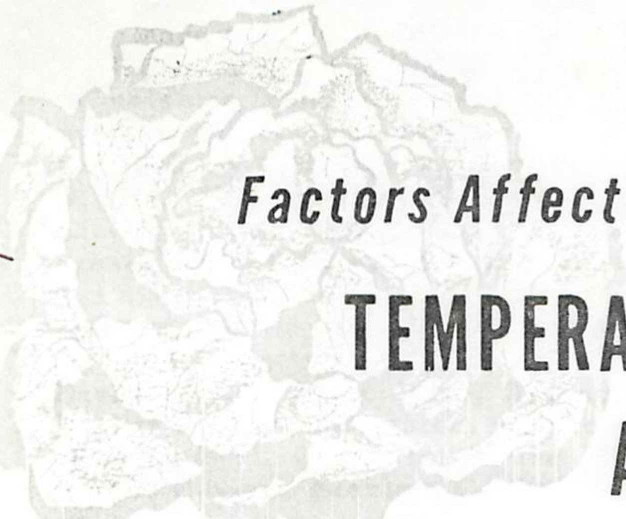
0195 dup.

Barger '61



Factors Affecting

TEMPERATURE REDUCTION AND WEIGHT-LOSS IN VACUUM-COOLED LETTUCE

BARGER '61

U.S.D.A. Mkt. Res. Rpt. No 469*

Marketing Research Report No. 469

UNITED STATES DEPARTMENT OF AGRICULTURE
Marketing Quality Research Division
Agricultural Marketing Service

PREFACE

More than 80,000 carloads of Iceberg-type lettuce are vacuum-cooled annually. Cooling by this method depends upon the evaporation of moisture from the leaves. To obtain adequate cooling, the lettuce must be subjected to vacuum conditions that will reduce the temperature quickly to 40° F or lower without causing freezing damage or wilting. This report discusses the various factors that affect the efficacy of cooling such as type of package, vacuum tank pressure, condenser temperature, rate of evacuation, free moisture on the lettuce and maturity of lettuce.

The assistance of Mr. J. K. Stewart and Mr. Fred L. Cook, U.S. Department of Agriculture, Agricultural Marketing Service, Market Quality Research Division, Horticultural Crops Branch, is gratefully acknowledged. Credit for figure 1 is due "P.G.&E. Progress" of the Pacific Gas and Electric Company, San Francisco, Calif.

CONTENTS

Washington, D. C. April 1961

FACTORS AFFECTING TEMPERATURE REDUCTION AND WEIGHT-LOSS IN VACUUM-COOLED LETTUCE

W. R. Barger, senior horticulturist,
Horticultural Crops Branch,
Market Quality Research Division,
Agricultural Marketing Service, Fresno, Calif.

SUMMARY

Factors affecting the rate of cooling, final temperature, and weight-loss in vacuum-cooling Iceberg lettuce were studied. These factors were: The initial temperature of the lettuce, time in the vacuum tank, speed of tank evacuation, tank pressure, consenser temperature, free moisture on the lettuce, packaging materials, and maturity of the lettuce.

During vacuum cooling, lettuce lost approximately 1 percent moisture for each 10 degrees (F.) drop in temperature. Weight-loss during vacuum cooling was related to temperature reduction. Under similar vacuum conditions, final temperatures were nearly the same, regardless of the initial temperature of the lettuce. However, warm heads lost proportionately more moisture than cool heads during the cooling process.

Cooling the lettuce to temperatures below 40° F. required 25 to 30 minutes. Delay in reaching the flash point (the point at which pressure of the air in the tank dropped below the vapor pressure in the leaves) increases the time required to cool the lettuce. But the speed at which pressure was reduced after the flash point had little effect on the rate of subsequent cooling. The lettuce, especially the butts, cooled much more slowly than a wet-bulb thermometer in the tank. For final lettuce temperatures below 40°, continuous holding under vacuum was necessary for 10 minutes or more after the wet-bulb had cooled to 32° or 33°.

Subfreezing tank pressures (below 4.6 mm. hg.) increased the rate and degree of lettuce cooled and were not injurious during the usual time required for vacuum cooling when the condenser was operated at a safe temperature. Conversely, freezing occurred at safe pressures when condenser temperatures were below 29° F.

Wetting the lettuce before vacuum cooling had little effect on the final temperature, but the pre-wet lettuce cooled slightly faster and lost less moisture from the leaves. Wetting prevented wilting of lettuce that was unusually warm at the beginning of the vacuum cooling.

Unwrapped lettuce packed in cartons lost moisture more readily and cooled faster under vacuum than lettuce packed in polyethylene-film lined cartons or in individual non-perforated film bags. Adequate ventilation in all containers and wrappers to insure easy escape of moisture vapor from the lettuce is essential for effective vacuum cooling.

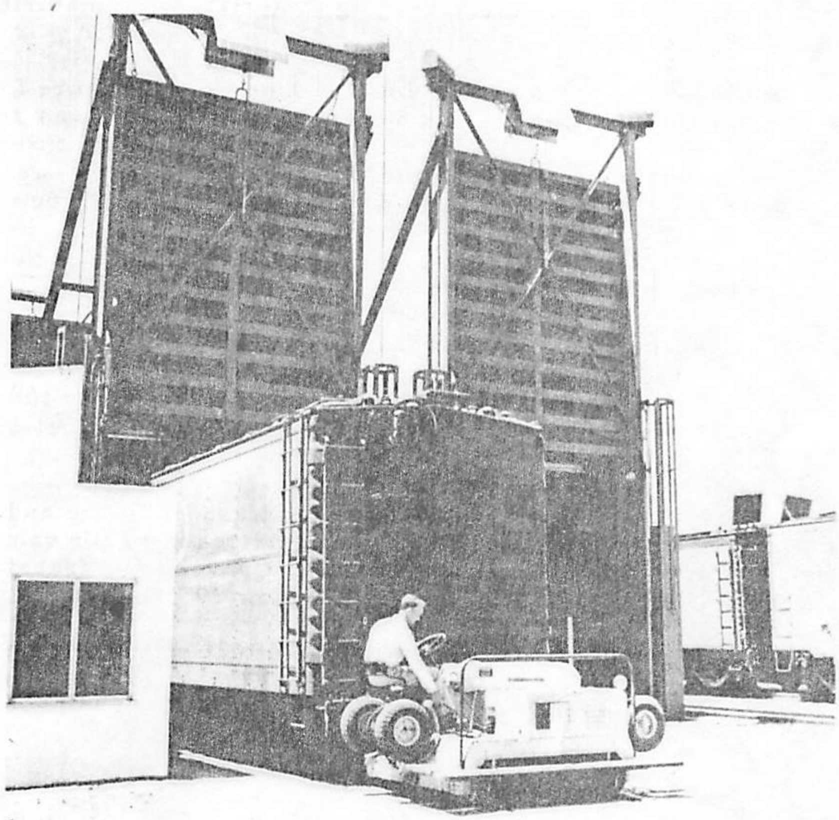
Loosely formed (soft) heads lost slightly more moisture and cooled to a slightly lower temperature than compact (hard) heads when vacuum cooled under the same conditions. Consequently, danger of freezing is greater in soft than in hard lettuce during vacuum cooling.

