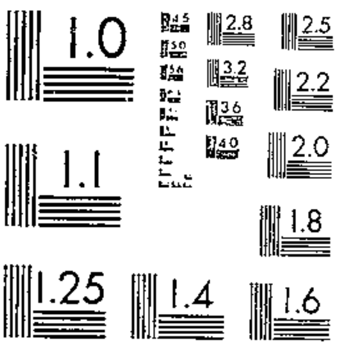
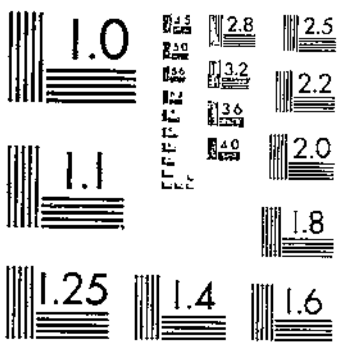
TB 519 (1936) USDA TECHNICAL BULLETINS UPDATA
TRANSIT AND STORAGE DISEASES OF FRUIT AND VEGETABLES AS AFFECTED BY
BROOKS, C ; BRATLEY, C O ; MCCOLLOCH, L P 1 OF 1

START



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

Technical Bulletin No. 519 June 1936

UNITED STATES DEPARTMENT OF AGRICULTURE
WASHINGTON, D. C.

TRANSIT AND STORAGE DISEASES OF FRUITS AND VEGETABLES AS AFFECTED BY INITIAL CARBON DIOXIDE TREATMENTS

By CHARLES BROOKS, *principal pathologist*, C. O. BRATLEY, *associate pathologist*, and L. P. McCOLLOCH, *principal scientific aide, Division of Fruit and Vegetable Crops and Diseases, Bureau of Plant Industry* [1]

CONTENTS

INTRODUCTION

It is generally recognized that the keeping quality of fruits and vegetables is greatly influenced by the conditions that prevail between the time the product is harvested and the time it reaches a fairly low temperature in transit or storage. Delays in cooling are responsible for much of the spoilage that develops later in transit, in storage, or on the market. Prompt precooling adds greatly to the storage life of the product, but unfortunately the facilities for this are not generally available. Even when the produce is placed promptly under refrigeration, 1 to 3 days may elapse before the field heat is removed and a sufficiently low temperature attained. This is particularly true when the warm product is loaded in a refrigerator car without precooling.

Exposure to carbon dioxide gas has been shown to furnish as rapid a method of retarding the softening and decay of certain products as precooling and to bring them under control far more speedily than is usually accomplished in a refrigerator car (*4*),[2] but the treatment

[1] The writers are indebted to W. T. Pentzer and C. E. Asbury for cooperation in the experiments reported from Fresno, Calif., to A. L. Ryall and E. D. Mallison for cooperation in the experiments at Yakima, Wash., and to the Everglades Experiment Station of Florida for cooperation in the experiments at Belle Glade, Fla.

[2] Italic numbers in parentheses refer to Literature Cited, p. 23.

52588°—36——1

has its limitations in the fact that prolonged exposure to atmospheres containing a high percentage of the gas may result in objectionable changes in the flavor of the product. This bulletin reports experiments in which initial gas treatments were used as a supplement to ice refrigeration and gives a discussion of the benefits and limitations of such treatments.

METHODS

The methods of experimentation were similar to those reported in an earlier publication (*4*). In the tests in which a constant percentage of carbon dioxide was maintained, flowmeters were used for gas control instead of the equipment previously described. In the experiments in which solid carbon dioxide was used, the refrigerators were of tighter construction than those previously described, with the result that less of the solid material was required to secure a particular gas concentration.

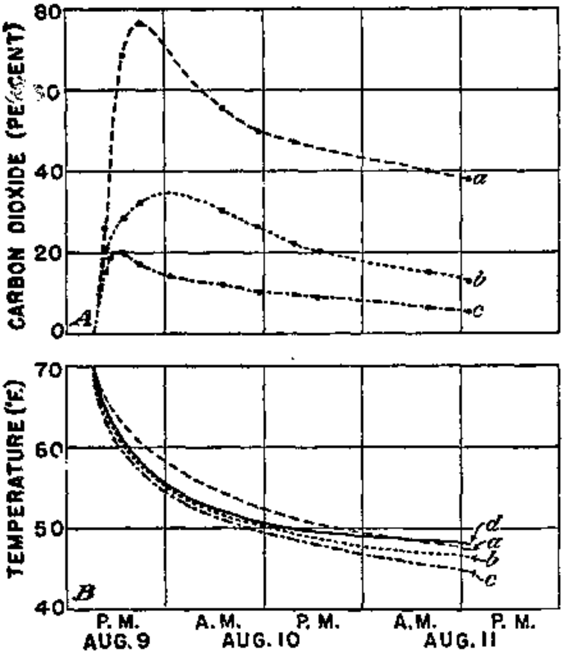


FIGURE 1.—Carbon dioxide curves (*A*) and temperature curves (*B*) in an experiment with Tragedy plums and Bartlett pears, Yakima, Wash., Aug. 9 to 11, 1932. Refrigerators *a*, *b*, and *c* received 15, 10, and 8 pounds of solid carbon dioxide, respectively, in addition to the regular icing, and refrigerator *d* was held as control without solid carbon dioxide.

The experiments in pony refrigerators were intended to produce conditions similar to those that usually prevail in a refrigerator car. The temperature was gradually lowered by means of ice refrigeration, and the results obtained with the supplementary use of solid carbon dioxide were compared with those secured with ice refrigeration alone or with immediate storage at low temperatures. Typical temperature and carbon dioxide conditions in such experiments are shown in figure 1.

SWEET CHERRIES

Experiments reported in an earlier publication (*4*) have shown that cherries are quite resistant to carbon dioxide injury and that a storage atmosphere containing 40 percent of carbon dioxide has as great inhibiting effect upon brown rot as an 18° F. lowering of temperature. These experiments were made on sour cherries and on such sweet cherries as could be obtained in eastern markets.

In the summer of 1932 similar experiments were made on freshly picked sweet cherries from the Yakima Valley. Fruit that was gradually cooled in pony refrigerators with and without the supplementary use of solid carbon dioxide was compared with other fruit that was placed immediately at various constant temperatures.

The nature of the refrigerator treatments is shown in figure 1, and the results of the various treatments are given in table 1. One box of cherries was used for each storage condition, and 10 or more inoculations were made with each fungus for each condition in which inoculations are reported.

TABLE 1.—*Effect of low temperature and initial 48-hour treatment with carbon dioxide upon decay and quality of sweet cherries, Yakima, Wash., June 1932*

Lot no.	Date	CO_2 in atmosphere during treatment			Temperature during treatment			Holding temperature after treatment	Period held after treatment	Condition at end of holding period						
										Decay on noninoculated fruit of—			Average diameter of decay in inoculations with—			Flavor and quality
		Early high	Final low	Average	Initial high	Final low	Average			Royal Ann	Bing	Lambert	*Monilia fructicola*	*Cladosporium* sp.	*Rhizopus nigricans*	
		Pct.	*Pct.*	*Pct.*	° *F.*	° *F.*	° *F.*	° *F.*	*Hrs.*	*Pct.*	*Pct.*	*Pct.*	*Mm*	*Mm*	*Mm*	
1a	June 16	48	40	45	63	40	45	60	168	13.7	6.8	-----	-----	-----	-----	Best.
1b [1]		---	---	-----	63	50	52	60	168	20.5	27.2	-----	-----	-----	-----	Fair.
1c [2]		---	---	-----	32	32	32	60	168	22.1	22.7	-----	-----	-----	-----	Good.
2a	June 21	70	50	61	69	40	45	60	120	12.5	13.3	1.9	-----	2.9	-----	Do.
2b		40	19	32	69	46	49	60	120	10.3	17.7	8.6	-----	3.8	-----	Do.
2c		38	15	24	69	50	54	60	120	16.5	28.0	4.1	-----	3.9	-----	Do.
2d [1]		---	---	-----	69	42	47	60	120	31.5	51.0	6.5	-----	4.4	-----	Do.
2e [2]		---	---	-----	41	41	41	60	120	13.0	15.4	7.9	-----	4.6	-----	Do.
2f [2]		---	---	-----	62	62	62	60	120	46.9	64.9	34.5	-----	6.8	-----	Fair.
3a	June 25	74	42	61	70	40	45	63	96	-----	2.3	12.0	3.8	1.7	7.5	Best.
3b		29	19	25	70	47	52	63	96	-----	3.3	10.0	6.2	1.9	9.8	Good.
3c		10	5	7	70	50	53	63	96	-----	4.6	-----	9.8	3.4	10.2	Do.
3d [1]		---	---	-----	70	50	56	63	96	-----	5.2	23.0	14.2	4.8	22.4	Do.
3e [2]		---	---	-----	32	32	32	63	96	-----	7.2	8.7	9.6	2.5	-----	Do.
3f [2]		---	---	-----	41	41	41	63	96	-----	4.0	17.0	7.6	3.9	10.7	Do.

