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RELATIONSHIP OF FIELD AND PROCESSING FACTORS TO THE QUALITY OF FROZEN STRAWBERRIES

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There are few fruits which equal the strawberry in its dessert quality and consumer appeal. Indeed, the strawberry is used rather extensively in the frozen form. Of the 1960 U. S. production of 466,789,000 lbs of strawberries, 51% were consumed fresh, 47% frozen and approximately 2% in other miscellaneous style packs. The attractive red color, pleasant aromatic flavor, and smooth fine-grained texture are among the qualities that are important to the high degree of acceptance of strawberries.

During the course of handling and processing strawberries, certain changes occur that result in a loss of certain of the desirable characteristics of the fruit. In fact, the morphology and cellular configuration of the fruit make it susceptible to breakdown. The edible receptable of the fruit is composed of cortical and medullar layers of cells. These tissues can vary widely in their physical states since varieties can be observed that have a tough cortex and soft, mealy medulla while others have a tender cortical layer and hard medullar layer. These variations in the firmness characteristics seriously affect the identity of the fruit during handling and processing. In frozen strawberries, the extensiveness of the breakdown and loss in identity of intact slices has resulted in consumer complaints. The latter prompted an investigation of some of the factors that may influence this, and thus point the way to potential methods of handling and processing strawberries that retain a high degree of consumer appeal.

A number of investigators have reported on various phases of the cultural, handling and processing procedures as they affect, either directly or indirectly, the ability of the strawberry to resist physical breakage. Soft varieties, over-mature fruit, and climate and soil were reported as having an important influence on firmness (3,13,15,18,19). Heavy rains, high humidity and heavy fertilization were found to decrease total solids and firmness of the fruit while increasing size of leaves and fruit (3,15). High temperatures in the range of 86° to 100° F after harvest increased the metabolic activity and degraded the fruit although cooling the fruit resulted in a toughening of the cortical tissue and decreased the damage from handling and holding after harvest (17).

Incidence of rot in the field and in transit was greater when the fruit was grown under high levels of nitrogen (4). Careless handling and picking added to losses from injury as well as increased the damage from fungi (2).

Detergent washing of fresh strawberries and Captan sprays applied during flowering decreased the incidence of molds (11,19). However, the development of microorganisms in strawberries did not significantly affect the mold counts during the first 12 hours after harvest regardless of temperature, but thereafter the count was directly proportional to storage temperature (15).

Types of mixers for mixing strawberries with sugar during preparation for freezing influenced the texture of frozen sliced strawberries (19,20). The screw-type mixer produced 20% and the ribbon-type 13% mushy slices as compared to a syrup pack that showed 3% mushy slices (20). Also, the rate of freezing packaged strawberries was found to affect color, degree of oxidation and mushiness (7,13). Temperature changes during storage of frozen strawberries affected texture, appearance and palatability (8,9,13).

The addition of colloidal materials such as pectin and sodium alginate, improved the firmness of frozen strawberries under some conditions (12,21). Variations in reaction to these materials were attributed to variety, maturity and method of application.

The objectives of the strawberry research during the past four years, 1958-61 inclusive, have been directed toward the goal of recording the extent of quality changes in strawberries during growing, handling and processing. Since the problem of the loss in texture of frozen strawberries appeared to be complex, and likewise, with the extreme likelyhood that no single factor would be found responsible for the loss in character, each variable connected with strawberry growing, handling and processing was assessed for its role in character and quality breakdown.

A study was made of the following variables: variety, date of harvest, fertilizer levels, seasonal variations, mold inhibitor sprays, holding time and temperature after harvest, method of slicing, speed of slicing, method of mixing, length of time of mixing fruit and sugar,method of sugaring, type of filler, speed of filler, method of freezing, rate of freezing and length of frozen storage.

In order to approach a problem of this magnitude it was necessary to obtain the cooperation of a number of departments and a branch station of the Oregon Agricultural Experiment Station. They were: Food Science and Technology, Horticulture, Plant Pathology, Agricultural Engineering, Statistics, and the North Willamette Experiment Station. Numberous processing plants cooperated with the research team during two years of the study.

MATERIALS AND METHODS

Six separate experiments were used to evaluate the effect of the previously mentioned variables on quality of frozen strawberries. Five of these experiments were performed on a pilot plant basis and one was carried out in various commercial processing plants.

Experiment No. 1. Northwest, Marshall, Siletz and Puget Beauty varieties of strawberries were obtained from replicated field plantings. Fruits from these varieties were obtained from three harvests each of two years. This fruit was used to evaluate both the effect of variety and harvest date on the characteristics of the fruit which may contribute to the firmness of strawberries.

Experiment No. 2. Marshall and Northwest varieties grown in one location and harvested two times and Marshall in a second location and harvested three times were treated as follows: To one-half of the plots in each location, the mold inhibitor N-trichloromethyl thiotetrahydrophthalimide (Captan) was applied beginning at the first bloom and continuing at 7-8 day intervals until flowering was completed. The rate of spray application of Captan was 2½ lbs active ingredient per acre. The remainder of the plots were untreated and served as the control. Random samples of the fruit from these treatments were held as long as 18 hours at 60° 80° F prior to processing to determine the influence of location, variety, mold inhibitor and length of holding on the factors responsible for texture in frozen strawberries.

Experiment No. 3. To evaluate the influence of fertilizers on the factors contributing to texture, the Northwest variety was grown at the North Willamette Experiment Station under different levels of fertility. Fruit was obtained each of two years from plots which had received a fall application of fertilizer calculated to supply 60-120-60 lbs of N-P-K respectively. In the spring (March), one set of plots was supplied with an additional 40 lbs of N, and a second set with an additional 40 lbs of N plus 40 lbs of K. The third set received no spring application of fertilizer and was used as a control. These plots were also subdivided for the application of Captan as stated in Experiment No. 2, and the fresh fruit was sampled for a 24 hour holding period before processing.

Experiment No. 4. To evaluate the effect of holding time and temperature, method of slicing, rate of freezing and duration of fruit/sugar mixing, Siletz strawberries were obtained from a uniform lot that had been supplied to a local processing plant.

