

Freezing Temperature and Length of Frozen Storage for Foods Frozen in Household Freezers¹

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The usual instruction concerning the rate of freezing of foods is to freeze them as rapidly as possible. With the increase in the number of home freezers, such general directions have become inadequate. In addition, recent studies have indicated that very rapid freezing may be injurious rather than beneficial to certain foods.

The factors which must be considered in producing good frozen foods may be summarized briefly as follows:

1. Selection of raw materials,
2. Preparation for freezing,
3. Packaging in moisture-vapor-proof material, with minimum air space,
4. Speed of freezing,
5. Temperature and time of storage,
6. Preparation for table use.

In the work reported below, emphasis was placed on items 4 and 5. To obtain a palatable frozen product, however, it was necessary to take into account the other factors.

REVIEW OF LITERATURE

Many investigations have been undertaken to determine the optimum rate of freezing and length of storage of frozen foods. A large number of these studies have utilized commercial freezing equipment. The results from such work are often not directly applicable to home freezers, as the amount of food frozen per batch is much greater than could be handled in any household unit. The studies included below contain information which bears chiefly on the problem of freezing in small quantities.

Plagge (16) reported that a temperature of approximately 0° F. is satisfactory for freezing fruits and vegetables. Lutz *et al.* (13)

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found that extremely low temperatures were no better than temperatures around 0° F. for freezing strawberries. Diehl (4) reported that strawberries, raspberries, cranberries and peaches had better eating qualities if not frozen too rapidly, and stated that excessive ice crystal formation should be avoided. Woodroof (23) concluded that removal of part of the cellular liquid of fruits by freezing at moderately low temperatures was partially reversible in thawing and, therefore, less injurious than more complete removal at very low temperatures, since the latter tended to precipitate the cell colloids irreversibly. It has been reported by Morris and Barber (14) and by Adriano, Valenzuela and Miranda (1) that freezing strawberries at temperatures above 0° F. gave products inferior to those frozen at 0° F. or below.

Lee, Gortner and Whitcombe (11) studied the effects of five different freezing rates on vegetables. They found that rate of freezing did not alter vitamin retention. The only palatability factor affected was texture, the vegetables frozen in liquid air being softer than those frozen more slowly. Heiss (7) found that only a few varieties of vegetables were improved by extremely rapid freezing, and that in some cases this rapid freezing had a deleterious effect on the retention of ascorbic acid. However, Joslyn and Kilner (10) indicated that too slow freezing had an adverse effect on the texture of asparagus. Joslyn and Marsh (9) had previously reported that, with the possible exception of asparagus, freezing in dry ice did not alter the texture of the fruits and vegetables studied from those frozen in air at 0° F.

Stewart *et al.* (19) found that freezing at -67° C, -45.6° C. or -20.5° C. had no effect on the palatability scores for broiling chickens. DuBois, Tressler and Fenton (5) state that while quick-frozen (Birds-eye freezer) roasts were somewhat more palatable than slow-frozen (still air at 0° F.), the slow-frozen meat was very good. Heiss (6) reported that the freezing temperature for meat should not be higher than -17° to -20° C. Ary and McLean (2) studied lamb leg roasts frozen at -10, 0, 10 and 20° F. They found that weight losses during freezing and thawing increased with increase in freezing temperature, but that cooking time and losses, and eating quality were approximately the same for all the samples.

Perry (15) states that too low temperatures are undesirable because they tend to over-freeze the outer surfaces of the food and to increase the loss by evaporation during freezing. Taylor (20) also considers extremely low temperatures detrimental to the quality of the product.

GENERAL METHODS AND MATERIALS

The instructions for operating the home freezer must take into consideration several factors, among which are, 1) the load and temperature should permit the foods to freeze rapidly enough to give a reasonable storage life; 2) most home freezers will be used for storage as well as freezing; and 3) the cost of operation increases rapidly as the temperature goes below 0° F. In addition, operation of freezer units at temperatures much below 0° F. decreases the efficiency of the mechanism, and often leads to increased mechanical breakdowns. The temperature which has been established as best for storage of frozen foods is 0° F. or lower (3, 5, 6, 8, 14, 23, 24). With these facts in mind, a series of experiments was initiated to investigate the palatability and storage life of foods frozen at various temperatures.

Foods most commonly frozen were chosen for this study. The items tested included fruits, vegetables, meat and eggs. Freezing temperatures used during the first year were 0, -20, -40 and -60° F., with storage up to 12 months at 0° F. However, the scores indicated no special advantage from the use of temperatures as low as -60° F. Therefore, it was decided to drop -60° F. as a freezing temperature and use 10° F., in an attempt to center the range more closely around the temperatures which would be practical for home use. In addition, it was decided to reduce the longest storage period from 12 to 9 months, in order to make better use of the space available.

Separate units were used for freezing and storage. The freezer employed had a 7-cubic food freezing space, $\frac{3}{4}$ h.p. motor, and a temperature control permitting regulation within $\pm 1^\circ$ F. The load placed in the freezer at one time was small since it is recognized that the capacity of the home freezer is limited. The maximum freezing load at any one time was: fruits, 30 pint cartons; vegetables, 18 1½-pound cartons; eggs, 24 cubes plus 3 pint cartons; meat, 30 pounds. The bottom of the freezing compartment measured 20" x 38", allowing ample space for air circulation and contact between each package of food and the metal surface next to the freezing coils. The storage facilities included a converted ice cream cabinet, a refrigerated display cabinet, and lockers in the storage room of the local locker plant.² In all cases, it was intended to maintain storage temperatures between 0 and -10° F. However, this was not always possible. The first year the mechanical condition of the storage equipment was not good, and there was

²Space supplied through the courtesy of Mr. G. H. Knapp, Capitol City Locker Plant, East Lansing, Mich.

considerable fluctuation in temperatures. The second year there was some fluctuation, but much less than in the previous year although the maximum temperature reached was above 20° F. on 4 days. The third year the equipment was functioning with only an occasional small fluctuation in temperature. Continuous temperature records were kept on the refrigerated display case, and the temperatures of the other units were checked daily. The number of days the storage temperatures went above 0° F., and the highest temperatures attained, are indicated in Table 1.

TABLE 1—Number of days the storage temperature rose above 0° F. and maximum temperature reached

Oct. 1, 1944—Aug. 31, 1945		Sept. 1, 1945—Aug. 31, 1946		Sept. 1, 1946—Aug. 31, 1947	
Temperature °F.	Number of days	Temperature °F.	Number of days	Temperature °F.	Number of days
9.....	1	27.....	1	12.....	1
8.....	1	25.....	2	9.....	1
7.....	7	22.....	1	7.....	1
6.....	11	17.....	1	6.....	2
5.....	4	16.....	1		
4.....	5	10.....	1		
3.....	3	5.....	7		
Total.....	32		14		5

Fluctuations in storage temperature may cause extensive dehydration of frozen food even in a hermetically-sealed, moisture-vapor-proof package, especially if there are many air spaces in the packages, as in dry-packed fruits and vegetables. As the temperature rises, moisture from the food evaporates into the air spaces in the package. As the temperature drops again, this water tends to condense as ice crystals on the inner surface of the package, rather than be reabsorbed by the food. Woodroof and Shelor (26) reported that storage temperatures which fluctuated between -10 and 10° F. caused more rapid deterioration in the fruits studied than did storage at a constant temperature of 10° F.

The methods of preparation and packaging of the foods were

chosen to be representative of the instructions most frequently given for home use. After freezing and storage, the foods were prepared as for table use, and scored by a panel of experienced judges. The scoring scale ranged from 1 to 7, 7 being the most desirable. Any score of 3 or lower usually indicated an unacceptable product.

Analysis of variance, as outlined by Snedecor (18), was applied to parts of the data, particularly the acceptability scores. The tenderness scores, shear values, and total cooking losses for beef roasts were also treated statistically.

FRUITS

The fruits studied included: first year, peaches, pears, plums; second year, strawberries, red cherries, black raspberries, blueberries; third year, sweet cherries, red raspberries, dewberries and cantaloupe. Rhubarb, although not truly a fruit, is included in this group because it is eaten as a fruit. Sweet cherries, red raspberries and dewberries were purchased on the market. The other fruits came from the College farms and experimental sub-stations. Details of the preparation, freezing and storage of these items are given in Table 2. All the fruits were frozen in one-pint waxed cartons with slip-in lids.

Thermocouples were inserted through holes in the lids into the center of representative packages, and the subsequent change in temperature was followed with a potentiometer. Freezing rate curves for raspberries are shown in Fig. 1. The curves illustrate the difference between packages having no sirup and those containing added sirup. Very little difference was observed in rates of freezing between different locations in the freezer. The curves obtained for the other fruits were very similar to those shown for raspberries.

Enough cartons of each fruit were frozen to allow duplicate samples for scoring and single samples for ascorbic acid analysis after 3, 6, and 9 or 12 months' storage.

The packages were removed from the freezer and held overnight in a refrigerator at 40 to 45° F. before scoring or analysis, with the exception of rhubarb, which was cooked from the frozen state. All fruits were scored as they came from the package except the rhubarb. Seventy-five grams water and 60 grams sugar were added to each package of frozen rhubarb, brought to a boil, cooked 1½ minutes, then cooled before scoring. Ascorbic acid analyses were done on both the raw and cooked rhubarb. Ascorbic acid determinations were made by the method of Roe and Oesterling (17) for total ascorbic acid.