[1] Control; not treated with CO_2.
[2] Placed immediately in low-temperature storage.

There was considerable variation in the results with the fruit that was not inoculated, but in general decay was held in check as well by gradual cooling with immediate exposure to atmospheres containing 30 percent or more of carbon dioxide as by immediate storage at 32° F. Most of this decay was caused by *Rhizopus*, but some of it by *Penicillium*. The results with the inoculated fruit were more consistent and the checking effect of the carbon dioxide treatments was even greater than that of immediate storage at 32°. With lot 2 no fruit was held at 32°, but the initial gas treatments gave better results than immediate storage at 41°. It should be noted that the gas treatments gave favorable results with *Cladosporium* and *Rhizopus* as well as with *Monilia*. The results seem to confirm fully the previously published statements as to the value of gas treatments in the control of decay on cherries.

The flavor of the different lots of fruit was tested by five or more individuals without knowledge as to treatments, and the gas-treated lots were usually rated with the best, any suspicion of abnormal flavor usually falling on the untreated lots. The treated fruit seemed to show a slight reduction in acidity, however, which was more evident with the Lambert cherries than with the other varieties and with severe treatments than with more moderate ones. This apparent reduction in acidity is in agreement with the findings of Thornton (*16*) and those of Miller and Dowd (*11*).

PLUMS

Experiments previously reported (*4*) on carbon dioxide treatments of Italian Prunes have shown decidedly favorable results in the control of decay and the maintenance of firmness without harmful effect upon flavor. Wickson plums have also been reported (*4*) as resistant to carbon dioxide injury.

Ryall (*13*) has recently reported that Italian Prunes exposed to atmospheres containing 40 percent of carbon dioxide showed a decrease in their ethyl alcohol and acetaldehyde content and a depression in the carbon dioxide output as compared with fruit in normal air. Such exposure for 48 hours resulted in a decrease in the development of mold and in the rate of softening without any unfavorable effect upon flavor.

In 1932 the writers carried out two separate holding tests with Italian Prunes at Yakima, Wash. The conditions and the results of the experiments are shown in table 2. The prunes were freshly picked and of good quality. Approximately 20 pounds of fruit were used under each condition.

TABLE 2.—*Carbon dioxide experiments with plums at Yakima, Wash., and Fresno, Calif., in 1932*

Variety and lot no.	Location	Date	Period of treatment	CO_2 in atmosphere during treatment			Temperature during treatment			Holding temperature after treatment	Period held after treatment	Condition at end of holding period [1]	
				Early high	Final low	Average	Initial high	Final low	Average			Pressure test	Soft fruit
			Hrs.	*Pct.*	*Pct.*	*Pct.*	*°F.*	*°F.*	*°F.*	*°F.*	*Days*	*Oz.*	*Pct.*
Italian Prunes:													
1a	Yakima	Aug. 11	48	52	32	38	62	[2]	[2]	66	11	6.6	------
1b				32	4	21	62	47	53	66	11	6.7	------
1c				32	0	14	62	49	53	66	11	6.9	------
1d [3]				----	----	----	62	45	48	66	11	5.1	------
1e [4]				----	----	----	32	32	32	66	11	5.9	------
1f [4]				----	----	----	45	45	45	66	11	5.3	------
2a	do	Aug. 19	48	48	18	29	67	[2]	[2]	66	3	8.5	------
2b				30	10	21	67	49	51	66	3	8.7	------
2c				29	0	12	67	48	50	66	3	8.4	------
2d [3]				----	----	----	67	50	52	66	3	7.5	------
2e [4]				----	----	----	32	32	32	66	3	8.6	------
2f [4]				----	----	----	45	45	45	66	3	8.2	------
Tragedy plums:													
3a	Fresno	July 8	38	40	10	22	58	40	44	60	8	----	25.5
3b				29	10	16	58	44	47	60	8	----	24.4
3c				12	0	6	58	47	51	60	8	----	40.0
3d [3]				----	----	----	58	54	56	60	8	----	64.6
3e [4]				----	----	----	33	33	33	60	8	----	48.2
3f [4]				----	----	----	46	46	46	60	8	----	55.2
4a	Yakima	Aug. 9	40	76	38	50	70	48	54	66	6	----	------
4b				34	13	22	70	47	52	66	6	----	------
4c				20	0	10	70	45	51	66	6	----	------
4d [3]				----	----	----	70	48	53	66	6	----	------
4e [4]				----	----	----	32	32	32	66	6	----	------
4f [4]				----	----	----	45	45	45	66	6	----	------

[1] Flavor was good in all lots.
[2] No record made.
[3] Control; not treated with CO_2.
[4] Placed immediately in low-temperature storage.

After 48 hours under different storage conditions all lots were held in cellar storage at 66° F., and it was found that the fruit exposed to carbon dioxide at the higher temperatures retained its firmness, quality, and flavor as well as or better than the fruit placed immediately in 32° storage. All of the lots were practically free from decay.

In the summer of 1932 tests were made at Fresno, Calif., and Yakima, Wash., with freshly picked Tragedy plums. The conditions and the results of the experiments are shown in table 2. Approximately 10 pounds of fruit were used under each condition. In the Fresno test the fruit was held under the experimental conditions for 38 hours and then moved to 60° F., storage; in the Yakima test the fruit was held for 46 hours and then moved to a temperature of 66°.

No unfavorable effect upon flavor, quality, or later ripening of the fruit resulted from any of the carbon dioxide treatments. In the Fresno experiment there was about twice as much excessively soft fruit in the lot from 33° F. storage as in the lots that had been held at higher temperatures but exposed to atmospheres in which the carbon dioxide averaged 16 percent or more (table 2). In the Yakima experiment no definite count was made as to firmness, but it was noted that the fruit receiving either the high or the medium carbon dioxide treatment retained its freshness and firmness as well as fruit from the 32° storage and that the fruit from the mildest treatment held up as well as that from the 45° storage.

Diamond and Kelsey plums were included in the 1932 experiments at Fresno. The fruit was from a commercial pack but somewhat immature, and exposure for 38 hours or more to cold-storage temperatures or to carbon dioxide gas permanently inhibited normal ripening. Diamond plums from the control refrigerators or from 45° or 46° F. storage ripened with some quality, and the Kelsey plums from these conditions were better than those exposed to carbon dioxide or to low temperature.

French prunes and Satsuma plums were also included in the Fresno experiments. Holding the fruit for 40 hours at a temperature that averaged about 42° F. but dropped gradually from 52° to 39° and in an atmosphere in which the carbon dioxide averaged 22 percent but dropped gradually from 41 to 8 percent gave results that were as favorable to flavor, quality, and firmness as immediate storage at 34°.

APRICOTS

Apricots were included in carbon dioxide experiments at Fresno, Calif., on July 8 and July 13, 1932 (table 3). Holding the fruit for 2 days at an average temperature of 47° F. in an atmosphere in which the carbon dioxide averaged 29 percent but dropped gradually from 42 percent to 16 percent gave no unfavorable effects upon flavor as compared with fruit held in storage at 34° or 37°. However, none of the fruit was of high quality. The development of decay on fruit that had been inoculated with *Sclerotinia fructicola* (Wint.) Rehm or *Penicillium expansum* (Lk.) ex Thom was retarded more by the carbon dioxide treatment at 47° than by immediate storage at 34°. Holding the fruit at an average temperature of 49° in an atmosphere in which the carbon dioxide averaged 18 percent had approximately the same retarding effect upon decay as immediate storage at 34°.

TABLE 3.—*Carbon dioxide experiments with apricots, nectarines, and peaches, 1932 and 1933*

