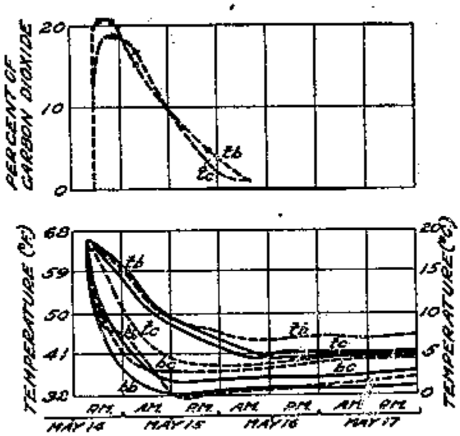

FIGURE 11.—Carbon dioxide curves and temperature curves in an experiment with Klondike strawberries shipped in standard refrigerator cars from Chadbourn, N. C., May 14, 1928. The broken lines give the records for the test car, the solid lines the records for the control car: *tc*, Top center; *tb*, top bunker; *bc*, bottom center; *bb*, bottom bunker; 1,084 pounds of solid CO_2 was used in the test car. It was held on a scaffold in the center of the car about 14 inches above the load. Both cars received 2 per cent of salt at the shipping point and at all reicing stations. The control car required a total of 800 pounds more ice at the reicing stations than the carbon dioxide car. Each car contained 237 crates of berries, making the loads three layers high at the bunkers. The top bunker record for the carbon dioxide car was from the third layer, whereas that from the control was from the second layer

Part of the beneficial effect of solid carbon dioxide on the fruit was due to actual differences in temperature; but the curves in Figures 8 to 11, inclusive, and the reduction in the rots and in the softening of the fruit in the bottom of the test car, as well as in the top, indicate that it must have been largely the result of the inhibiting action of the carbon dioxide gas.

PEACH EXPERIMENTS

Experiments similar to those already described for strawberries were made with peaches. The firmness of the fruit was determined with a pressure tester by the methods described by Magness and Taylor (*22*). The determination of the flavor of the fruit at the close of an experiment was almost as difficult as with strawberries, and debatable points were settled in a similar manner (p. 8). As with strawberries, the first objectionable result of the carbon dioxide treatments was a slight loss of aroma. With more prolonged and severe treatments there was a still greater loss of normal peach flavor, often accompanied by the development of definitely objectionable flavors.

In the study of the behavior of the peach rots two different methods of inoculation were used. In one, the spores were pushed into the fruit by means of a needle, and two punctures were made in each peach; in the other, 10 punctures were made in each peach with No. 18 wire (paper-clip wire), and the peaches were then inoculated by rolling them gently back and forth in large paper bags together with rotten but firm peaches that were heavily covered with spores. The peaches inoculated by the second method are referred to in the tables as "Monilia dusted."

Inoculations were made with Rhizopus and Monilia. The Rhizopus was obtained from the same source as that reported for strawberries (p. 8) and was therefore known to be *R. nigricans*. The Monilia was obtained from an active peach rot and identified as *Sclerotinia fructicola* (Wint.) Rehm.

PEACHES AT CONSTANT TEMPERATURES

The effect of carbon dioxide upon peaches was tested at various constant temperatures. From 5 to 15 peaches, usually 10, were used under each condition. The peaches were selected individually and with great care in order that those to be compared under different conditions should be as nearly alike as possible in maturity, firmness, size, color, and freedom from injuries. The results of the experiments are shown in Table 5.

Duplicate treatments did not always have the same effect on the flavor, a fact indicating that no sharp line can be drawn as to the tolerance of peaches for carbon dioxide. At 68° and 77° F. a change in flavor sometimes resulted from exposure for 24 hours to atmospheres containing 25 per cent or more of carbon dioxide, and at 50° and 59° from exposure for 48 hours to atmospheres containing 30 per cent of carbon dioxide; yet in many instances much more severe treatments were given without the detection of any change in flavor.

High percentages of carbon dioxide were more injurious than lower ones; yet, with concentrations of 25 per cent or more of the gas, the differences in injury were not particularly pronounced.

As already reported for strawberries (p. 13), there was a marked difference between the carbon dioxide tolerance of peaches at the higher temperatures and that at the lower temperatures. In general, the results in Table 5 indicate that one day's exposure to a particular carbon dioxide treatment at 77° F. is as likely to produce objectionable flavors as two days' exposure to the same treatment at 59°, three days' exposure at 50°, or four days' exposure at 41°. These data are in harmony with the temperature gradients obtained in plant responses in general and suggest a close relationship between the general metabolic activities of the fruit and the degree of susceptibility to injury from atmospheres containing carbon dioxide.

The carbon dioxide treatments had a decided effect upon the firmness of the fruit. At the higher temperatures, atmospheres containing 30 per cent or more of the gas had a checking effect upon the rate of softening approximately equal to a drop of 18° F. in temperature, and at the end of the experiment the fruit had a resistance to pressure about 50 per cent greater than that obtained in the untreated fruit at the same temperatures. In the few tests made with 25 per cent of carbon dioxide, the differences in firmness between the treated and the untreated peaches were practically as great as when the higher percentages of the gas were used.

Carbon dioxide had a very significant inhibiting action upon the development of both Rhizopus and Monilia rots with both methods of inoculation. The extent of the inhibition was determined by holding the fruit at the temperature at which the experiment was made for several days after the test lot was removed from the atmosphere containing carbon dioxide, and then comparing the growth curves of the rots so as to determine the number of hours the rots on the treated fruit lagged behind those on the control fruit. The results, reported in Table 5, are for inoculations made just before the experiment was started and therefore include the incubation period of the rot. However, in a number of duplicate experiments made with rots that had already started, the degree of inhibition was found to be practically the same as in the experiments that included the first stages of rot development.

After removal of the fruit from carbon dioxide the rots usually enlarged at practically the same rate as those on fruit that had not received the gas treatment; but in some instances, especially with the higher concentrations of carbon dioxide, normal activity was not regained immediately upon removal from carbon dioxide, thus indicating that the inhibitory action had extended beyond the period of treatment.

The delay in rot development resulting from exposure to various percentages of carbon dioxide is shown in Table 5. The columns following those that give the hours of delay show the reduction in the efficiency of the fungus as indicated by the ratio of the hours of delay to the hours of treatment.

The reduction in efficiency, or degree of inhibition, was somewhat greater at the lower temperatures than at the higher ones, but the difference was not particularly marked.

The reduction in efficiency varied with the percentage of carbon dioxide used and was approximately in proportion to it. No inhibitory effect was evident after treatment wth 5 per cent of carbon dioxide, but with 10, 25, 30, and 37 per cent the average percentage of reduction in efficiency during the period of treatment was equal to approximately twice the percentage of carbon dioxide used. With 50 per cent of carbon dioxide, almost complete inhibition was obtained during the period of treatment; in some cases a definite inhibitory action extended beyond the time of removal. With 80 per cent of carbon dioxide, the period of delay was nearly always greater than the period of treatment, the fungi showing very definite inhibition after the fruit was removed to normal air.

TABLE 5.—*Effects of different percentages of carbon dioxide on peaches at various constant temperatures*

Variety	Date	CO_2 in atmosphere	Temperature	Length of treatment	Pressure test		Flavor		Delay in rot development due to carbon dioxide after indicated inoculation			Reduction in efficiency of the fungus due to CO_2 as indicated by ratio of hours of delay to hours of treatment after indicated inoculation					
												Monilia needle		Monilia dusted		Rhizopus needle	
					After CO_2 treatment	Control	After CO_2 treatment	Control	Monilia needle	Monilia dusted	Rhizopus needle	Individual experiments	Average	Individual experiments	Average	Individual experiments	Average
		Per cent	°F.	*Hours*	*Lbs.*	*Lbs.*			*Hours*	*Hours*	*Hours*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
Belle	July 13, 1927	5	59	72			Good	Good		0				0	0		
Hiley	July 1, 1927	5	50	24			do	do									
Belle	July 5, 1927	5	50	48			do	do									
Do	July 13, 1927	5	50	72			do	do		0				0	0		
Do	Aug. 26, 1927	10	68	72			Bad	do		14				19			
Do	July 18, 1927	10	59	72			Good	do		20				28			
Elberta	July 25, 1927	10	59	72			do	do		37				51	35		
Belle	Aug. 26, 1927	10	59	72			Slightly off	do		19				26			
Do	July 18, 1927	10	50	72			Good	do		35				49			
Do	Aug. 26, 1927	10	50	120			Slight CO_2 taste	do		12				10	30		
Do	do	10	41	120			Good	do		0				0	0		
Do	Sept. 3, 1927	25	77	48			Slight CO_2 taste	do	11			23					
Elberta	Sept. 10, 1927	25	77	24			Slightly off	do	10			42	33				
Belle	Sept. 3, 1927	25	68	48			Slight CO_2 taste	do	23			48					
Elberta	Sept. 10, 1927	25	68	24			do	do	12			50	49				
Belle	July 18, 1927	25	59	72			Good	do	20			28					
Hiley	Aug. 8, 1927	25	59	72			Slightly off	do		38				53			
Elberta	Aug. 31, 1927	25	59	72			Good	do		30			40	42	48		
Belle	Sept. 3, 1927	25	59	72			Slight CO_2 taste	Fair	28			39					
Elberta	Sept. 10, 1927	25	59	48	2.9	1.4	do	Good	26			54					
Hiley	June 29, 1927	25	50	24	2.7	2.4	Good	do									
Elberta	Aug. 31, 1927	25	50	72			do	do		16				22			
Belle	Sept. 3, 1927	25	50	72			do	Fair	55			76					
Elberta	Sept. 10, 1927	25	50	72	5.4	3.5	do	Good	53			74	75				
Do	Aug. 31, 1927	25	41	72			do	do		31				43			
Do	Sept. 7, 1927	25	41	144			Slight CO_2 taste	Flat	140			97	83				
Belle	Sept. 3, 1927	25	41	120			do	Good	82			68					
Elberta	Aug. 23, 1928	30	77	24	12.8	4.7	Good	do	4			17					
Do	Aug. 27, 1928	30	77	24	7.7	2.7	Overripe taste	do	19		10	79	53			42	
Do	Aug. 30, 1928	30	77	24	13.9	8.5	Good	do	15	16	24	63		67		100	71
Do	Aug. 23, 1928	30	68	48	6.4	4.3	do	do	21			44					

Do	Aug. 27, 1928	30	68	24	6.9	4.6	Overripe taste	do	18		26	75	60			108	104
Do	Aug. 30, 1928	30	68	48	7.3	2.7	Slightly insipid	Fair	29	31	48	60		65		100	
Do	Aug. 23, 1928	30	59	96	6.7	3	do	Good	58			60					
Do	Aug. 27, 1928	30	59	48	6.1	5.9	do	do	36			75	62				
Do	Aug. 30, 1928	30	59	72	10.4	3.4	do	do	37	38		51		53			
Do	Aug. 23, 1928	30	50	96	14.7	7.3	Good	do	79			82					
Do	Aug. 27, 1928	30	50	48	10	7.1	Slightly insipid	do	48			100	79				
Do	Aug. 30, 1928	30	50	96	8.4	6.2	Good	do	53	66		55		69			
Do	Aug. 23, 1928	30	41	144	13.4	10	do	do	180			125	97				
Do	Aug. 30, 1928	30	41	120	12.4	11.6	do	do	83	85		69		71			
Carman	Aug. 14, 1928	37	77	24	3.9	1.6	do	do	24			100	100				
Elberta	Aug. 17, 1928	37	77	24	2.8	2.1	Off taste	do	24		24	100				100	
Carman	Aug. 14, 1928	37	68	24	2.9	1.6	Slightly insipid	do	19			79					
Elberta	Aug. 17, 1928	37	68	24	5.7	2.5	do	do	17			71	63				
Do	Sept. 6, 1928	37	68	24	7.3	6.7	Slight CO_2 taste	do	19		22	38				92	
Carman	Aug. 14, 1928	37	59	48	5.8	2	Good	do	39			81	93				
Elberta	Aug. 17, 1928	37	59	25	3.4	4.1	do	do	26			104					
Carman	Aug. 14, 1928	37	50	72	8.7	4.2	do	do	53			74	81				
Elberta	Sept. 6, 1928	37	50	77	9.1	5.7	Slightly insipid	do	67			87					
Carman	Aug. 14, 1928	37	41	96	9	10.5	Good	do									
Elberta	July 25, 1927	46	77	72			Bad	do		40				16			
Belle	Aug. 22, 1927	46	77	48			Strong CO_2 taste	do		9				19	54		
Do	July 31, 1928	46	77	22	5.7	2.5	Slightly insipid	do	14	19	19	64		86		86	
Elberta	July 25, 1927	46	68	72			Bad	do		28				39			
Belle	Aug. 22, 1927	46	68	48			Slightly off	do		20				42			
Do	July 31, 1928	46	68	22	4.5	2.3	Good	do	22	12	24	100		55	42	109	
Elberta	Sept. 11, 1928	46	68	18	9.1	5.9	do	do	11			61	75				95
Do	Sept. 4, 1928	46	68	25	8.1	5.6	Slightly insipid	do	16	8	20	64		32		80	
Belle	July 13, 1927	46	59	72			Good	do		59				82			
Elberta	July 25, 1927	46	59	72			Slight staleness	do		76				100	79		
Belle	Aug. 22, 1927	46	59	48			Slight CO_2 taste	do		17				35			
Do	Aug. 3, 1928	46	59	46	4.2	1.6	Good	do	48	46	80	104		100		174	
Hiley	June 29, 1927	46	50	24	2.4	2.4	do	do									
Do	July 1, 1927	46	50	24			do	do									
Belle	July 5, 1927	46	50	48			do	do									
Do	July 13, 1927	46	50	72			do	do									
Elberta	July 25, 1927	46	50	72			do	do		78				108			
Hiley	Aug. 8, 1927	46	50	72			Slightly insipid	do		64				89			
Belle	Aug. 22, 1927	46	50	48			Slight CO_2 taste	do		6				13	77		
Do	July 31, 1928	46	50	70	4.7	1.6	Good	do	90	90		129		129			
Elberta	Sept. 4, 1928	46	50	48	10.5	9.3	do	do	48	22		100	121	46			
Do	Sept. 11, 1928	46	50	48	9.1	7.1	do	do	64			133					
Hiley	Aug. 8, 1927	46	41	72			do	do									
Belle	Aug. 22, 1927	46	41	120			do	do		12				10	44		
Do	July 31, 1928	46	41	96	3.4	3	Slightly insipid	do	82	75		85		78			
Elberta	Sept. 4, 1928	75	68	25	8	5.6	Slightly off	do	24	20	32	96		80		128	146
Do	Sept. 6, 1928	75	68	24	7.8	6.7	Slight CO_2 taste	do	22		39	92	107			163	
Do	Sept. 11, 1928	75	68	18	11.5	5.9	Good	do	24			133					
Do	Sept. 4, 1928	75	50	48	9.7	9.3	do	do	54	75		113		156			
Do	Sept. 6, 1928	75	50	77	9.2	5.7	Slightly off	do	90			117	118				
Do	Sept. 11, 1928	75	50	48	10.1	7.1	Good	do	60			125					