TABLE 2—Preparation, freezing and storage of fruit

Fruit	Variety	Preparation	Packaging		Freezing		Storage time in months
			Added materials	Yield	Temperatures °F.	Load for each freezing period	
Peaches.....	Elberta.....	Scald, peel, pit, slice...	175 g. 50% sirup to 250 g. fruit	.....	0, -20, -40, -60	18 pints	3, 6, 12
Pears.....	Bartlett.....	Peel, core, slice.....	Same as peaches..	.....	0, -20, -40, -60	18 pints	3, 6, 12
Plums.....	Italian.....	Wash, halve, pit.....	Same as peaches..	5 lb. yields 4½ lbs. pitted halves	0, -20, -40, -60	18 pints	3, 6, 12
Rhubarb.....	Macdonald.....	Wash, trim, cut in 1-inch lengths	None.....	5½ lb. yields 8 pint cartons	10, 0, -20, -40	12 pints	3, 9
Strawberries.....	Robinson.....	Wash, hull, slice.....	140g. 40% sirup to 300 g. fruit	12 qt. yields 22 pt. cartons sliced fruit	10, 0, -20, -40	24 pints	3, 6, 9
Red cherries.....	Montmorency.....	Wash, stem, pit.....	1 part sugar to 4 parts fruit by wt.	10 lb. yields 10 pt. cartons pitted fruit	10, 0, -20, -40	30 pints	3, 6, 9
Black raspberries..	.....	Wash, pick over.....	225 g. 40% sirup to 235 g. fruit	5 quarts yields 9 pint cartons	10, 0, -20, -40	12 pints	3, 6, 9
Sweet cherries....	Bing.....	Wash, stem.....	200 g. 50% sirup to 250 g. fruit	5 lb. yields 8 pint cartons	10, 0, -20, -40	18 pints	3, 6, 9
Blueberries.....	Rubel, Jersey.....	Wash, pick over.....	150 g. 40% sirup to 250 g. fruit	12 qt. yields 24 pt. cartons	10, 0, -20, -40	18 pints	3, 9
Red raspberries..	Cuthbert.....	Wash, pick over.....	Some with none, some 175 g. 40% sirup to 225 g. fruit	8 pt. yields 8 pt. cartons	10, 0, -20, -40	14 pints	3, 6, 9
Dewberries.....	.....	Wash, pick over.....	200 g. 40% sirup to 250 g. fruit	12 qt. yields 26 pt. cartons	10, 0, -20, -40	18 pints	3, 6, 9
Cantaloupe.....	.....	Cut in half, remove seeds, peel, dice	None, 160 g. 40% sirup, or 70 g. sugar to 280 g. fruit	.....	10, 0, -20, -40	9 pints	3, 6, 9

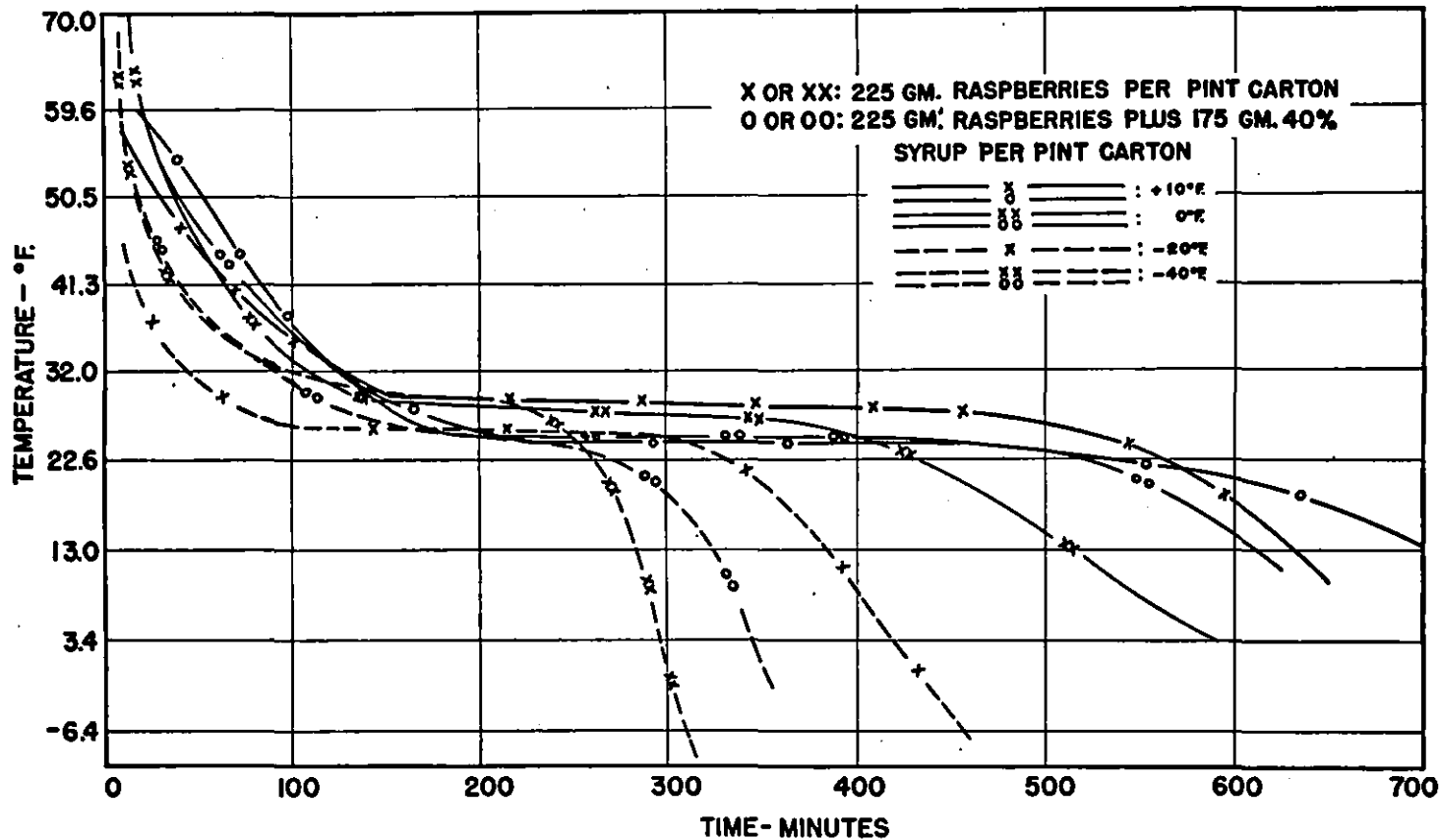


Fig. 1. Rates of freezing of raspberries.

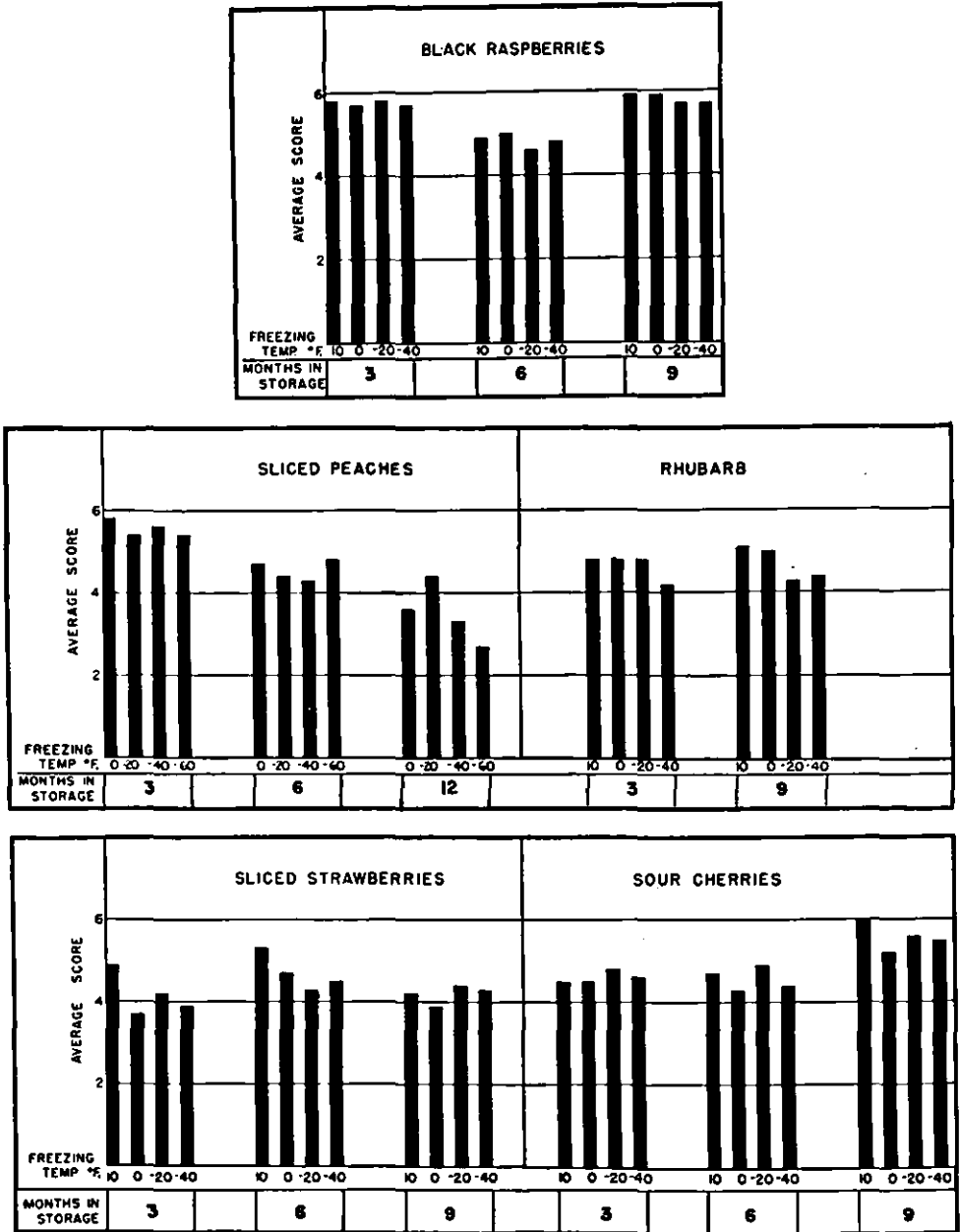


Fig. 2. Acceptability scores for certain fruits.

Typical results from scoring are illustrated in Fig. 2.

PEACHES

The scores for peaches showed a decided decrease in palatability with increasing storage time. After 1 year of storage, fruit frozen at -20° F. was considered best, while that frozen at -40° F. was barely

acceptable and that frozen at -60° F. was not acceptable. After 3 and 6 months' of storage, 0° F. gave top or near top scores in most cases.

It was observed that in the storage interval from 6 to 12 months, the entire surface—sides and bottom as well as top—of the frozen mass of peaches had turned brown. It was suggested that the waxed barrier of the cartons might have degenerated with prolonged storage, allowing air to penetrate into the packages.

A few cartons of sliced peaches were prepared with 0.2-percent ascorbic acid in the sirup, as suggested by Tressler and Du Bois (22). These retained their appearance and color much better than did the corresponding packages containing no added ascorbic acid. These scores are shown in part A, Fig. 3.

PEARS

The pears, like the peaches, decreased in palatability with increasing storage. In addition, the pears did not stand up well under frozen storage. Only the 3-month storage samples were considered acceptable by the judges. The freezing temperature which gave the best product after 3 months' storage was 0° F.

The loss of palatability which occurred during storage seemed to be due principally to change in texture, as the pear slices tended to disintegrate into a soft, rather gritty mass. With this in mind, several series of pear halves were tested to investigate whether or not pears could be successfully frozen. The pears were peeled, cut in half, cored, and frozen in 50-percent sugar sirup. The first series included samples frozen raw, and samples blanched 3, 4 and 5 minutes in steam before packaging. These were scored after 6 months' storage. The next year another series was prepared which included raw pears, pears blanched 4 minutes in steam and pears blanched 2 minutes in boiling 50-percent sirup. These were scored after 3 and 9 months' storage.

The scores for the pear halves are shown in part B, Fig. 3. The unblanched pears turned brown rather quickly. The samples blanched 5 minutes in steam resembled canned pears. Pears given 4-minute steam blanch and the 2-minute sirup blanch received about the same scores. Both treatments resulted in very acceptable frozen products.