Fruit and lot no.	Location	Date	Period of treatment	CO_2 in atmosphere during treatment: Early high	CO_2 in atmosphere during treatment: Final low	CO_2 in atmosphere during treatment: Average	Temperature during treatment: Initial high	Temperature during treatment: Final low	Temperature during treatment: Average	Holding temperature after treatment	Period held after treatment	Condition at end of holding period: Flavor	Diameter of rots on inoculated fruit: *Monilia*	Diameter of rots on inoculated fruit: *Penicillium*
			Hours	*Percent*	*Percent*	*Percent*	*° F.*	*° F.*	*° F.*	*° F.*	*Days*		*Mm*	*Mm*
Apricots:														
1a	Fresno, Calif.	*1932* July 13	48	42	16	29	62	41	47	52	2	Fair	12.1	1.7
1b				33	9	18	62	45	49	52	2	do	14.1	3.1
1c				14	4	7	62	46	50	52	2	do	17.9	6.0
1d[1]							62	50	52	52	2	do	26.8	10.5
1e[2]							34	34	34	52	2	do	16.7	2.9
1f[2]							37	37	37	52	2	do	18.5	2.5
Apricots, nectarines, and Tuskena peaches:														
2a	Fresno, Calif.	July 8	38	40	10	23	58	40	44	56	8	Poor		
2b				20	10	17	58	44	49	56	8	do		
2c				12	0	5	58	47	51	56	8	do		
2d[1]							58	54	56	56	8	do		
2e[2]							33	33	33	56	8	do		
2f[2]							46	46	46	56	8	do		
3a		July 21	40	50	24	33	52	32	38	56	3	Good		
3b				41	9	24	52	39	42	56	3	do		
3c[1]							52	46	47	56	3	do		
3d[2]							34	34	34	56	3	do		
Slappey peaches:														
4a	Yakima, Wash.	Aug. 9	46	76	38	50	70	48	54	66	5	Best		
4b				34	13	22	70	47	52	66	5	Good		
4c				20	6	10	70	45	51	66	5	do		
4d[1]							70	48	53	66	5	Poor		
4e[2]							32	32	32	66	5	do		
4f[2]							45	45	45	66	5	Fair		
Elberta and J. H. Hale peaches:														
5a	Yakima, Wash.	Aug. 10	48	48	18	29	67			66	1	Excellent		
5b				30	10	21	67	49	51	66	1	do		
5c				29	0	12	67	48	50	66	1	do		
5d[1]							67	50	52	66	1	do		
5e[2]							32	32	32	66	1	do		
5f[2]							45	45	45	66	1	do		
Belle and J. H. Hale peaches:														
6a	Washington, D. C.	*1933* Aug. 21	40	48	48	48	59	59	59	75	1	Best[3]		
6b[1]							59	59	59	75	1	Fair[3]		
6c[2]							32	32	32	75	1	do.[3]		

[1] Control; not treated with CO_2.
[2] Placed immediately in low-temperature storage.
[3] J. H. Hale peaches. Corresponding ratings for Belle peaches: Poor; best; good.

NECTARINES AND PEACHES

Nectarines and Tuskena peaches were included in two carbon dioxide experiments at Fresno, Calif., in July 1932, under the conditions shown in table 3. The various carbon dioxide treatments had no unfavorable effect upon flavor or quality. The fruit that was exposed to carbon dioxide at the higher temperatures usually retained its firmness better than the fruit that was placed immediately in 34° F. storage.

In August 1932 two separate holding tests were made with peaches at Yakima, Wash., as shown in table 3. Approximately 20 pounds of fruit were used under each experimental condition. The peaches were freshly picked and of good quality. In the first experiment Slappey peaches were used; in the second, Elberta and J. H. Hale peaches. After 46 to 48 hours' experimental treatment all lots were moved to cellar storage at 66° F. and tested at various times for flavor. The rating as to flavor and quality given the fruit that had been exposed to carbon dioxide was usually as good as or better than that of fruit held at 32°, 45°, or in the control refrigerator. There seemed to be a possibility that the Elberta peaches that had received the carbon dioxide treatments had a little less peach flavor than the others, but if there was any real difference most individuals were unable to detect it.

The fact that the J. H. Hale peaches showed evidence of being especially resistant to carbon dioxide injury in the Yakima experiments led to a comparative test the following year at Washington, D. C., of eastern-grown J. H. Hale and Belle peaches. The temperature was held at 59° F. and the carbon dioxide was maintained at approximately 48 percent by continuous renewal of the storage atmosphere. Control lots of fruit were held at the same temperature without carbon dioxide but with continuous air renewal; other lots were held at 32°.

Fruit was removed at different times and held at room temperature for tests on flavor. Belle peaches that were removed from the carbon dioxide treatment after 24 hours were somewhat poorer in flavor and quality than similar fruit from the controls, and those removed from the treatment after 40 hours were distinctly poor and flat in flavor. In contrast with this the J. H. Hale peaches that were removed after 40 hours' exposure to 50-percent carbon dioxide were found by all persons testing to have fine flavor and quality and to be as good as or better than the controls. It should be noted in this connection that Harding and Haller (*7*) have found that J. H. Hale peaches stand low-temperature storage better than Belle and Elberta peaches.

The above results would indicate that the tolerance of peaches to carbon dioxide varies widely with the variety and probably with the conditions under which the fruit is grown. The carbon dioxide treatment of the Elberta peaches in the Yakima experiments was more extreme than eastern Elbertas have been reported (*4*) to stand without injury to flavor, and the experiments with the J. H. Hale variety from eastern as well as western orchards indicate an unusual tolerance to carbon dioxide treatments.

The efficiency of carbon dioxide treatments in the control of peach decays was emphasized in an earlier publication (*4*).

APPLES AND PEARS

Favorable results have been reported from short-period carbon dioxide treatment of apples prior to storage. Brooks et al. (*4*), Brooks and Harley (*2*), and Gerhardt and Ezell (*5*) have found that such treatments have a favorable effect upon the maintenance of firmness and also in the prevention of the later development of certain low-temperature functional diseases. Their experimental data also indicate that apples have a relatively high tolerance for carbon dioxide treatments.

It has been known for a long time that certain varieties of pears ripen well under conditions that approach smothering, and recent experiments have shown that carbon dioxide may be used in the storage of pears with decidedly favorable results. Thornton (*15*) found that pears exposed to carbon dioxide tend to lose their astringency but that long exposure (7 days) to high percentages of the gas results in discoloration and break-down. Trout (*17*) and Kidd, West, and Trout (*9*) have shown that the storage life of pears may be prolonged by the proper increase in the carbon dioxide and reduction in the oxygen content of the storage atmosphere. Brooks et al. (*4*) reported that 1 or 2 days' exposure of freshly picked Bartlett pears to 25 percent or more of carbon dioxide had a decidedly favorable effect in checking the decay and softening of the fruit and in decreasing the later development of internal break-down. They found Bartlett and Seckel pears relatively resistant to injury from short-period carbon dioxide treatments and Anjou pears fairly resistant.

In July 1932 carbon dioxide experiments were made with Bartlett pears from the Sacramento Valley in California. The temperature, length of exposure, and carbon dioxide conditions of the experiments were the same as those shown in lots 1a to 1f of table 3. After removal from the experimental conditions the fruit was held at 68° F. for 8 days, and it was found that the pears exposed to carbon dioxide at an average temperature of 48° maintained their firmness better than those held in storage at 34° and had as good or better flavor.

In August 1932 two different sets of experiments were carried out with freshly picked Bartlett pears at Yakima, Wash. The temperature and carbon dioxide conditions of the first experiment were the same as those shown in lots 4a to 4f of table 2, and those of the second experiment were the same as those shown in lots 1a to 1f of table 2.

After 46 to 48 hours under the different storage conditions, approximately one-half bushel of the fruit from each lot was moved to cellar storage at 66° F., and 1 bushel from each lot was placed in 32° storage for 1 month and then moved to 66° for ripening. The fruit that had been exposed to carbon dioxide developed as good flavor in all cases as the controls. With the fruit that was ripened immediately after removal from the special storage conditions, the pressure resistance of the fruit in the carbon dioxide lots, held at temperatures averaging 51° to 54°, fell slightly below that of the fruit held at 32° but was decidedly higher than that of the fruit held at similar temperatures in the control refrigerator. In the case of the fruit held in 32° storage a month before ripening, the pressure resistance of the fruit in the carbon dioxide lots was decidedly greater in all instances than that of the fruit held at 32°, at 45°, or in the control refrigerator.

In the first experiment at Yakima, Wash., 30 inoculations were made with *Botrytis cinerea* Auct. for each condition of storage. After 46 hours under the different storage conditions, all lots were moved to cellar storage at 66° F., and it was found that the development of decay had been delayed more by both the high and the medium carbon dioxide treatments than by immediate storage at 32° and delayed more by the low carbon dioxide treatment than in the control refrigerator or by immediate storage at 45°.

RASPBERRIES

Red raspberries have been reported (*4*) to be rather susceptible to carbon dioxide injury. Experiments with Cuthbert berries at Yakima in the summer of 1932 seem to support this view. The fruit was picked in the Puyallup berry section the day before the experiments were started. In the first, second, and fourth experiments, 6 quarts of berries were included under each condition; and in the third experiment, 64 quarts under each condition. The conditions and the results of the experiments are shown in table 4.