In most of the experiments, tests were carried out at several different temperatures at the same time with peaches from the same lot. This gave an opportunity to compare the development of the rots on the treated fruit at the higher temperatures with that on the untreated fruit at the lower temperatures, thus converting the inhibitory action of the carbon dioxide into approximate temperature equivalents. The temperature curves of Figures 12 and 13, showing the working efficiency of Monilia and Rhizopus at different temperatures, were also of aid in this conversion of values (*6*). While the results have been somewhat variable, it can be said in general that holding peaches at 77° F. in 10, 25, 30, 37, and 46 per cent of carbon dioxide had effects upon the rots roughly equivalent to holding them during the period of treatment at temperatures 12°, 22°, 27°, 33° and 40° lower, respectively. Similar gas treatments at 68° had inhibitory effects upon the rots approximately equivalent to temperature reductions of 6°, 14°, 20°, 26° and 32°, respectively. Similar treatments at 59° caused corresponding inhibitions approximately equivalent to reductions of 6°, 12°, 16°, 22°, and 25°, respectively. Putting the results in more general terms, atmospheres carrying 30 to 37 per cent of carbon dioxide had a checking effect upon the rots theoretically equivalent to the immediate cooling of the fruit from common summer loading temperatures to temperatures that are usually obtained only after one or often two days of refrigeration.

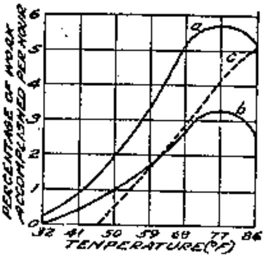

FIGURE 12.—Temperature curves for the incubation period of peach rots, showing the relative efficiency of the fungi at different temperatures: *a*, Monilia needle inoculations; *b*, Monilia dusted inoculations; *c*, Rhizopus needle inoculations. (After Brooks and Cooley, *6*)

PEACHES IN PONY REFRIGERATORS

The pony-refrigerator experiments with peaches were carried out as described under Methods and Apparatus (p. 7). The results are shown in Table 6 and in Figures 14 to 21, inclusive.

The use of solid carbon dioxide as a supplementary refrigerant usually resulted in lower temperatures and more rapid cooling, but possibly its most striking refrigerating effect was in delaying the melting of the ice. A similar condition has already been pointed out under the discussion for strawberries. (P. 15.)

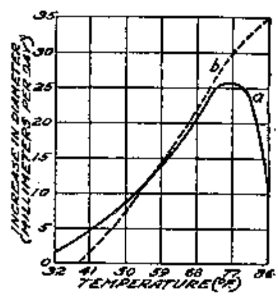

FIGURE 13.—Temperature curves based on the hourly increase in diameter of peach rots: *a*, Monilia; *b*, Rhizopus. (After Brooks and Cooley, *6*)

Judging by most of the results in the constant-temperature experiments with peaches (Table 5), it would hardly be expected that the gas treatments shown in Figures 14 to 21, inclusive, would affect the flavor of the fruit; but in several instances the peaches were rendered insipid or developed objectionable flavors. The correlation between treatment and effect was not particularly close. In general it may be said that under the conditions of the experiments peaches that were subjected to 25 per cent or more of carbon dioxide for as long a period as 24 hours were usually found at the close of the experiment either to be lacking in flavor or to have a distinctly objectionable taste. In experiments where high percentages of carbon dioxide were maintained for somewhat shorter periods the flavor of the peaches remained unaffected.

The effect of the gas treatments upon the firmness of the peaches was usually pronounced. Excluding the tests in which the flavor of the peaches was affected, at the end of the experiments the average resistance to pressure was decidedly higher in the refrigerators in which solid carbon dioxide was used than in the controls. The temperature differences between the various refrigerators were not sufficient to account for much of this difference; it must therefore be attributed largely to the effect of the gas.

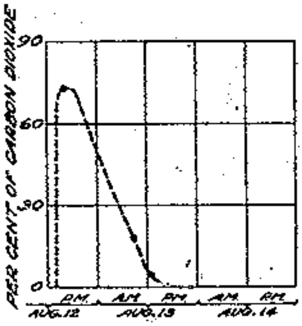

FIGURE 14.—Carbon dioxide curve in an experiment with Hiley peaches in pony refrigerators, August 12 to 14, 1927. The refrigerators were of the 32-quart size. The control refrigerator received 60 pounds of ice, the test refrigerator 40 pounds of ice and 20 pounds of solid CO_2. The curve above shows the approximate percentage of carbon dioxide in the test refrigerator. The temperature in the test refrigerator was 33° F. at midnight August 12 and 42° at 9 p. m. August 13. The minimum temperature for the control refrigerator was 47°

The carbon dioxide gas also had a very decided inhibiting effect upon both Rhizopus and Monilia rots. (Table 6.) In most instances the peaches were held at a temperature of 59° F. for several days after removal from the pony refrigerators, and daily measurements of the rots were taken during this period. On the basis of growth at this temperature, the rots on the fruit from the various refrigerators containing solid carbon dioxide were one to three days behind those on the fruit from the control refrigerators. In some instances, especially with Rhizopus and with Monilia-dust inoculations, the rots were greatly decreased in number as well as in size. Rose and Butler (*29*) have shown that when fungus cultures are moved from lower to higher temperatures there is a lag in growth that is correlated with, and apparently due to, the temperatures at which they had previously been held. In the present experiments, however, the control lots of fruit were subjected to practically the same changes in temperature as were the test lots; therefore the effect of the previous temperature is not a factor in later comparisons.

TABLE 6.—*Condition of peaches held in pony refrigerators with solid carbon dioxide as a supplementary refrigerant* [1]

Figure reference [1]	Ice		Solid CO_2	Pressure test upon removal	Flavor upon removal	Rots from indicated inoculations							
						Rhizopus needle		Monilia dusted		Monilia needle			
										Average diameter of rots after removal [2]		Reduction in efficiency of fungus due to CO_2 gas, expressed as—	
	At beginning	At end				Average infection after removal [2]	Average diameter of rots after removal [2]	Infection upon removal	Infection after removal [2]	First record	Later record	Inhibition period from beginning of experiment	Percentage for total period in refrigerator
	Pounds	*Pounds*	*Pounds*	*Ounces*		*Per cent*	*Mm*	*Per cent*	*Per cent*	*Mm*	*Mm*	*Hours*	*Per cent*
Fig. 14	60	0	0	10	Good				(1) 86				
	40	6	20	12.6	do				(1) 22				
Fig. 15:													
a	60		0	1.2	do			33					
b	40		20	2.9	do			5					
Fig. 16:													
a	60	9	0	6.2	do					(0) 3	(2) 16.7		
b	30	9	26	8.1	do					(0) 0	(2) .2	89	100
Fig. 17:													
a	60+58		0	5.5	Poor	(2) 100	(2) 21.5			(0) 16.5	(2) 26.7		
b	35		25+15	8	Slightly off	(2) 0	(2) 0			(0) 0	(2) 0	78	100
Fig. 18:													
a	135	4	0	5.1	Good					(1) 9	(2) 21.5		
b	120	12	15	7.5	do					(1) 0	(2) 5.5	70	100
c	110	8	25	8.1	do					(1) 0	(2) 0	96	100
d	100	18	35	9.1	do					(1) 0	(2) 9.1	61	94
Fig. 19:													
a	141	5	0	9.4	do			5	(1) 34	(0) 7.1	(1) 21.3		
b	126	15	15	9.7	do			0	(1) 0	(0) .3	(1) 7.7	39	62
c	111	20	30	11.4	Slightly off [3]			0	(1) 0	(0) 0	(1) 8.2	42	65
d	87	25	50	10	Distinctly off [3]			0	(1) 0	(0) 0	(1) 3.7	68	96

Fig. 20:													
a	140	10	0	12.6	Fair			0	(2) 69	(0) 6.3	(1) 16.5		
b	90	33	50	13	do			0	(2) 4	(0) 0	(1) 0	69	100
c	90	34	50	13.5	do			0	(2) 1	(0) 0	(1) 0	72	100
d	90	35	50	14.1	do			0	(2) 4	(0) 0	(1) 0	78	100
Fig. 21:													
a	140	0	3	4.6	Fair to good	(3) 95	(3) 52.6	30	(1) 46	(0) 16.5	(1) 24		
b	120	6	20	6.5	Slightly insipid	(3) 50	(3) 6.8	0	(1) 0	(0) 0	(1) 5	65	93
c	100	19	40	7.9	Insipid	(3) 75	(3) 4.5	0	(1) 3	(0) 0	(1) 0	84	100
d	100	17	40	5.3	Slightly insipid	(3) 60	(3) 6	0	(1) 14	(0) 0	(1) 0	79	100

[1] For data on variety, CO_2, temperature, and length of treatment see Figs. 14 to 21, inclusive.
[2] Numbers in parentheses indicate number of days fruit was held at 59° F. after removal.
[3] The flavor became normal after the fruit had been held 2 days at 59° F. after removal.

By the use of the equivalent temperature values shown in Figures 12 and 13, it is possible to separate the effect of carbon dioxide gas on the rots from the effect of any differences in temperature. If the temperature values of Figures 14 to 21 are converted into work units according to the Monilia needle-inoculation values of Figures 12 and 13, it is possible to compare the relative efficiency of the fungus under the different treatments, with the temperature factor eliminated. The results of such a comparison are shown in the last two columns of Table 6. In 9 out of the 14 cases analyzed, the fungus was checked by the carbon dioxide treatment to a degree equivalent to total inhibition during the entire period in the refrigerator, and in

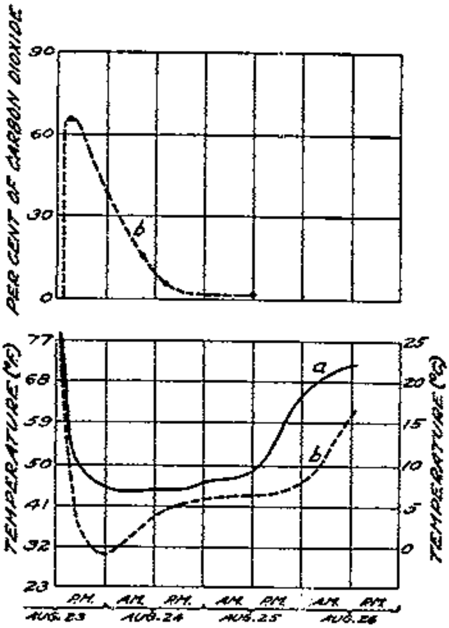

FIGURE 15.—Carbon dioxide curve and temperature curves in an experiment with Belle peaches in 32-quart pony refrigerators, August 23 to 26, 1927: *a*, Control refrigerator with 60 pounds of ice; *b*, refrigerator with 40 pounds of ice and 20 pounds of solid CO_2. The thermographs were covered with fruit but near the top of the refrigerator

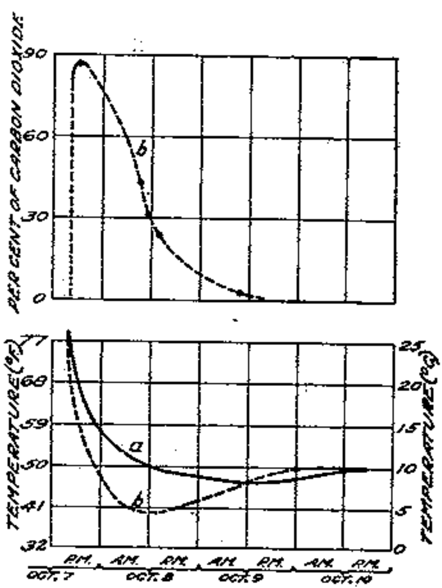

FIGURE 16.—Carbon dioxide curve and temperature curves in an experiment with Krummel peaches in 32-quart pony refrigerators, October 7 to 10, 1927: *a*, Control refrigerator with 60 pounds of ice; *b*, refrigerator with 30 pounds of ice and 26 pounds of solid CO_2

several instances complete inhibition can be considered to have extended over into the period of storage at 59° F. When it is noted from the curves in Figures 14 to 21 that the carbon dioxide had usually escaped from the refrigerators several hours before the fruit was removed, the extent of the inhibition is still more emphasized.

The number of hours of inhibition or the percentage of inhibition reported in any particular instance must, of course, be regarded as approximate; but the results as a whole give great emphasis to the possible value of carbon dioxide gas as a deterrent to fungal invasion.

Mathematical computation of the inhibition in Rhizopus needle inoculations and in the dusting inoculations with Monilia has not been attempted; but the data given in Table 6, and other records not reported, are sufficient to show that the inhibition in both of these cases was as great as that with the Monilia needle inoculations.

PEACHES IN REFRIGERATOR CARS

Solid carbon dioxide was used also in car-lot shipments of peaches. The method of handling has been described under Methods and Apparatus (p. 7), and the methods used in the inoculation of the fruit are described on page 22.