BACKGROUND

Vacuum cooling is a relatively new method of cooling fresh produce. The first few lots of dry-pack head lettuce (Iceberg type) were cooled in 1947 at a pilot plant in Salinas, California. Now nearly all the 80,000 carloads of lettuce shipped annually from California and Arizona are vacuum cooled. The process quickly removes field heat from the lettuce and also replaces the costly practice of adding crushed ice to each package.

Vacuum cooling has lead to changes in shipping and packaging methods. Lettuce cooled by vacuum is not top-iced for transit, which makes it possible to use fiberboard shipping containers at considerable saving in cost.

For vacuum cooling, lettuce previously packed in the field is placed in strong steel tanks from which the air is exhausted. The reduced pressure promotes cooling of the lettuce by rapid evaporation of moisture from the leaves. Suction pumps to evacuate the tanks are of two basic designs; one employs steam jets and barometric condensers, and the other uses mechanical rotary-pumps (6).[1] Commercial vacuum-cooling tanks usually hold one-fourth or one-half carload of lettuce, but some can hold two loaded railway cars (fig. 1).



BN-12126

Figure 1.--Vacuum tanks for precooling refrigerator cars loaded with lettuce.

The water vapor given off by the lettuce must be removed from the tank to obtain desired cooling; otherwise the air would become saturated, and prevent further evaporation. In steam plants, some of the vapor is liquified by the barometric condensers, and the rest is exhausted to the outside air. In mechanical plants, the vapor is usually passed over refrigerated coils where it condenses on the cold surfaces. If the moisture were not condensed, very large pumps would be required to exhaust the tanks, since each pound of water expands to approximately 3,000 cubic feet of vapor at the low pressures necessary for effective cooling (table 1).

[1] Underscored numbers in parentheses refer to Literature Cited, page 15.

TABLE 1.--Properties of water and water vapor at various pressures

Pressure			Boiling point[1]	Heat of vaporization[2]	Volume of vapor
Mm. hg.	*In. hg.*	*Lb./in.* [2]	°*F.*	*Btu./lb.* [3]	*Cu. Ft./lb.*
[4] 760.0	29.92	14.7	212.0	970	27
362.0	14.25	7.0	176.9	991	54
51.7	2.04	1.0	101.8	1035	336
15.2	.60	.3	72.4	1051	800
10.1	.40	.2	52.7	1061	1550
5.1	.20	.1	34.6	1070	2990
4.6	.18	.09	32.0	1072	3304
4.0	.16	.08	28.8	--	--
3.5	.14	.07	26.0	--	--
3.0	.12	.06	23.0	--	--
2.5	.10	.05	19.5	--	--
2.0	.08	.04	14.5	--	--

[1] Sublimation point of ice at pressures below 4.6 mm. hg.
[2] Heat required to change water from liquid to vapor with no change in temperature.
[3] B.t.u.--British thermal unit, or amount of heat required to raise 1 pound of water 1 degree F. under standard conditions.
[4] Normal atmospheric pressure at sea level.

Lettuce can be vacuum cooled to temperatures below 40° F. in 30 minutes. Cooling the lettuce to temperatures as close to 32° as is practical, before shipment, and maintaining temperatures below 38°, in transit, help to maintain the initial quality and condition of the lettuce.

Several investigators have determined the effectiveness of the vacuum process for cooling lettuce (1, 2, 3, 4, 5, 7, 8, 10). Others have described the equipment in commercial use (6). However, little attention has been given to the effect of operating practices and handling conditions on the weight-loss and final temperature of the lettuce. The objectives of this study were to determine how the efficacy of cooling and the quality of the lettuce were affected by: (1) initial temperature, (2) vacuum-cooling time, (3) speed of evacuation of the tank, (4) tank pressure, (5) temperature of condenser, (6) free moisture on the surface of leaves, (7) packaging materials, and (8) maturity of the heads.

BASIC PRINCIPLES OF VACUUM COOLING

Vacuum cooling lettuce depends upon the evaporation of water from the leaves. Heat is used to change the water from liquid to vapor. Evaporation of 1 pound of water requires 970 B.t.u.[2] at a normal atmospheric pressure (760 mm. hg.) and 1,072 B.t.u. at a pressure of 4.6 mm. hg. (table 1). Reducing the pressure lowers the boiling point of water from 212° F. at 760 mm. hg. to 32° at 4.6 mm. (table 1). Consequently, if lettuce is placed in a tank and the pressure is reduced to 4.6 mm. hg., the water in the lettuce evaporates, or boils, and the heat is absorbed from the leaves until they cool to 32°. At higher pressures, less cooling would take place.

Since lettuce is about 95 percent water, it can lose a considerable amount of moisture before wilting. Theoretically, the evaporation of 3 pounds of water from 100 pounds of lettuce under typical vacuum cooling conditions (4.6 mm. hg.) would remove 3,216 B.t.u. (table 1) and would cool the lettuce 32.16 degrees F. Removing 3 percent of the moisture from lettuce would not cause visible wilting becuase moisture removal is not confined to the outer leaves but occurs rather uniformly from all of the plant tissue.

[2] B.t.u., British thermal unit, or the amount of heat required to raise 1 pound of water 1 degree F. under standard conditions.

EQUIPMENT AND METHODS

A pilot-model vacuum cooler, having a tank with approximately 50 cu. ft. capacity and a mechanical rotary pump capable of reducing the pressure to 2 mm. hg., was used in these tests. The rated capacity of the pump was 60 c.f.m. A coil cooled with circulating ice water or cold brine was used to condense the moisture that evaporated from the lettuce. This coil had a surface of approximately 45 sq. ft., and the temperature could be lowered to 23° F.

Pressures in the tank were read, with a McLeod high-vacuum gage, as millimeters of mercury. Minimum pressures from 2.0 mm. hg. to 5.0 mm. hg. were tested.

Temperatures were taken with a 12-lead thermocouple cable that extended through the tank wall and was connected to a recording potentiometer outside. The thermocouples registered wet- and dry-bulb readings in the tank air, in the coil, and in several heads of lettuce.

Lettuce temperatures were taken in the fleshy core (butt) and in the center of the leafy portion of the heads. They were averaged to obtain the commodity temperatures reported herein.