TABLE 4.—*Effect of treatment with carbon dioxide upon flavor and decay of Cuthbert raspberries, Yakima, Wash., 1932*

Lot no.	Date	Period of treatment	CO_2 in atmosphere during treatment			Temperature during treatment			Holding temperature after treatment	Period held after treatment	Condition at end of holding period	
			Early high	Final low	Average	Initial high	Final low	Average			Decay	Flavor
		Hours	*Percent*	*Percent*	*Percent*	*°F.*	*°F.*	*°F.*	*°F.*	*Days*	*Percent*	
1a	June 21	48	70	40	59	68	40	45	51	2	17.0	Off.
1b			40	19	32	68	46	50	51	2	14.4	Fair.
1c			37	15	26	68	50	54	51	2	6.8	Do.
1d[1]						68	42	47	51	2	54.1	Good.
1e[2]						41	41	41	51	2	26.5	Do.
1f[2]						62	62	62	51	2	45.5	Do.
2a	June 25	48	72	43	58	70	40	45	62	1	7.7	Off.
2b			29	19	24	70	47	52	62	1	14.0	Fair.
2c			11	5	8	70	50	53	62	1	38.8	Do.
2d[1]						70	51	55	62	1	30.9	Do.
2e[2]						32	32	32	62	1	21.3	Do.
2f[2]						41	41	41	62	1	22.5	Do.
3a	June 29	29	42	29	34	68	38	43	63	3	15.6	Excellent.
3b			23	14	18	68	44	49	63	3	.6	Do.
3c			19	7	14	68	43	46	63	3	7.0	Do.
3d[1]						68	42	47	63	3	40.4	Do.
3e[2]						32	32	32	63	3	27.2	Do.
3f[2]						41	41	41	63	3	39.7	Do.
4a	Aug. 9	48	66	30	48	66	47	52	65	1	16.5	Off.
4b			32	13	21	66	47	52	65	1	21.7	Fair.
4c			19	6	13	66	45	49	65	1	35.3	Good.
4d[1]						66	48	52	65	1	50.4	Do.
4e[2]						32	32	32	65	1	34.2	Do.
4f[2]						45	45	45	65	1	44.1	Fair.

[1] Control; not treated with CO_2.
[2] Placed immediately in constant temperature storage.

The results emphasize both the efficiency and the danger of carbon dioxide treatments for red raspberries. Carbon dioxide was even more efficient than prompt cooling in the control of decay. Fruit that was gradually cooled from around 70° to 40° or 50° F., as in a refrigerator car, but exposed to 20 percent or more of carbon dioxide during the early stages of cooling had less than half as much decay as fruit held at 41° or in a control refrigerator without carbon dioxide and less than fruit placed immediately at 32°.

Fruit exposed to carbon dioxide was firmer and had a better appearance than fruit held under other conditions.

52588°—36——2

There was a loss of flavor, and in the more severe treatments a distinctly objectionable flavor, resulting from 48 hours' exposure to carbon dioxide; but this was not true, even with 30 to 40 percent, of the gas in the experiment in which the treatment was limited to 29 hours. It should be noted that 29 hours is sufficient time to cover the most critical period in the cooling of a refrigerator car.

BLACKBERRIES AND DEWBERRIES

Very favorable results have been reported (*4*) in carbon dioxide treatments of blackberries and dewberries, both as to freedom from injury and control of decay. The present data substantiate the earlier results.

The experiments were carried out in widely separated sections of the country; those on blackberries, at Fresno, Calif., Yakima, Wash., and Rosslyn, Va.; and those on dewberries at Fresno, Calif., Savannah, Ga., and Gloucester, Va. The results are shown in table 5.

TABLE 5.—*Effect of carbon dioxide treatments upon the flavor, firmness, and decay of dewberries (Young variety) and blackberries*

Fruit and lot no.	Location	Date	Fruit under each condition	Period of treatment	Carbon dioxide in the atmosphere during treatment			Temperature during treatment			Holding temperature after treatment	Period held after treatment	Final condition of fruit		
					Early high	Final low	Average	Initial high	Final low	Average			Decay	Firm berries	Rating on flavor
Blackberries:			Qts.	Hrs.	Pct.	Pct.	Pct.	°F.	°F.	°F.	°F.	Dys.	Pct.	Pct.	
1a	Fresno, Calif.	1932 July 21	2	40	41	8	22	52	39	42	53	2	----	----	Good.
1b [1]					---	---	---	34	34	34	53	2	----	----	Do.
2a	Yakima, Wash.	Aug. 9	2	48	66	30	48	66	47	52	66	5	----	----	Fair.
2b					32	13	21	66	47	52	66	5	----	----	Good.
2c					19	0	13	66	45	49	66	5	----	----	Do.
2d [2]					---	---	---	66	48	52	66	5	----	----	Poor.
2e [1]					---	---	---	32	32	32	66	5	----	----	Good.
2f [1]					---	---	---	45	45	45	66	5	----	----	Fair.
3a	----do	Aug. 11	3	48	55	32	38	63	46	49	66	2	13.9	73.9	Good.
3b					31	4	20	63	47	52	66	2	19.3	68.9	Do.
3c					31	1	15	63	49	52	66	2	29.4	57.4	Do.
3d [2]					---	---	---	63	44	47	66	2	32.1	47.8	Do.
3e [1]					---	---	---	32	32	32	66	2	17.0	63.9	Do.
3f [1]					---	---	---	45	45	45	66	2	31.0	51.1	Do.
4a	----do	Aug. 19	3	48	48	17	29	68	44	49	66	3	2.3	90.9	Do.
4b					32	9	21	68	48	51	66	3	5.0	90.1	Do.
4c					24	1	17	68	48	50	66	3	2.5	91.8	Do.
4d [2]					---	---	---	68	50	52	66	3	17.5	76.0	Do.
4e [1]					---	---	---	32	32	32	66	3	0.1	83.3	Do.
4f [1]					---	---	---	45	45	45	66	3	13.0	78.3	Do.
5a	Rosslyn, Va.	1934 July 11	8	45	50	29	38	76	46	50	----	0	2.0	85.8	Do.
5b					31	7	19	76	41	46	----	0	3.8	85.9	Do.
5c [2]					---	---	---	76	43	48	----	0	14.9	70.6	Do.
5d [1]					---	---	---	32	32	32	----	0	1.1	85.9	Do.
5e [1]					---	---	---	40	40	40	----	0	5.4	70.1	Do.
Dewberries:															
1a	Fresno, Calif.	1932 July 21	2	40	41	8	22	52	30	42	53	2	----	----	Do.
1b [1]					---	---	---	34	34	34	53	2	----	----	Do.
2a	Savannah, Ga.	1933 May 17	55	40	60	10	30	80	52	56	78	1	18.8	66.9	Do.
2b [2]					---	---	---	80	57	60	78	1	60.5	23.4	Do.
3a		May 19	60	43	42	1	23	78	47	52	75	1	5.8	87.8	Do.
3b [2]					---	---	---	78	51	55	75	1	[illegible]	63.9	Do.
4a		May 22	64	40	(3)	(3)	(3)	68	45	49	67	2	0.1	73.0	Do.
4b [2]					---	---	---	68	47	49	67	2	17.5	50.0	Do.
5a	Gloucester, Va.	June 13	64	48	(3)	(3)	(3)	70	44	48	---	0	2.9	70.0	Do.
											45	1	9.8	69.6	Do.
5b [2]					---	---	---	70	45	49	---	0	20.9	68.9	Do.
											45	1	22.2	43.8	Do.

[1] Placed immediately in low-temperature storage.
[2] Control; not treated with CO_2.
[3] Similar to lot 3a.

The flavor of blackberries was not affected by somewhat extreme treatments with carbon dioxide for a period of 48 hours, during the process of gradual cooling from summer temperatures to temperatures of 45° to 50° F. (table 5). Much milder treatments gave as favorable results in the prevention of the softening of the fruit and practically as good results in the prevention of decay as immediate storage at 32°.

The dewberries used in the experiments were all of the Young variety, outstanding for its high quality but generally considered too soft for commercial shipments. In the experiments reported in lots 4 and 5, the berries were shipped in the pony refrigerators from the point where grown to the Arlington Experiment Farm, Rosslyn, Va., and it was not possible to secure a complete record of the carbon dioxide in the atmosphere. Judging by the quantity of solid material used, the treatment was similar to that in the experiment reported in lot 3.

As with blackberries, the flavor of the dewberries (Young variety) was not affected by exposure to relatively high percentages of carbon dioxide for a period of 48 hours. In some instances the berries had a sharp carbon dioxide taste immediately after removal from the gas, but this soon disappeared. The carbon dioxide treatments reduced the decay to about one-third of that found on control fruit held at a similar temperature, and resulted in an increase varying from 30 to 180 percent in the number of firm berries in the different experiments. The firmer condition of the treated fruit was readily evident in its general appearance.

MELONS

Carbon dioxide experiments were made with muskmelons and Honey Dew and Honey Ball melons, but the results were not conclusive. Little disease of importance occurred, and it was difficult to determine the effect upon quality and flavor because of the great variability within the lots.

MUSKMELONS

The temperature and carbon dioxide conditions in the muskmelon experiments are shown in table 6. Most of the melons were at the half-slip stage of maturity. In the experiment at Fresno, Calif., the muskmelons exposed to carbon dioxide were thought to have a somewhat better flavor than those in the control lots, whereas in the experiment at Yakima, Wash., the reverse condition held. In the latter experiment the melons were first tested for flavor after being held for 1 day at 32° F., and at that time those that had been exposed to carbon dioxide were distinctly lacking in flavor. The melons were moved to 66° and after 4 days at that temperature were tested again. It was found that the treated melons had gained greatly in flavor and were fairly good, yet there still appeared to be fewer high-quality melons than in the untreated lots.

The carbon dioxide treatments had a favorable effect upon the maintenance of firmness in the melons and also a favorable effect in retarding decay.