PLUMS

The plums decreased in palatability with increasing storage. However, all of the samples were acceptable after a year of storage. Freez-

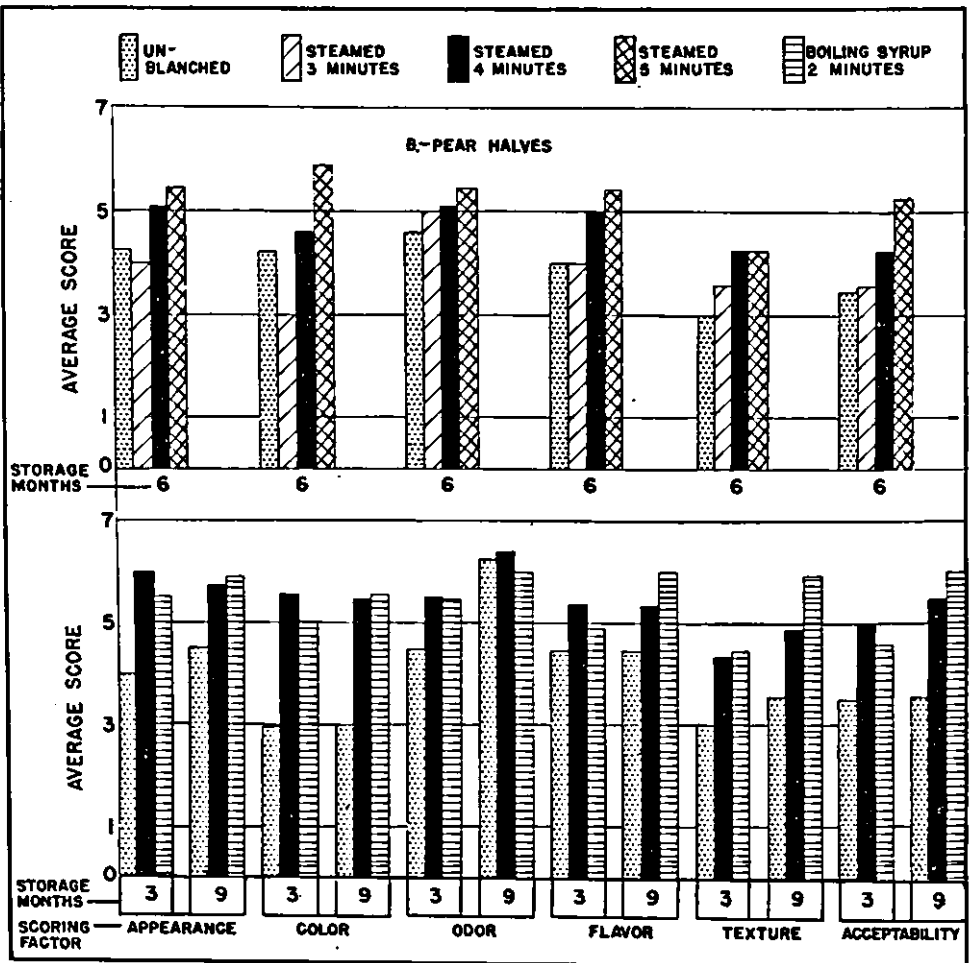
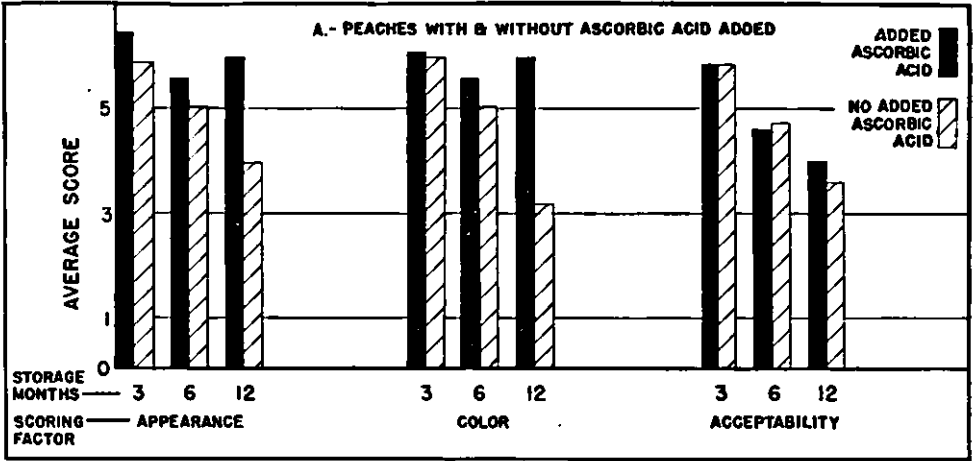


Fig. 3. Average scores for special peach and pear items.

ing temperatures of 0, -40, and -60° F. gave about equally good results over all, with -20° F. slightly lower at the end of the year.

RHUBARB

There seemed to be little if any change in palatability of rhubarb with increasing storage time. Freezing temperatures of 10 and 0° F gave equally good results, with -20 and -40° F. slightly lower in score.

STRAWBERRIES

The samples held in frozen storage for 6 months were given slightly higher scores than the samples held 3 and 9 months. Freezing at 10° F. gave the best results for temperature, with 0, -20 and -40° F. about equal and slightly lower. However, none of the differences in acceptability was great enough to be statistically significant.

RED CHERRIES

The cherries improved with increasing storage time, particularly in color, flavor and texture. The samples stored 9 months scored the highest of the whole series, except for odor. The 6-month samples were best for odor. The differences due to freezing temperature were small.

BLACK RASPBERRIES

The 3-month and 9-month storage samples of black raspberries scored about the same, with the 6-month samples being somewhat lower. The differences due to freezing temperature were negligible.

BLUEBERRIES

The 3- and 9-month storage samples of blueberries seemed to be about equal in score, with a slight preference of the 3-month Rubel samples offset by a similar slight preference for the 9-month Jersey samples. The differences caused by freezing temperatures were small, with possibly a slight advantage at 0° F.

RED RASPBERRIES

The samples of red raspberries frozen at 0° F. scored somewhat higher than those frozen at the other experimental temperatures. In general, the samples stored 3 months received slightly higher scores, with the 6- and 9-month samples being about equal as to score.

The raspberries frozen in sirup received higher scores in almost all instances than those packed without sugar or sirup. The superiority of the sirup-packed fruit was especially marked for appearance, flavor and texture. Certain of these scores are illustrated in Fig. 4.

DEWBERRIES

All the samples of dewberries were very good, with only small differences in score due to freezing temperature or length of storage.

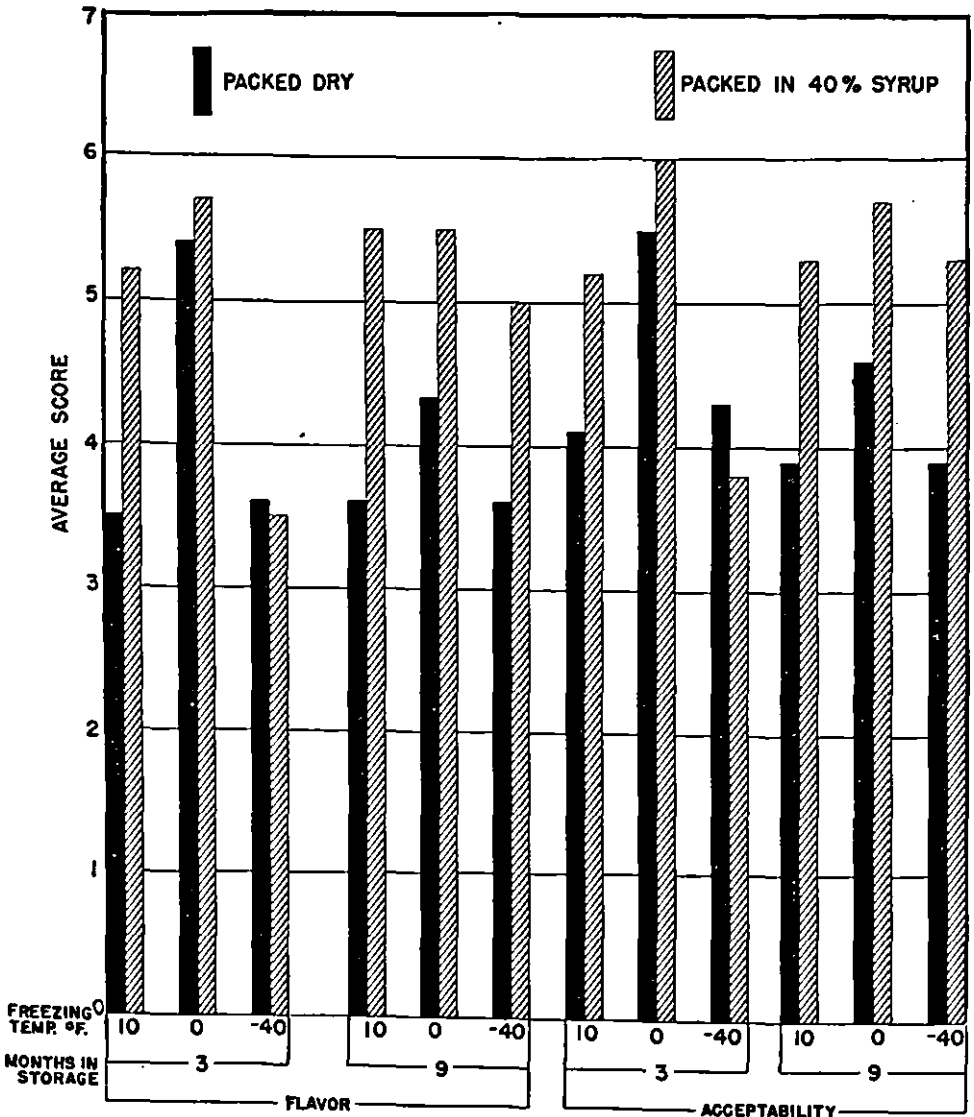


Fig. 4. Average scores for flavor and acceptability of red raspberries.

BING CHERRIES

The samples frozen at 0° and at -20° F. scored slightly higher than those frozen at 10 and at -40° F. The 3-month storage samples scored a little higher than those held 6 and 9 months.

DICED CANTALOUPE

The samples stored 6 months were generally superior to those stored either 3 or 9 months. The freezing temperature made very little difference on the scores.

The cantaloupe was put up dry, in 40-percent sirup, and in 1 part sugar to 4 parts fruit. The dry sugar pack received the highest scores, with the sirup pack being slightly lower, and the dry pack lowest of the three. Almost all of the samples were considered acceptable.