Final temperatures were taken, immediately after the tank was opened, by inserting thermocouples into tissue and heads not previously punctured. This final reading was made as a check against the minimum readings obtained during the vacuum cycle. The final readings were usually slightly higher than the minimums recorded before the vacuum was broken, because they were not affected by excessive evaporation at the point where the thermocouple injured the tissue. The temperatures recorded at intervals during the vacuum cycle probably were slightly lower than the actual temperature of the lettuce. No way was found to effectively seal the thermocouples in place to prevent excessive evaporation from the punctured tissue.

The vacuum cooling time (cycle) was usually 20 to 30 minutes. During this time, the pressure in the tank was reduced from an initial 760 mm. hg. (atmospheric) to 50 mm. in the first 3 to 4 minutes, from 50 mm. to 5 mm. during the next 6 to 7 minutes, and was held at or below 5 mm. for the remainder of the run. Pressure was maintained at the desired level by bleeding air into the tank through capillary tubes when necessary.

The lettuce was weighed to determine moisture loss during vacuum cooling and examined for injury due to low pressure or freezing. More than 100 vacuum-cooling runs were made, each covering one or more of the objectives.

RESULTS

Relation of Temperature Reduction to Weight-Loss

Temperature reductions in vacuum-cooled lettuce ranged from 4° to 60° F., depending upon initial lettuce temperatures, ventilation of containers or wrappers, and other factors. Weight-losses under these conditions varied from 0.4 to 5.8 percent (fig. 2). Lettuce cooled approximately 10 degrees for each 1 percent loss in weight. This ratio is slightly less than the calculated cooling potential of water by evaporation under vacuum which is based on heat requirement for changing water from liquid to vapor (table 1).

Effects of Various Factors on Cooling and Weight-Loss

Initial Temperature

Lettuce with initial temperatures ranging from 88° to 54° F. was cooled to nearly the same final temperature when vacuum cooled 22 minutes (fig. 3). The warm lettuce

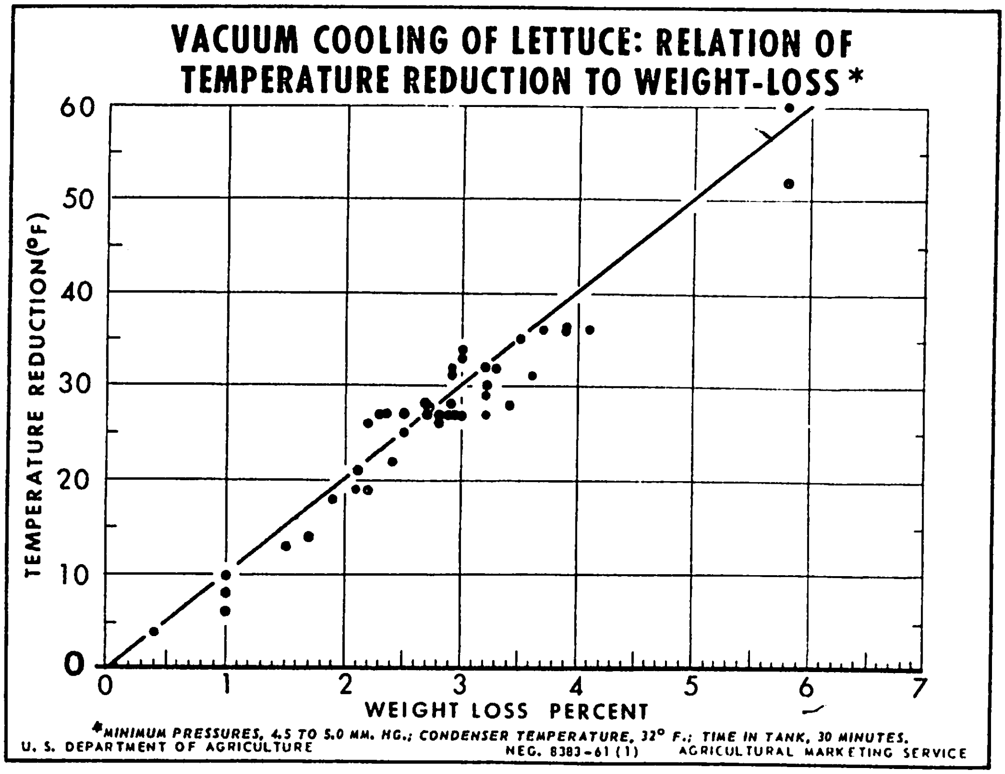


Figure 2

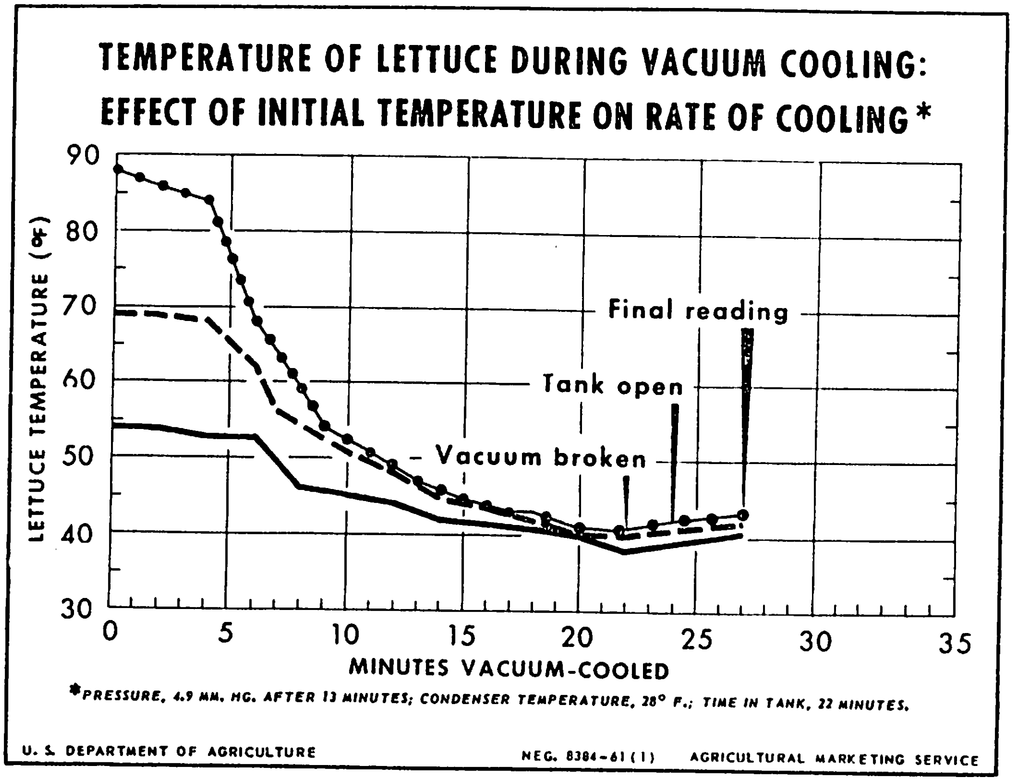


Figure 3

cooled faster than the cool lettuce because of the greater difference in vapor pressure between the warm heads and air in the tank during the early part of the vacuum cycle. Weight-loss was 5.1 percent in the warmest lot and 1.8 percent in the coolest lot.