All the inoculations were made at one time and the inoculated fruit packed at once beside the recording thermometers. It often happened

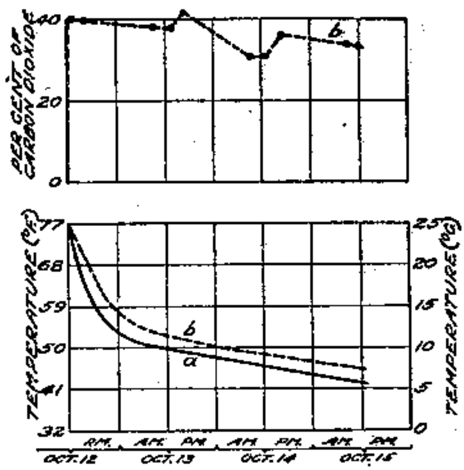

FIGURE 17.—Carbon dioxide curve and temperature curves in an experiment with Elberta peaches in 32-quart pony refrigerators, October 12 to 15, 1927: *a*, Control refrigerator with 60 pounds of ice at the beginning of the experiment, 31 pounds added October 13 at 4 p. m., and 27 pounds added October 14 at 1 p. m.; *b*, refrigerator with 35 pounds of ice and 25 pounds of solid CO_2 at the beginning of the experiment and 15 pounds solid CO_2 added October 14 at 1 p. m. One layer of insulating felt was used between the fruit and the ice pan in *a*, and two layers of felt in *b*

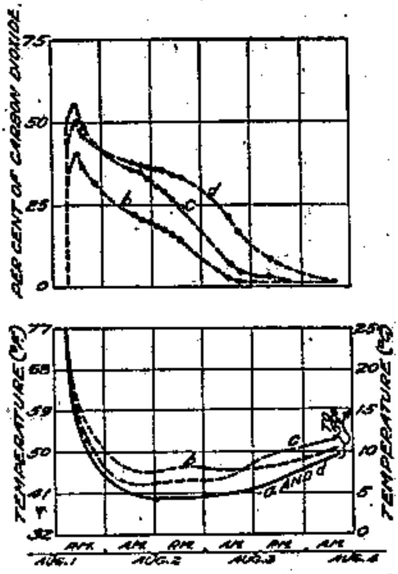

FIGURE 18.—Carbon dioxide curves and temperature curves in an experiment with Belle and Elberta peaches in 80-quart pony refrigerators, August 1 to 4, 1928. *a*, Control refrigerator with 135 pounds of ice; *b*, refrigerator with 120 pounds of ice and 16 pounds of solid CO_2; *c*, refrigerator with 110 pounds of ice and 25 pounds of solid CO_2; *d*, refrigerator with 100 pounds of ice and 35 pounds of solid CO_2. The temperatures reported are the average of records from the top and bottom layers of baskets. On August 4 record fruit was transferred to 59° F. storage chamber

that one of the cars was loaded earlier than the others; in such cases an effort was made to maintain similar temperature conditions by placing all the test fruit in the car that was being loaded. This sometimes resulted in a drop in temperature during loading followed by a rise in temperature when the test crates were finally placed in position together with warmer fruit. The temperature and carbon-dioxide records are given in Figures 22 to 26, inclusive, and the icing records and the time and place of shipment are reported in the legends to these figures.

As shown in Figures 22, 23, 24, and 26, the solid carbon dioxide resulted in a more rapid cooling of the fruit in the top of the load, but Figure 25 shows that the cooling in the top of the carbon dioxide car was slightly behind that in the control car and decidedly behind that in the blower car.

In the experiment of Figure 22 the carbon dioxide content of the air in the refrigerator car remained about 18 to 20 per cent for the first 5 hours after the car was closed and probably dropped rapidly after that. In the experiment of Figure 26 the carbon dioxide was above 20 per cent for 10 hours and above 10 per cent for 18 hours, and in the experiments shown in Figures 23, 24, and 25 it was above 20 per cent for about 14 hours and above 10 per cent for 23 hours or longer. The percentage of gas in some shipments (figs. 23 and 24) was but little greater than in others (figs. 25 and 26), yet far more solid carbon dioxide was used. This difference was apparently due to the fact that the cars of the later shipments were new, whereas those of the earlier shipments were not.

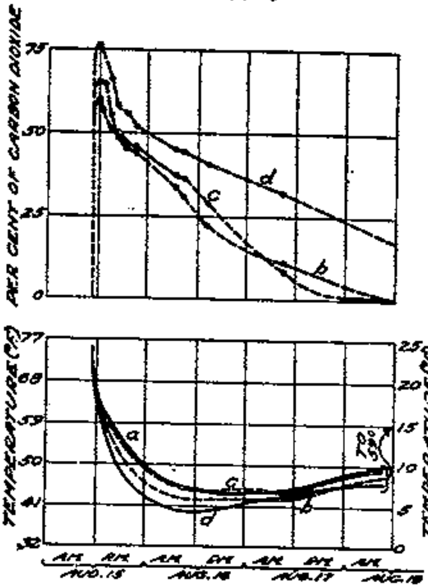

FIGURE 19.—Carbon dioxide curves and temperature curves in an experiment with Belle peaches in 80-quart pony refrigerators, August 15 to 18, 1928: *a*, Control refrigerator with 141 pounds of ice; *b*, refrigerator with 126 pounds of ice and 15 pounds of solid CO_2; *c*, refrigerator with 111 pounds of ice and 30 pounds of solid CO_2; *d*, refrigerator with 87 pounds of ice and 50 pounds of solid CO_2. The temperatures reported are the average of records from the top and bottom layers of baskets

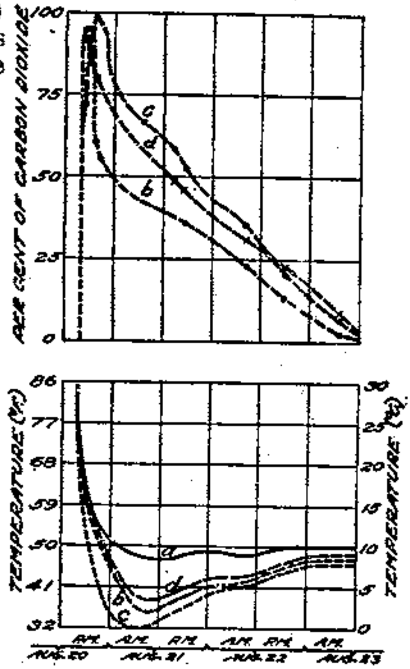

FIGURE 20.—Carbon dioxide curves and temperature curves in an experiment with Belle peaches in 80-quart pony refrigerators, August 20 to 23, 1928: *a*, Control refrigerator with 140 pounds of ice; *b*, *c*, and *d*, three different refrigerators, each with 90 pounds of ice and 50 pounds of solid CO_2; *b* differed from the others in having two ⅝-inch holes in the bottom of the fruit chamber. The temperatures reported are the average of records from the top and bottom layers of baskets

In all cases critical tests were made as to the flavor of the fruit at destination, but there was no indication of any unfavorable effect resulting from exposure to the carbon dioxide gas. The peaches from the test cars tasted somewhat greener in some instances than did those in the control cars, and the pressure tests showed that they were actually less mature; but the differences in flavor were not unlike the differences found between the fruit in the top and the bottom of the same car. In one shipment (fig. 24) the fruit was held in cold storage for two weeks after unloading; at the end of that time the flavor of the peaches from the test car was fully as good as that of the peaches from the control car.

Sample lots of fruit from the other shipments were forwarded to Washington, D. C., for further tests on flavor. In no instance was any distinctly objectionable flavor detected, but in two shipments (figs. 25 and 26) the fully ripened peaches of the test cars had a slightly different flavor from those of the control car. The variation within the particular lots was much greater than the difference between the lots, but on the whole the fruit from the test car seemed to show a slight reduction in aroma, acidity, and juiciness, and a slight increase in sweetness. In Elberta peaches the usual bitter flavor was lacking in the treated fruit while still present in the untreated. Of a group of 8 persons who critically tested the fruit from the first of these shipments (Belle), 3 could detect no difference in flavor, 4 preferred the fruit that had been exposed to carbon dioxide, and 1 preferred the fruit from the control car; and of a group of 16 who tested the fruit from the second shipment (Elberta), 5 could find no difference in flavor, 5 preferred the fruit from the test car, and 6 preferred the fruit from the control car.

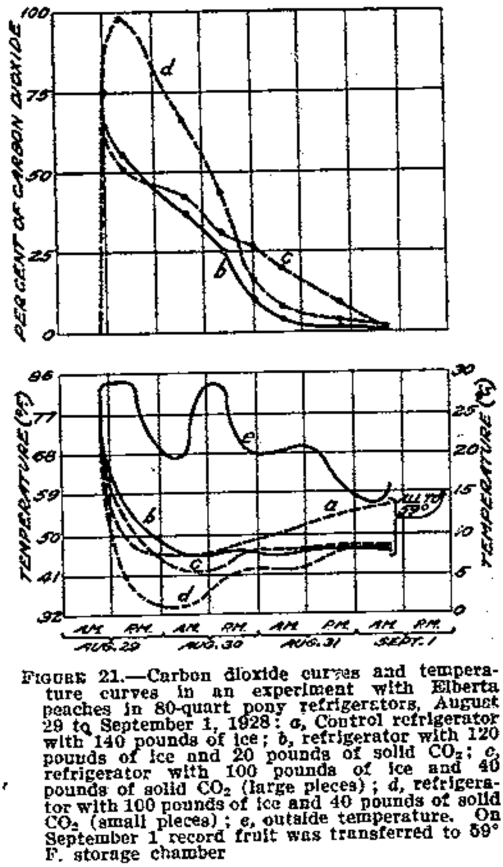

FIGURE 21.—Carbon dioxide curves and temperature curves in an experiment with Elberta peaches in 80-quart pony refrigerators, August 29 to September 1, 1928: *a*, Control refrigerator with 140 pounds of ice; *b*, refrigerator with 120 pounds of ice and 20 pounds of solid CO_2; *c*, refrigerator with 100 pounds of ice and 40 pounds of solid CO_2 (large pieces); *d*, refrigerator with 100 pounds of ice and 40 pounds of solid CO_2 (small pieces); *e*, outside temperature. On September 1 record fruit was transferred to 59° F. storage chamber

As in previous experiments, the carbon dioxide had a very decided effect upon the firmness of the fruit. The average resistance to the pressure tester for the peaches in the top of the five test cars was practically the same as that for the peaches in the bottom of the five control cars and differed but little from that before shipment, whereas the average pressure test for the peaches in the top of the five control cars was 36 per cent lower.

The carbon dioxide did not show quite so great inhibiting action on the growth of the fungi as it did on the softening of the fruit, yet the contrasts were very significant. The average development of the rot organisms in the top of the test car was greater than that in the

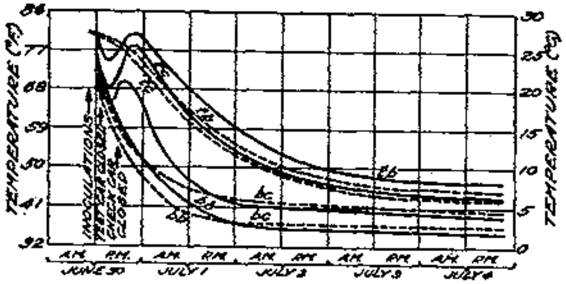

FIGURE 22.—Temperature curves in an experiment with Belle peaches shipped in refrigerator cars from Fort Valley, Ga., June 30, 1927. The broken lines give the records for the test car, the solid lines the records for the control car; *tc*, Top center; *tb*, top bunker; *bc*, bottom center; *bb*, bottom bunker. The test car received, in addition to standard icing, 430 pounds of solid CO_2 held in crates scattered over the top of the load and somewhat insulated from it. At 2 p. m. the atmosphere in the test car contained 12.5 per cent of CO_2; at 2.30 p. m., 18 per cent; and from 3.30 till 7 p. m., 20 to 21 per cent. The top center and bottom bunker atmospheres showed practically no difference. There were 476 crates of peaches in each car

bottom of the control car, but less than the average development in the control car.

The average difference in temperature between the top and bottom of the control cars was 13.1 degrees Fahrenheit, and the average difference in temperature between the top of the control cars and the average temperature for these cars was 6.6 degrees. Expressed in temperature values, the use of solid carbon dioxide had an effect upon the softening of the fruit equal to a 13.1-degree reduction in temperature during the entire trip and an effect upon the rots greater than that of a 6.6-degree reduction in temperature during the entire trip. If it is assumed that this inhibiting effect upon the rots was confined to the first 36 hours after loading, as it probably was to a large extent, it may be said that during this period the solid carbon dioxide had an inhibiting effect upon the rots approximately equal to that of an 18-degree drop in temperature.

If the behavior of the Monilia rots is studied on the basis of the values in Figures 12 and 13, the differences in growth may be interpreted in terms of the degree of inhibition in the test car as compared with that in the control car. It is found, for example, that in the shipment shown in Table 7 under Figure 23 the rots in the

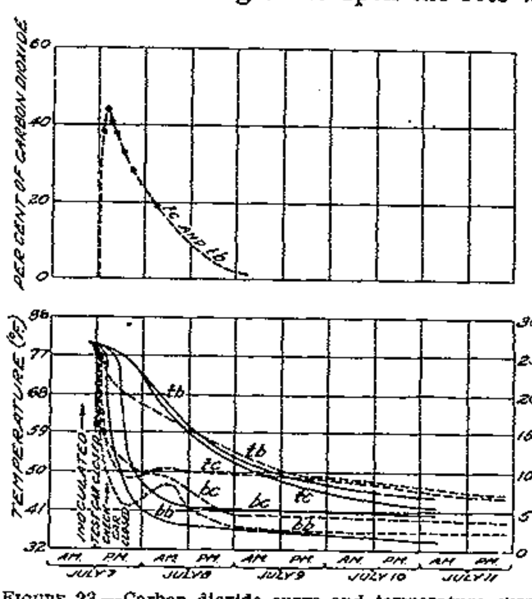

FIGURE 23.—Carbon dioxide curve and temperature curves in an experiment with Hiley peaches shipped in refrigerator cars from Fort Valley, Ga., July 7, 1928. The broken lines give the records for the test car, the solid lines the records for the control car: *tc*, Top center; *tb*, top bunker; *bc*, bottom center; *bb*, bottom bunker. The test car received, in addition to standard icing, 884 lines the records for the control car: *tc*, Top center; of the car about 16 inches above the load. The test car received 100 pounds more ice at the reicing stations than did the control car but was unloaded 18 hours later than the control car

top of the test car showed a reduction in efficiency equal to 19 per cent for the whole shipping period, and those in the bottom of the car a similar reduction of 8 per cent; in the shipment described in Figure 24 the rots in the top of the test car showed a reduction of 48 per cent, and those in the bottom a reduction of 44 per cent. The data in Table 7 show that the inhibition of the Rhizopus rots was equally great.