ASCORBIC ACID RETENTIONS

The total ascorbic acid values determined for the fruits are listed in Table 3. The retention of ascorbic acid was somewhat better in the samples frozen at -20° and -40° F., than in the others. However, the over-all loss of ascorbic acid was never greater than 35 percent, even after 12 months' storage. The rhubarb lost an additional amount in cooking, the 9-month cooked sample having only 45 percent as much ascorbic acid as was found in the original raw material. Four fruits—strawberries, red cherries and red and black raspberries—showed apparent gains in total ascorbic acid during the first three months of storage, followed by a gradual loss. This was particularly marked in the strawberries. Additional work is in progress to determine whether this gain is due to biologically active ascorbic acid.

Freezing red raspberries in 40-percent sirup did not increase the retention of ascorbic acid, although Todhunter and Robbins (21) had previously reported that the addition of sugar to red raspberries before freezing seemed to have some protective effect on the ascorbic acid content.

VEGETABLES

The vegetables investigated were: first year—cauliflower, broccoli; second year—spinach, peas, wax beans, asparagus tips; third year—cut corn. Broccoli, cauliflower, and asparagus were purchased on the market. The other vegetables were obtained from the College farms. The vegetables were prepared, frozen and stored as outlined in Table

TABLE 3—Total ascorbic acid values for fresh fruits and fruits frozen at different temperatures and stored for different lengths of time (mg/100 gm. fresh weight)

Fruit	Storage, months	Fresh	Freshly prepared	+10°F.	0°F.	-20°F.	-40°F.	-60°F.	Average
Peaches	0	14.8	12.0	.....	.....	.....	.....	.....	13.4
	3	.....	.....	.....	10.5	16.0	11.8	14.3	12.2
	6	.....	.....	.....	10.4	15.0	11.1	12.8	11.6
	12	.....	.....	.....	13.0	13.2	10.2	15.0	12.5
Pears	0	4.7	4.0	.....	.....	.....	.....	.....	4.4
	3	.....	.....	.....	2.9	2.7	3.6	3.1	3.0
	6	.....	.....	.....	2.9	3.6	3.6	3.4	3.3
Plums	0	12.7	.....	.....	.....	.....	.....	.....	12.7
	3	.....	.....	.....	9.8	10.7	9.4	9.1	9.7
	6	.....	.....	.....	9.9	9.8	9.4	9.8	9.7
	12	.....	.....	.....	10.2	11.2	10.4	10.7	10.5
Strawberries .	0	47.5	.....	.....	.....	.....	.....	.....	47.5
	3	.....	.....	79.1	82.4	82.4	89.1	.....	83.3
	6	.....	.....	66.5	66.0	64.6	68.8	.....	66.5
	9	.....	.....	47.0	51.0	51.0	54.2	.....	50.8
Red cherries .	0	11.7	.....	.....	.....	.....	.....	.....	11.7
	3	.....	.....	16.0	17.4	16.0	14.4	.....	16.2
	6	.....	.....	10.4	10.1	12.2	10.8	.....	10.7
	9	.....	.....	12.0	13.2	13.0	13.0	.....	12.9
Black raspberries	0	16.7	.....	.....	.....	.....	.....	.....	16.7
	3	.....	.....	22.7	22.6	19.0	20.1	.....	21.4
	6	.....	.....	14.9	17.6	.....	.....	.....	16.3
	9	.....	.....	13.8	12.7	11.1	13.3	.....	12.7
Blueberries, Rubel	0	5.9	.....	.....	.....	.....	.....	.....	5.9
	3	.....	.....	5.4	5.8	5.8	6.3	.....	5.8
	9	.....	.....	4.5	5.7	6.7	4.7	.....	5.4
Jersey	0	8.0	.....	.....	.....	.....	.....	.....	8.0
	3	.....	.....	8.4	7.8	8.1	8.1	.....	8.1
	9	.....	.....	8.3	7.6	8.4	8.6	.....	8.2
Rhubarb	0	16.0	.....	.....	.....	.....	.....	.....	16.0
	3	.....	.....	18.4	13.0	17.2	19.0	.....	16.9
	6	.....	.....	12.3	13.2	14.7	11.7	.....	13.0
	9	.....	.....	8.1	10.5	9.0	13.3	.....	10.2
Red raspberries, dry	0	17.8	.....	.....	.....	.....	.....	.....	17.8
	3	.....	.....	18.1	18.7	23.3	26.8	.....	21.8
	6	.....	.....	14.4	16.5	21.3	19.1	.....	17.8
	9	.....	.....	14.9	13.4	16.8	21.9	.....	16.8
40% sirup . . .	3	.....	.....	16.5	19.7	.....	24.5	.....	20.2
	6	.....	.....	13.8	15.3	.....	21.5	.....	16.9
	9	.....	.....	.....	.....	.....	.....	.....	.....
Bing cherries .	0	6.0	.....	.....	.....	.....	.....	.....	6.0
	3	.....	.....	5.1	5.8	6.6	6.6	.....	6.0
	6	.....	.....	5.4	4.8	5.6	7.0	.....	5.7
	9	.....	.....	6.0	5.2	6.5	6.7	.....	6.1
Dewberries . .	0	16.5	.....	.....	.....	.....	.....	.....	16.5
	3	.....	.....	15.4	16.5	16.5	16.5	.....	16.2
	6	.....	.....	18.2	18.9	14.9	16.7	.....	17.2
	9	.....	.....	14.6	16.8	16.8	16.3	.....	16.1

4. All vegetables were packed in sealed cellophane bags in collapsible cardboard cartons. One-pound cartons were used for spinach, peas, wax beans and corn, and 1½-pound containers for cauliflower, broccoli and asparagus tips.

Thermocouples were inserted into pieces of vegetable in the center of representative cartons, and freezing curves obtained with a potentiometer. Sample curves for cut corn are shown in Fig. 5. The curves

TABLE 4—Preparation, freezing and storage of vegetables

Vegetable	Variety	Preparation	Blanching	Yield	Freezing		Storage time, in months
					Temperature °F.	Load for each freezing temperature	
Cauliflower.....		Wash, trim, break in flowerets, soak 15 min. in 5% NaCl, wash in clear water	4 min. in boiling water, cool in ice water, drain	1 bushel filled 18—1½ lb. packages	10, 0, -20, -40, -60	9 to 18 cartons	3, 6, 12
Broccoli.....	Italian Green Sprouting	Wash, trim, soak 15 min. in 5% NaCl, wash in clear water	5½ min. in steam, cool in ice water, drain	1 bushel filled 18—1½ lb. packages	0, -20, -40, -60	18 cartons	3, 6, 12
Spinach.....		Wash in 5 waters, drain	2 min. in boiling water, cool in running water, drain	7 lb. a.p.*filled 7 1 lb. cartons	10, 0, -20, -40	9 cartons	3, 6, 9
Asparagus tips..	Mary Washington	Wash, drain, cut tips 5 inches long	3 min. in boiling water, cool in running water, drain	9 lb. a.p.* filled 8—1½ lb. cartons	10, 0, -20, -40	9 cartons	3, 6, 9
Peas.....	Thomas Laxton	Shell.....	1½ min. in boiling water, cool in running water, drain	24 lb. a.p.* filled 10—1 lb. cartons shelled peas	10, 0, -20, -40	9 cartons	3, 6, 9
Wax beans.....	Sensation.....	Wash, discard tips, snap in 1-inch pieces	3 min. in boiling water, cool in running water, drain	5 lb. a.p.* filled 4—1 lb. cartons	10, 0, -20, -40	10 cartons	3, 6, 9
Cut corn.....	Golden Cross Bantam	Remove husk and silk, trim, scrub with brush and cold water	3 min. in boiling water, cool in running water, cut off cob	12 large ears filled 8—1 lb. cartons	10, 0, -20, -40	10 cartons	3, 6, 9

*a.p.—as purchased.

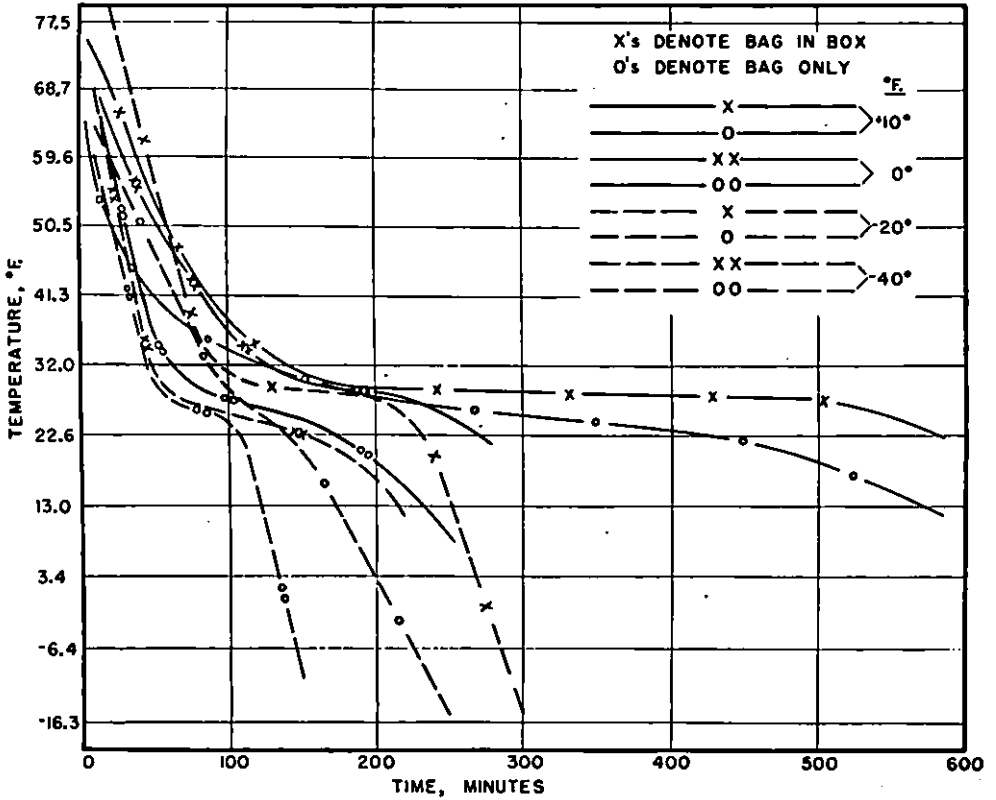


Fig. 5. Freezing curves for cut corn.