HONEY DEW AND HONEY BALL MELONS

On July 20, 1933, a crate of California Honey Dew melons was purchased on the market at Washington, D. C., and carefully divided into three lots of three melons each. One lot was held at a constant temperature of 59° F. in a continuously renewed atmosphere in which the carbon dioxide was maintained at 50 percent; another lot was held at 59° in a continuously renewed atmosphere without carbon dioxide, and a third in 32° storage.

One melon was removed from each condition at the end of 1 day, another at the end of 2 days, and the third melon at the end of 4 days. In every instance the flavor of the melon that had been exposed to carbon dioxide was found to be the sweetest and best.

Other experiments were made with Honey Dew melons as shown in table 6. The melons were purchased on the Washington, D. C., market but had been shipped from California.

The melons were tested for flavor immediately upon removal from the experiments, and the carbon dioxide treated melons were found to be distinctly sweeter and better than the controls. They were tested again after being held for 1 day at 50° F., and while the contrast was less pronounced the treated melons were still given the higher rating.

In the single experiment with Honey Ball melons the results were similar to those with muskmelons. The treated melons were found to have poorer flavor than the untreated ones when tested immediately after removal from the experiment, but a day later this contrast had largely if not entirely disappeared.

TABLE 6.—*Carbon dioxide treatments with melons*

Variety and lot no.	Location	Date	Melons under each condition	Period of treatment	Carbon dioxide in the atmosphere during treatment: Early high	Carbon dioxide: Final low	Carbon dioxide: Average	Temperature during treatment: Initial high	Temperature: Final low	Temperature: Average	Holding temperature after treatment	Period held after treatment	Final condition at end of holding period: Decay	Final condition: Flavor[1]
			No.	*Hrs.*	*Pct.*	*Pct.*	*Pct.*	*°F.*	*°F.*	*°F.*	*°F.*	*Days*	*Pct.*	
Muskmelons:														
1a	Fresno, Calif.	*1932* July 16	12	48	49	14	31	61	34	36	38	2	----	Best.
1b					30	8	10	52	39	42	38	2	----	Fair.
1c					13	5	10	65	41	45	38	2	----	Do.
1d[2]					---	----	----	55	44	40	38	2	----	Do.
1e[3]					---	----	----	34	34	34	38	2	----	Do.
2a	Yakima, Wash.	Aug. 13	20		40	14	27	61	38	42	[4]32-60	[4]1-4	0	Poorest.
2b					31	13	22	61	44	47	32-60	1-4	10	Fair.
2c					23	1	13	61	44	47	32-60	1-4	5	Do.
2d[2]					---	----	----	67	43	46	32-60	1-4	15	Do.
2e[3]					---	----	----	32	32	32	32-66	1-4	5	Do.
2f[3]					---	----	----	45	45	45	32-60	1-4	15	Do.
Honey Dew and Honey Ball melons:														
3a	Washington, D. C.	*1934* June 26	[5]9+9	44	59	30	40	68	59	61	50	1	----	
3b					33	13	22	68	53	56	50	1	----	
3c[2]					---	----	----	68	47	51	50	1	----	
Honey Dew melons:														
4a	do	July 11	10	45	50	20	38	76	46	50	40	1	----	Good.
4b					31	7	19	70	41	46	40	1	----	Do.
4c[3]					---	----	----	76	43	48	40	1	----	Fair.

[1] For further notes on flavor, see p. 12.
[2] Control; not treated with CO_2.
[3] Placed immediately in low-temperature storage.
[4] Held 1 day at 32° F. and 4 days at 60°.
[5] 9 of each variety under each condition.

TOMATOES

A number of carbon dioxide experiments have been carried out with tomatoes and with organisms that cause their decay. Most of these experimental treatments extended over a period of 48 hours and were made in pony refrigerators in which the warm fruit was gradually cooled by the use of ice; the temperature dropped from an initial 75° to 85° F. to a final 45° to 55° and averaged around 50° to 60°. Four refrigerators were used, and solid carbon dioxide was added to three of them as a source of carbon dioxide gas. In one refrigerator the carbon dioxide in the atmosphere averaged around 40 percent, in another around 30 percent, and in a third around 20 percent. In each case the percentage of gas was about twice as high at the beginning of the experiment as at the close. The control refrigerator, to which no carbon dioxide was added, usually ran at a slightly lower temperature than the three other refrigerators. The tomatoes held in these refrigerators for 2 days were compared with similar lots that were stored at constant temperatures of 32°, 40°, 50°, 60°, and 70° for the same length of time.

During the summers of 1931 and 1932, 11 different experiments with tomatoes were carried out as described, at the Arlington Experiment Farm, Rosslyn, Va. One to five varieties were used in each experiment. There was a total of five tests each with Bonny Best, Greater Baltimore, and Break o' Day, four tests each with Stone, Globe, and Marglobe, and two tests with Earliana.

The tomatoes were either picked or carefully sorted for color and maturity. There were 8 series of experiments with mature green tomatoes, 7 series with tomatoes that were turning, 18 series with pink tomatoes, and 6 with tomatoes that were practically full red. From 5 to 20, usually 10 to 15, tomatoes of a particular maturity and variety were included under each experimental condition.

After removal from the experimental conditions the tomatoes were held for 3 to 5 days at 70° F. and notes taken on decay, firmness, and the rate and character of maturing. The results were too indefinite and erratic to justify a completely tabulated report.

It was evident throughout the experiments that the carbon dioxide had a decidedly inhibiting action upon the ripening of the tomatoes. Holding the tomatoes at a temperature that was gradually falling from around 80° to around 50° F. in an atmosphere containing 30 percent or more of carbon dioxide had a retarding effect upon ripening equal to or greater than that of immediate storage at 32° without carbon dioxide. Exposure to atmospheres containing 20 percent of carbon dioxide under the above temperature conditions had a retarding effect upon ripening greater than storage at 40° and often equal to that of storage at 32°.

It was difficult to determine whether the tomatoes matured as satisfactorily after ripening was checked by gas as when checked by low temperature. This difficulty may have been partly due to the fact that some of the gas treatments seemed to check the maturing of the tomatoes more than did 32° storage, and the ripening might therefore be expected to be correspondingly delayed and affected.

There were instances in which the tomatoes held at 32° F. or exposed to carbon dioxide gas did not develop as bright or even coloring upon removal as the fruit which had been held without the gas and at a temperature of 50° or higher. The ripening of the greener portions of the tomato, especially those around the stem, apparently was checked more than that of the riper portions, and this sometimes resulted in uneven maturity in the different parts of the fruit. The tomatoes held at 32° or exposed to carbon dioxide gas were usually firmer than those from the other storage conditions, but there were a few instances in which they developed a peculiar softness. There was no instance in which the gas-treated tomatoes developed a complete softening of the carpel walls as described by Thornton (*15*) on tomatoes exposed to carbon dioxide for long periods.

As compared with storage at 32° F., the unfavorable effects upon color and firmness were somewhat more common on tomatoes held for a 2-day period in an atmosphere in which the carbon dioxide averaged 40 percent or above, just about as common on those held in 30 percent of carbon dioxide, and somewhat less common on those held in an atmosphere containing about 20 percent of carbon dioxide. The effect of various temperatures upon the ripening of tomatoes has been recently discussed by Barker (*1*), Haber (*6*), and by Wright et al. (*18*).

The effects of the gas treatments in retardation of color development were more evident in tomatoes that were turning and mature green than in pink tomatoes. The favorable effects upon firmness were rather general, and the few instances of unfavorable effects were confined to tomatoes in the pink stage.

At the time of removal from the gas treatments the flavor of the tomatoes was abnormal, but a few hours later this condition had disappeared. Tests at various times during the period of holding at 70° F. indicated that the gas-treated tomatoes had a flavor fully as good as that of tomatoes held at 32° but not so good in many cases as that of tomatoes held continuously at 50° or higher. There was no indication of a high increase in acidity as reported by Sando (*14*) for tomatoes held for long periods in atmospheres having a reduced oxygen supply.

Not enough decay developed in any of the tests just described to give an indication as to the relative effects of the different treatments. Some *Rhizopus* developed during the holding period at 70° F., but without any apparent relation to previous treatments.

Separate experiments were carried out in which the tomatoes were inoculated with decay organisms. *Phoma destructiva* Plowr., *Fusarium* sp., and *Colletotrichum phomoides* (Sacc.) Chester were included in these experiments. Spores and mycelium of these fungi were forced into tomatoes, and the decay spots were allowed to attain a measurable size before the tomatoes were placed under the experimental conditions. The effect of carbon dioxide upon the enlargement of the decay areas was then followed under various temperature conditions. Similar studies were made in which the fungi were grown on carrot agar in Petri plates.

At temperatures of 50° to 77° F., atmospheres containing 25 percent or more of carbon dioxide caused a definite checking of growth of the fungi, the rate of development in the carbon dioxide atmosphere usually being about half of that in normal air at the same temperature and similar to that in normal air at a temperature 5° to 10° lower. Within the above range the inhibition due to carbon dioxide was somewhat greater at the higher than at the lower temperatures.