In some instances the better condition of the fruit in the test car, as to firmness and decay, may have been partly due to differences in temperature; but a study of the curves in Figures 22 to 26, inclusive, leads to the conclusion that it must have been largely due to the effect of the carbon dioxide gas.

From the economic standpoint it should be noted that, as shown in Table 7 under Figure 23, the fruit in the test car was in distinctly better condition on arrival than that in the control car, both as to firmness and rot development, in spite of the fact that the control car was unloaded 18 hours earlier. In two cars unloaded at practically the same time (fig. 24), the condition of the fruit in the control car was such as to make it necessary to place it on the market at once, whereas the fruit in the test car was placed in storage to be held for later sales. The inoculated fruit from both cars was transferred to cold storage, however, and it was found that the development of rots on the peaches from the test car after two weeks in storage only slightly exceeded that of the rots on the peaches from the control car at the time of unloading.

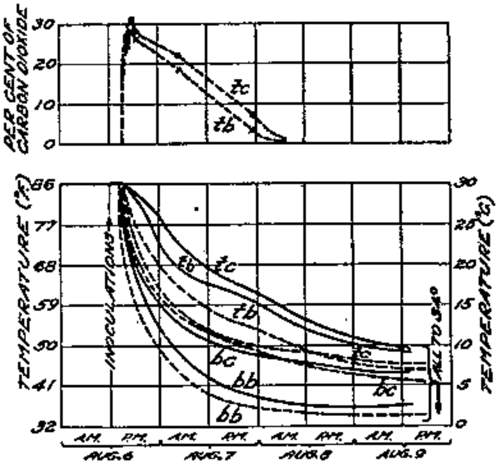

FIGURE 24.—Carbon dioxide curves and temperature curves in an experiment with Elberta peaches shipped in refrigerator cars from Hamlet, N. C., August 6, 1928. The broken lines give the records for the test car, the solid lines the records for the control car: *tc*, Top center; *tb*, top bunker; *bc*, bottom center; *bb*, bottom bunker. The test car received, in addition to standard icing 1,000 pounds of solid CO_2 held on a scaffold in the center about 16 inches above the load. The test car also received 2 per cent of salt in the bunkers at the shipping point. The control car required 2,100 pounds more ice at the reicing stations than the test car. On August 9 record fruit was transferred to 34° F. storage

One shipment (fig. 25) included a car in which a Galloway precooling apparatus[4] was used in comparison with the carbon dioxide car and with the control car. The results, as given in Table 7, show practically the same resistance to pressure in the fruit of the blower car (with precooling apparatus) as in that of the carbon dioxide car. The development of Monilia and Rhizopus rots, however, was very much greater in the blower car than in the carbon dioxide car and not greatly different from that in the control car.

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[4] GALLOWAY, A. G. A PORTABLE PRECOOLING APPARATUS. U. S. Department of Agriculture, Bur. Plant Indus., July 15, 1929. [Mimeographed.]

Another shipment (fig. 26) included a salted car in addition to the control car and the carbon dioxide car, the latter also salted. The average results on firmness and decay in the salted car fell about halfway between those in the control car and those of the carbon dioxide car, but in the top of the load the results on both firmness and decay were practically the same as those in the control.

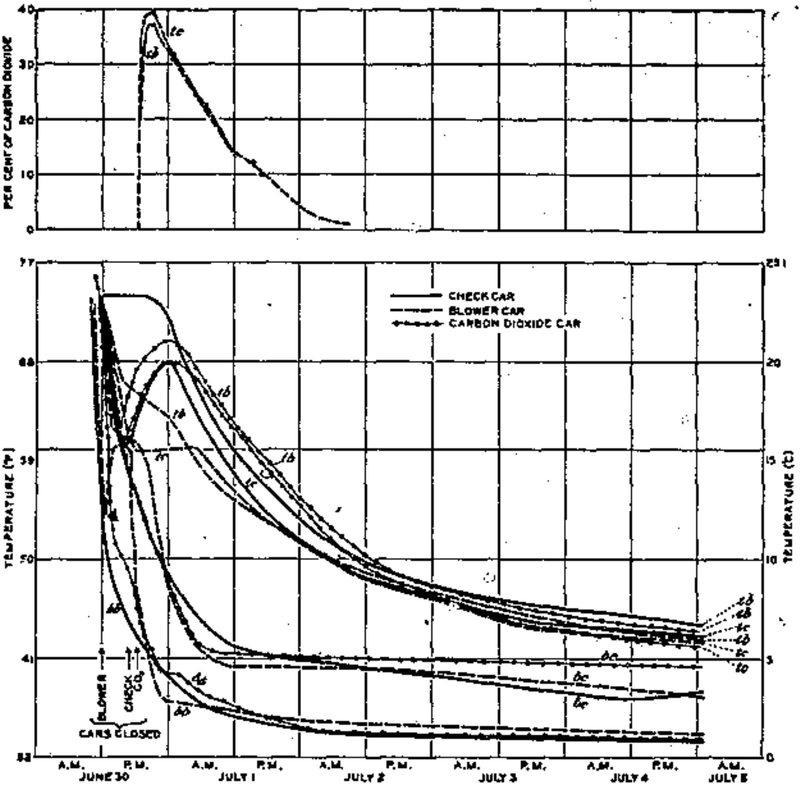

FIGURE 25.—Carbon dioxide curves and temperature curves in an experiment with Hiley peaches shipped in refrigerator cars from Thomason, Ga., June 30, 1930: *tc*, Top center; *tb*, top bunker; *bc*, bottom center; *bb*, bottom bunker. The carbon dioxide car received 450 pounds of solid CO_2 placed in crates on top of the load. The carbon dioxide car had 400 pounds of salt added at the shipping point and the blower car 300 pounds. The solid carbon dioxide car required 200 pounds and the control car 1,070 pounds more ice than did the blower car

DEWBERRY EXPERIMENTS

The dewberry is even more perishable than the strawberry but may be exposed to carbon dioxide gas with far less danger of injury than either the peach or the strawberry.

In the experiments with dewberries no inoculations were made, and no satisfactory method was devised for measuring the firmness of the fruit. Before the experiments were started, however, sample lots of fruit were graded, and the berries were classified as firm, soft, or rotten. At the end of the experiments similar lots were graded according to the same standards to determine the increase in rot and the decrease in the number of firm berries.

DEWBERRIES IN PONY REFRIGERATORS

The pony-refrigerator experiments were carried out as described for strawberries (p. 7). The results are shown in Table 8. In the experiments of Figures 3, 4, 7, and 20, only a few baskets of dewberries were used in each refrigerator, the main experiment being upon another fruit. In the experiments shown in Figures 27 and 28 the refrigerators were filled with dewberries, with the exception of small lots of other fruits, as will be pointed out later.

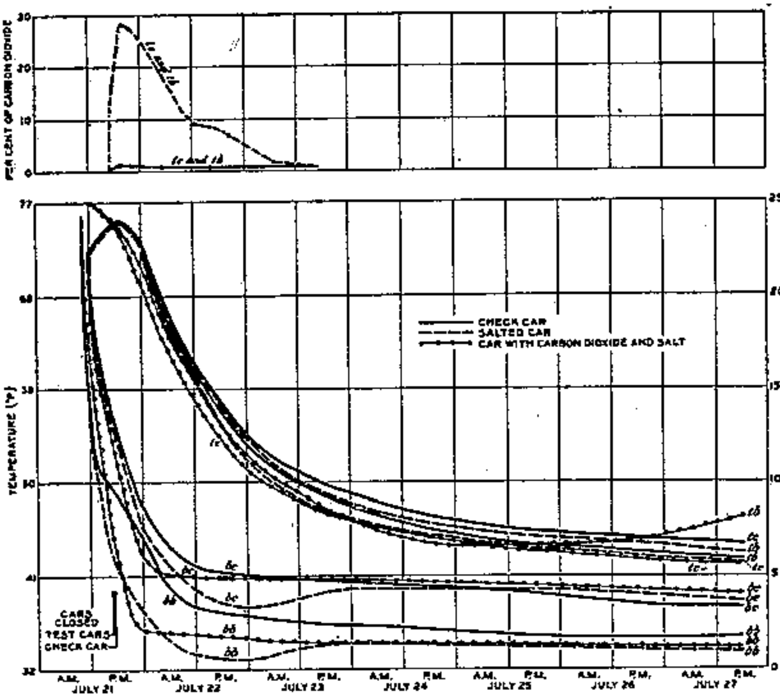

FIGURE 26.—Carbon dioxide curves and temperature curves in an experiment with Elberta peaches shipped in refrigerator cars from Thomaston, Ga., July 21, 1930: *tc*, Top center; *tb*, top bunker; *bc*, bottom center; *bb*, bottom bunker. The carbon dioxide car received 466 pounds of solid CO_2 placed in crates on top of the load and an additional 113 pounds placed in the bunkers. The carbon dioxide car had 400 pounds of salt added at the shipping point and the salted car 300 pounds at shipping point and 189 pounds en route. The salted car required 4,284 pounds and the control car 5,870 pounds more ice than did the solid carbon dioxide car

The flavor of the dewberries remained unimpaired under all the conditions of the various experiments, despite the fact that the carbon dioxide treatment was sometimes even more severe than that which had usually spoiled the flavor of peaches and strawberries. In the experiment reported in Figure 4 a small lot of dewberries was included with a strawberry test, and in the experiments reported in Figures 27 and 28 small lots of strawberries were included with the dewberry tests. In all three experiments the flavor of the dewberries was unaffected by the carbon dioxide treatment, whereas the flavor of the strawberries was rendered either insipid or distinctly bad.

TABLE 7.—*Condition of peaches and peach-rot organisms after shipment in standard refrigerator cars with different methods of cooling*

Figure reference [1]	Location in car	Flavor of peaches in—				Pressure test of peaches in—				Rots from Monilia needle inoculations					
										Peaches infected in—		Diameter of rots on peaches in—			
		Carbon dioxide car	Control car	Blower car	Salted car	Carbon dioxide car	Control car	Blower car	Salted car	Carbon dioxide car	Control car	Carbon dioxide car	Control car	Blower car	Salted car
						Ounces	*Ounces*	*Ounces*	*Ounces*	*Per cent*	*Per cent*	*Mm*	*Mm*	*Mm*	*Mm*
Fig. 22	Top center	Good	Good			15.2	10.2								
	Top bunker	do	do			13.4	3.2								
	Average top of car					14.3	6.7								
	Bottom center	Good	Good			15.2	13.5								
	Bottom bunker	do	do			17.1	14.5								
	Average bottom of car					16.2	14								
	Average for car					15.2	10.4								
Fig. 23 [2]	Top center	Good	Good			13.1	7.2			100	100	15.8	28.9		
	Top bunker	do	do			11.8	9.3			100	100	28.7	31.4		
	Average top of car					12.5	8.3			100	100	22.3	30.4		
	Bottom center	Good	Good			12.6	13.2			95	100	7.1	9.9		
	Bottom bunker	do	do			12.8	12.5			90	100	4.6	4.2		
	Average bottom of car					12.7	12.9			92.5	100	5.9	7.1		
	Average for car					12.6	10.6			96.3	100	14.1	18.7		
Fig. 24	Top center	Good	Good			13.4	6.2			55	100	4.7	33.5		
	Top bunker	do	do			12.8	8.4			95.1	100	6.7	26.2		
	Average top of car					13.1	7.3			75.1	100	5.7	29.9		
	Bottom center	Good	Good			14.4	12.1			15	90	3	7.7		
	Bottom bunker	do	do			13.8	14.2			5	53.6	3	2.8		
	Average bottom of car					14.1	13.2			10	71.8	3	5.3		
	Average for car					13.6	10.2			42.5	85.9	4.4	17.6		
Fig. 25	Top center	Good	Good	Good		14.6	13.6	14.3				38.5	45.1	41.2	
	Top bunker	do	do	do		14.4	12.4	14.7				32.4	45.2	46.3	
	Average top of car					14.5	13	14.5				35.5	45.2	43.8	
	Bottom center	Good	Good	Good		14	13.8	13.7				17.2	20.3	23.2	
	Bottom bunker	do	do	do		14	14.7	14.5				9.3	17.1	19.5	
	Average bottom of car					14	14.3	14.1				13.3	19	21.4	
	Average for car					14.3	13.6	14.3				24.4	32.1	32.6	
Fig. 26	Top center	Good	Good		Good	11.2	6.1		5.6			44	54.5		52
	Top bunker	do	do		do	10.2	5.9		7.3			40.8	55.4		52.7
	Average top of car					10.7	6		6.5			42.4	55		52.4
	Bottom center	Good	Good		Good	14.7	[3] 7.8		[3] 12.7			14.4	[3] 22.1+6		[3] 13.1+3.2
	Bottom bunker	do	do		do	13.5	[3] 14		[3] 13.5			4	[3] 6.0+4		[3] 2.7+1.8
	Average bottom of car					14.1	10.9		13.1			9.2	14.1		7.9
	Average for car					12.4	8.5		9.8			25.8	34.6		30.2
Average	Top of car					13	8.3			87.6	100	26.5	40.1		
	Bottom of car					14.2	13.1			51.3	85.9	7.9	11.4		
	Entire car					13.6	10.7			69.4	93	17.2	25.8		