TABLE 5—Details of cooking frozen vegetables

Vegetables	Average weight, in grams	Water, in grams	Salt, in grams	Cooking time*, in minutes
Cauliflower.....	504	240	2	3
Broccoli.....	320	240	2	3
Spinach.....	359	200	2	1
Asparagus tips.....	279	150	2	3
Peas.....	460	240	2	3
Wax beans.....	294	240	2	4
Cut corn.....	344	120	2	Brought just to boiling

*Cooking time counted when all ice was gone and mixture started to boil. Vegetables were placed in boiling, salted water, and the frozen mass carefully separated with a fork as it thawed.

for the other vegetables were very similar. An extra set of cut corn samples was frozen in the bag before being placed in the carton. The difference in freezing rate is also shown in Fig. 5. Sufficient cartons

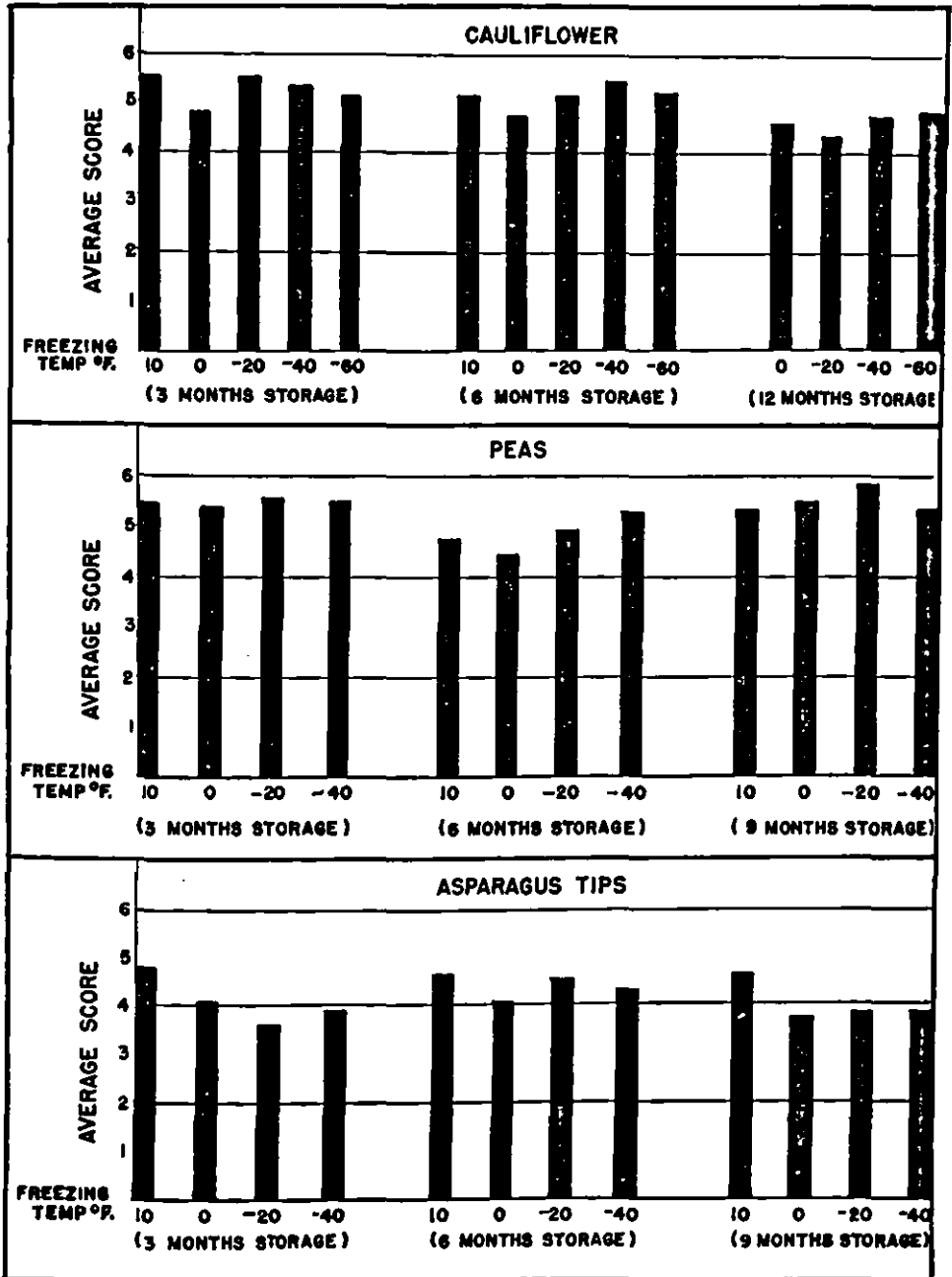


Fig. 6. Average acceptability scores for certain vegetables.

were frozen to allow duplicate samples for scoring, and single samples for ascorbic acid analysis after 3, 6, and 9 or 12 months' storage. The storage conditions were the same for the vegetables as for the fruits.

The samples for scoring were removed from storage, cooked as detailed in Table 5, drained, and scored while hot. Representative scores are shown in Fig. 6.

The samples for ascorbic acid analysis were removed from storage box and unwrapped. Sufficient material was cut from the frozen block for determination of the ascorbic acid in the raw vegetable. The remaining vegetable was cooked according to the methods outlined for scoring, and both the drained vegetable and the cooking liquid sampled for ascorbic acid analysis. The analyses were made by the total ascorbic acid method of Roe and Oesterling (17) with the exception of the wax beans, for which the reduced ascorbic acid method of Loeffler and Ponting (12) was employed.

CAULIFLOWER

The palatability scores for cauliflower decreased with increasing storage. This was particularly marked for appearance and color, as a pinkish-tan color developed in the vegetable during storage. The lower freezing temperatures (-20 , -40 and -60° F.) seemed to give slightly better results, but all the samples were acceptable.

BROCCOLI

The samples of broccoli decreased sharply in palatability with increasing storage. The freezing temperature of -20° F. gave the best results, although the differences were small. Samples frozen at 0° F. had the highest scores for texture. Both broccoli and cauliflower became tough and flabby in texture after freezing.

PEAS

The scores for the peas decreased at 6 months, then increased at 9 months' storage. No one freezing temperature was consistently superior.

WAX BEANS

The wax bean scores decreased at 6 months, but were higher again after 9 months' storage. However, this trend was not so consistent in the wax beans as in the peas. All the freezing temperatures gave about the same results.

ASPARAGUS TIPS

Length of storage occasioned only small changes in scores of asparagus tips. The lower freezing temperatures gave the best results for appearance and color, while the samples frozen at 10° F. were superior in odor, flavor and acceptability.

SPINACH

The spinach samples all decreased in palatability with increasing storage time. The freezing temperature caused only small variations in score.

CUT CORN

The samples of corn decreased slightly in palatability during the nine-month period of storage, but the changes were small. The freezing temperature employed did not affect the scores significantly.

The samples frozen before they were placed in the outer carton, froze more rapidly than those completely packaged before freezing, but the scores for the two lots were very similar.

ASCORBIC ACID RETENTIONS

The ascorbic acid values are listed in Table 6. Freezing temperatures of 0° and -20° F. resulted in maximum retention of ascorbic acid in most cases. The loss of ascorbic acid during blanching and cooling was generally greater than that which occurred during subsequent freezing and storage up to 6 months. The loss during storage was small up to 6 months, after which the ascorbic acid decreased rather sharply in many instances.

EGGS

Eggs were tested as whole eggs and also after being separated into yolks and whites. The whole eggs and the egg yolks were mixed thoroughly, and ½ teaspoon salt added for each cup of whole egg or egg yolk.

The whole eggs were frozen in two forms, in heavily-waxed pint cartons with slip-in lids, and in individual cubes. The cubes, each equivalent to one egg, were frozen in flexible plastic ice cube containers. When frozen, the cubes were removed from the containers and packed in sealed cellophane bags in collapsible cardboard cartons. The egg whites and yolks were frozen as individual cubes. Each cube contained two egg whites or three egg yolks.

TABLE 6—Average ascorbic acid values for vegetables (mg/100 gm. wet weight)

Vegetable	Freezing Temp., in °F.	No storage		3 Months			6 Months			9 Months			12 Months		
				Raw	Cooked		Raw	Cooked		Raw	Cooked		Raw	Cooked	
		Fresh	Blanched		Solids	Liquid		Solids	Liquid		Solids	Liquid		Solids	Liquid
Broccoli.....	unfrozen	102.6	79.4												
	0.....			60.3	33.9	21.9	55.3	29.4	22.6				18.2	7.7	3.5
	-20.....			63.6	41.9	24.7	64.8	42.2	29.3				22.1	13.0	6.1
	-40.....			57.3	31.5	19.6	57.0	32.9	21.3				20.6	10.7	3.5
	-60.....			64.8	38.5	19.2	64.8	29.2	20.9				17.1	7.1	3.4
Cauliflower.....	unfrozen	80.5	55.7												
	10.....			54.4	46.0	41.6	54.0	38.9	33.4						
	0.....			54.7	38.6	32.2	56.4	39.9	39.1				20.3	15.4	10.9
	-20.....			60.6	36.0	26.5	52.2	36.4	25.0				28.6	13.7	8.2
	-40.....			55.9	45.1	33.4	52.2	41.6	32.2				24.5	15.3	8.2
-60.....			50.7	42.6	31.1	68.9	47.6	34.7				17.4	5.8	4.7	
Spinach.....	unfrozen	41.3	28.2												
	10.....			14.7	12.7	7.8	13.8	11.0	7.3	13.6	11.8	8.3			
	0.....			18.9	8.2	8.2				7.0	7.0	4.0			
	-20.....			17.5	15.0	10.8	17.0	11.7	7.5	9.0	8.5	5.1			
	-40.....			22.5	10.0	8.6	15.9	11.7	7.8	17.2	7.4	6.4			
Asparagus.....	unfrozen	21.8	19.9												
	10.....			22.7	17.7	13.2	17.5	15.1	10.4	9.3	6.8	4.4			
	0.....			27.0	21.7	13.7	13.7	12.3	11.4	12.5	10.5	6.9			
	-20.....			28.6	21.7	12.7				14.4	13.0	10.8			
	-40.....			24.9	19.9	9.7				12.8	8.8	4.2			
Peas.....	unfrozen	33.6	24.0												
	10.....			15.0	9.3	8.2	17.2	13.1	6.0	14.0	10.9	15.1			
	0.....			15.4	13.6	8.3	18.5	15.3	6.0	16.3	13.5	17.4			
	-20.....			24.7	24.7	16.5	18.5	15.3	6.2	13.5	13.0	11.9			
	-40.....			23.8	18.5	14.9	19.8	18.5	6.6	16.3	12.5	20.1			
Wax beans.....	unfrozen	17.6	15.1												
	10.....			12.5	7.8	7.2	14.1	10.1	10.9	10.0	4.7	6.9			
	0.....			15.5	10.7	11.3	17.6	13.5	17.1	7.0	4.5	3.3			
	-20.....			15.9	13.1	12.9	20.2	15.7	14.7	11.3	5.3	6.2			
	-40.....			14.3	10.0	10.3	15.5	12.6	12.1	10.0	6.1	6.2			
Corn.....	unfrozen	11.8	9.9												
	10.....			9.1	6.3	2.1	8.5	5.3	2.9	9.6	6.3	2.3			
	0.....			12.5	6.9	3.2	10.5	7.7	2.1	11.0	7.7	2.0			
	-20.....			11.3	10.0	2.7	10.5	7.4	1.3	8.5	7.4	1.3			
	-40.....			10.8	7.4	2.6	8.8	6.0	2.0	9.1	9.4	1.9			

The eggs were frozen at 10, 0, -20 and -40° F. Rate of freezing was followed with thermocouples. Figure 7 shows the curves obtained for whole eggs, in the pint cartons. Samples were tested after 3 and 12 months' storage. The 6-month samples were discarded because of premature thawing and subsequent spoilage. The eggs were frozen during the latter half of the first year of work, so the storage conditions were partly those of the first year, and partly those of the second.