Experiment No. 5. In the course of the evaluation of numerous selections of strawberries as to their suitability for processing, certain physical and chemical tests, which have been found to relate to the firmness characteristics of the fruit, were performed. These selections, which represented a wide variety of inherited characteristics for both firmness and quality, were evaluated for two successive years.

Experiment No. 6. Incidental to a study on the rate of freezing of palletized cased strawberries which was conducted by another agency, the authors were privileged to obtain samples and rate of freezing data from four processing plants. These samples, after freezing and storage, were analyzed to determine the influence of the rate of freezing on the firmness of the fruit.

Coincidentally, a study was made on the effect of the various unit operations, i.e. slicing, sugar addition and mixing, conveying and filling on the breakdown of the fruit.

Preparation for freezing. In the pilot plant studies the fruit was prepared for freezing by washing in a McLauchlan berry washer and draining on a screen to remove water. All the fruit was sliced with a high-speed, serrated blade slicer (McLauchlan) except where slicing of fruit was the variable under observation. Another method of slicing consisted of slicing the berries by hand into halves to minimize bruising of slices. A third method was the use of a slow-speed centrifugal slicer (Urschel). The mechanical slicers were set to slice 7/16 inch in thickness.

Sugar was added at the rate of 1 lb to 4 lb of fruit. The fruit and sugar were placed directly into a large-mouthed, 5-gal. glass jar which had been fitted with crossbars to mix fruit and sugar during rotation. After closing the jar, it was rotated horizontally on motor-driven rollers at a speed of 26 r.p.m. A mixing time of 1 min was used as a standard for all lots except those where mixing time was increased. The mixed fruit and sugar was filled into 1 lb fiberboard, metal-end cartons; then, closed by a semi-automatic metal-end capper and frozen to 0^{o} F in 3 to 4 hr in a freezing room at -18^{o} F.

In order to control directly the exact weight of fruit and sugar in each sample, some of the studies were set up by weighing the sliced fruit and sugar accurately into each container. Mixing was accomplished by rotating the closed containers. This made it possible to determine the change in resistance to shear due to freezing, and to obtain accurate drained weights after thawing frozen strawberries.

Analytical. The ascorbic and dehydroascorbic acids were determined by the method of Roe, Mills, Oesterling, and Domron (16). The resistance to puncture was measured on the fresh fruit by a pressure tester with a 3/16 in diameter plunger. One lb samples of fresh fruit were ground in a Waring Blendor for the determination of soluble and total solids, per cent seed, pH, total acidity, consistency, pectin fractions and cellulose. Soluble solids were determined with a refractometer. Total solids were obtained on 10 gm samples of blended strawberries after drying for 24 hr at 158^{o} F and 27 inch of vacuum. Total acidity was calculated from the ml of 0.2 N NaOH to titrate a 10 gm sample to an end-point of pH 8.0 with the aid of a pH meter and stirring device. Consistency was recorded as the distance of flow in inches of a constant volume of the ground sample in a Bostwick consistometer immediately after grinding. The per cent seed was determined by the A.O.A.C. method (1). Pectin fractions were analyzed by the method of Dietz and Rouse (5). The residue after the pectin fractions were removed was dissolved in 60% H_2SO_4 and determined as cellulose by the phenol sugar method (6).

The frozen product was analyzed after 6 months of storage at 0^{o} F. Samples of fruit were thawed for 2 hours in a water-bath at 68^{o} F prior to determination of drained weight, mushy slices, and viscosity of syrup. In addition, the other objective tests made on the fresh fruit except resistance to puncture were included.

Drained weight was recorded as the weight of strawberries remaining on a No. 8 mesh screen after 3 min. of draining. Mushy or disintegrated slices were separated from the intact slices with a fork during the draining period.

These were weighed after the removal of intact slices. A sample of the syrup was filtered through 2 thicknesses of cheesecloth before the determination of the rate of flow from a size 300 Oswald pipette at a constant temperature of 68° F.

Resistance to shear was determined on the fresh and frozen fruit in most instances by placing 150 g or more sample of fresh or thawed frozen strawberries in the cell of a modified Kramer shear-press and measuring the maximum force to shear and the work curve. After recovering the sample from the cell the fruit was ground for the chemical analyses previously mentioned.

In processing plant studies, samples were obtained directly from the lines at representative intervals during the processing season and analyzed. The samples were collected after the slicing, mixing, conveying and filling operations. The samples were weighed to obtain a net weight; then drained on a No. 2 mesh (½ inch) screen to find the drained weight. The fruit was then rinsed on the screen by submerging it in a bucket of water, rinsing up and down three times within 5 seconds, draining for 10 seconds, and re-weighing the screen and contents. Most of the fruit left on the screen was whole slices. The residue that was rinsed into the water was retrieved by filtration. Appropriate calculations were made to obtain the loss during subsequent operations of the preparation procedure in the commerical plants. These included adjustments necessary in the sample weights to account for water extraction and sugar uptake as plotted in Figure 2. Duplicate samples were frozen and kept for analyses after storage. The shear-press measurement of firmness was made on the fruit remaining on the screen for all the frozen samples.

RESULTS AND DISCUSSION

In order to enumerate individual differences and to clarify the discussion of the many phases of these studies, each variable will be assessed separately as much as possible. Although all these data recorded in this presentation were statistically analyzed, statistical differences have not been shown in each individual table. During the discussion of the tables the significant differences will be noted. Minor differences and trends in these data will be indicated as trends.

Variety. There were wide differences between varieties of strawberries during the four year study. It has been recognized that the Northwest variety retains its firmness during slicing, mixing, conveying, and freezing better than the Marshall, Puget Beauty, and Siletz varieties. The Northwest variety comprises about 65% of the total acreage, while the other 35% is distributed among the other three.

There were significant differences between the four varieties when measured by many different physical and chemical tests on the fresh and frozen fruit in 1959, and in 1960 (Tables 1,2,3,4). The measurement of firmness of the fresh fruit by the pressure test was found to be a good criterion for judging the firmness of the thawed frozen sliced strawberries except in the Puget Beauty variety. This variety was equal to Northwest in firmness of the fresh fruit by the pressure test. Siletz and Marshall were softer varieties. However, Puget Beauty was softer than any of the other varieties after freezing and thawing (Table 3,4). This was a peculiar phenomenon that could not be explained on the basis of cell-wall constituents or any other chemical component. Also, from the results obtained on selections, it appeared to be a weak characteristic that was transmitted to F_1 hybrids when Puget Beauty was used as one of the parents.