Figure reference[1]	Rots from Monilia dusted inoculations				Rots from Rhizopus needle inoculations						Increase in diameter of colonies of rot organisms in Petri dish							
	Peaches infected in—		Diameter of rots on peaches in—		Peaches infected in—		Diameter of rots on peaches in—				Monilia in—				Rhizopus in—			
	Carbon dioxide car	Control car	Carbon dioxide car	Control car	Carbon dioxide car	Control car	Carbon dioxide car	Control car	Blower car	Salted car	Carbon dioxide car	Control car	Blower car	Salted car	Carbon dioxide car	Control car	Blower car	Salted car
	Per cent	*Per cent*	*Mm*	*Mm*	*Per cent*	*Per cent*	*Mm*	*Mm*	*Mm*	*Mm*	*Mm*	*Mm*	*Mm*	*Mm*	*Mm*	*Mm*	*Mm*	*Mm*
	36	30.8	6.2	8.5	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Fig. 22	51.4	96.7	8.3	14.1	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	43.7	63.8	7.3	11.3	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	34.3	99.5	6.4	9.8	0	86	0	5	—	—	—	—	—	—	—	—	—	—
	90.5	94.5	7	10	0	0	0	0	—	—	—	—	—	—	—	—	—	—
	62.4	97	6.7	9.9	0	43	0	2.5	—	—	—	—	—	—	—	—	—	—
Fig. 23[2]	15	20	2.3	2.8	0	0	0	0	—	—	—	—	—	—	—	—	—	—
	23.6	.5	2.1	2	0	0	0	0	—	—	—	—	—	—	—	—	—	—
	19.3	10.3	2.2	2.4	0	0	0	0	—	—	—	—	—	—	—	—	—	—
	40.9	53.7	4.4	6.2	0	21.5	0	1.3	—	—	—	—	—	—	—	—	—	—
	5	87	3.4	10.9	0	45.1	0	5.5	—	—	—	—	—	—	—	—	—	—
	5	60	4	10.3	0	39.9	0	8.3	—	—	—	—	—	—	—	—	—	—
	5	73.5	3.7	10.6	0	42.5	0	6.9	—	—	—	—	—	—	—	—	—	—
Fig. 24	3	8	3	10	0	0	0	0	—	—	—	—	—	—	—	—	—	—
	3	2	3	2	0	0	0	0	—	—	—	—	—	—	—	—	—	—
	3	5	3	6	0	0	0	0	—	—	—	—	—	—	—	—	—	—
	4	39.3	3.4	8.3	0	21.3	0	3.5	—	—	—	—	—	—	—	—	—	—
							1.5	6.7	13.4	—	26	36	34.5	—	—	—	—	—
							13.2	18.6	17.4	—	27	38.8	34	—	—	—	—	—
							7.4	12.7	15.4	—	26.5	37.4	34.3	—	—	—	—	—
Fig. 25							0	0	0	—	7.9	13.2	14.5	—	17.5	28	36	—
							.5	.8	0	—	1.1	3	5.2	—	5	5.5	16.5	—
							.3	.4	0	—	4.5	8.1	9.9	—	11.3	16.8	26.3	—
							3.8	6.5	7.7	—	15.5	22.8	22.1	—	—	—	—	—
							2	3.2	—	2	20.7	36	—	33.5	—	—	—	—
							4.7	9.4	—	4.7	24.5	35.5	—	37	—	—	—	—
							3.4	6.3	—	3.4	22.6	35.8	—	35.3	—	—	—	—
Fig. 26							0	0	—	0	0	[3] 12	—	[3] 6	4	11	—	6
							0	0	—	0	0	[3] 4	—	[3] 3	0	0	—	0
							0	0	—	0	0	8	—	4.8	2	5.5	—	3
							1.7	3.2	—	1.7	11.3	21.9	—	20.1	—	—	—	—
	33.7	85.3	5.2	10.3	—	—	2.7	7.1	—	—	24.6	36.6	—	—	—	—	—	—
Average	11.2	7.7	2.6	4.2	—	—	.1	.1	—	—	2.3	8.1	—	—	6.7	11.2	—	—
	22.5	46.5	3.9	7.3	—	—	1.4	3.6	—	—	13.4	22.4	—	—	—	—	—	—

[1] For data on variety, CO_2, temperature, and treatment, see Figs. 22 to 26, inclusive.
[2] The test car was unloaded 18 hours after the control car, but no adjustment has been made in the data.
[3] The bottom of the salted car was unloaded 28 hours and the bottom of the control car 48 hours after the carbon dioxide car. The sum of the two numbers given under Monilia represents the total growth at the time of unloading, the first of the numbers giving the estimated growth at the time the carbon dioxide car was unloaded, and the second number the estimated growth during the further delay. The change in the Rhizopus rots and in the softening of the fruit during the delay was probably extremely small.

TABLE 8.—*Condition of dewberries after being held in pony refrigerators with solid carbon dioxide as a supplementary refrigerant*

Figure reference[1]	Ice		Solid CO_2	Flavor	Decrease in firm berries	Increase in rotten berries
	At beginning	At end				
		Pounds	*Pounds*		*Per cent*	*Per cent*
Fig. 3	135	16	0	Good		
	120	32	15	do		
	110	40	25	do		
	100	47	35	do		
Fig. 4	144	36	0	do	64.1	32.5
	119	42	15	do	17.3	4.3
	119	23	20	do	18.4	8.9
	110	44	30	do	25.7	9.3
Fig. 7	163	22	0	do		
	117	23	7	do		
	94	12	12	do		
Fig. 20	140	10	0	do		
	90	33	50	do		
	90	34	50	do		
	90	35	50	do		
Fig. 27	163	18	0	do	53.9	46.1
	133	33	28	do	9.1	13.8
	97	45	28	do	17.0	18.5
Fig. 28	170	13	0	do	11.5	9.1
	133	30	35	do	6.8	2.8
	101	46	36	do	1.4	1.3

[1] For data on temperature, CO_2 and length of treatment, see Figs. 3, 4, 7, 20, 27, and 28.

The carbon dioxide always had an inhibiting action on the rots of the dewberries and always helped to maintain the firmness of the fruit. In the three experiments in which complete records were kept, both the average percentage of rot and the average decrease in firm berries in the treated lots were less than a third of the averages in the fruit from the control refrigerators. (Table 8.) In some cases these differences may have been partly due to the differences in temperature, but a study of the temperature curves (figs. 4, 27, and 28) convinces one that they must have been mainly due to the presence of the carbon dioxide gas.

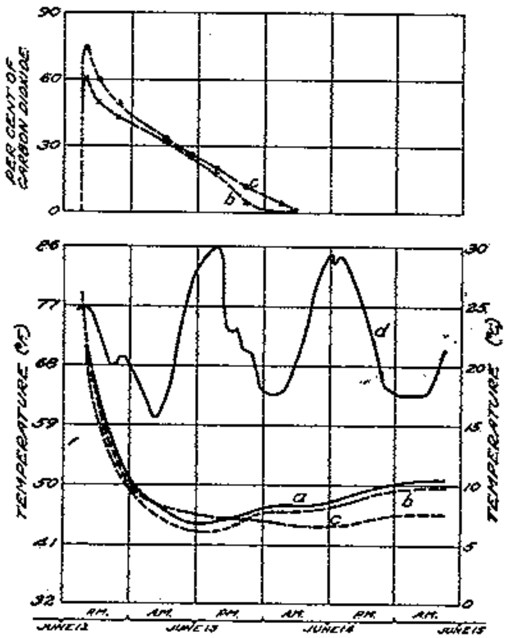

FIGURE 27.—Carbon dioxide curves and temperature curves in an experiment with dewberries in 80-quart pony refrigerators, June 12 to 15, 1929: *a*, Control refrigerator with 163 pounds of ice; *b*, refrigerator with 133 pounds of ice and 28 pounds of solid CO_2; *c*, refrigerator with 97 pounds of ice and 28 pounds of solid CO_2; *d*, outside temperature. The refrigerator in *c* was not of standard construction and has been described in the legend to Figure 6. The temperatures shown are the averages of records from the top and bottom layers of baskets

DEWBERRIES IN REFRIGERATOR CARS

The car-lot shipments of dewberries were carried out as already described for strawberries. The results are shown in Table 9 and in Figures 29 to 33, inclusive.

TABLE 9.—*Condition of dewberries and dewberry-rot organisms in standard refrigerator cars with different methods of cooling*

Figure reference [1]	Location in car	Flavor of berries in—			Soft berries in—			Rotten berries in—			Increase in diameter of colonies of rot organisms in Petri dishes					
											Gloeosporium in—			Rhizopus in—		
		Carbon dioxide car	Blower car	Control car	Carbon dioxide car	Blower car	Control car	Carbon dioxide car	Blower car	Control car	Carbon dioxide car	Blower car	Control car	Carbon dioxide car	Blower car	Control car
					Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Mm*	*Mm*	*Mm*	*Mm*	*Mm*	*Mm*
Fig. 29	Top center	Good		Good			16.1			6						
	Top bunker	do		do	[2] 10.5		19.2	[2] 7.7		7.8						
	Average top of car				10.5		17.7	7.7		6.9						
	Bottom center	Good		Good	[2] 6.6		15.9	[2] 4.5		5.3						
	Bottom bunker	do		do	[2] 7.1		12.1	[2] 3.3		2						
	Average bottom of car				6.9		14	3.9		3.7						
	Average for car				8.7		15.8	5.8		5.3						
Fig. 30	Top center	Good		Good	12.6		18.6	1.2		7.9						
	Top bunker	do		do	10.5		13.6	2.8		3.1						
	Average top of car				11.6		16.1	2		5.5						
	Bottom center	Good		Good	6.8		15.1	1.1		1.7						
	Bottom bunker	do		do	9		10.2	.5		1.4						
	Average bottom of car				7.9		12.7	.8		1.6						
	Average for car				9.7		14.4	1.4		3.5						
Fig. 31	Top center	Good		Good	7.5		13.1	1.7		5.8						
	Top bunker	do		do	7		9.3	3.5		2.7						
	Average top of car				7.3		11.2	2.6		4.3						
	Bottom center	Good		Good	9.6		12.1	1.6		2						
	Bottom bunker	do		do	4.8		7.5	.9		.5						
	Average bottom of car				7.2		10.3	1.3		1.3						
	Average for car				7.2		10.8	1.9		2.8						
Fig. 32	Top center	Good	Good	Good	9.1	16.4	10.9	0	0.8	.9	9.5	10.5	13.5	6	5.2	25.5
	Top bunker	do	do	do	7.9	15	18.1	1.1	.2	2.3	8.5	15.2	14.5	7	23	16
	Average top of car				8.5	15.7	14.5	.6	.5	1.6	9	12.9	14.	6.5	14.1	20.8
	Bottom center	Good	Good	Good	10.9	10.3	3.7	0	.3	.3	6	8.5	8.5	0	.3	1.5
	Bottom bunker	do	do	do	10.4	11.9	7.5	2.9	.2	.7	2	5	5.5	0	0	0
	Average bottom of car				10.7	11.1	5.6	1.5	.3	.5	4	6.8	7	0	.2	.8
	Average for car				9.6	13.4	10.1	1	.4	1.1	6.5	9.8	10.5	3.3	7.1	10.8

[1] For data on temperature, CO_2, and length of treatment, see Figs. 29 to 33, inclusive.
[2] Record after 20 hours' exposure to outside temperature. See legend for Fig. 29.

TABLE 9.—*Condition of dewberries and dewberry-rot organisms in standard refrigerator cars with different methods of cooling*—Continued

Figure reference	Location in car	Flavor of berries in—			Soft berries in—			Rotten berries in—			Increase in diameter of colonies of rot organisms in Petri dishes					
											Gloeosporium in—			Rhizopus in—		
		Carbon dioxide car	Blower car	Control car	Carbon dioxide car	Blower car	Control car	Carbon dioxide car	Blower car	Control car	Carbon dioxide car	Blower car	Control car	Carbon dioxide car	Blower car	Control car
					Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Mm*	*Mm*	*Mm*	*Mm*	*Mm*	*Mm*
Fig. 33	Top center	Good	Good		13.9	22.6		.7	1.5		7.5	10.7		[3] 45.7	[3] 59	
	Top bunker	do	do		20.3	34.6		1.6	10.5		11	13.5		[3] 63.3	[3] 76.5	
	Average top of car				17.1	28.6		1.2	6		9.3	12.1		54.5	67.8	
	Bottom center	Good	Good		12.4	20.8		1	1.7		6	5.5		[3] 35	[3] 31.5	
	Bottom bunker	do	do		16.1	14.5		.7	1.9		5	3.5		[3] 16	[3] 6.8	
	Average bottom of car				14.3	17.7		.9	1.8		5.5	4.5		25.5	19.2	
	Average for car				15.7	23.1		1	3.9		7.4	8.3		40	43.5	
Average of Figs. 30 to 32.	Top of car				9.1		13.9	1.7		3.8						
	Bottom of car				8.6		9.5	1.2		1.1						
	Average for car				8.8		11.8	1.4		2.5						
Average of Figs. 32 and 33.	Top of car				12.8	22.2		.9	3.3		9.2	12.5		30.5	41	
	Bottom of car				12.5	14.4		1.2	1.1		4.8	5.7		12.8	9.7	
	Average for car				12.7	18.3		1	2.2		7	9.1		21.7	25.8	

[3] Inoculations were made 20 hours before loading.

The flavor of the berries was tested at destination, and sample lots were returned to Washington, D. C., for further tests. In no instance could any change in flavor be detected.

In the shipment reported in Figure 29, the control car arrived a day later than the test car. The records for the test car were taken after the fruit had been exposed to an outside temperature of more than 70° F. for 20 hours, whereas those for the control car were taken immediately after unloading. Despite this difference in treatment, the control car showed practically the same percentage of rot as the test car and a far higher percentage of soft berries.

In the shipments described in Figures 30, 31, and 32, the different cars were unloaded at practically the same time; the records show 25 per cent less soft berries and 42 per cent less rotten berries in the test car than in the control car.