The samples for scoring were thawed overnight in a refrigerator at 40 to 45° F. The whole eggs were soft scrambled, the egg whites made into angel food cakes, and the egg yolks prepared as baked custards. Fresh eggs, purchased on the market, were made up in the same products and used as controls for each scoring session. Representative average scores are shown in Fig. 8.

RESULTS

WHOLE EGGS

The fresh eggs scored higher than the frozen ones in all cases. All the frozen samples showed a slight pink discoloration, which tended to lower the scores, especially for color. This pink discoloration disappeared when the eggs were thoroughly cooked (hard scrambled). Therefore, it was suggested that this color might be due to metal contamination from the beater, as it seemed to be similar to the pink color which is sometimes observed in angel food cake batter before it is baked.

The whole eggs frozen in tubs scored slightly higher than those frozen as individual cubes. However, the difference was not significant statistically. All scores decreased with increasing storage.

Freezing at 0° F. seemed to give slightly better results than did the other temperatures, although the differences were small. One interesting observation was that the eggs frozen at 10° F. and stored for 12 months had gelled so that the thawed raw eggs appeared to be partially cooked.

EGG YOLKS

The custards made from fresh egg yolks were little if any better than the ones made from frozen yolks. Increasing storage lowered the scores, particularly the scores for consistency. No one freezing temperature seemed preferable, with the exception of -40° F. which yielded the best consistency scores.

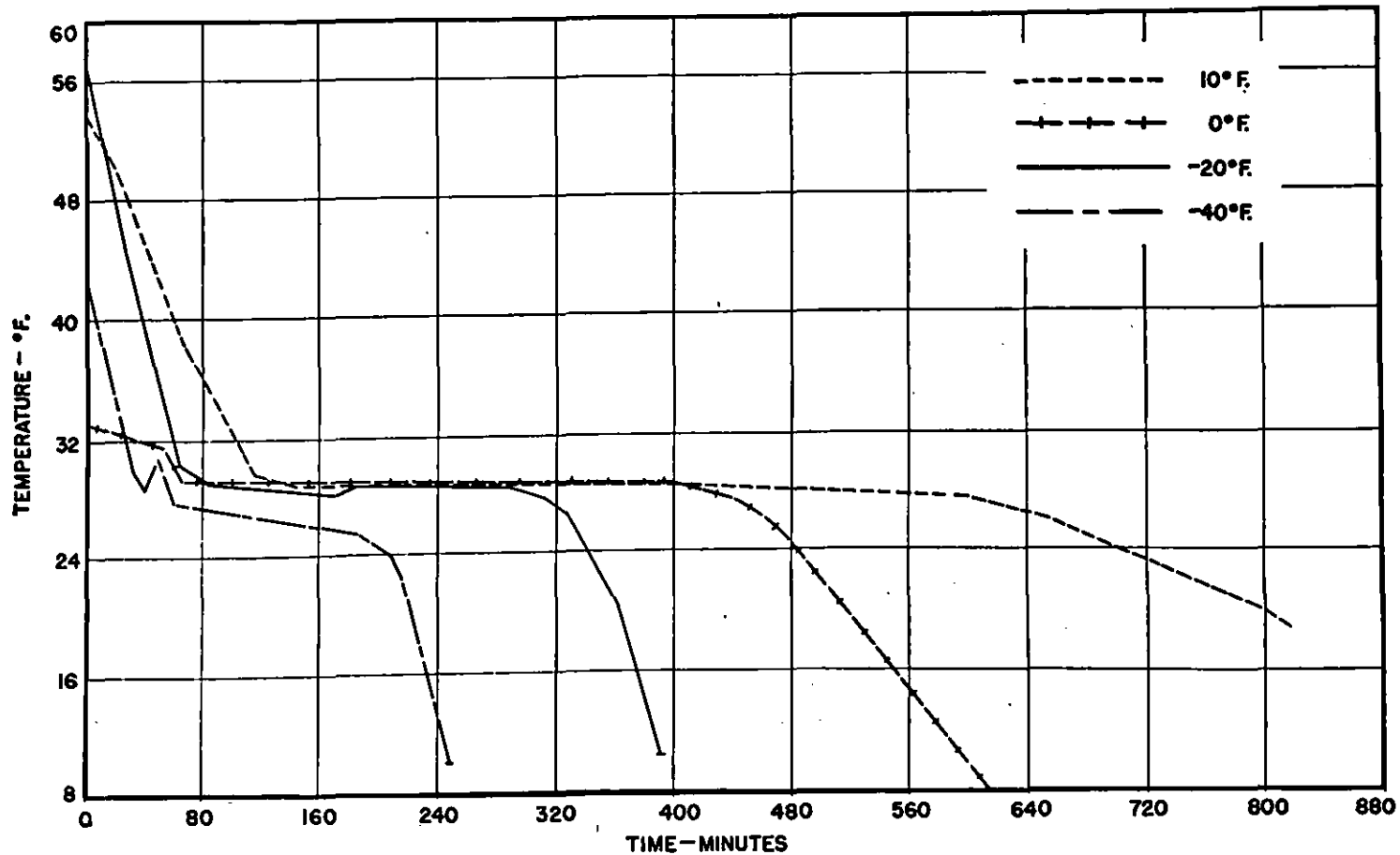


Fig. 7. Rate of freezing of whole eggs at various temperatures; 1.5 cups mixed egg meats in 1-pint containers

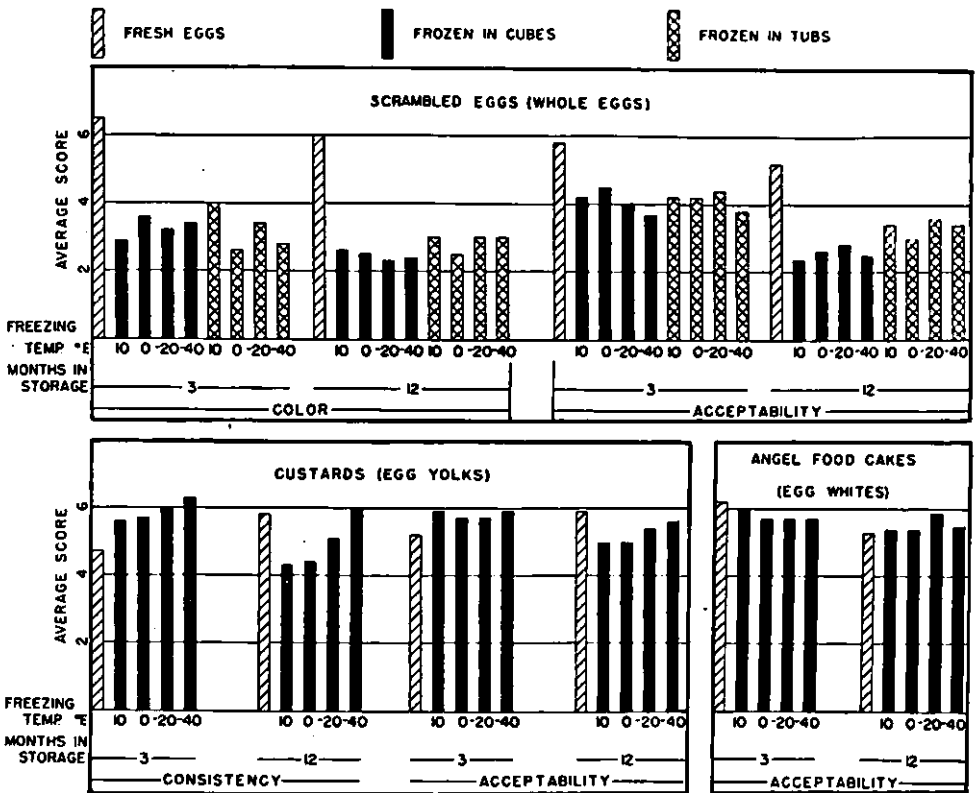


Fig. 8. Average score for products made with frozen eggs.

The samples frozen at 10° F. and stored 12 months had set to a stiff gel and were difficult to disperse in the custard mix. However, the finished custards scored as high as any of the others, except for consistency. They were slightly thinner than custards made from yolks frozen at lower temperatures.

EGG WHITES

The frozen egg whites made as good angel food cakes as did the fresh ones. The scores for the cakes made with frozen egg whites decreased with increased length of storage of the eggs, but the differences were not significant in most cases. The different freezing temperatures gave about the same results. The egg whites frozen at 10° F. and stored 12 months were considerably thicker than the other 12-month samples and, consequently, more difficult to beat up to a foam. The final product, however, received only slightly lower scores than those for cakes made from egg whites frozen at lower temperatures.

BEEF

The beef used in this study was obtained from the Animal Husbandry Department. Rounds with the rump on from two, good-grade steers were used. The carcasses were hung for 10 days at 34 to 36° F., between slaughter and cutting. After the hanging period, the rounds were separated into muscles and the semitendinosus, semimembranosus and biceps femoris utilized for study of the effect of freezing temperatures. These are the large muscle from the top round, and the two muscles of the bottom round. Each muscle was cut into three roasts, making a total of 12 roasts for each group from the two animals. The roasts from each muscle were distributed at random over the four freezing temperatures (10, 0, -20, and -40° F.), and three storage periods (3, 6 and 12 months). This gave three replications of the experimental series from the three muscles.

Five pairs, representing corresponding cuts from the two animals, were frozen at 0° F. and tested after 3 months' storage, to check on any difference in scoring factors between the two animals.

A set of four pairs of roasts, representing pairs from the right and left sides of the same animals, were frozen to compare the effect of wrapping prior to freezing on freezing rate and palatability. One roast of each pair was wrapped as described below before freezing, the other was frozen, then wrapped. One pair was frozen at each of the four experimental temperatures, and all were scored after 6 months' storage.

The roasts were wrapped in moisture-proof cellophane (MSAT No. 300) and enclosed in stockinette. Thermocouples were inserted into the center of certain of the roasts so that the rate of freezing might be followed. The curves in Fig. 9 show the rate of freezing for the different freezing temperatures. After freezing, the roasts were placed in storage at 0° F. The meat was tested during the first year of work so that storage conditions were as indicated previously for that period.