Warm lettuce consistently lost more moisture than cool lettuce when vacuum cooled at the same time. The average weight-loss in tests covering a fairly wide range of operating conditions was 5.8 percent in heads with initial temperatures near 95° F. and 1.9 percent when initial pulp temperatures were 54° (fig. 4). Average weight-losses at intermediate initial temperatures were of proportional magnitudes. The slope of the curve comparing initial temperature with average weight-loss indicates that, at the pressures and condensor temperature used, the temperature of the lettuce could be reduced to a point close to 32°. However, under usual operating conditions, final lettuce temperatures seldom averaged below 35°.

Vacuum-cooling Time

In trials using similar conditions of pressure, condenser temperature, and initial pulp temperature, lettuce was cooled several degrees more in 30 minutes than in 12 or 20 minutes (fig. 5). The butt cooled somewhat slower than the leafy portion of the head, resulting in a differential of 5 degrees in the final reading after 12 minutes of vacuum cooling. This differential was reduced slightly in 20 minutes and materially in 30 minutes.

During evacuation, a sharp rise in the wet-bulb temperature of the air in the tank occurred in 4 to 6 minutes (fig. 5). This "flash" was caused by a sudden release of moisture from the lettuce when the vapor pressure of the air in the tank dropped below the vapor pressure of the moisture in the leaves. This change removed heat from the lettuce and increased the relative humidity in the air, thus raising the temperature of the wet-bulb. Continued operation of the pump and condenser removed enough vapor from the air to promote further evaporation of moisture from the lettuce and further cooling. The lettuce cooled very little before the flash point was reached.

In each instance, the wet-bulb cooled to 33° F. in 9 minutes and remained near this temperature until the end of the run. Lettuce temperatures were well above the wet-bulb temperature after 10 minutes and approached it only after 30 minutes of cooling (fig. 5).

Weight-losses and final temperatures of the lettuce were also proportional to vacuum-cooling times. There was a 2.8 percent weight-loss during 12 minutes of vacuum cooling, and final temperatures averaged 45° F. In 30 minutes, 3.5 percent weight-loss occurred, and the lettuce cooled to 37°.

Most of the evaporation and consequently most of the cooling occurred at and shortly after the flash. However, continued holding at low pressure was necessary to obtain a desirable final temperature for the entire head.

Speed of Evacuation

A delay of 2 minutes in reaching the flash point (7 vs. 5 minutes) increased the time required to cool the lettuce to 40° F. by 3 minutes and to 38° by 4 minutes (fig. 6). In another test, a delay of 4 minutes in reaching the flash point (8 vs. 4 minutes) during a 20-minute vacuum-cooling time resulted in final lettuce temperatures that averaged 6 degrees higher.

Slow evacuation after the flash, in which 12 instead of 5 minutes were required to reduce the pressure from 22 mm. hg. (pressure at flash) to 4.6 mm. hg. (final pressure), had little effect on the rate or amount of cooling (fig. 7). The lettuce in both lots cooled to approximately 45° F. in about 12 minutes following the flash. Subsequent cooling to around 37° was much slower, but the rate was nearly the same regardless of the speed of reduction in pressure after the flash.