The average percentage of soft berries for the top of the carbon dioxide cars was lower than the average for the bottom of the control cars. The average percentage of rotten berries in the top of the test cars was about halfway between the average for the bottom of the control cars and the total average for the control cars. Converting these results into temperature values on the basis of the temperature curves of the control cars, as has been outlined in the discussion for strawberries and peaches, it is found that the solid carbon dioxide had an effect upon the softening of the fruit in the top of the car equal to that of a reduction of 14° F. in temperature during the entire trip, and an effect upon the rots in the top of the car equal to that of a 10° reduction in temperature during the entire trip. If it is assumed that the action of the solid carbon dioxide was confined to the first 36 hours after loading, it is estimated that during this period there was an inhibiting effect upon the softening of the fruit approximately equal to that of an average reduction in temperature of 26° and of a retarding action upon the rots equal to a 19° reduction in temperature.

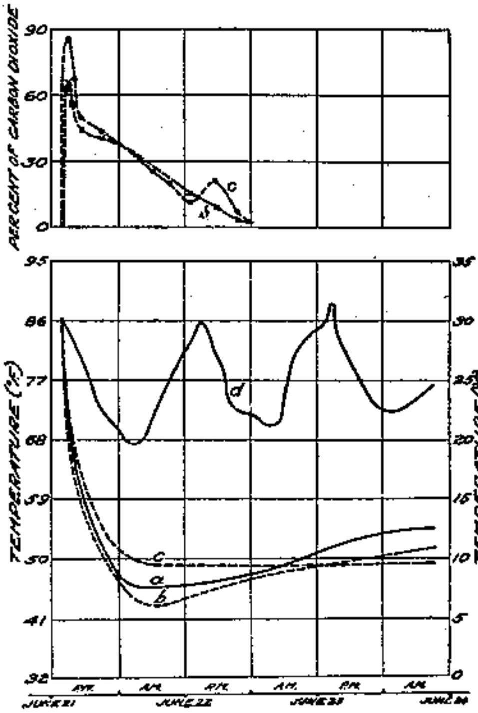

FIGURE 28.—Carbon dioxide curves and temperature curves in an experiment with dewberries in 80-quart pony refrigerators, June 21 to 24, 1929: *a*, Control refrigerator with 170 pounds of ice; *b*, refrigerator with 133 pounds of ice and 35 pounds of solid CO_2; *c*, refrigerator with 101 pounds of ice and 86 pounds of solid CO_2; *d*, outside temperature. The refrigerator in *c* was the same as described under *c* of Figure 6. The temperatures shown are the averages of records from the top and bottom layers of baskets

The temperatures in the tops of the test cars were usually lower than those in the tops of the control cars, but always far above the temperatures in the bottoms of the control cars, indicating that the reduction in softening and decay in the test cars must have been largely due to the presence of the carbon dioxide gas.

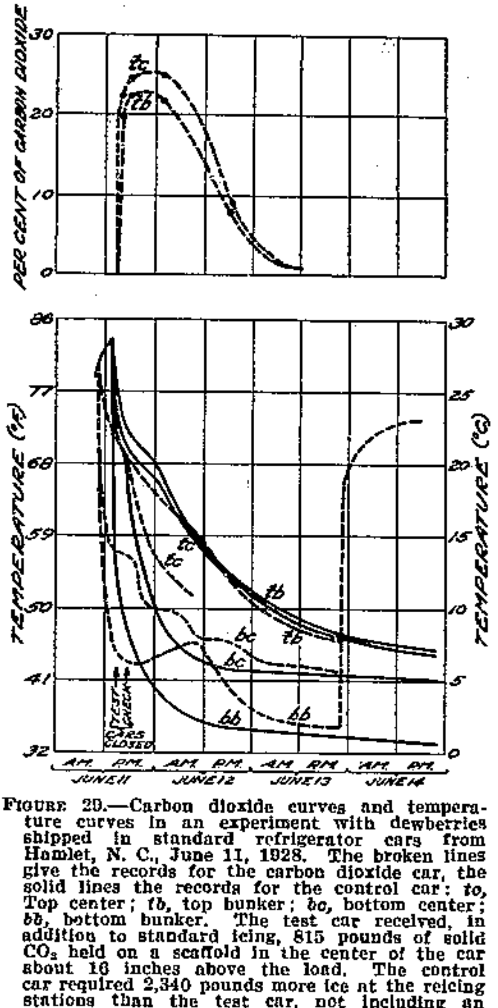

FIGURE 29.—Carbon dioxide curves and temperature curves in an experiment with dewberries shipped in standard refrigerator cars from Hamlet, N. C., June 11, 1928. The broken lines give the records for the carbon dioxide car, the solid lines the records for the control car: *tc*, Top center; *tb*, top bunker; *bc*, bottom center; *bb*, bottom bunker. The test car received, in addition to standard icing, 815 pounds of solid CO_2 held on a scaffold in the center of the car about 16 inches above the load. The control car required 2,340 pounds more ice at the reicing stations than the test car, not including an extra 800 pounds that was added on account of the delay in unloading the control car. Each car contained 224 crates of berries

Sample lots of fruit were held at outside temperature for several days after removal from the cars, and it was found that the differences in firmness and decay at the time of unloading were fully maintained under marketing conditions.

In the shipment described in Figure 32 a blower or precooled car was used for comparison with a carbon dioxide car and a control car. In the shipment indicated in Figure 33, a similarly, precooled car was used for comparison with a carbon dioxide car. In the first shipment there were more soft berries in the blower car than in the control car, and in the second shipment as many soft berries in the bottom of the blower car as in the top of the carbon dioxide car. In some instances the inhibition of the rot organisms was greater in the carbon dioxide car and in other instances greater in the blower car; but if an average of the two cars is taken the results show a greater inhibition in the carbon dioxide car in all cases. The average inhibition of rots in the top of the carbon dioxide cars was about the same as that for the entire blower cars.

EXPERIMENTS WITH OTHER FRUITS AND WITH VEGETABLES

BLACKBERRIES

Small lots of blackberries were included in the tests described in Figures 3, 15, 19, and 20. The flavor of the fruit remained unaffected under all the conditions of these experiments, whereas, as already pointed out in Table 6, the flavor of peaches under certain of these conditions was spoiled. (See fig. 19.)

Experiments were also made in which blackberries were held at constant temperatures of 50° and 68° in maintained atmospheres containing 40 per cent of carbon dioxide. The flavor of the fruit was normal after treatment for 2 days and doubtful at 68° after 3 days and at 50° after 5 days. The results indicate that blackberries will stand much longer exposure to high percentages of carbon dioxide than peaches or strawberries, yet it is evident that there is a definite limit to their tolerance.

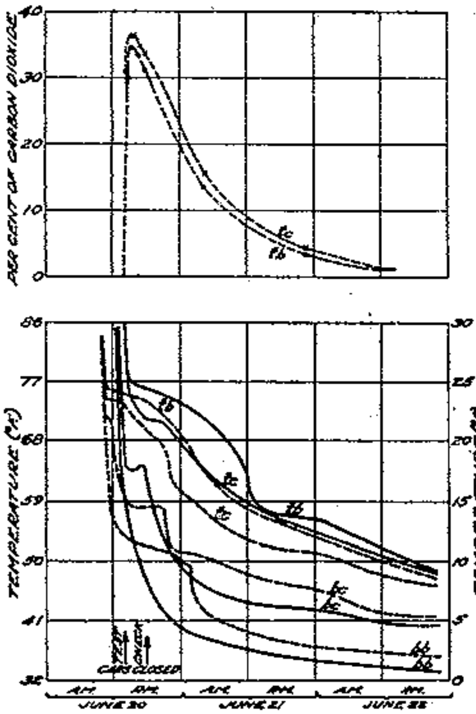

FIGURE 30.—Carbon dioxide curves and temperature curves in an experiment with dewberries shipped in standard refrigerator cars from Hamlet, N. C., June 20, 1928. The broken lines give the records for the test car, the solid lines the records for the control car: *tc*, Top center; *tb*, top bunker; *bc*, bottom center; *bb*, bottom bunker. The test car received, in addition to standard icing, 940 pounds of solid CO_2 held on a scaffold in the center of the car about 16 inches above the load. The control car required 1,500 pounds more ice at the reicing stations than the test car. The control car carried 190 crates of berries, the test car 224 crates

RASPBERRIES

Small lots of red raspberries were included in the tests indicated in Figure 27, and small lots of both red and black raspberries were included in the tests reported in Figure 28. Under the carbon dioxide treatments described for these experiments the flavor of the red raspberries was affected as much as that of the strawberries included in the same tests, whereas the flavor of the black raspberries was unaffected.

BLUEBERRIES

Wild blueberries were held at constant temperatures of 50° and 68° F. in maintained atmospheres containing 40 per cent of carbon dioxide. The test at 68° was continued for six days and that at 50° for eight days, but no change in the flavor of the fruit could be detected as a result of the carbon dioxide treatment.

CURRANTS

Small lots of currants were included in the tests reported in Figure 28. The flavor remained normal under all the conditions described.

APRICOTS

Apricots were included in the tests described in Figure 28. At the end of the experiment it was found that their flavor had been affected by the carbon dioxide treatments fully as much as that of the peaches and red raspberries.

CHERRIES

Early Richmond cherries were included in the tests reported in Figure 3, Blackheart cherries in those in Figure 27, and Bing and Montmorency cherries in the tests described in Figures 27 and 28. None of the carbon dioxide treatments in these various experiments had any evident effect upon the flavor of either the sweet or the sour varieties.

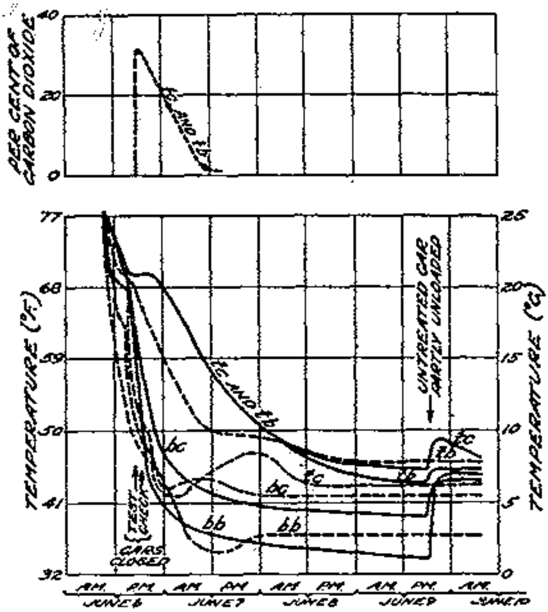

FIGURE 31.—Carbon dioxide curves and temperature curves in an experiment with dewberries shipped in standard refrigerator cars from Cameron, N. C., June 6, 1929. The broken lines give the records for the test car, the solid lines the records for the control car: *tc*, Top center; *tb*, top bunker; *bc*, bottom center; *bb*, bottom bunker. The test car received, in addition to the usual bunker icing, 1,000 pounds of solid CO_2 held on a scaffold in the center of the car about 16 inches above the load. The test car received 2 per cent of salt at the shipping point. Each car contained 224 crates of berries

Windsor cherries were held at 68° and 50° F. in maintained atmospheres containing 40 per cent of carbon dioxide. At 68° the cherries in carbon dioxide had a normal flavor, as compared with the controls, at the end of five days, but were slightly insipid at the end of six days. The experiment at 50° was discontinued at the end of eight days, with the flavor of the cherries in carbon dioxide still entirely normal.

Bing cherries were exposed to 40 per cent of carbon dioxide for two days at 32°, 41°, 50°, 59°, and 68° F., without any impairment of flavor as compared with the controls. A part of the cherries from the various lots had been inoculated with Monilia when the experiment was started and were held at 50° in normal atmosphere after the end of the 2-day treatment. It was found that the rots on the cherries that had been held in carbon dioxide at 68° and 50° were much smaller than those on the controls held at a temperature 18° lower, and that the rots on the cherries held in carbon dioxide at 50° were only slightly larger than those on the controls held at 32°.

PLUMS AND PRUNES

Wickson plums, purchased on the Washington market, were exposed to 40 per cent of carbon dioxide for 48 hours at 32°, 41°, 50°, 59°, and 68° F. without any impairment of flavor. A part of the fruit had been inoculated with Monilia, and after the 2-day treatment the different lots were removed from the various temperatures and stored at 50° in normal atmosphere. It was found that the rots on the plums that had been held in carbon dioxide at 68°, 59°, and 50° developed several hours later than those on the controls at temperatures 18° lower and that the rots on the fruit held in carbon dioxide at 50° were practically identical in size with those on the controls held at 32°.

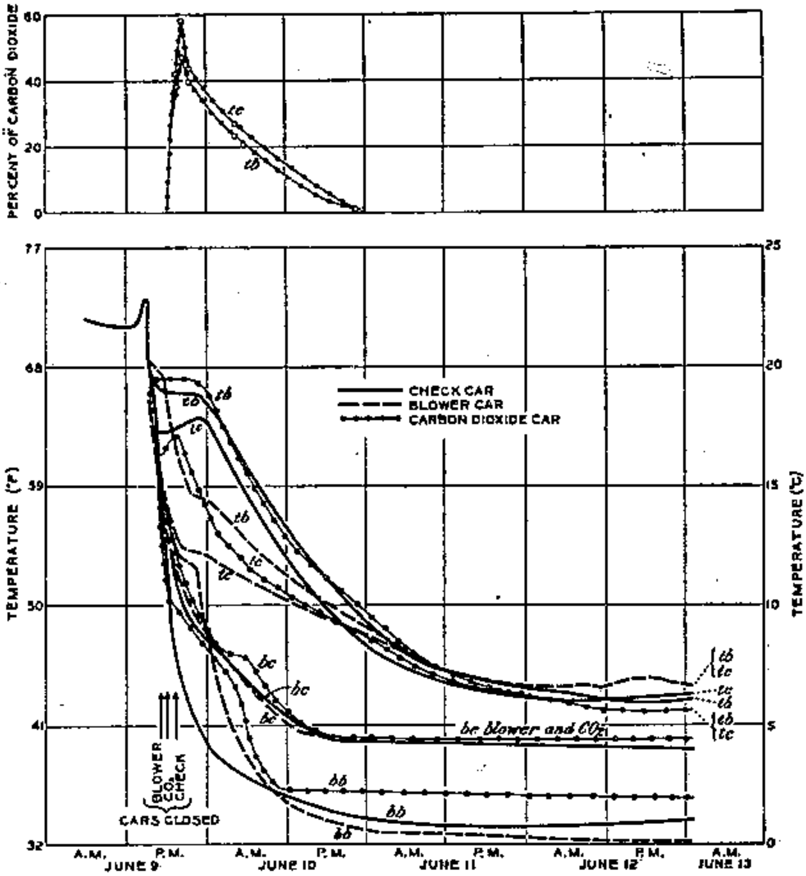

FIGURE 32.—Carbon dioxide curves and temperature curves in an experiment with dewberries shipped in standard refrigerator cars from Cameron, N. C., June 9, 1930: *tc*, Top center; *tb*, top bunker; *bc*, bottom center; *bb*, bottom bunker. The carbon dioxide car received 700 pounds of solid CO_2 placed on a scaffold about 16 inches above the load. The carbon dioxide car received 3 per cent of salt at the shipping point and the blower car 3 per cent. Each car carried 280 crates

Italian Prunes, purchased on the Washington market, were exposed to 50 per cent carbon dioxide under constant-temperature conditions. In one experiment fruit held at a temperature of 66° F. had become rather insipid by the end of 7 days, but that held at 48° had retained its normal flavor at the end of 17 days. In another experiment fruit retained its normal flavor at 67° for 13 days and at 49° for 17 days, but later developed a dry and slightly objectionable taste at both temperatures.