Low water-soluble pectin content was usually associated with firmer strawberries. In most instances, the quantities of pectin were similar in the Northwest, Siletz and Marshall varieties (Tables 1,2,3,4). In 1959, the amount of pectin in fresh fruit of Marshall variety was significantly lower than in the other varieties. This was the first year after the planting was made and the fresh fruit was firm in two of the three harvests (Table 3). Water-soluble pectin as well as total pectin of the Puget Beauty variety was always higher than in the other varieties.

Varieties as well as selections reacted differently to freezing. Frozen Marshall strawberries had more dehydroascorbic acid, lower viscosity of syrup, and lower water-soluble pectin than the other varieties (Table 3). Dehydroascorbic acid has been shown to be directly related to deterioration in quality (9). Low viscosity of the syrup increased the soupiness of the thawed sliced strawberries. Rates of flow in seconds of 50 or below were unusually low. Ascorbic acid values for Siletz variety were lower, but the citric acid values were higher than in the other varieties (Tables 1,3). Northwest strawberries were consistently firmer and more attractive in the thawed frozen sliced pack in many different tests during the four year study than the other varieties, and most of the selections tested.

TABLE 1

The effect of variety on objective tests for quality on fresh strawberries in 1959

Objective test	*Means for varieties Marshall	Northwest	Siletz	Puget Beauty
% soluble solids	8.50	8.00	9.07	10.57
% total solids	10.86	9.04	10.69	11.96
% acid as citric	.85	.78	.97	.87
pH value	3.60	3.55	3.61	3.64
Pressure test (gms)	171.5	222.0	182.7	272.2
Water-soluble pectin (mg/100 g)	140.2	170.6	167.7	184.6
Hexametaphosphate-soluble pectins (mg/100 g)	63.1	80.2	91.4	84.1
Alkali-soluble pectins (mg/100 g)	105.2	109.7	111.5	112.2
Total pectins (mg/100 g)	308.6	360.5	350.6	380.9
Ascorbic acid (mg/100 g)	50.8	50.1	50.2	51.0
Dehydroascorbic acid (mg/100 g)	9.3	5.5	4.6	6.4

*Means of 3 harvests and 3 replications

TABLE 2

The effect of variety on objective tests for quality on fresh strawberries in 1960

Objective test	*Means for varieties Marshall	Northwest	Siletz	Puget Beauty
% soluble solids	9.95	8.90	8.25	13.55
% dry matter	11.82	10.09	9.92	15.34
% total sugars	7.855	6.845	5.690	10.145
Consistency (inches flow)	10.000	11.425	11.475	4.425
% seed	1.311	0.3775	0.6865	0.6185
H_2O soluble pectins (mg/100 g)	211.15	230.00	200.7	299.3
Alkali soluble pectins (mg/100 g)	168.35	167.35	153.7	229.3
Total pectins (mg/100 g)	379.5	399.35	354.4	528.3
Pressure test (gms)	159.25	235.05	182.80	223.7
Shear-press, maximum force (lbs)	40.15	59.45	44.50	51.60
Shear-press, work curve (in.lbs)	24.35	40.15	32.2	34.35

*Means of 3 harvests and 3 replications

TABLE 3

Effect of variety on the chemical and physical Measurements of quality of frozen sliced strawberries (1959).

Variety	Dr'd Wgt. (gms)	Broken Slices (gms)	Rate of Syrup Flow (sec)	Hunter Color "L"	% Soluble Solids	% Total Solids	Pectins: Water-Soluble (mg/100 g)	Pectins: Alkali-Soluble (mg/100 g)	Asc Acid (mg/100 g)	Dehy Asc Acid (mg/100 g)	% Citric Acid	Shear-Press: Max Force (lbs)	Shear-Press: Work Curve (in lbs)
Marshall													
6/5	220	52	51	20.8	25.5	27.1	201	134	51.6	10.0	.61	43.1	20.0
6/15	244	56	56	19.5	25.9	27.8	211	138	51.4	10.1	.65	40.8	18.5
6/24	269	109	52	17.6	30.1	31.6	221	144	47.5	13.6	.65	28.2	13.1
Puget Beauty													
6/5	247	54	124	21.8	27.8	29.3	252	161	55.5	6.4	.63	35.9	16.2
6/15	271	77	123	18.8	24.8	26.2	239	160	54.6	10.3	.63	37.6	16.5
6/24	294	44	103	21.3	27.7	29.1	301	173	52.7	9.4	.67	25.3	14.9
Northwest													
6/5	246	25	99	20.9	24.8	25.8	222	141	51.8	8.1	.63	39.9	20.8
6/15	264	36	94	18.3	25.3	26.4	223	141	52.8	7.5	.70	50.9	20.7
6/24	276	44	74	16.0	28.2	29.1	206	129	45.6	8.3	.56	41.5	20.2
Siletz													
6/5	243	54	89	20.2	24.3	25.9	256	152	49.0	7.5	.77	43.8	22.4
6/15	257	63	90	20.4	26.8	28.3	240	151	43.5	7.5	.81	47.9	21.3
6/24	258	79	70	18.5	26.7	28.2	252	145	45.5	9.8	.73	32.0	16.4

TABLE 4

The effect of variety on objective tests for quality of frozen strawberries

Objective Test	*Means for varieties Marshall	Northwest	Siletz	Puget Beauty
Drained weight (gms)	223.5	220.0	205.75	228.25
Rate of flow, seconds	48.5	60.7	46.0	83.2
% soluble solids	29.17	23.3	23.3	25.0
Shear-press area of work	23.0	31.7	24.7	23.7
Shear-press maximum force	46.4	65.6	49.2	39.6
Weight broken slices	77.0	22.75	68.25	45.25
% total sugars	25.96	24.59	24.87	27.13
H_2O soluble pectins (mg/100 g)	198.0	197.3	170.5	226.15
Alkali soluble pectins (mg/100 g)	141.15	127.85	134.65	190.50
Total pectins (mg/100 g)	339.15	325.175	303.15	416.65

*Means of 3 harvests and 3 replications

Harvest Date. Variety cannot be eliminated entirely when discussing the harvest date or maturity of strawberries. Maturity for processing has been difficult to control in commercial operations due to adverse weather condttions during harvest, and lack of labor for harvesting under such conditions.