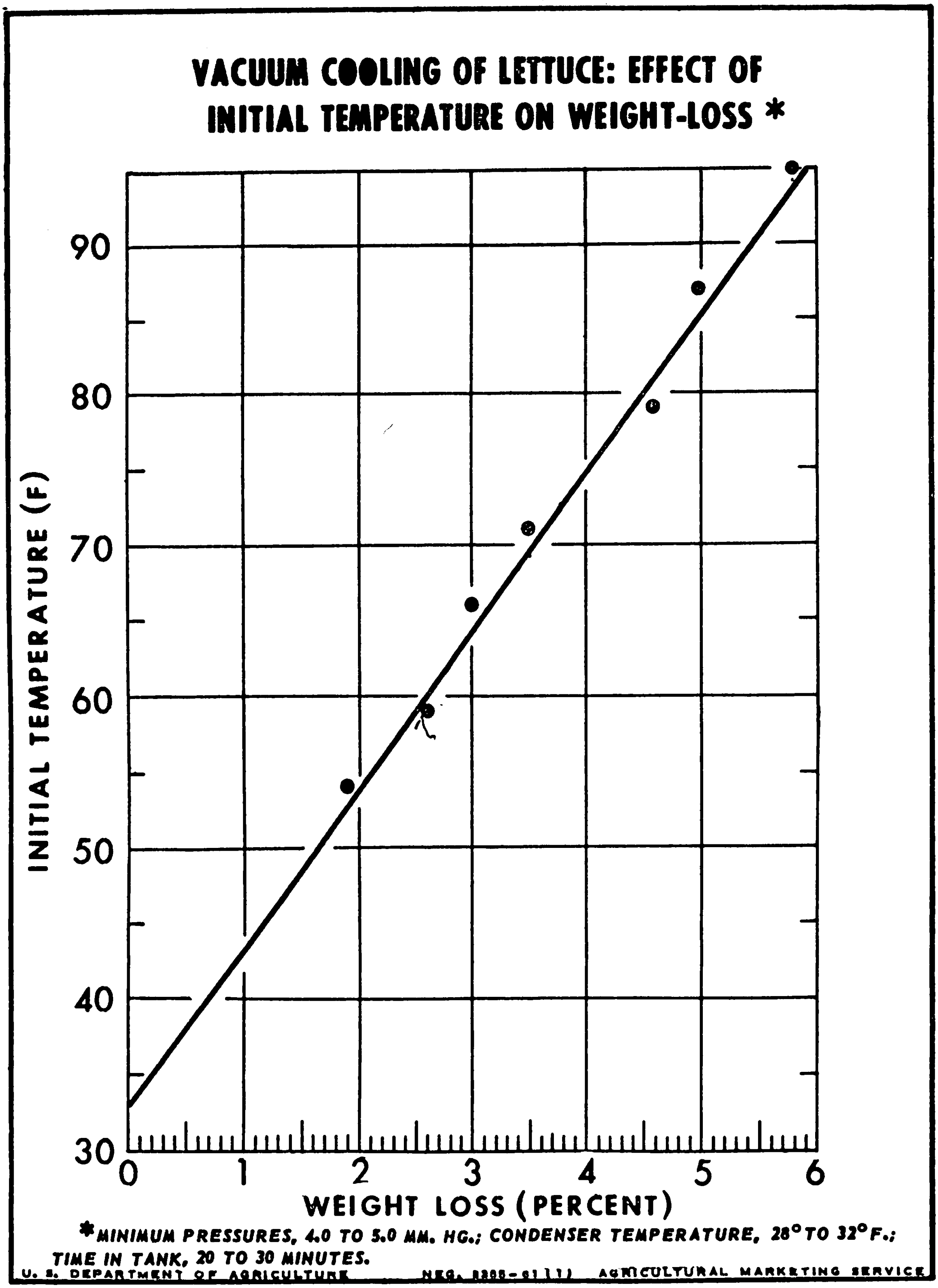

VACUUM COOLING OF LETTUCE: EFFECT OF INITIAL TEMPERATURE ON WEIGHT-LOSS *
INITIAL TEMPERATURE (F)
30
40
50
60
70
80
90
0
1
2
3
4
5
6
WEIGHT LOSS (PERCENT)
*MINIMUM PRESSURES, 4.0 TO 5.0 MM. HG.; CONDENSER TEMPERATURE, 28° TO 32° F.; TIME IN TANK, 20 TO 30 MINUTES.
U. S. DEPARTMENT OF AGRICULTURE
AGRICULTURAL MARKETING SERVICE

Figure 4

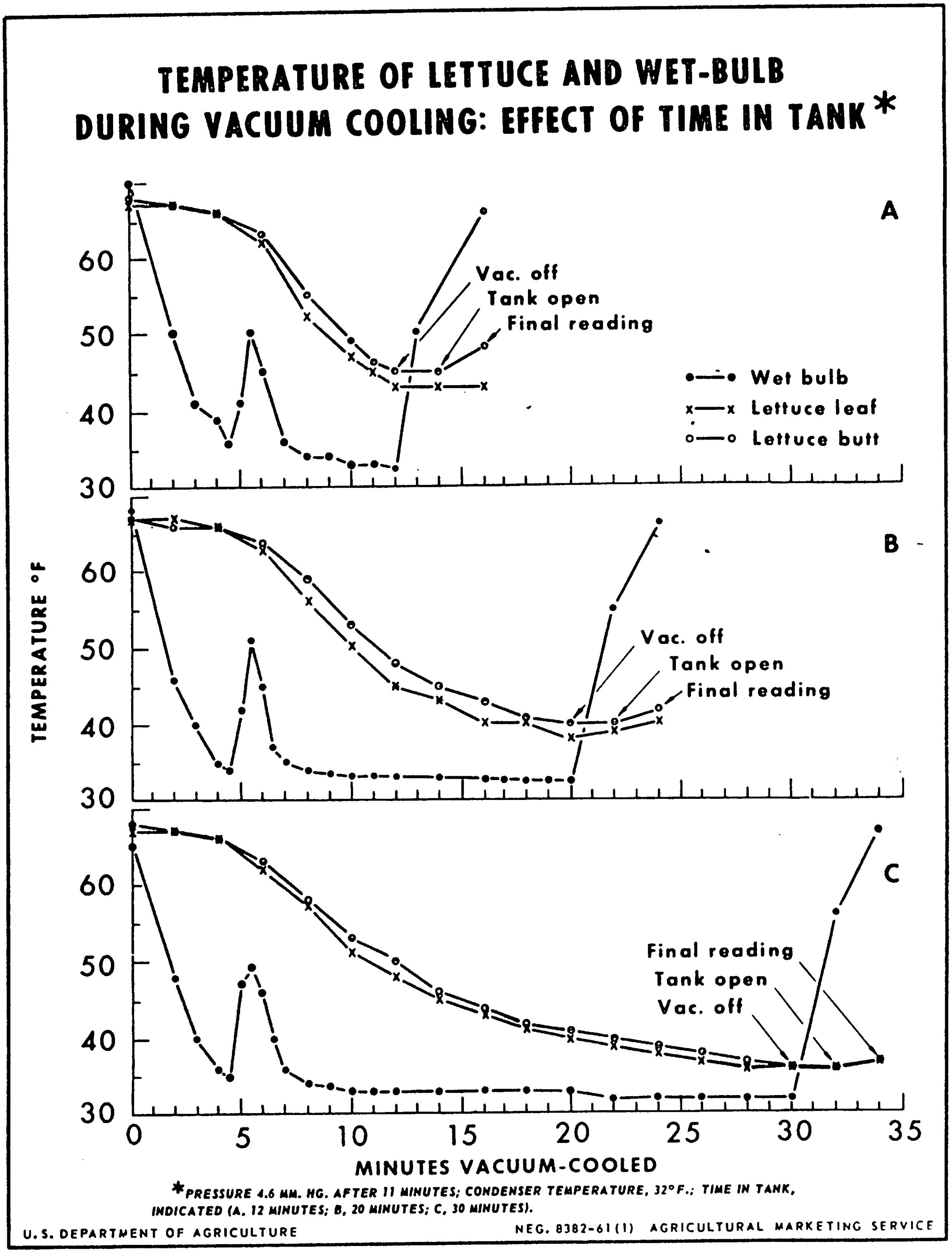

TEMPERATURE OF LETTUCE AND WET-BULB
DURING VACUUM COOLING: EFFECT OF TIME IN TANK*
A
B
C
Vac. off
Tank open
Final reading
Wet bulb
Lettuce leaf
Lettuce butt
TEMPERATURE °F
30
40
50
60
0
5
10
15
20
25
30
35
MINUTES VACUUM-COOLED
*PRESSURE 4.6 MM. HG. AFTER 11 MINUTES; CONDENSER TEMPERATURE, 32°F.; TIME IN TANK, INDICATED (A, 12 MINUTES; B, 20 MINUTES; C, 30 MINUTES).
U.S. DEPARTMENT OF AGRICULTURE
NEG. 8382-61(1) AGRICULTURAL MARKETING SERVICE