In the summer of 1930 pony-refrigerator experiments were made at Wenatchee, Wash., with fresh Italian Prunes that had just been picked at a proper stage of maturity for commercial shipment. The refrigerators were of the type described in the legend of Figure 6 and had capacity of 4 bushels. Half the storage space was filled with Italian Prunes and half with Bartlett pears. Two refrigerators were loaded and iced exactly alike, but one of them received

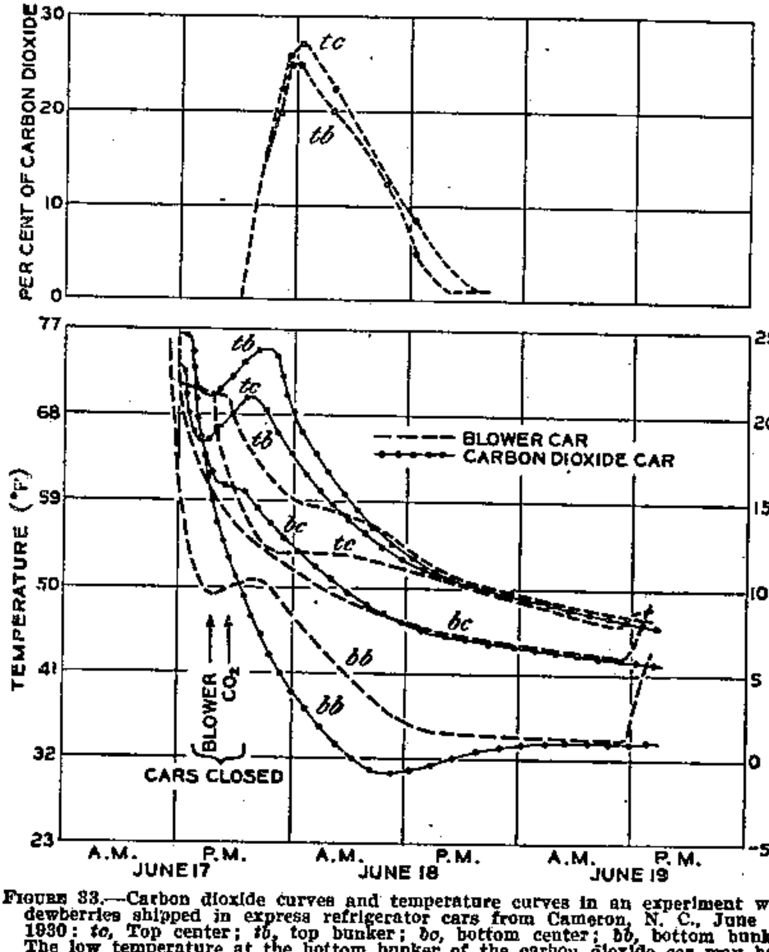

FIGURE 33.—Carbon dioxide curves and temperature curves in an experiment with dewberries shipped in express refrigerator cars from Cameron, N. C., June 17, 1930: *tc*, Top center; *tb*, top bunker; *bc*, bottom center; *bb*, bottom bunker. The low temperature at the bottom bunker of the carbon dioxide car may have been due to air currents resulting from a defective water trap. The carbon dioxide car received 530 pounds of solid CO_2 placed on a scaffold about 16 inches above the load. The blower car received 400 pounds of salt at the shipping point and the carbon dioxide car 315 pounds. Each car carried 280 crates

a continuous stream of carbon dioxide gas from a carbon dioxide cylinder. The experiments were carried out in a laboratory where the temperature ranged between 70° and 80° F., averaging about 75°. In the first experiment the fruit in the control refrigerator was cooled to 52° in about 24 hours with little further change in temperature; in the second experiment it was cooled to 55° in 24 hours and fell to 50° before the end of the experiment. The fruit in the carbon dioxide refrigerator was usually about 2 degrees warmer than that in the control refrigerator.

The carbon dioxide was run rapidly into the test refrigerator for a half hour; the rate was then decreased until it balanced that of the leakage from the refrigerator. In the first experiment the carbon dioxide in the refrigerator was held at approximately 30 per cent for the first 6 hours and at 20 per cent for the next 42 hours; in the second experiment it was held at approximately 15 per cent for the first 8 hours, at 12 per cent for the next 64 hours, and tapered off to 3 per cent by the end of the fourth day.

In the first experiment a part of the fruit was removed from the refrigerators at the end of 1 day, and the remainder at the end of 2 days; in the second experiment a part of the fruit was removed at the end of 2 days, and the remainder at the end of 4 days.

After removal from the refrigerators the fruit was held at laboratory temperatures. The prunes from the carbon dioxide refrigerator were firmer than the others and ripened more slowly; in order to bring the two lots to a like maturity, it was necessary to hold the control fruit in a refrigerator at 45° F. for several days, while the test fruit was exposed to an outside temperature of 75°.

When fully ripened, no difference in flavor could be detected between the fruit receiving any of the carbon dioxide treatments and that which had been held in the control refrigerator.

In both experiments needle inoculations were made with Monilia and Rhizopus, as described for peaches. In the first experiment the inoculated prunes were removed from the refrigerator and placed at the outside temperature at the end of 1 day, in the second experiment at the end of 4 days. In both experiments and with both fungi, the rots on the fruit from the carbon dioxide refrigerator were a full day later than those on the fruit from the control refrigerator, the 1-day treatment under the conditions of the first experiment causing somewhat greater delay than the 4-day treatment under the conditions of the second experiment.

PEARS

As already mentioned, half the refrigerator space in the experiments described above was given to Bartlett pears. The pears had been picked less than 24 hours before the experiments were started. Those of the first experiment showed a pressure resistance of 17 pounds and those of the second experiment a resistance of 15.6 pounds.

In both experiments pears were inoculated with *Botrytis cinerea*, held in the refrigerators the full period of the test, and then removed to room temperature. In both instances the rots on the fruit from the carbon dioxide refrigerator were found to be almost exactly two days later than those on the fruit from the control refrigerator, indicating that the rots were held completely in check in the 2-day treatment of the first experiment but were not completely inhibited with the lower percentage of gas in the 4-day treatment of the second experiment.

In order to determine the effect of the carbon dioxide treatments upon flavor and keeping quality, some of the pears were held in a warm room for immediate ripening and the remainder placed in storage at 32° F. Sample lots were removed from storage on September 15 and October 11 and shipped to Washington, D. C., by ordinary express; larger lots were removed to the Wenatchee laboratory on October 16 and 24. In all cases the fruit that had been subjected to carbon dioxide was found to be firmer and to have less yellow in the ground color than that from the control refrigerators. The treated pears that were removed from storage October 16 and 24 showed an average resistance to pressure of 15.5 pounds and the untreated ones a resistance of 12.2 pounds. When the different lots were held under suitable temperature conditions to bring them to a like maturity no difference in flavor could be detected between the treated and untreated fruit, regardless of whether ripened immediately or held in storage. When the different lots were held at room temperature for six days after removal from storage it was found that the control fruit had a much higher percentage of internal breakdown and several times as many rots as the fruit that had been exposed to carbon dioxide.

A third experiment was made with Bartlett pears in pony refrigerators, but with the treated fruit inclosed in 9-quart jars. The experiment was continued 64 hours, and 10 different carbon dioxide treatments were given, varying in percentage of gas and in period of exposure, and ranging all the way from 25 per cent for 12 hours to 25 per cent for 24 hours, followed by 45 per cent for 40 hours. After removal from the experiment the pears were stored and sampled, as described above. No difference in flavor could be detected between the treated and untreated fruit. The pears of this experiment were slightly more mature than those of the first two experiments.

Pony-refrigerator experiments, similar to those already reported for Italian Prunes and Bartlett pears, were made with Anjou pears and Jonathan apples. The fruit was cooled somewhat more slowly than in the previous experiments and the temperature in the carbon dioxide refrigerator averaged about 5° F. higher than that in the control refrigerator. The carbon dioxide content of the air in the test refrigerator was maintained at practically 20 per cent throughout the experiment. Part of the fruit was removed at the end of one day and the remainder at the end of two days; each lot was taken immediately to cold storage. Sample lots of the fruit were removed from storage on October 11 and shipped to Washington, D. C., by ordinary express; the remainder was removed to the Wenatchee laboratory on November 10.

It was extremely difficult to decide upon the flavor of the different lots of Anjou pears, as slight differences in maturity had a greater determining value than the carbon dioxide treatments and the variation within the lot was much greater than that between the lots; but, on the whole, the percentage of pears that were somewhat lacking in flavor and juiciness was apparently larger with the treated fruit than with the untreated. No distinction could be made between the fruit that had received the carbon dioxide treatment for one day and that which had received it for two days.

At the time of picking, the Anjou pears showed a pressure resistance of 13 pounds. When removed from storage the treated fruit showed a resistance of 12.4 pounds and the untreated a resistance of 12.2 pounds. After three days in a warm room the treated fruit showed a resistance of 10 pounds and the untreated a resistance of 8.1 pounds.

A later picking of Anjou pears was made, and carbon dioxide treatments were given as described in the third experiment for Bartlett pears, with the same wide range in percentage of gas and period of exposure. The storing and sampling were carried out as described above for the Anjou pears. When fully ripe no difference could be detected between the flavor of the treated fruit and that of the untreated fruit. The pears of this experiment were slightly more mature than those of the preceding experiment, and it is possible that this accounts for the fact that they stood the more extreme treatments with no evidence of reduced flavor.

Seckel pears were included in the tests reported in Figures 16, 17, and 20, without impairment of flavor under any of the carbon dioxide treatments.

In another experiment Seckel pears were held for 11 days at 66° F. in an atmosphere containing 50 per cent of carbon dioxide, and for 17 days at 48° in a similar atmosphere, without impairment in flavor or other evident injury.

In the summer of 1931 pony-refrigerator experiments similar to those reported for berries and peaches were made with freshly picked Bartlett pears from the Hudson River Valley. The temperature in the different refrigerators was practically the same, dropping to 50° F. in about 24 hours and remaining between 45° and 52° the remainder of the time. After three days' treatment the pears were placed in storage at 32° F. Similar lots had been stored immediately at that temperature, and other lots were held at outside mean temperature of approximately 65° for the three days and then stored at 32°. After six weeks' storage it was found that fruit that had been exposed to an atmosphere in which the carbon dioxide content was about 50 per cent in the beginning and tapered off to 25 per cent at the end of 20 hours and to 10 per cent at the end of 30 hours was in better condition both as to firmness and as to the presence of internal breakdown than fruit that had been stored immediately at 32°. Pears that had been held in an atmosphere containing 50 to 75 per cent carbon dioxide in the beginning and tapering off to 25 per cent in 40 hours and to 10 per cent in 50 to 60 hours showed a resistance to pressure 50 per cent greater than the immediately stored fruit and had less than half as much internal breakdown. The fruit that was held at outside temperature for three days and that held in pony refrigerators without carbon dioxide for three days was much softer than the immediately stored fruit and had a far greater percentage of internal breakdown. No contrast in flavor was found between the pears from the different treatments when fruit of similar maturity was compared.

APPLES

As mentioned previously, Jonathan apples were included with the pears in the first Anjou experiment. The storing and sampling were carried out as already described in that experiment. In the fruit shipped to Washington, D. C., it was found that the differences within lots were greater than those between lots, yet on the whole the treated fruit was firmer and had slightly less flavor and juiciness than the untreated. Among the apples removed to the Wenatchee laboratory no difference could be detected in flavor or quality.

The apples of the experiment described above were immature at picking time and came from orchards where the fruit is of notoriously poor quality. A second experiment was made with Jonathan apples that were more mature and of better quality. The carbon dioxide treatments were given as described in the third experiment with Bartlett pears, with the same wide range in the percentages of gas and in the periods of exposure. After being held in storage, as described for the Anjou pears, sample lots were shipped to Washington, D. C., and other lots were removed to the Wenatchee laboratory. The treated fruit was slightly firmer and made a better appearance than the untreated, and in all cases had fully as good flavor.

Yellow Newtown apples were subjected to the carbon dioxide conditions reported in Figure 25, without impairment of flavor.

In the fall of 1931 pony-refrigerator experiments similar to those reported for berries and peaches were made with freshly picked Grimes Golden and Delicious apples from Virginia and Jonathan apples from Maryland and from New York. After two days in the refrigerators the fruit was placed in storage at 30° to 32° F. with other lots that had been held at outside temperature. Additional lots were placed at 32° at the time of picking. After several months' storage the fruit that had been exposed to carbon dioxide was found to be in better condition as to firmness and freedom from soft scald and other diseases than fruit that had been placed immediately at 32°, while the fruit that had been delayed at outside temperature or held in refrigerators without carbon dioxide was found to be softer and to have a higher percentage of decay. No contrast in flavor was found between the apples from the different treatments when fruit of similar maturity was compared.