Regardless of field treatment, the factor of date of harvest has shown significant differences in objective measurements of quality. Usually the water-soluble pectin, broken slices, soluble and total solids, and dehydroascorbic acid increased with subsequent harvests, (Table 3). Concurrently, the rate of syrup flow, ascorbic acid, firmness, and Hunter "L" value decreased as the season progressed.

Obviously, certain varieties when harvested late in the season have been as firm or firmer than fruit harvested earlier. For example, in 1960 the Northwest variety, which was grown under differnt fertilizer levels, showed greater firmness in the mid-season harvest when measured by the pressure test and shear-press (Tables 5,6). The tendency for poorer quality as the season progressed could have been due to physiological maturity. Since this phenomenon happened consistently across a large number of selections and varieties, it was concluded that an increase in field temperatures at harvest made it difficult to harvest and process strawberries under optimum conditions.

Fertilizer Levels. In the two year study on fruit grown at the North Willamette Experiment Station, there were significant differences due to fertilizer levels. Important differences as a result of fertilizer levels were more difficult to detect on the fresh fruit than on the frozen fruit. This was attributed to the type of tests run on the frozen fruit. The broken slices and rate of syrup flow were quite important in relation to quality of the thawed frozen slices. Also, differences in firmness between treatments as measured by the shear-press were greater on the thawed frozen slices than on the fresh fruit (Tables 5,6).

The water-soluble pectin content was significantly higher in fresh strawberries from plots that received spring applications of nitrogen and potash. Furthermore, the firmness measurements on fresh fruit from these plots showed a tendency for softer fruit although the differences were not significant (Table 5). The differences in strawberries grown on plots with different fertilizer levels were more pronounced in certain harvests than in others. Water level, temperature and maturity probably imposed these greater differences. Three harvests were analyzed fresh and two harvests analyzed after freezing each year of the study. The lack of fruit from the late season harvest permitted analysis of the fresh fruit only. There were significant correlations between firmness measurements of fresh fruit and thawed frozen sliced fruit (Table 7).

Seasonal variations. The seasonal variations were revealed in a number of the separate experiments. These differences were attributed to physiological maturity, weather factors and condition of the strawberry plants at the time of harvest. In the two year study on varieties, the Marshall variety did not grow well because of disease. In the second year, it was impossible to obtain harvests of fruit that were comparable to the other varieties. The strawberries, which were grown in plots that received different fertilizer levels,

TABLE 5

Effect of fertilizer level and Captan spray on fresh strawberries

Objective Tests	Means of *Fertilizer and Captan Treatments					
	1	1A	2	2A	3	3A
Consistency (in. flow)						
Harvest 1	12.5	12.5	12.9	13.1	12.9	12.9
Harvest 2	12.5	12.3	12.0	11.9	11.9	11.7
% Soluble solids						
Harvest 1	7.5	8.6	8.6	8.6	9.1	9.1
Harvest 2	9.4	9.4	10.2	10.3	10.3	10.3
% Total sugars						
Harvest 1	5.3	6.3	6.6	6.2	6.7	6.5
Harvest 2	7.3	7.5	7.2	7.3	7.2	7.6
% Dry matter						
Harvest 1	8.9	9.5	9.9	9.6	10.1	9.9
Harvest 2	10.8	11.1	11.3	11.4	11.7	11.6
% Seed						
Harvest 1	0.9	0.6	0.7	0.5	0.9	0.7
Harvest 2	0.7	0.7	0.7	0.7	0.9	0.8
Water-soluble pectin (mg/100 g)						
Harvest 1	216.7	218.7	228.0	231.3	235.3	230.7
Harvest 2	258.0	260.7	268.0	282.7	291.3	278.0
Alkali-soluble pectin (mg/100 g)						
Harvest 1	190.7	178.7	161.3	162.7	186.7	166.0
Harvest 2	169.3	165.3	199.3	182.7	217.3	215.3
Pressure test (gms)						
Harvest 1	209.4	214.2	208.8	219.0	201.4	203.8
Harvest 2	220.8	227.4	232.2	223.0	225.0	219.0
Shear-press, Maximum force (lbs)						
Harvest 1	50.5	51.8	45.5	45.5	45.1	44.6
Harvest 2	59.3	63.0	56.7	60.1	61.2	59.0
Shear-press, Work curve (in.lbs)						
Harvest 1	35.6	33.7	30.7	31.2	30.9	30.8
Harvest 2	44.9	47.3	47.2	46.1	41.9	41.2

* 1-3. Fall application of 60-120-60 lbs N-P-K /A
2. Plus 40 lbs N /A in spring
3. Plus 40 lbs N and 40 lbs K /A in spring
1-3A. Indicates Captan spray in addition to fertilizer