Figure 5

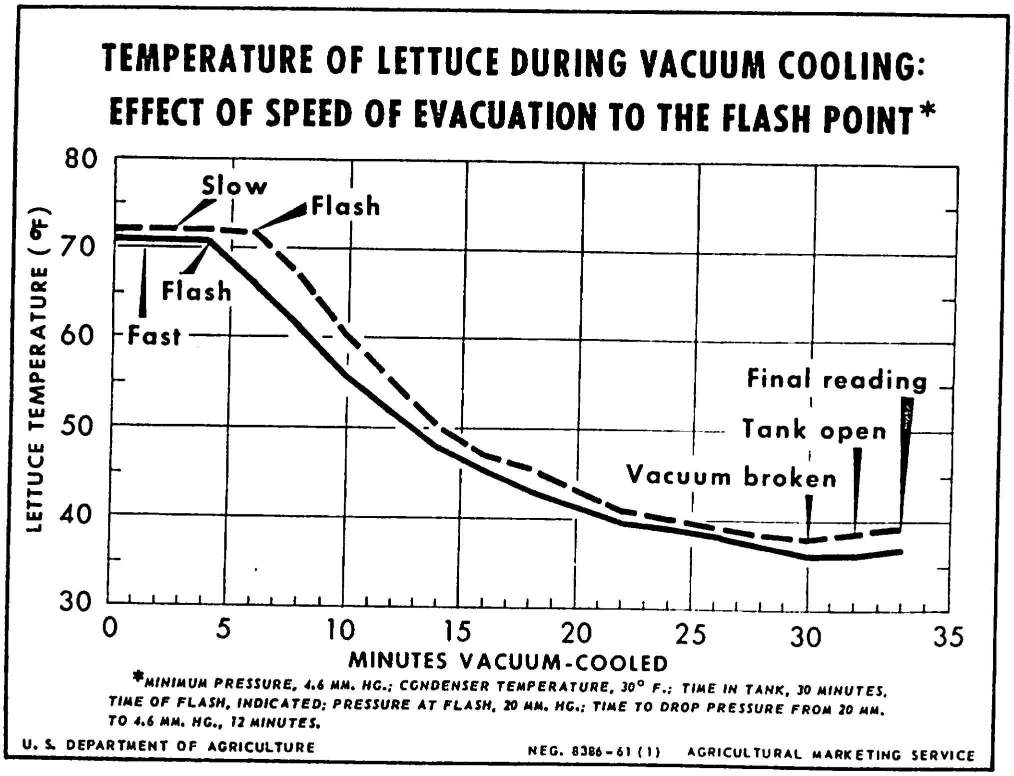


Figure 6

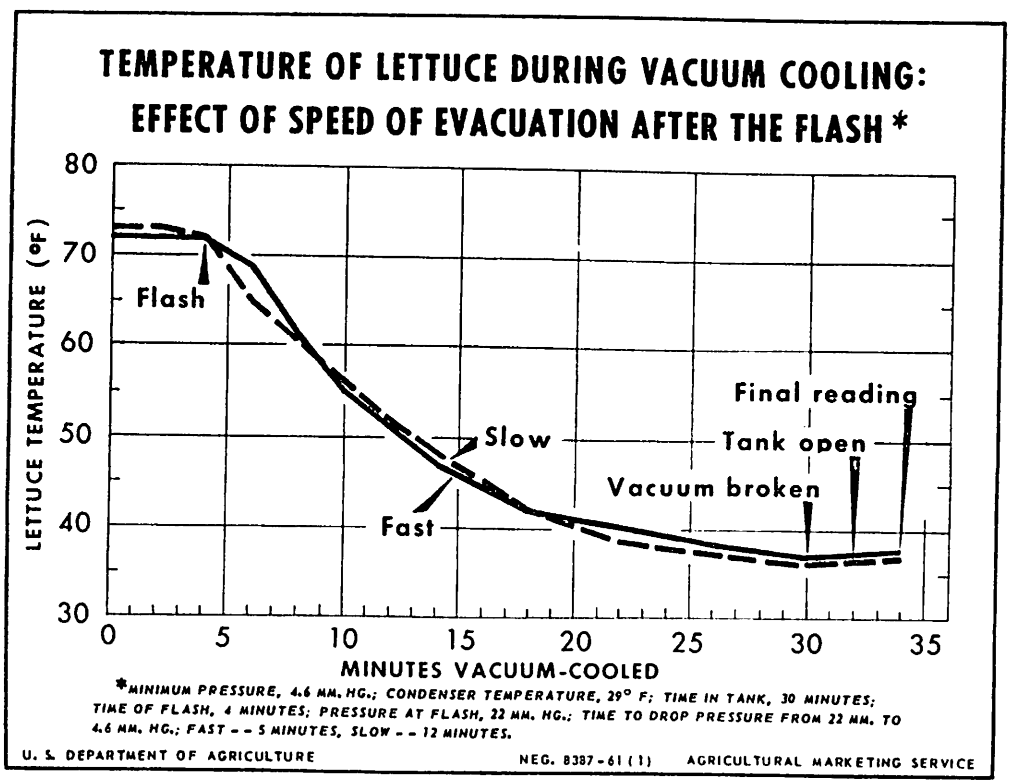


Figure 7

Tank Pressure

Lettuce was vacuum cooled under similar conditions of initial pulp temperature (59° to 61° F.), condenser temperature (30°), and time (30 minutes), but at tank pressures dropping gradually to minimums ranging from 2.0 mm. to 4.1 mm. hg. Tank pressures lower than the vapor pressure of the moisture (ice) on the condenser (4.2 mm. hg. at 30°) were obtained by limiting the load of lettuce in the tank to a few heads to minimize the amount of moisture given off during evacuation.

Final temperature of the lettuce was several degrees higher in both the butt and leafy portions when exposed to air pressures of 4.1 mm. hg. than when exposed to 2.0 mm. hg. pressure (table 2). Lettuce temperature dropped 21 degrees and weight-loss was 2.1 percent at the higher pressure, and 26.5 degrees and 2.7 percent, respectively, at the lower pressure.

At pressures as low as 2.0 mm. hg. the wet-bulb remained at or above 30° F., and no freezing of the lettuce occurred (table 2). At this low pressure, the cooling potential was 14.5° (table 1). Freedom from freezing at pressures below 4.4 mm. hg. (vapor pressure at a 31° freezing point for lettuce) was attributed to the moisture that evaporated at pressures below 4.6 mm. hg. freezing on the surface of the leaves. This prevented the lettuce from cooling below 32° until after the coating of ice had evaporated, a condition that did not occur during 30 minutes evacuation. Similarly, icing of the wet-bulb and slow subsequent evaporation of the ice from it prevented the wet-bulb temperature from going below 30° in the 30 minute cycle.

Temperature of Condenser

Lettuce was vacuum cooled under similar conditions of initial temperature (66° to 68° F.), pressure (4.9 to 5.0 mm. hg.), and time (21 minutes), but condenser temperatures were varied from 29° to 23°. Wet-bulb and final lettuce temperatures were several degrees higher when the condenser temperature was 29° than when it was 25° or lower (table 3). The wet-bulb leveled off at 31° when the condenser was 29°, and at 27° when the condenser was 23°. The lettuce froze when the condenser was colder than 29°. Freezing was mainly at the thin margin of the outer leaves; therefore, temperatures in the pulp, which were obtained with thermocouples inserted in the butt and in the center of the leafy portion, did not reflect the minimum temperatures. In other tests, when low pressures (4.0 to 4.2 mm. hg.) and subfreezing condenser temperatures (25° to 26°) were used in combination, the whole head of lettuce froze.