After the appropriate storage periods, the roasts were removed from storage, unwrapped, and placed on racks in open pans. They were roasted without prior thawing to an internal temperature of 58° C. at an oven temperature of 177° C. Thermometers were inserted into the center of the roasts after they had been in the oven long enough to thaw (approximately 1 hour). When the internal temperature reached 58° C., the roasts were removed from the oven, allowed to come to maximum temperature, then sliced and scored. It was not

possible to obtain scores on the flavor of the fat, as most of the roasts had very little external fat.

Appropriate weights were taken for the determination of total, dripping and evaporation losses during cooking. Shear force readings were made on most of the cooked samples using the Warner-Bratzler shearing machine.

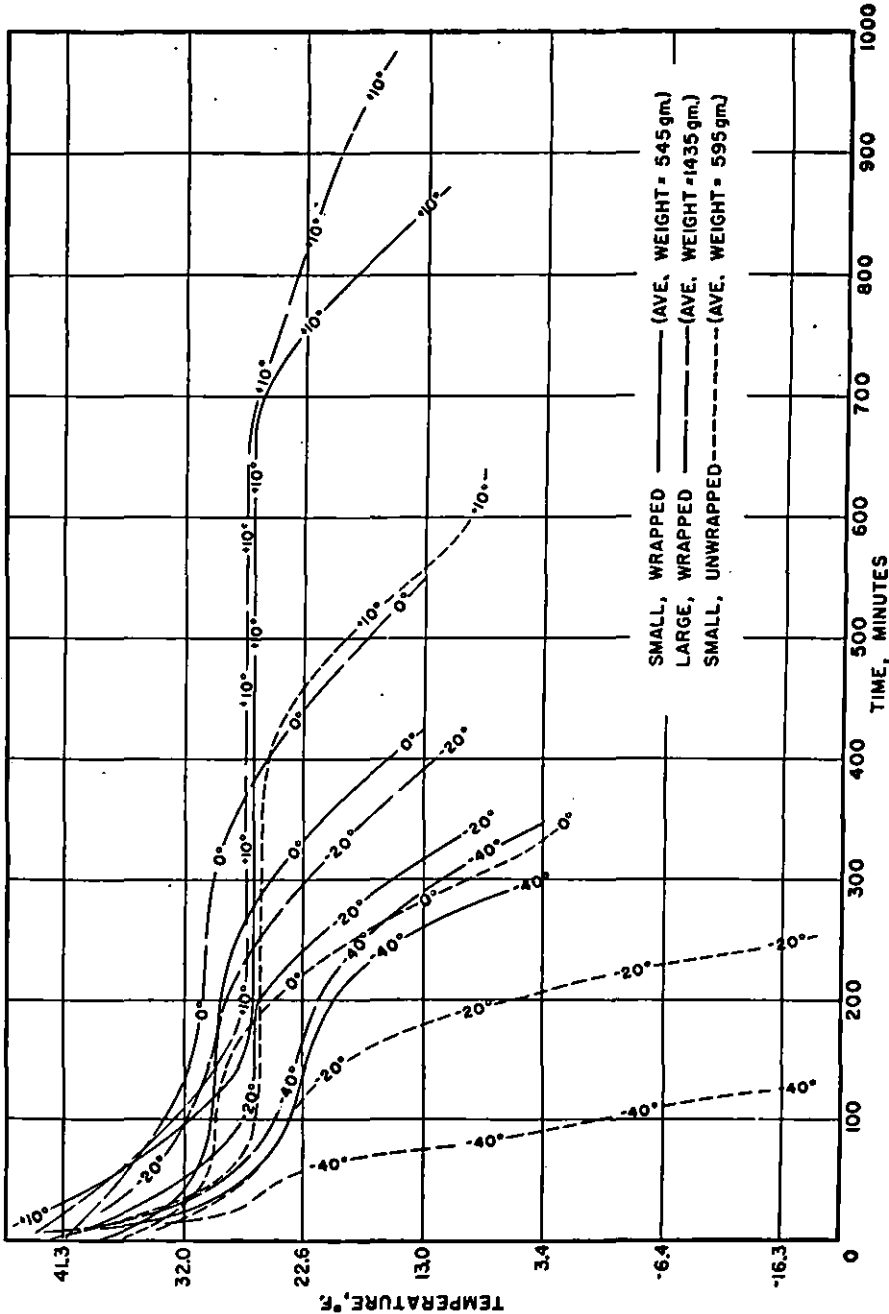


Fig. 9. Freezing curves for beef. Note: Temperature on curves denotes temperature of freezer in ° F.

RESULTS

The roasts frozen before wrapping froze more rapidly than those that were wrapped before freezing, as can be seen in Fig. 9. However, there was no clear indication from the scores (Fig. 10) that this more rapid freezing improved the palatability of the meat, while it increased the cooking losses except at 10° F. The roasts frozen before wrapping were difficult to handle as they froze to the bottom and sides of the freezing cabinet, and had to be pried out by force. Also, they showed some evidence of surface desiccation from the one night of exposure to the dry atmosphere of the freezing chamber. The roasts wrapped before freezing had an average loss of weight during freezing and storage of 0.6 percent, while those frozen before wrapping lost an average of 1.8 percent.

The data for certain scoring factors, shear, and cooking losses for the three series of roasts frozen at 10, 0, -20 and -40° F. are illustrated in Figs. 11 and 12.

All of the roasts stored 12 months showed some evidence of freezer burn, with the exception of one roast which had been double wrapped. However, the over-all loss of weight during storage was small, averaging 1.7 percent.

The three series, representing three different muscles, differed in many places in actual score and also in the trend of the score. This was expected as it is recognized that there are pronounced differences among the various muscles of the beef carcass. Certain of these scores are illustrated in Fig. 11.

There was some evidence of decrease in palatability with increasing time of storage, although the decrease was never great enough to make the meat unacceptable. In many cases, the scores were actually higher for the longer storage periods, especially for the 6-month period.

There were no clear-cut differences in score attributable to the different freezing temperatures.

The roasts of the semitendinosus series generally decreased in tenderness with storage, while the semimembranosus and biceps femories series increased in tenderness, especially at the 6-month interval. The fact that the semitendinosus received as good or better scores for tenderness than the semimembranosus was unexpected, as the semitendinosus is usually considered less tender than the semimembranosus. Since the data from the pairs tested at 3 months to check on differences between the two animals had shown a significant difference in

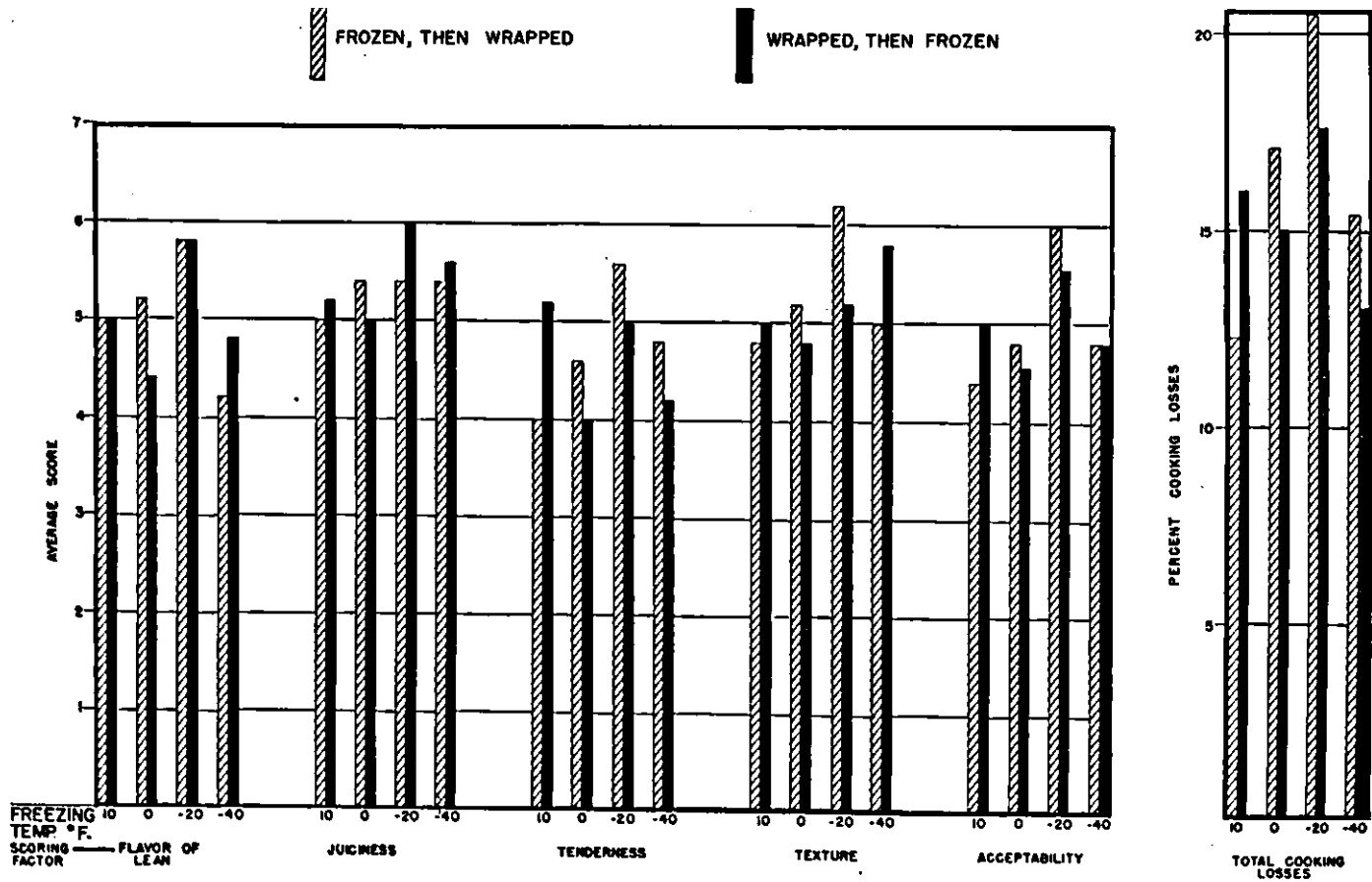


Fig. 10. Average scores and cooking losses for roasts frozen before and after wrapping.