TABLE 6

Effect of fertilizer level and Captan spray on frozen strawberries

Objective Tests	*Means of Fertilizer and Captan Sprays					
	1	1A	2	2A	3	3A
Drained Weight (gms)						
Harvest 1	219.3	206.0	212.7	204.0	204.3	204.7
Harvest 2	213.7	206.7	213.7	214.7	202.3	202.0
Broken Slices (gms)						
Harvest 1	16.0	16.7	17.0	20.0	26.3	19.7
Harvest 2	24.7	27.0	43.7	36.0	49.7	36.3
Syrup flow (sec.)						
Harvest 1	67.3	67.0	78.0	81.7	75.7	74.0
Harvest 2	88.3	87.3	89.7	101.7	96.0	93.3
% Soluble Solids						
Harvest 1	27.3	27.1	26.8	27.1	28.1	27.5
Harvest 2	27.2	27.1	27.1	27.3	27.5	27.7
% Total Sugars						
Harvest 1	27.3	26.8	26.9	26.7	27.5	26.5
Harvest 2	26.8	25.7	26.8	26.6	26.1	26.4
Water-soluble Pectin (mg/100 g)						
Harvest 1	217.7	216.3	213.7	188.0	183.0	191.7
Harvest 2	208.7	209.3	211.7	208.3	201.0	206.0
Alkali-soluble Pectin (mg/100 g)						
Harvest 1	149.3	142.3	141.7	137.0	117.3	143.3
Harvest 2	155.3	152.7	146.7	150.3	144.7	145.7
Shear-press, Maximum force (lbs)						
Harvest 1	64.1	56.7	57.0	51.0	53.0	57.5
Harvest 2	70.9	70.9	68.8	61.9	62.8	67.2
Shear-press, Work curve (in.lbs)						
Harvest 1	29.2	27.5	26.6	24.1	23.2	26.9
Harvest 2	31.3	30.5	29.9	27.1	26.0	26.7

* 1-3. Fall application of 60-120-60 lbs N-P-K /A
2. Plus 40 lbs N /A in spring
3. Plus 40 lbs N and 40 lbs K /A in spring
1-3A. Indicates Captan spray in addition to fertilizer

TABLE 7

Correlations between firmness measurements of fresh and frozen strawberries from fertilizer and variety experiments

Relationship	Correlation Coefficients: Fertilizer Treatments	Correlation Coefficients: Among Varieties
Maximum Force, Fresh		
Work Area, Frozen	.584**	.826**
Maximum Force, Frozen	.822**	.577*
Work Area Fresh		
Work Area, Frozen	.669**	.739**
Maximum Force, Frozen	.867**	.570*
Pressure Test, Fresh		
Work Area, Frozen	.481*	.511*
Maximum Force, Frozen	.644**	.806**
Work Area, Fresh	.857**	.499*
Maximum Force, Fresh	.807**	.322

* Indicates significance at 5% level.
** Indicates significance at 1% level.

did not show the same chemical and physical characteristics each year. Although these seasonal differences were imposed upon field, handling and processing factors, consistent quality differences were detected by many of the physical and chemical tests performed on the fresh and frozen fruit (Tables 1,2,5,6,8).

Mold Inhibitor Spray. Although the incidence of mold was decreased and the percentage of moldy fruit was higher in unsprayed plots, the differences in quality were difficult to detect by the objective tests employed on the fresh and frozen fruit (Table 5,6). On the last harvest of each year the fresh fruit was more attractive in color when sprayed with Captan due to the reduction in numbers and kinds of fungi. At times there appeared to be differences in quality between sprayed and unsprayed lots when examined visually. However, the physical and chemical tests conducted on the fruit during the three years did not reveal significant differences in quality. These results agreed with the findings of other investigators (2,15). Much of these data have not been shown, and in other cases means of harvests include sprayed and unsprayed plots (Table 8).

Holding Time and Temperature after Harvest. In general, holding strawberries after harvest at room temperature significantly increased the water-soluble pectin, per cent broken slices and firmness of thawed frozen sliced strawberries. The rate of syrup flow, drained weight, alkali-soluble pectin and cellulose were significantly decreased by holding (Tables 8,9). The firming effect that developed during holding probably was due primarily to a drying out of the cortex or a thickening of the cell wall, since this effect was revealed by the pressure test as well as the shear-press test for firmness. It has been mentioned previously under the discussion on varieties that a decrease in rate of syrup flow was related to soupiness of thawed frozen strawberries. The increase in broken slices, water-soluble pectin, and decrease in cellulose and alkali-soluble pectin were also associated with the increase in soupiness in the fruit. Drained weight decreases were probably due to changes in the water holding capacity of the cell wall constituents. There were differences in reaction to holding that was attributed to condition of the fresh fruit. Holding was not too detrimental to firmness of thawed frozen strawberries when the fresh fruit was in good condition if the storage time was not extended beyond 8 hours (Table 9).

Method of Slicing. Fruit that was sliced on the high-speed, serrated blade slicer (McLauchlan) was more mushy than fruit sliced on the slow-speed centrifugal slicer (Table 10). Damage to fruit during slicing was directly related to firmness and rigidity of the entire receptable. Soft fruit did not have sufficient resistance to the cutting blades of the slicer to prevent crushing while being forced through the blades. Certain varieties and selections sliced smoothly but due to mealiness of the medulla region, the mechanical breakage during mixing was excessive. In commercial operations, the losses attributed to slicing were about 3 to 5% when using the ½ inch screen test to measure losses (Table 11).

Speed of Slicing. For this variable, the serrated blade slicer (McLauchlan) was attached to a variable-speed motor. Speeds of 800 to 2400 r.p.m. were tested. It was found that speeds of 900 to 1800 r.p.m. produced sliced strawberries that were firmer and higher in drained weight than either the lower or the higher speeds (Figure 1).