As shown in the recent report of Nightingale and Ramsey (*12*), it was found that the above fungi make practically no growth at 41° F., and only a very slow growth at 50°. This extreme response to temperature as compared with the relatively slight response to carbon dioxide tends to minimize the practical value of gas treatments in connection with these transit and storage decays of tomatoes. Kidd and West (*8*) found that at 12° C. or lower, exposure to atmospheres containing more than 5 percent of carbon dioxide increased injury of tomatoes by fungi. They obtained the least wastage at 12° C. in an atmosphere containing 5 percent of carbon dioxide and 5 percent of oxygen.

BEANS

Carbon dioxide experiments with beans were carried out at the Arlington Experiment Farm, Rosslyn, Va., in the summers of 1931 and 1932. The treatment and methods were the same as reported for tomatoes. Three series of experiments were made with Refugee snap beans, three with Burpee Stringless Green Pod, and two with Henderson bush lima beans.

After 2 days' treatment the beans were removed from the various conditions and held [illegible]0° F. There was no case in which the appearance of the beans was injured by the carbon dioxide treatments. Thornton (*15*) has reported injury on stringless beans that were exposed for 3 days at 0° or 15° C. to atmospheres containing 18 percent of carbon dioxide, or for 3 days at 4° or 10° to atmospheres containing 30 percent of carbon dioxide. Sample lots from the various carbon dioxide and temperature conditions were cooked for a flavor test. The snap beans that had been exposed to high percentages of carbon dioxide at the higher temperatures were usually given a lower rating than those held continuously at 32° or 40° F. without carbon dioxide. The flavor of lima beans from the carbon dioxide treatments was as good as or better than that of the beans from low-temperature storage.

Experiments were included in which *Sclerotium rolfsii* Sacc., *Rhizoctonia solani* Kühn, *Colletotrichum lindemuthianum* (Sacc. and Magn.) Briosi and Cav., and *Bacillus carotovorus* L. R. Jones were grown for 24 to 48 hours on beans and on agar and were then subjected to carbon dioxide gas and to low temperature. The first two organisms were delayed as much by the gas treatments as by a 15° to 20° F. lowering of the temperature, but the last two organisms showed little response to the carbon dioxide treatments.

CARROTS

Several carbon dioxide experiments have been made with carrots. The treatments, methods, and location of the work were the same as reported for tomatoes.

The carrots exposed to carbon dioxide showed greater wilting of the tops than the untreated lots. When they were held under moist conditions after removal from carbon dioxide, the tops regained their normal turgidity without any evidence of injury. The flavor of the treated carrots that had been gradually cooled in the refrigerators was as good as or better than that of the carrots that were placed at once at 32° F., and distinctly sweeter and better than that of the carrots held under similar temperature conditions without carbon dioxide. These favorable effects are in agreement with results reported in other publications (*4, 11*).

Exposure to carbon dioxide had a decided inhibiting effect upon decay in carrots inoculated with *Rhizoctonia* sp. or *Sclerotinia sclerotiorum* (Lib.) Mass., but little if any effect upon decay resulting from inoculations with *Bacillus carotovorus*.

CELERY

Thornton (*15*) has shown that celery is quite susceptible to carbon dioxide injury. Slight injury resulted from 7 days' exposure at 0°, 4°, and 10° C. to atmospheres containing 25 percent of carbon dioxide and still greater injury with atmospheres containing 50 percent or more of carbon dioxide.

The present experiments were carried out in pony refrigerators with gradually falling temperature, as described for tomatoes. After 3 days' treatment with carbon dioxide all lots were held at 70° F. for 4 days. Exposure for 3 days to an atmosphere in which the carbon dioxide averaged 50 percent resulted in slight injury to the celery tops and a slight browning of the vascular tissue at the base of the stalks. A similar exposure to 20 percent of carbon dioxide caused no injury to the tops and only the slightest traces of browning at the base. In both cases the celery stalks broke away from the stem much more readily in the treated than in the untreated lots. The taste of the treated celery was slightly lacking in character and quality as compared with the untreated celery.

ASPARAGUS

Carbon dioxide experiments with asparagus were carried out at constant temperatures, as described on page 2. In some of the tests the atmosphere was controlled by continual renewal and in others the air was left stagnant after the addition of the desired quantity of carbon dioxide. The asparagus was cut the morning the tests were started. Five different experiments were carried out in the summer of 1931 and six different experiments in the summer of 1933.

In all of the experiments the asparagus that had been exposed to carbon dioxide was greener and fresher looking than the control lots. This was especially true after cooking. It also had a fresher taste, but with more extreme treatments this was somewhat overshadowed by a peculiar flavor which was confined to the tips. Asparagus exposed to 25 to 30 percent of carbon dioxide at temperatures of 60° to 70° F. for 18 to 24 hours had a better flavor than asparagus held at the same temperature without carbon dioxide and as good as or better flavor than asparagus held at 32° or 40° for the same period. Asparagus that was exposed to 25 to 30 percent of carbon dioxide for 48 hours or to 40 percent or more of carbon dioxide for 24 hours was sometimes found to have an objectionable flavor. Thornton (*15*) has reported a browning of the outer bud scales and the development of water-soaked areas on asparagus exposed to 50 to 80 percent of carbon dioxide for 3 days.

In one series of these experiments the asparagus was sprayed with a *Rhizopus* spore suspension before the tests were started. Upon holding the asparagus after removal from the experimental treatments a 40-percent reduction in the number of tips affected with *Rhizopus* mold was found in the lots held in 25 percent of carbon dioxide at 60° F. for 2 days as compared with asparagus held without carbon dioxide but otherwise under similar conditions.

CABBAGE, CHINESE CABBAGE, BROCCOLI, AND CAULIFLOWER

In February 1931 carbon dioxide experiments were carried out in the market-garden section at Belle Glade, Fla. It was possible to obtain various vegetables fresh from the field and include them in pony-refrigerator experiments a few hours later. The experiments extended over 2-day periods, and the refrigerators were gradually cooled as previously described. The weather was relatively cool, and the initial temperature of the closed refrigerators was around 65° F. The temperature fell to 40° in about 12 hours and averaged 40° to 45° for the entire run. At these low temperatures it is not to be expected that the effects of the carbon dioxide treatments, either beneficial or harmful, would be as pronounced as at higher temperatures. In one refrigerator the carbon dioxide was held very high, starting around 80 percent, ending around 20 percent, and averaging about 50 percent. In another refrigerator the carbon dioxide tapered off gradually from about 45 percent to around 5 percent, with an average of 20 to 25 percent. A third refrigerator was used for a control without the addition of carbon dioxide. After the 2-day treatment the various products were held for several days in an iced refrigerator at a temperature of approximately 40°.

Cabbage and broccoli were included in five different experiments as described above, Chinese cabbage in three experiments, and cauliflower in two experiments. There was no indication of injury even with the high carbon dioxide treatments, and no effect on flavor could be detected. The treated broccoli seemed to be definitely fresher and greener, but otherwise no benefits from the treatments were evident during the short period of holding.

KOHLRABI, SWISS CHARD, ROMAINE, COLLARDS, AND ESCAROLE

Swiss chard, romaine, and escarole were included in two of the experiments described above and kohlrabi and collards in one of the experiments. The romaine was badly injured and broken down by both the high and the medium carbon dioxide treatments. The Swiss chard and the escarole were injured by the high carbon dioxide treatment but not by the medium. The injury in the case of the Swiss chard consisted in the development of water-soaked areas and brown pitting and in the case of the escarole in the browning of the central leaves. The kohlrabi and collards were not injured.

SPINACH, NEW ZEALAND SPINACH, LETTUCE, AND TURNIPS

Lettuce and New Zealand spinach were included in three of the experiments just described above (p. 17), turnips in two, and spinach in one. In two of the experiments the Big Boston variety of lettuce was used; in one of them the Iceberg variety. The Big Boston variety was badly injured by the high carbon dioxide treatments and slightly injured by the medium treatments. The injury was in the nature of a withering and discoloration of the outer leaves. The Iceberg variety was not injured and the treated lots seemed to have less bitterness. The tips of the New Zealand spinach were killed by the high carbon dioxide treatments, but no injury resulted from the medium treatments. No injury was evident on the spinach and turnips.

PEPPERS, EGGPLANTS, RADISHES, BEETS, PEAS, AND CORN

Beets and peas were included in six different experiments as described above (p. 17), corn and peppers in four, eggplants in three, and radishes in two. The peppers, eggplants, and radishes were injured by the high carbon dioxide treatment and in some cases by the medium treatment. The injury to the peppers and eggplants consisted in a pitting, scalding, and browning of the tissue and with the radishes in a wilting and breaking down of the tops. The peas (Little Marvel) were injured by exposure to high percentages of carbon dioxide in three of the six experiments. The injury appeared as a pitting of the pods and was worst on the least mature lots. The corn and beets showed no injury, but during the period of holding no benefits were evident. Exposure to carbon dioxide has been reported (*10*) to retard the loss of sugar in corn and peas.