GRAPES

Several varieties of grapes were tested and all showed extreme tolerance of carbon dioxide. Cornichon grapes were included in the experiment of Figure 4, Sultanina (*Thompson Seedless*) grapes in the experiments of Figures 14 and 15, Catawba grapes in the experiment of Figure 16, and Concord and Malaga grapes in the experiment of Figure 20, with no apparent modification in flavor in any case.

Experiments were also made at the constant temperatures with maintained percentages of carbon dioxide. In one test Sultanina grapes were subjected to 40 per cent carbon dioxide at 68° F. for five days and at 50° for seven days, and the flavor was still normal at the end of the experiment.

In a second test Sultanina, Flame Tokay, Niagara, Delaware, and Concord grapes were held in 50 per cent carbon dioxide at 66° F., with no impairment in flavor at the end of 9 days, but with the first three varieties becoming overripe and somewhat insipid at the end of 12 days. Similar lots were held at 48°, with no impairment in flavor at the end of 15 days, but with the Flame Tokay and Concord varieties noticeably insipid at the end of 17 days and the Delaware at the end of 20 days.

In a third experiment, Cornichon, Niagara, Concord, and Delaware grapes were held in 50 per cent carbon dioxide at 67° F., with good flavor at the end of 11 days and nothing more objectionable than slight overripeness at the end of 13 days. Similar lots held at 49° retained good flavor at the end of 17 days, but were slightly overripe and losing flavor at the end of 20 days.

In a fourth experiment, started later in the season (October 30), Flame Tokay and Concord grapes were held in 50 per cent carbon dioxide for eight days at 68° and 50° F. At the end of the experiment the flavor of the Flame Tokay grapes was good at both temperatures, and that of the Concord was good at 50° but slightly off at 68°.

In the last experiment, part of the grapes of each variety were inoculated with Botrytis before the test was started. At the end of eight days the control lots had 100 per cent of infection at 68° F. and about 90 per cent of infection at 50°, whereas the grapes held in 50 per cent carbon dioxide were entirely free from rot at both temperatures. The experiment indicates that the use of solid carbon dioxide should make it possible to greatly reduce grape rots in transit without affecting the flavor of the fruit.

In storage experiments carried out in the fall of 1931 it was found that shattering could be greatly reduced on Moore Early, Niagara, Concord, Worden, Delaware, and Golden Muscat grapes by a day's exposure to carbon dioxide gas. In most cases the period that the fruit could be held without shattering was doubled by the carbon dioxide treatments.

ORANGES AND MANGOS

Oranges and mangos were included in the tests reported in Figure 25. The carbon dioxide treatments of this experiment had no evident effect upon the flavor of either of these fruits.

TOMATOES, STRING BEANS, AND PEAS

Small lots of ripe tomatoes were included in the tests reported in Figure 26. The carbon dioxide treatments described for this experiment had no evident harmful effect upon the tomatoes.

In one experiment string beans were held at 68° F. in 46 per cent carbon dioxide for 24 hours; in another experiment string beans and peas were held at 72° in 30 per cent carbon dioxide for 48 hours, without impairment in flavor or condition.

CORN, CARROTS, AND CAULIFLOWER

Sweet corn was included in the tests reported in Figures 15, 17, 19, and 26. It was also included in the test in which beans were exposed to 46 per cent carbon dioxide for 24 hours at 68° F.; in other tests it was exposed to 40 per cent carbon dioxide for 48 hours at 32°, 41°, 50°, 59°, and 68°. Several different varieties of sweet corn were used, and in all cases the corn that had been subjected to carbon dioxide was fresher and sweeter at the end of the storage test than that which had been held in normal air. Its superior condition was evident after cooking as well as before.

Carrots and cauliflower were held in 30 per cent carbon dioxide at 72° F. for 48 hours. At the end of the experiment both the green and the edible parts of these treated products were much fresher in appearance than were those of similar untreated ones. The carrots and cauliflower that had been subjected to carbon dioxide were much sweeter than the controls. This was evident before cooking and still more so afterwards. When cooked the treated carrots were distinctly superior to the untreated. The treated cauliflower showed a slight reduction in flavor or odor that made the question of quality a matter of personal preference.

DISCUSSION

As pointed out in the beginning (p. 1) the present investigation was undertaken with the hope of finding at least a partial remedy for the spoilage that results from the warm condition of fruit during the first hours after loading for shipment. The studies that have been reported emphasize the hazards that must be met in attempting to secure such a remedy by means of treatment with carbon dioxide. In order to give satisfactory inhibition of the rots it has been found desirable to have a concentration of carbon dioxide approaching 25 per cent, but experiments have shown that the exposure of peaches or strawberries to 25 per cent of carbon dioxide gas for as long a period as 24 hours is liable to affect the flavor, especially if the fruit is held at the usual summer temperatures. This leaves but little margin for safety. By using solid carbon dioxide in sufficient quantities to insure the escape of most of the carbon dioxide gas from the car within 24 hours, it has been found possible to make four experimental shipments with strawberries and five with peaches in which a very significant reduction in rots and in the softening of the fruit was obtained without any appreciable effect upon the flavor of the fruit. Certain precautions were taken, however, which would be impracticable in commercial shipments. The shipments were followed in transit and frequent records taken of the gas concentration. Moreover, the cars were examined in advance, and allowance was made for tightness and newness of construction. In some instances a part of the solid carbon dioxide was placed in the bunker, on top of the ice, so that it could be conveniently removed if there was an indication of excess treatment.

Despite its practical difficulties, it should be noted that, as compared with other methods of protecting the fruit during the first hours after loading, the carbon dioxide method has made a particularly good showing, indicating that even if the quantity of solid carbon dioxide was considerably reduced the treatment would still be more effective than any convenient method of precooling now available. Such a reduction would decrease the cost of the treatment as well as increase its safety. With the products mentioned in this bulletin, aside from peaches, apricots, strawberries, and red raspberries, this reduction would apparently be unnecessary, and in fact the tolerance tests indicate that in many instances the severity of the treatment might be increased, if found desirable.

The efficacy of the carbon dioxide treatment is shown in Figure 34. The solid-line curves of this figure give the average of the temperatures that prevailed in the control cars in 13 refrigerator-car experiments—4 with strawberries, 5 with peaches, and 4 with dewberries. The broken lines in the lower half of the figure give the approximate temperatures that would have been required in the top of the test cars to have secured the inhibition obtained by the use of solid carbon dioxide. The effect of the treatment upon the softening of the fruit in the top of the car was such as to justify a hypothetical temperature curve below the average for the bottom of the control cars. The effect upon the rots in the top of the test car was sufficient to bridge about 75 per cent of the gap between the results in the top and the bottom of the control cars and to require a temperature curve almost identical with that for the bottom center of the control cars, averaging approximately 10 degrees lower than the curve for the top of the control cars.

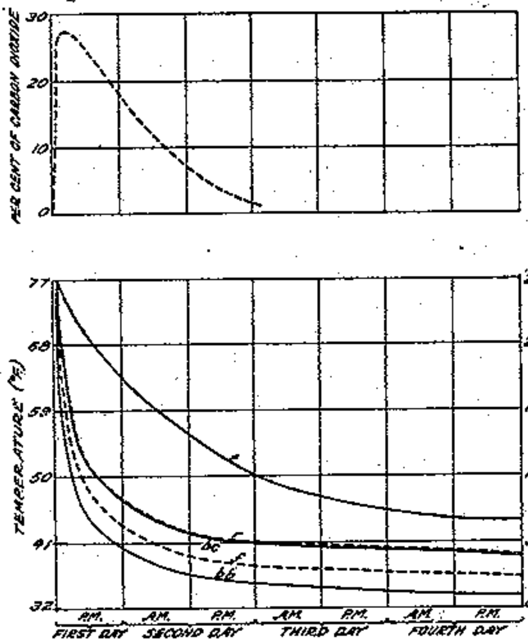

FIGURE 34.—Curves showing average carbon dioxide and temperature conditions in 13 refrigerator-car shipments—4 with strawberries, 5 with peaches, and 4 with dewberries. The upper curve gives the average percentage of CO_2 gas where solid CO_2 was used. The solid lines of the lower curves give the average temperatures in the control cars: *t*, Top of car; *bc*, bottom center; *bb*, bottom bunker; *r*, approximate temperatures that would have been required in the top of the test cars to have produced the effects upon the rots that were actually obtained by the supplementary use of solid CO_2; *f*, a similar record for the effects upon the rate of softening of the fruit

The hypothetical temperature curves indicate the value of the carbon dioxide treatments, but it is not considered that they give a proper picture as to the time when the inhibition actually occurred. Within a half hour to an hour after loading the carbon dioxide gas had mounted to a percentage that should cause an inhibition of the rots equal to that resulting from a drop in temperature of 20° to 40° F.; this inhibition probably continued in varying degrees from 12 to 36 hours, leaving the control of the rots during the latter part of the shipping period to be determined largely by temperature. The quickness with which the action of the carbon dioxide can be made effective is an important point in its favor.

Mention has been made of the fact that the carbon dioxide treatments seem to favor the preservation of the sugar content. Chemical studies are in progress on this phase of the problem.

SUMMARY

Various fruits and vegetables have been subjected to different percentages of carbon dioxide, under a variety of temperature conditions, with the object of finding a method of decreasing the spoilage that occurs in the first 24 to 36 hours after loading a warm product in a refrigerator car. The control of diseases and other forms of spoilage has been readily accomplished, but the effect of the carbon dioxide upon the flavor of the product has been found to set definite limitations to this method of treatment.

The most serious limitations have been found with peaches, apricots, strawberries, and red raspberries. Plums, cherries, blackberries, blueberries, black raspberries, currants, pears, apples, and oranges have shown a greater tolerance of the gas. Grapes, peas, sweet corn, and carrots have stood extreme treatments with particularly favorable results.

The first objectionable effect resulting from excessive carbon dioxide treatments was a slight loss of aroma. With more prolonged or severe treatments, this was followed by a still greater loss of flavor and sometimes by the development of an odor of fermentation or other objectionable quality. Products having a definite and characteristic aroma were the most easily affected.

High percentages of carbon dioxide were more harmful than lower ones; yet, with 25 per cent or more of the gas, increase in concentration did not greatly shorten the period of safe treatment.

The effect of the carbon dioxide upon the flavor increased with an increase in temperature in a manner that indicated a relationship with general metabolic activities. Exposure of peaches to 25 per cent or more of carbon dioxide for 1 day at 77° F. had about the same effect upon flavor as 2 days' exposure at 59°, 3 days' exposure at 50°, or 4 days' exposure at 41°.

The flavor of peaches and strawberries remained normal in pony-refrigerator and other experiments where the carbon dioxide content of the air had fallen to 25 per cent by the end of 12 hours and to 10 per cent within 24 hours, but in cases where this treatment was greatly exceeded there was often a question in regard to flavor. Apricots and red raspberries showed a similar susceptibility to injury, while all the other products that were tested showed a much greater tolerance of carbon dioxide, most of them a tolerance two to six times as great.

With strawberries at temperatures ranging from 32° to 77° F., Botrytis and Rhizopus rots were fairly well inhibited by 23 per cent of carbon dioxide and completely inhibited by 37 per cent or more of the gas. Botrytis inoculations on Bartlett pears and Monilia inoculations on Italian Prunes were held completely in check by 20 to 30 per cent of carbon dioxide and greatly inhibited by 12 to 15 per cent.

In a series of experiments with Monilia inoculations on peaches it was found that within the range of 10 to 50 per cent of carbon dioxide the average reduction in efficiency of the fungus was approximately twice that of the percentage of gas used. At 77° F., within a range of 10 to 40 per cent, the carbon dioxide had an effect upon Monilia rot approximately equivalent to that of reducing the

temperature as many degrees as the percentage of gas used. At lower temperatures the reduction in the efficiency of the fungus was equally great, if not greater, but the equivalent temperature reduction was necessarily less.

Carbon dioxide was even more efficient in checking the softening of the fruit than in preventing the development of rots. With 25 per cent or more of the gas the softening of strawberries was almost completely inhibited, and the softening of warm peaches was as greatly checked as by a drop in temperature of 18 degrees or more.

In pony-refrigerator experiments, Bartlett pears and Grimes Golden, Jonathan, and Delicious apples were held as firm and as free from disease by initial carbon dioxide treatments as by immediate storage at 32° F.

Carbon dioxide treatments have been found of value in preventing the shattering of grapes.

Sweet corn, cauliflower, peaches, and carrots that had been exposed to carbon dioxide were found to be distinctly sweeter than those held in normal air at the same temperature.

Fourteen refrigerator-car experiments were made in which solid carbon dioxide was used as a supplementary refrigerant and as a source of carbon dioxide gas. Four of these were with strawberries, five with peaches, and five with dewberries. In one instance the carbon dioxide content of the air remained below 10 per cent, and in another instance it stood at about 15 per cent for several hours and fell below 10 per cent at the end of 12 hours; but in most cases it was above 20 per cent for 5 to 12 hours and above 10 per cent for 15 to 24 hours.

These carbon dioxide treatments had no objectionable effect upon flavor, but in two peach shipments that received the maximum treatment a slight change in flavor could be detected when the fruit was held till fully ripened.

The carbon dioxide treatments had an average effect upon the rots in the top of the car equivalent to a lowering of 10° F. in temperature throughout the trip, or to an average lowering of temperature of 21° during the first 36 hours of the trip.

The fruit in the top of the test cars showed greater firmness at destination than the fruit in the bottom of the control cars, despite the fact that the temperature in the bottom of the control cars averaged about 13° F. lower than the temperature in the top of the same cars.

The carbon dioxide treatments had a favorable effect upon the fruit in the bottom of the test car, as compared with fruit in a similar position in the control car; but in both cases this fruit was already well protected by the usual methods of cooling.

Under the conditions of the shipping experiments reported, the inhibiting effect of the solid carbon dioxide has been almost entirely due to the carbon dioxide gas, the refrigerating effect of the solid carbon dioxide being largely offset by a slower melting of the ice in the bunkers.

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