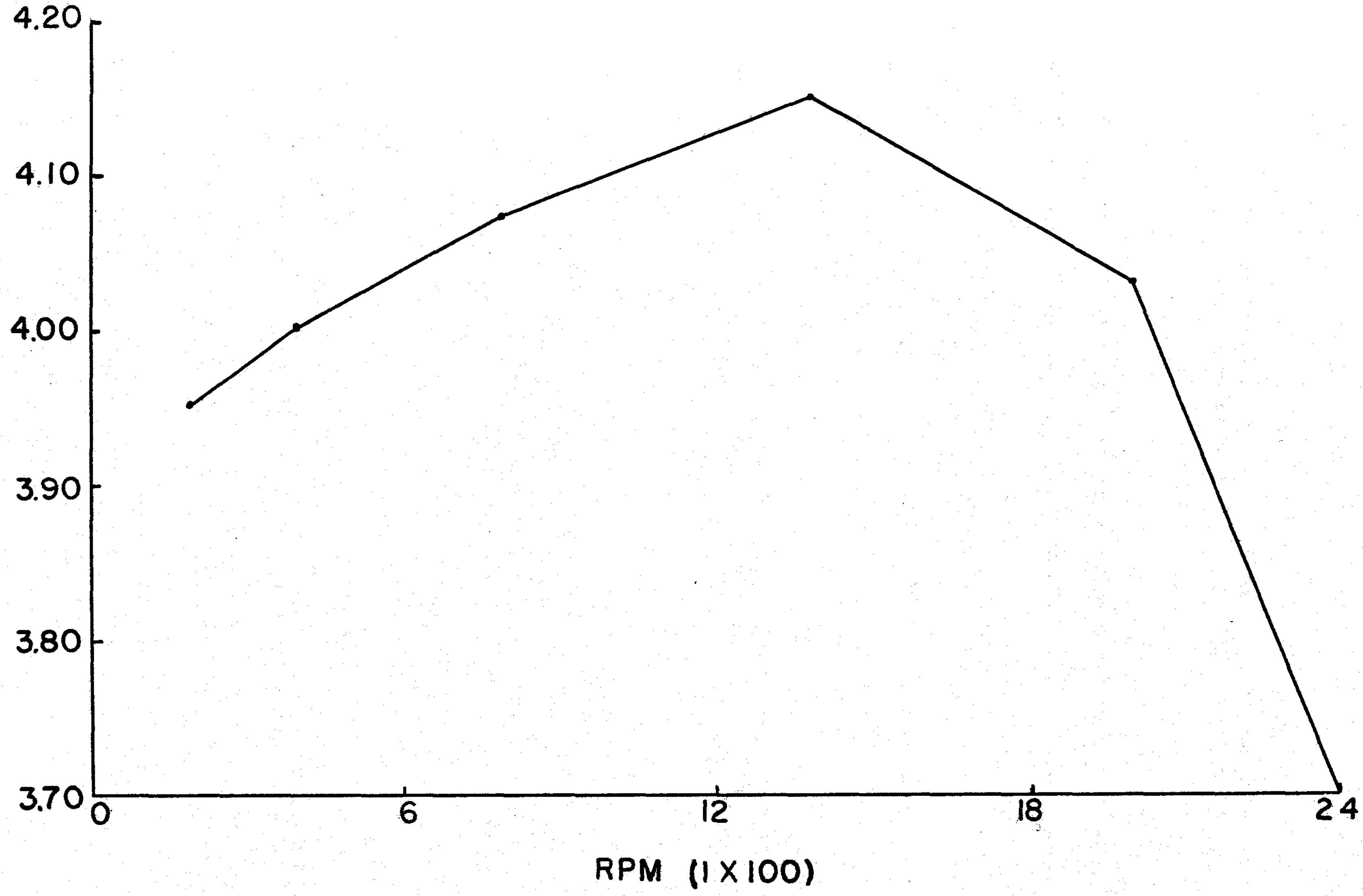

FIGURE 1. EFFECT OF SLICER SPEED ON SHEAR RESISTANCE OF THAWED FROZEN STRAWBERRIES

TABLE 8

Effect of harvest dates and holding on chemical composition and firmness of frozen strawberries, Northwest variety

Objective Test	*Means of harvests Harvest 1	Harvest 1 (Held)	Harvest 2	Harvest 2 (Held)
% Soluble Solids	26.7	25.9	26.5	26.8
% Total Solids	27.78	27.41	27.61	27.44
% Total Sugars	26.69	25.32	24.97	26.16
Drained Weight (gms)	222	211	182	173
Broken Slices (gms)	20	22	35	47
Syrup flow (sec.)	109	102	39	19
Water-soluble Pectin, mg/100 g	184	176	196	187
Alkali-soluble Pectin, mg/100 g	148	159	125	77
Cellulose, mg/100 g	410	350	387	397
Shear-press, Maximum Force (lbs)	69.6	73.4	69.0	69.0
Shear-press, Work Curve (in.lbs)	65.7	69.6	55.8	52.5

*Means of 6 treatments and 3 replications

TABLE 9

Effect of temperature and time of holding prior to freezing on quality measurements of frozen sliced strawberries, Siletz variety

Holding Treatments	% Mushy Slices	Rate of Syrup flow (sec.)	Water-sol. Pectin mg/100g	% Total Acid as Citric	Shear-press Maximum Force (lbs.)	Shear-press Work Curve (in.lbs)
Control	18.3	75	158	.63	52.0	22.5
8 hr 34° F	27.9	63	159	.64	53.7	20.6
8 hr 78° F	22.5	55	170	.65	53.8	21.3
8 hr field & pilot plant (60° to 78° F)	28.1	68	166	.67	49.4	18.5
18 hr 34° F	31.5	67	164	.62	51.7	23.3
18 hr pilot plant	36.6	48	170	.67	52.2	25.7
8 hr field, 18 hr pilot plant	31.2	48	165	.61	57.5	30.3

TABLE 10

Effect of slicing and mixing on quality measurements of frozen sliced strawberries, Siletz variety

Treatments	% Mushy Slices	Rate of Syrup flow (Sec.)	Water-sol. Pectin mg/100 g	% Total Acid as Citric	Shear-press Maximum Force (lbs.)	Shear-press Work Curve (in.lbs)
Control, high speed slicer	26.1	64	205	.67	32.7	22.1
Slow-speed slicer	18.6	68	206	.63	27.2	18.6
Sliced by hand	8.5	69	207	.66	25.4	19.0
15 min. mix	30.9	83	196	.67	22.4	15.0
30 min. mix	45.4	90	218	.68	24.6	12.6
Coarse sugar	28.1	68	208	.69	21.9	15.8
50% syrup	15.5	34	164	.55	22.8	16.7

TABLE 11

Per cent of sliced strawberries retained on one-half inch screen before and after freezing

Plant Number		% Retention by Weight: After Slicing (No sugar)	Mixer Discharge	Conveyor Discharge	Filled Cartons
1.	Fresh	--	75.2	65.5	62.7
	Frozen	--	49.5	47.5	40.6
2.	Fresh	95.1	66.2	---	59.0
	Frozen	62.0	52.4	---	40.6
3.	Fresh	96.3	73.3	---	59.5
	Frozen	70.7	56.3	---	43.6
4.	Fresh	97.7	70.2	---	60.3
	Frozen	68.7	51.9	---	43.1

Method of Mixing. It was found that about 1 min. was required to extract enough juice from the fruit to dissolve the sugar under the gentle mixing conditions using the 5 gal. jar. Fruit and sugar had to be kept in motion immediately following the addition of sugar, otherwise the sugar hardened and dissolved with difficulty. The commercial mixers were found to be quite detrimental to the texture and discretness of sliced strawberries. Wherever the mixing of sliced fruit was minimized, the breakage was not serious. Per cent loss during mixing, as measured on the 1/2 inch screen, was about 15% (Table 11). The breakdown of sliced strawberries in the mixer was attributed to mechanical abrasion with time.