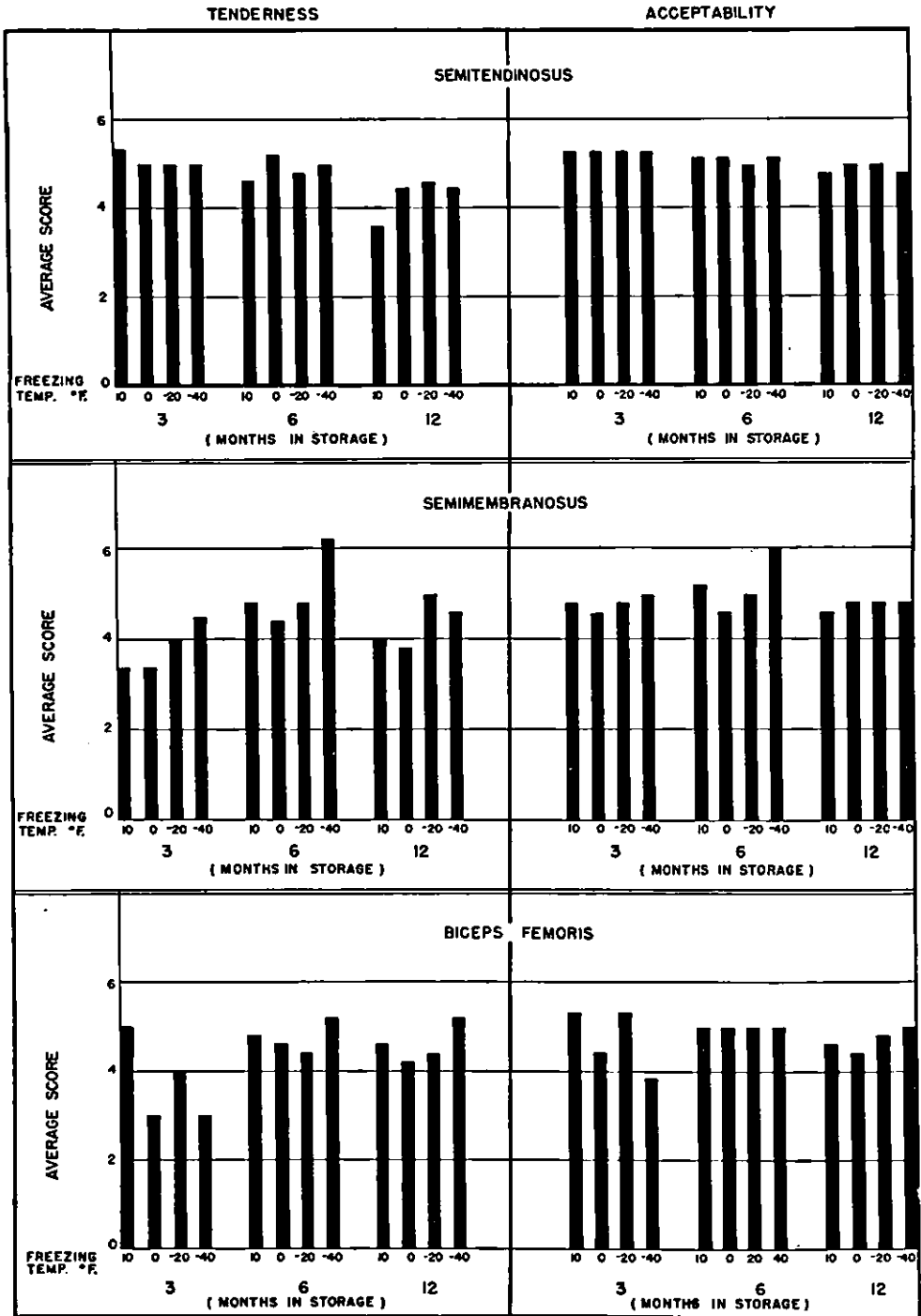


Fig. 11. Average scores for tenderness and acceptability of beef roasts.

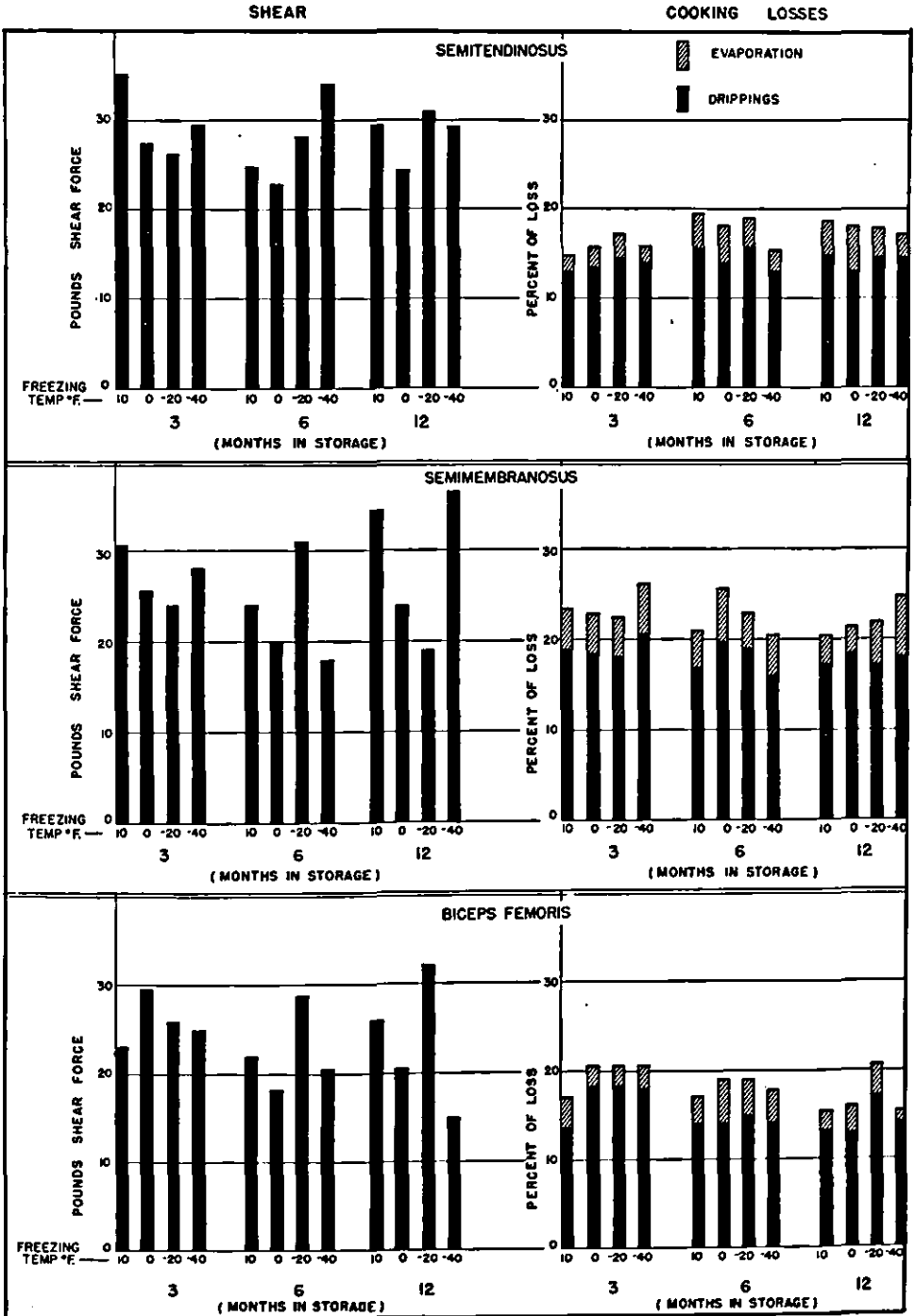


Fig. 12. Shear force and cooking losses of beef roasts.

tenderness, the tenderness scores were further analysed statistically to check on the difference between the two animals. For these muscles, the difference was not significant.

The correlation between tenderness scores and shear was not so high as is usually noted, the correlation coefficient being -0.24 . When the data for the three muscles were analyzed separately, the correlation coefficients were as follows: semitendinosus, $+0.165$; semimembranosus, -0.42 ; biceps femoris, -0.545 .

The cooking losses showed no definite trend attributable to freezing temperature or length of storage. The semimembranosus had significantly higher losses than the other two muscles. This was expected, as the roasts from the semimembranosus were larger, more compact, and had more external fat, than the roasts from the other two muscles.

Summary

A considerable number of foods were studied for the effect of freezing temperature on palatability and storage life. The foods employed included 12 fruits, 7 vegetables, whole and separated eggs, and beef roasts. These foods were prepared for freezing according to standard recommendations. The freezing temperatures used were 10 , 0 , -20 , -40 and -60° F., and the storage periods 3, 6 and 9 or 12 months. The storage temperature was held as closely as possible to 0° F., although there was some variation, especially during the storage of peaches, pears, plums, cauliflower, broccoli, eggs and beef.

The general results of this study may be summarized as follows:

1. All the freezing temperatures and storage periods used gave acceptable results, with the exception of: peaches frozen at -40 and -60° F. and stored 12 months; sliced pears frozen at -40° F. for all storage periods; sliced pears frozen at 0 , -20 and -60° F. and stored 12 months; plums frozen at -20° F. and stored 12 months; broccoli frozen at -40° F. and stored 6 months; broccoli frozen at any of the experimental temperatures and stored for 12 months; whole eggs frozen at any of the experimental temperatures and stored for 12 months.

All the unacceptable products were those stored during the first year and first part of the second year, during which times the storage conditions were not optimum because of fluctuation in the storage temperature.

2. The results indicated a slight advantage for 10° F. as a freezing temperature for three months of storage and -20° for storage greater than 6 months. However, in almost all cases the differences among various scores were too small to be statistically significant.

3. The differences among the average scores for the various storage periods were highly significant for a number of products. The acceptability decreased gradually with increasing storage for peaches, pears, plums, red raspberries, Bing cherries, broccoli, cauliflower, asparagus tips, spinach and whole eggs. Peas, wax beans and black raspberries received higher scores at 3 and 9 months than at 6 months. Red cherries scored highest in 9 months. The other items, including blueberries, rhubarb, strawberries, dewberries, beef, egg yolks and egg whites, showed no significant change in acceptability scores with storage. Again, the importance of constant storage temperature is demonstrated, as over half of the items which showed significant decrease in acceptability scores with increasing length of storage were stored during the first year when there was the most frequent fluctuation in temperature.

An indicated, several items seemed to improve with increased storage. There were no known irregularities in preparation and storage of the samples which would account for these increases in scores. Since the judging panel has proven to be both reliable and consistent on a number of other items, it seems unwise to attribute these results wholly to lack of reliability on the part of the judges.

When the design and expense of equipment are considered along with the results of this work, recommendations for the operation of home freezers might be formulated somewhat as follows. A freezing temperature of 0° F. is adequate for most foods, provided the load frozen at any one time is small enough so that all the packages to be frozen can be placed against the bottom or sides of the freezing chamber with space around them for circulation of air. When the same compartment is used for freezing and storage, the amount frozen at any one time should be small enough so that the temperature of the whole compartment is not raised appreciably, to avoid damage to the stored products from temperature fluctuations. Freezing at temperatures of 10° F. or above is not recommended as this is too high a temperature for storage (most home units being used for both storage and freezing). A few products such as eggs may be damaged by such slow freezing.

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