The wet-bulb tended to cool to the condenser temperature during vacuum cooling, even though the tank pressure was held above that corresponding to the freezing point of lettuce. Consequently, lettuce may freeze at safe pressures, if the condenser temperature is below the freezing point. The precise minimum temperature at which a condenser could be considered safe would depend upon the surface area of the coil and the capacity of the vacuum pump. Lettuce would cool rapidly to the coil temperature if the condenser were large and the pump capacity high in relation to the volume of water vapor in the tank. In the pilot vacuum cooler, a coil temperature of 29° F. was not injurious to the lettuce (table 3).

Free Moisture on the Surface of Lettuce

Spraying the commodity with water before vacuum cooling has been tried experimentally with several vegetables and fruits (1, 2, and 5) and is recommended for sweet corn (8, 9, and 11). If the heat required to evaporate such water is drawn from lettuce, it may be cooled without extracting much moisture from the leaves. Lettuce harvested on foggy days or following heavy dews may contain much more free moisture than that harvested in dry weather.

A comparison was made between heads of dry lettuce and heads that were immersed in water and allowed to drain for several minutes before being placed in the vacuum tank.

TABLE 2.--Effect of tank pressure on the temperature of the wet-bulb and on the temperature and weight-loss of lettuce during vacuum cooling[1]

Pressure	Minimum wet-bulb temperature	Lettuce temperature				Temperature reduction average	Weight-loss average
		Initial[2]	Final				
			Leaf	Butt	Average		
Mm. hg.	°*F.*	°*F.*	°*F.*	°*F.*	°*F.*	°*F.*	*Percent*
4.1	32	59	37	39	38.0	21.0	2.1
3.0	31	61	35	39	37.0	24.0	2.3
2.0	30	61	33	36	34.5	26.5	2.7

[1] Vacuum conditions: Minimum pressure, as indicated; condenser temperature, 30° F.; time in tank, 30 minutes.
[2] Average of leaf and butt.

TABLE 3.--Effect of condenser temperature on the temperature of the wet-bulb and on the temperature and weight-loss of lettuce during vacuum cooling[1]

Condenser temperature	Minimum wet-bulb temperature	Lettuce temperature				Temperature reduction average	Weight-loss average
		Initial[2]	Final				
			Leaf	Butt	Average		
°*F.*	°*F.*	°*F.*	°*F.*	°*F.*	°*F.*	°*F.*	*Percent*
29	31	66	44	46	45	21	2.8
25	28	68	[3] 38	42	40	28	3.1
23	27	66	[3] 38	38	38	28	3.0

[1] Vacuum conditions: Minimum pressure, 4.9 to 5.0 mm. hg.; condenser temperature, as indicated; time in tank, 21 minutes.
[2] Average of leaf and butt.
[3] Freezing at margin of outer leaves.

The temperature of the water used was about the same as the temperature of the lettuce. Pre-wetting did not result in lower final temperatures (table 4), but the pre-wet lettuce cooled slightly faster than the dry heads.

Weight-losses in dry lettuce during vacuum cooling were approximately 4, 3, and 2 percent when initial temperatures were about 75, 65, and 55° F., respectively (table 4). At these initial temperatures the pre-wet lettuce lost 3 to 4 percent of its wet weight. In one instance, adding 4.4 percent moisture by pre-wetting nearly offset the amount required to cool the head from an initial 74° to a final temperature of 37°.

Wetting the lettuce before vacuum cooling lessened the loss of moisture from the leaf tissue. Obviously, the value of wetting would be greater on hot than on cool days, since warm lettuce loses much more moisture than cool lettuce during vacuum cooling, to reach the same final temperature.

TABLE 4.--Effect of free moisture (pre-wetting) on temperature and weight-loss of lettuce during vacuum cooling[1]

Treatment	Temperature[2]			Weight-loss		
	Initial	Final	Reduction	Water added	Loss during cooling	Net change in original weight
	°F.	°F.	°F.	Percent	Percent	Percent
Dry.......	79	35	44	0	4.6	-4.6
	76	36	40	0	4.2	-4.2
	65	37	28	0	3.3	-3.3
	64	38	26	0	3.2	-3.2
	54	36	18	0	2.2	-2.2
	53	35	18	0	2.3	-2.3
Pre-wet....	85	33	52	6.7	6.0	+0.7
	74	37	37	4.3	4.4	-0.1
	66	35	31	6.1	4.0	+2.1
	65	36	29	5.6	4.1	+1.5
	52	37	15	4.9	2.8	+2.1
	51	34	17	7.7	3.0	+4.7

[1] Vacuum conditions: Minimum pressure, 4.0 to 4.2 mm. hg.; condenser temperature, 30 to 31° F.; time in tank, 20 minutes.
[2] Average of leaf and butt.

Packaging Materials (wrappers and liners)

Since the temperature reduction by vacuum cooling depends upon the freedom with which moisture can be evaporated from the commodity being cooled, adequate venting of containers or wrappers is necessary. To test this factor, lettuce was packed in cartons in which the heads were individually wrapped in perforated or nonperforated polyethylene bags that were closed by folding the top over the head. In another lot, the heads were packed in cartons with polyethylene liners that were either perforated or nonperforated and had loosely folded closures. These packs were compared with conventional carton packs. The cartons had the usual openings in the top and bottom at the closure of the flaps and at slots in the sides.

Lettuce temperatures after vacuum cooling were slightly lower in the conventional pack and considerably higher in the nonperforated bags than in the other packs (table 5). Weight-losses were proportional to the reductions in temperature, averaging 2.9 percent in the conventional pack and 2.1 percent in individual nonperforated bags. In the conventional pack, slightly less cooling and weight-loss occurred in heads in the corners of the carton than in those at or near the openings in the top, bottom, and sides, where evaporation of moisture was less restricted. Cooling was also retarded in the corner positions in the other types of packs.

Single heads of lettuce placed in heat-sealed, nonperforated polyethylene bags cooled only 4 degrees and lost only 0.4 percent moisture when vacuum cooled at the same time with exposed heads. The exposed heads cooled 30 degrees and lost 3.4 percent moisture. The initial temperature of the lettuce was 66° in each instance.