Length of Time of Mixing Fruit and Sugar. Significant increases in viscosity of syrup and per cent mushy slices were apparent when fruit and sugar were mixed for 15 and 30 min. (Table 10). Breakage was at a minimum after 1 min. of mixing in the 5 gal. jar. In a commercial-size mixer, it was calculated that fruit remained in the mixer a minimum of 10 to 15 min. under most conditions. In instances, where employee "breaks" and mechanical breakdowns delayed the preparation for freezing, the fruit and sugar remained in the mixer for 1 hr. Also, where sealing equipment and other packaging difficulties arose, mixed fruit and sugar were added back to the mixer to be filled again. These practices resulted in practically 100% breakage of slices during the mixing and filling operations.

Method of Sugaring. Sliced fruit that was packed in syrup was less mushy than the control lots, but water-soluble pectin, total acidity, and syrup viscosity were lower due to added water in the syrup (Table 10). The color of syrup-pack fruit was oxidized although fruit was firmer and slices were intact. In processing plants, many methods of sugaring fruit were employed. Method of sugaring did not affect breakage of slices unless the mixing operation was altered so that a minimum time of mixing was used. In instances, where attempts have been made to design better methods of mixing, the speed was too slow to be adapted to other high-speed operations during preparation for freezing.

Type of Filler. The fillers used for filling sliced strawberries and sugar have been designed for fluid products. One of the more common types in commercial use was the piston-type filler. Another type was the rotating pocket filler underneath a reservoir that was fitted with a stirring mechanism. Both of these types were rather destructive to the sliced fruit. There was a decrease in whole slices, as measured on the 1/2 inch screen, during the filling operation in different plants that were using different types of mixers. When using the present designs of fillers, extremely firm sliced fruit is a problem to fill uniformly. The juice of firm fruit does not extract readily when mixed with sugar; therefore, the mixture does not flow freely from the filler.

Speed of Filler. The high-speed lines that operate at speeds of 600 to 1000 cartons per minute showed more mechanical breakage of the slices than slower lines. Part of this breakage at certain times during the test might have been due to machine difficulties, resulting in some of the product having to be run through the filler again. There were no controlled studies on speed of filler in plants although samples were taken from two different lines simultaneously. It was observed that slower-type fillers with a small reservoir resulted in less slice breakage.

Method of Freezing. There were many methods of freezing employed in the processing plants that were studied. Most plants froze the packaged fruit after casing by stacking onto pallets. The freezer conditions varied from 0° F with low air velocity to -30° F with high air velocity. Another method of freezing was the plate-type in which the packages were frozen in a relatively short time. Both plate and tunnel-type freezers were sufficiently rapid to prevent oxidative color changes when the capacity was not overloaded, so that the packages had to be removed too soon. Losses in weight during freezing were 17-20%, as measured by the 1/2 inch screen test, regardless of freezing method.

Rate of Freezing. The rate of freezing varied in the different plants from a few hours in a tunnel-type freezer to a week for the product to reach 0° F in the center of the packages that were cased and stacked in pallets. However, it was found that freezing rate did not significantly influence either the firmness or the amount of whole slices retained on a 1/2 inch screen. A few plants froze strawberries at a slow rate primarily to equalize the color although it has been pointed out by some investigators that the color oxidized and flavor was less acceptable when frozen strawberries were exposed to temperatures above 0° F for long periods (8, 9). The change in color directly related to flavor changes and the decrease in ascorbic acid.

Length of Storage. Using the degradation of ascorbic acid as an indicator of quality changes during storage, it was shown that there was little change after 18 months of storage at 0° F. Although ascorbic acid was degraded to dehydroascorbic acid and diketogulonic acid when the temperature was allowed to fluctuate above 0° F (9), no significant change was noted in three different experiments where the fruit was abused prior to freezing and storage at 0° F.

Processing Plant Studies. In order to assess the total losses due to slicing, mixing, conveying, filling and freezing in the four plants that were studied, a pilot plant study was set up to simulate ideal commercial conditions. Firm Northwest strawberries were sliced and weighed into 32 quart jars as quickly as possible to prevent drip losses from the fruit. After adding sugar to make the final mixture 4 x 1 fruit to sugar, the jars were closed and gently rolled to mix the fruit and sugar. As soon as sugar was added moisture was extracted rapidly, while sugar moved into the fruit. At two minute intervals the samples were removed, one of which was used for the 1/2 inch screen test and the other one was frozen.

It was found that the losses during the gentle mixing were minor when the frozen samples were evaluated although there was a slow decline in weight during the sampling period of 75 min. (Figure 2). There was over 47% retention of weight as compared to 40% in the commercial operations (Table 11). However, the pilot plant study showed 13% loss during slicing, yet in the commercial operations this was usually 3 to 5%. This probably was due to the delay that was necessary when weighing samples for the pilot plant study. If one were to subtract this 8-10% difference in slicing between the two, one could conceivably reach somewhere close to 55% intact slices in an ideal situation, which is 15% higher than any of the commercial plants attained.

There were differences in weight retention between different plants at the various sampling stations, but after the sliced strawberries were frozen the weight retention was approximately 40% in all plants (Table 11).