In one experiment *Phomopsis vexans* (Sacc. and Syd.) Harter isolated from eggplant was grown on potato dextrose agar in Petri plates. It was completely inhibited during the period of treatment by both the high and medium percentages of carbon dioxide.

AVOCADOS, PAPAYAS, AND BANANAS

Bananas were included in five of the experiments, papayas in four, and avocados in one. Green and turning bananas turned black after the carbon dioxide treatments, those that were almost mature apparently ripened more slowly, and the fully mature ones were not affected in flavor or appearance. The carbon dioxide treatments seemed to improve the flavor of the avocados and papayas and caused no injury.

CITRUS

Thornton (*15*) found oranges and grapefruit quite resistant to carbon dioxide injury. He held Valencia oranges and Foster and Thompson grapefruit for 7 days without injury at temperatures of 0°, 4°, 10°, and 15° C. in atmospheres containing 50 percent of carbon dioxide. Tangerines and Wallers' grapefruit were injured by 50 percent of carbon dioxide under these conditions but not by 25 percent.

Brooks and McColloch (*3*) have reported that exposing grapefruit for 20 to 48 hours to atmospheres containing 20 to 45 percent of carbon dioxide before placing in low-temperature storage resulted in a decrease in the later development of pitting with no harmful effects upon flavor.

Limes, grapefruit, and Valencia oranges were included in the experiments at Belle Glade, Fla., previously described (p. 17). Neither the high nor the medium carbon dioxide treatments had any effect upon the flavor or appearance of the fruit.

In January 1932, Pineapple oranges and Marsh grapefruit were given 2 to 3 days' exposure to carbon dioxide at Miami, Fla. The experiments were carried out in pony refrigerators in which the temperature fell gradually from around 75° to around 50° F. In some cases the carbon dioxide stood as high as 60 percent in the beginning and gradually fell to about 30 percent; in other cases the concentration of gas was approximately half this amount. After the carbon dioxide treatments the fruit was shipped by boat to New York and held in 32° storage for 8 weeks. At the end of this time no injury in flavor or appearance had resulted from the various treatments.

The effect of carbon dioxide treatments upon citrus decay is shown in table 7.

In most of the experiments 10 to 15 inoculations were made for each condition; in a few instances the number was less than this and in others it was as high as 30.

The flavor of the oranges and grapefruit was not affected by the various carbon dioxide treatments.

Some of the experiments were carried out in pony refrigerators in which the fruit was gradually cooled with ice. One refrigerator was used as a control and solid carbon dioxide was added to the others as a source of gas. In other experiments the temperature was carefully controlled and the percentage of carbon dioxide was kept constant by a continual renewal of the atmosphere. Controls were held without carbon dioxide at the various temperatures reported and also at other temperatures, especially lower ones. This arrangement, followed by the removal of all lots to a common temperature, made it possible to compare the condition of the treated lots from particular temperature conditions with that of control lots from various lower temperatures and thus obtain a temperature evaluation for the various carbon dioxide treatments. The effect of the carbon dioxide upon decay is also expressed in the table as number of hours of delay in the development of rots resulting from the treatment. This, however, is the delay in terms of the growth at the common temperature to which all lots were removed and cannot be taken as an accurate measure of the reduction in efficiency except where the holding temperature was approximately the same as the temperature at which the experiments were made.

Diplodia natalensis Evans appeared to be inhibited least by the carbon dioxide treatments, with the other fungi in the following order: *Phomopsis citri* Fawc., *Penicillium digitatum* (Fr.) Sacc., and *P. italicum* Wehmer. On the basis of actual reduction in activity of the organisms, however, the contrast was not so great as the data might seem to indicate. In the experiments in which the holding temperature was approximately the same as the storage temperature, the ratio of the hours of delay to the hours of treatment indicates that the activity of *Diplodia* was reduced 50 percent by exposure to 35 to 40 percent of carbon dioxide and more than 60 percent by exposure to 50 percent of carbon dioxide. The reduction in the case of *Phomopsis citri* and *Penicillium digitatum* was probably a little greater than this and with *P. italicum* exposure to 45 percent of carbon dioxide gave almost complete inhibition.

The number of hours delay resulting from carbon dioxide treatments at the lower temperatures was not so great as that resulting

TABLE 7.—*Effect of carbon dioxide treatments upon citrus decay organisms*

Fungus	Grown on—	Location	Date	Period of treatment	Carbon dioxide in atmosphere during treatment: Early high	Carbon dioxide in atmosphere during treatment: Final low	Carbon dioxide in atmosphere during treatment: Average	Temperature during treatment: Initial high	Temperature during treatment: Final low	Temperature during treatment: Average	Holding temperature after treatment	Period held after treatment	Effect of treatment[1]: Delay in development	Effect of treatment[1]: Lowering of temperature required to produce a similar effect
			1932	*Hours*	*Percent*	*Percent*	*Percent*	*°F.*	*°F.*	*°F.*	*°F.*	*Days*	*Hours*	*°F.*
Diplodia natalensis	Potato-dextrose agar	Miami, Fla.	Jan. 2	63	30	8	20	75	46	51	65	2	0	0
	do		Jan. 5	46	56	31	44	73	47	51	65	2	0	0
	do		Jan. 7	46	60	32	46	73	50	56	65	2	14	--------
	do		do	46	33	21	27	73	50	56	65	2	11	--------
	Grapefruit		Jan. 2	63	30	8	20	75	46	51	65	2	0	0
	do		Jan. 5	46	56	31	44	73	47	51	65	2	0	0
	do	Washington, D. C.	do	48	36	20	28	59	59	59	72	2	12	3
	Oranges		Feb. 8	48	43	43	43	77	77	77	72	2	24	8
	do		do	48	24	24	24	77	77	77	72	2	13	4
	do		do	48	24	24	24	62	62	62	72	2	14	8
	Grapefruit		Feb. 23	48	35	35	35	72	72	72	72	2	24	8
	do		Feb. 27	48	50	50	50	72	72	72	72	2	30	10
	do		Mar. 9	48	40	40	40	72	72	72	72	2	24	8
Phomopsis citri	Potato-dextrose agar	Miami, Fla.	Jan. 2	63	30	8	20	75	46	51	65	2	21	--------
	Grapefruit		do	63	30	8	20	75	46	51	65	2	12	--------
	do		Jan. 5	46	56	31	44	73	47	51	65	2	12	--------
	do	Washington, D. C.	Apr. 19	48	44	44	44	77	77	77	72	4	31	13
	do		do	48	44	44	44	68	68	68	72	4	25	6
	do		do	48	44	44	44	59	50	59	72	4	17	3
Penicillium digitatum	Potato-dextrose agar	Miami, Fla.	Jan. 2	63	30	8	20	75	46	51	65	2	26	--------
	do		Jan. 7	46	60	32	46	73	50	56	65	2	21	--------
			1931											
	Oranges	Belle Glade, Fla.	Feb. 14	66	43	21	32	65	30	41	65	2	25	--------
			1932											
	Grapefruit	Miami, Fla.	Jan. 2	63	30	8	20	75	46	51	65	2	26	--------
	do		Jan. 5	46	56	31	44	73	47	51	65	2	36	--------
	do		do	46	30	20	24	73	47	51	65	2	12	--------
	do	Washington, D. C.	Jan. 13	48	44	44	44	77	77	77	72	1	24	23
	do		do	48	22	22	22	77	77	77	72	1	12	11
	do		do	48	44	44	44	68	68	68	72	1	13	11
	do		do	48	22	22	22	68	68	68	72	1	10	9
	do		do	48	22	22	22	50	59	59	72	1	13	7
	do		Mar. 17	48	43	43	43	72	72	72	72	2	21	20

	Potato-dextrose agar	Miami, Fla	Jan. 2	63	30	8	20	75	46	51	65	2	30	----
			1935											
Penicillium italicum	do	Washington, D. C.	Feb. 12	48	45	45	45	79	79	79	68	3	38	24
	do		do	48	45	45	45	68	68	68	68	3	30	20
	do		do	48	45	45	45	59	59	59	68	3	24	14
	do		do	48	45	45	45	52	52	52	68	3	10	10
	Oranges		do	48	45	45	45	79	79	79	68	3	48	33
	do		do	48	45	45	45	68	68	68	68	3	46	22
	do		do	48	45	45	45	59	59	59	68	3	39	20
	do		do	48	45	45	45	52	52	52	68	3	26	17

[1] Determined by comparing treated with untreated fruit.

from the treatments at the higher temperatures, but this difference was due largely, if not entirely, to the slower growth rate at the lower temperatures followed by the removal to higher temperatures for a test of results. The results do not indicate that the inhibiting action of the gas was any less at the lower temperatures, but they do indicate that it has very much less practical value at these temperatures.