Maturity of the Lettuce

Letttuce is usually classed as hard, firm, or soft, according to the maturity of the head. Soft heads cooled slightly more and lost slightly more moisture than hard heads when vacuum cooled at the same time (table 6). The compactness of the hard heads

TABLE 5.--Effect of packaging materials on temperature and weight-loss of lettuce during vacuum cooling[1]

Packaging material	Temperature[2]						Weight-loss	
	Initial		Final		Reduction			
	Range	Average	Range	Average	Range	Average	Range	Average
	°F.	°F.	°F.	°F.	°F.	°F.	*Percent*	*Percent*
Conventional carton...	64-70	66	36-38	37	27-32	29	2.7-3.3	2.9
Heads wrapped in polyethylene bags:								
Ventilated.......	65-72	67	38-39	38	27-33	29	2.8-3.0	2.9
Nonventilated.....	65-72	68	42-47	45	18-27	23	1.9-2.3	2.1
Cartons with polyethylene liners:								
Ventilated.......	64-70	66	36-41	39	25-29	27	2.7-3.2	2.9
Nonventilated.....	64-72	67	37-43	39	22-35	28	2.4-3.5	2.8

[1] Data from 4 tests. Vacuum conditions: Minimum pressure, 4.5 to 4.9 mm. hg.; condenser temperature, 31 to 32° F.; time in tank, 30 minutes.
[2] Average of leaf and butt.

TABLE 6.--Effect of lettuce maturity on temperature and weight-loss of lettuce during vacuum cooling[1]

Maturity	Temperature[2]						Weight-loss	
	Initial		Final		Reduction			
	Range	Average	Range	Average	Range	Average	Range	Average
	°F.	°F.	°F.	°F.	°F.	°F.	*Percent*	*Percent*
Hard......	64-68	67	38-44	41	23-29	26	2.8-3.4	3.1
Soft......	64-68	67	37-41	39	24-31	28	2.8-3.5	3.3

[1] Data from 5 tests. Vacuum conditions: Minimum pressure, 4.4 to 4.6 mm. hg.; condenser temperature, 29 to 32° F.; time in tank, 18 to 30 minutes.
[2] Average of leaf and butt.

probably retarded the evaporation of moisture from the inner leaves, thus lessening the average temperature reduction in the entire head.

The wide range in final temperatures within the lots shown in table 6 was due largely to the lengths of time in the tank, 18 to 30 minutes.

Since soft heads of lettuce gave up more moisture than hard heads during vacuum cooling, they could reach dangerously low temperatures considerably faster than hard heads.

DISCUSSION

Although many of the experimental conditions that were studied might contribute to freezing or excessive shrivelling of lettuce during vacuum cooling, these problems have not occurred frequently in commercial practice. Friedman and Kaufman (4) have shown that there is little difference in the condition and quality of vacuum-cooled and ice-packed lettuce received on the New York market. Cooling is usually stopped in commercial vacuum plants when the thermometers show a temperature of 32° F., which is slightly above the freezing point of lettuce. Actual lettuce temperatures, however, are usually somewhat higher. Occasionally, there are market reports of freezing throughout entire cartons or in single heads interspersed within a carton. Conversely, there are also reports of insufficient cooling. The current tests show that, to obtain the maximum cooling desirable for lettuce, the vacuum conditions must be close to those that might cause freezing. Consequently, careful and precise control of these conditions is necessary to prevent injury.

In mechanical vacuum-cooling plants, freezing may result from excessively low tank pressures or from subfreezing condenser temperatures. Control of tank pressure alone did not prevent freezing when condenser temperatures were extremely low, since the final lettuce temperature was influenced by the condenser temperature (table 3). However, by keeping the condenser temperature at or only slightly below the freezing point of lettuce (31° F.), freezing was prevented during the usual vacuum cycle even though tank pressures dropped to 2 mm. hg. (table 2). Automatic control of condenser temperature would be a valuable safety feature.

In steam-jet vacuum plants, there is no control of condenser temperature, and the degree of cooling can be controlled only by manipulating the steam valve. In such plants the continuous drop in tank pressure and exhaust of moisture-saturated air cool the lettuce to temperatures below the freezing point unless the steam jet is shut off at the appropriate time.

In many commercial vacuum-cooling plants, a wet-bulb thermometer is the only instrument used to determine the amount of cooling. Tests show that the wet-bulb cooled to temperatures close to the freezing point soon after the flash and long before the lettuce reached a desirable temperature. Consequently, the wet-bulb reading is not a reliable measure of the temperature of the lettuce. Readings taken with thermometers inserted in the lettuce heads in the packed cartons are closer to the true temperature, but even these readings are influenced by the increased evaporation from the injured leaves where the thermometer is inserted.

Weight-loss in lettuce during vacuum cooling was related to the amount of cooling accomplished. Lettuce temperature was reduced about 10 degrees F. for each 1 percent loss in weight during vacuum cooling.

The ease with which moisture can escape from the heads and containers is a major factor affecting the degree of cooling by vacuum. Effective cooling of packaged lettuce was possible only when the containers were adequately ventilated.

LITERATURE CITED

(1) Barger, W. R.
1949. Further tests with vacuum precooling on fruits and vegetables. Salinas, Calif. U. S. Bur. Plant Indus., Soils & Agr. Engin., Handling, Transportation, & Storage Off. Rpt. 244. August.

(2) Dewey, D. H.
1950. Air blast and vacuum cooling of lettuce; temperature and moisture changes. Amer. Soc. Hort. Sci. Proc. 56: 320-326.

(3)________
1952. Evaporative cooling of fruits and vegetables. Refrig. Engin. 60(12); 1281-1283, 1295.

(4) Friedman, B. A., and Kaufman, J.
1953. Comparison of the storage life of vacuum-cooled and ice-packed lettuce. U. S. Bur. Plant Indus., Soils & Agr. Engin., Handling, Transportation, & Storage Off. Rpt. 309.

(5)________, and Radspinner, W. A.
1956. Vacuum-cooling fresh vegetables and fruits. U. S. Dept. Agr., Agr. Mktg. Serv. Rpt. 107. April.

(6) Isenberg, F. M., and Hartman, John.
1958. Vacuum cooling vegetables. N. Y. State Col. Agr., (Cornell Univ.) Ext. Bul. 1012.

(7) Kasser, M.
1944. Method and apparatus for treating perishable articles. U. S. Patent Off., No. 2,344,151. 6 pp.

(8) Kaufman, J., Friedman, B. A., Joffe, M. J., and Hatton, T. T.
1960. Vacuum cooling. Prod. Mktg. 3(8): 10-12.

(9) Showalter, R. K.
1957. Effect of wetting and top-icing upon the quality of vacuum cooled and hydro-cooled sweet corn. Fla. State Hort. Soc. Proc. 70:214-219.

(10)________, and Thompson, B. D.
1956. Vacuum cooling of Florida vegetables. Fla. State Hort. Soc. Proc. 69: 1932-135.

(11) Stewart, J. K., and Barger, W. R.
1960. Effects of cooling method and top icing on the quality of peas and sweet corn. Amer. Soc. Hort. Sci. Proc. 75: 470-475.

LIST OF FIGURES

Growth Through Agricultural Progress

☆ U. S. GOVERNMENT PRINTING OFFICE : 1961 O - 592204