From the economic standpoint the last column of table 7 is particularly significant. Exposure to 43 to 45 percent of carbon dioxide at 77° to 79° F. had a checking effect that was approximately equivalent in the case of *Diplodia* to an 8° drop in temperature; in the case of *Phomopsis* to a 13° drop in temperature; in the case of *Penicillium digitatum* to a 23° drop in temperature; and in the case of *P. italicum* to a 33° drop in temperature. Most of this contrast between the different fungi is due to a difference in the minimum temperature for the growth of the organisms. *Diplodia* and *Phomopsis* are held completely in check at 40°, whereas both species of *Penicillium* are capable of producing serious decay at as low a temperature as 32°.

In most of the pony-refrigerator experiments the temperature dropped rapidly to a point where *Diplodia* was largely or entirely inhibited, with the result that little if any effect was evident from the carbon dioxide treatments. With the other three fungi, carbon dioxide treatments under similar temperature conditions resulted in decided inhibition.

FIGS

The effect of carbon dioxide has been tested on various varieties of figs with favorable results in the control of mold without injury to flavor or appearance. (The details of the experiments are withheld for later publication along with a study of temperature and humidity.)

SUMMARY

The results of short-period carbon dioxide treatments are reported for more than 40 different fruit and vegetable products.

Decidedly favorable results were obtained with carbon dioxide treatments of sweet cherries, plums, peaches, Bartlett pears, raspberries, dewberries, blackberries, figs, grapefruit, and oranges. Fruit that was exposed to carbon dioxide had less decay and was firmer and fresher than similar fruit held at the same temperature without exposure to CO_2. Initial carbon dioxide treatments at the temperatures that commonly prevail in a freshly loaded refrigerator car usually had as favorable an effect in retarding decay and in holding the firmness of the product as immediate storage at 32° F.

Most of the products mentioned were exposed for 2 days to relatively high percentages of carbon dioxide without injury to flavor, but there were a few that failed to stand such prolonged treatment. Cuthbert raspberries were not injured by exposure to 30 to 40 percent of carbon dioxide at the temperatures used for 29 hours but developed an objectionable flavor when the treatment was extended to 48 hours. J. H. Hale peaches were not injured by 40 hours' exposure to 50 percent of carbon dioxide at 59° F., whereas Belle peaches showed a loss of flavor from the same treatment at the end of 24 hours.

On oranges and grapefruit, *Penicillium digitatum* and *P. italicum* were held in check better than *Diplodia natalensis* and *Phomopsis citri*.

With products other than those mentioned the results of the carbon dioxide treatments were less conclusive or definitely objectionable.

Carbon dioxide treatments sometimes impaired the flavor of muskmelons and Honey Ball melons but appeared to improve the flavor of Honey Dew melons.

Carbon dioxide retarded the ripening of tomatoes and also the development of certain types of decay, but tomatoes exposed to high percentages of carbon dioxide sometimes failed to ripen satisfactorily upon removal.

Eggplant, radish, romaine, peppers, Big Boston lettuce, and green bananas were injured by 2 days' exposure at an average temperature of 40° to 45° F. to atmospheres in which the carbon dioxide averaged 20 to 25 percent. Swiss chard, escarole, peas, and New Zealand spinach were not injured by this treatment, but were injured when similarly exposed to atmospheres in which the carbon dioxide averaged 50 percent. Cabbage, Chinese cabbage, broccoli, cauliflower, kohlrabi, collards, spinach, turnips, beets, corn, Iceberg lettuce, ripe bananas, avocados, and papayas were not injured by either of these treatments. The carbon dioxide seemed to decrease the bitterness in the Iceberg lettuce and to improve the flavor of the avocados and papayas.

Exposure to carbon dioxide delayed the development of *Phomopsis vexans* from eggplant and of *Sclerotium rolfsii* and *Rhizoctonia solani* on beans, but not that of *Colletotrichum lindemuthianum* and *Bacillus carotovorus* on beans.

Celery was injured by 3 days' exposure to atmospheres in which the carbon dioxide averaged 50 percent and showed a slight browning of the vascular tissue after a similar exposure to atmospheres in which the carbon dioxide averaged 20 percent.

The freshness of asparagus appeared to be maintained as well by exposure for 18 to 24 hours to 25 to 30 percent of carbon dioxide at 60° or 70° F. as by immediate storage at 32° or 40°, but more severe treatments sometimes affected the flavor of the tips of the stalks.

Initial carbon dioxide treatments held carrots in as sweet and fresh condition as immediate storage at 32° F. The carbon dioxide had a decided checking effect upon decay resulting from inoculations with *Sclerotinia sclerotiorum* and *Rhizoctonia* sp., but not upon decay caused by *Bacillus carotovorus*.

LITERATURE CITED

(1) BARKER, J.
1928. COLD STORAGE TRIALS WITH TOMATOES. [Gt. Brit.] Dept. Sci. and Indus. Research, Food Invest. Bd. Rept. 1927: 43–44, illus.

(2) BROOKS, C., and HARLEY, C. P.
1934. SOFT SCALD AND SOGGY BREAKDOWN OF APPLES. Jour. Agr. Research 49: 55–69, illus.

(3) ——— and MCCOLLOCH, L. P.
1936. SOME STORAGE DISEASES OF GRAPEFRUIT. Jour. Agr. Research 52 319–351, illus.

(4) ——— MILLER, E. V., BRATLEY, C. O., COOLEY, J. S., MOOK, P. V., and JOHNSON, H. B.
1932. EFFECT OF SOLID AND GASEOUS CARBON DIOXIDE UPON TRANSIT DISEASES OF CERTAIN FRUITS AND VEGETABLES. U. S. Dept. Agr. Tech. Bull. 318, 60 pp., illus.

(5) Gerhardt, F., and Ezell, B. D.
1933. HANDLING OF JONATHAN APPLES FOR STORAGE. Wash. State Hort. Assoc. Proc. 29: 100–103, illus.

(6) Haber, E. S.
1931. ACIDITY AND COLOR CHANGES IN TOMATOES UNDER VARIOUS STORAGE TEMPERATURES. Iowa State Col. Jour. Sci. 5: 171–184.

(7) Harding, P. L., and Haller, M. H.
1935. PEACH STORAGE WITH SPECIAL REFERENCE TO BREAKDOWN. Amer. Soc. Hort. Sci. Proc. (1934) 32: 160–163.

(8) Kidd, F., and West, C.
1933. GAS-STORAGE OF TOMATOES. [Gt. Brit.] Dept. Sci. and Indus. Research, Food Invest. Bd. Rept. 1932: 209–211.

(9) ——— West, C., and Trout, S. A.
1932. THE GAS-STORAGE OF PEARS. [Gt. Brit.] Dept. Sci. and Indus. Research, Food Invest. Bd. Rept. 1931: 92–99, illus.

(10) Miller, E. V., and Brooks, C.
1932. EFFECT OF CARBON DIOXIDE CONTENT OF STORAGE ATMOSPHERE ON CARBOHYDRATE TRANSFORMATION IN CERTAIN FRUITS AND VEGETABLES. Jour. Agr. Research 45: 449–459, illus.

(11) ——— and Dowd, O. J.
1936. EFFECTS OF CARBON DIOXIDE ON THE CARBOHYDRATES AND ACIDITY OF FRUITS AND VEGETABLES IN STORAGE. Jour. Agr. Research. [In press.]

(12) Nightingale, A. A., and Ramsey, G. B.
1936. TEMPERATURE STUDIES OF SOME TOMATO PATHOGENS. U. S. Dept. Agr. Tech. Bull. 520. [In press.]

(13) Ryall, A. L.
1935. CERTAIN PHYSIOLOGICAL EFFECTS OF CARBON DIOXIDE TREATMENTS OF PLUMS. Amer. Soc. Hort. Sci. Proc. (1934) 32: 164–169, illus.

(14) Sando, C. E.
1920. THE PROCESS OF RIPENING IN THE TOMATO, CONSIDERED ESPECIALLY FROM THE COMMERCIAL STANDPOINT. U. S. Dept. Agr. Bull. 859, 38 pp., illus.

(15) Thornton, N. C.
1931. THE EFFECT OF CARBON DIOXIDE ON FRUITS AND VEGETABLES IN STORAGE. Contrib. Boyce Thompson Inst. 3: 219–244, illus.

(16) ———
1933. CARBON DIOXIDE STORAGE. IV. THE INFLUENCE OF CARBON DIOXIDE ON THE ACIDITY OF PLANT TISSUE. Contrib. Boyce Thompson Inst. 5: 403–418.

(17) Trout, S. A.
1930. EXPERIMENTS ON THE STORAGE OF PEARS IN ARTIFICAL ATMOSPHERES. Jour. Pomol. and Hort. Sci. 8: 78–91.

(18) Wright, R. C., Pentzer, W. T., Whiteman, T. M., and Rose, D. H.
1931. EFFECT OF VARIOUS TEMPERATURES ON THE STORAGE AND RIPENING OF TOMATOES. U. S. Dept. Agr. Tech. Bull. 268, 35 pp., illus.

U. S. GOVERNMENT PRINTING OFFICE: 1936

For sale by the Superintendent of Documents, Washington, D. C. - - - - - Price 5 cents

END