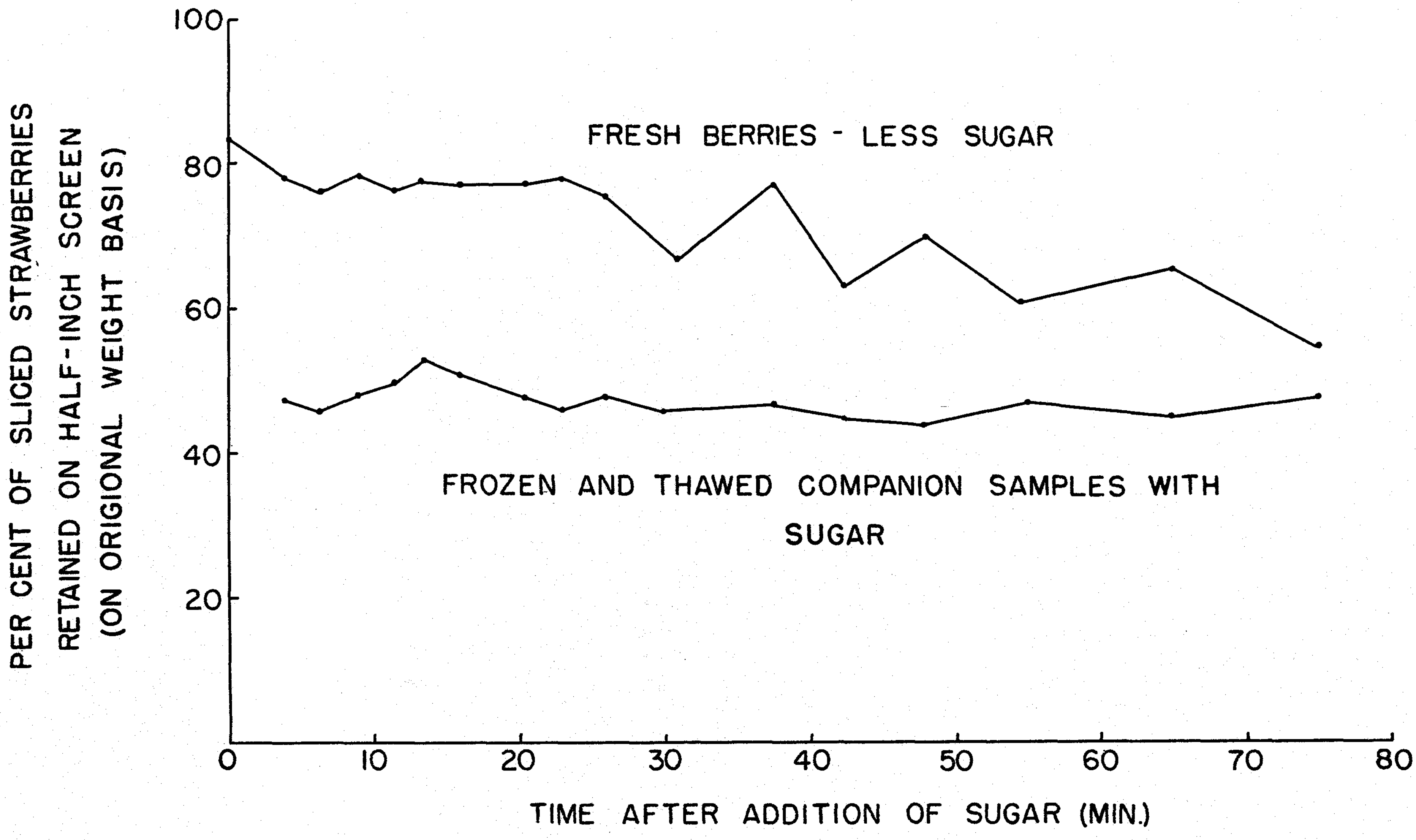

FIGURE 2. EFFECT OF GENTLE SUGAR MIXING ON PER CENT OF STRAWBERRY SLICES RETAINED ON HALF-INCH SCREEN

SUMMARY AND CONCLUSIONS

The problem of breakdown in thawed frozen sliced strawberries was found to be highly complex. Varieties and selections of strawberries reacted differently to freezing. The Northwest variety was consistently firmer in texture, and the thawed frozen sliced fruit was more attractive in appearance than the other varieties under different field, handling and processing conditions during the four year study.

Significant differences were found between varieties in the pressure test and shear-press test for firmness, viscosity of syrup, soluble solids, total solids, broken slices and pectin fractions. Harvest date or maturity produced significant differences in quality when measured by many of the different tests performed. There was an increase in the amount of water-soluble pectin, broken slices, soluble and total solids and dehydroascorbic acid with subsequent harvests. At the same time, the rate of syrup flow, ascorbic acid, firmness, and Hunter "L" value decreased in thawed frozen sliced strawberries.

The time of holding after harvest produced marked changes in certain lots of fresh fruit. Fruit that was in good condition at the time of harvest was held as long as 8 hr at 70° F without detectable changes in quality of thawed frozen fruit. However, the rate of syrup flow, drained weight, alkali-soluble pectin and cellulose of thawed frozen fruit were significantly decreased by holding fresh fruit 24 hr at 70° F, while the water-soluble pectin and broken slices increased.

When the mixing time was increased beyond the time necessary to dissolve the sugar, the broken slices were increased significantly. There were additional losses of intact slices during conveying and filling the mixed fruit and sugar. The freezing loss, as measured by the 1/2 inch screen test, in many oommercial plants and in pilot plant studies was consistently 17-20%. The total weight retention of discret slices, which was based on the weight of the sliced fruit, was approximately 42% in commercial plants as shown in Figure 3. Pilot plant studies, which employed gentle methods of mixing and filling, showed 47% weight retention.

The pressure test and the shear-press test for firmness of fresh fruit were found to be useful for predicting firmness of the thawed frozen sliced strawberries, although in certain varieties and selections the differential between fresh and frozen was greater than in others due to individual characteristics of the cortex and medulla regions of the receptacle. The pressure test, shear-press, pectin fractions, cellulose, drained weight, broken slices, ascorbic acid and dehydroascorbic acid aided in defining differences in quality when the fruit was subjected to different variables prior to processing by freezing. The soluble and total solids, pH and acidity appeared to have no relationship to breakdown of fruit.

The studies made on the many variables involved in this experimental work presented evidence of the causes of breakdown in thawed frozen sliced strawberries. The evidence suggested the following means of improvement:

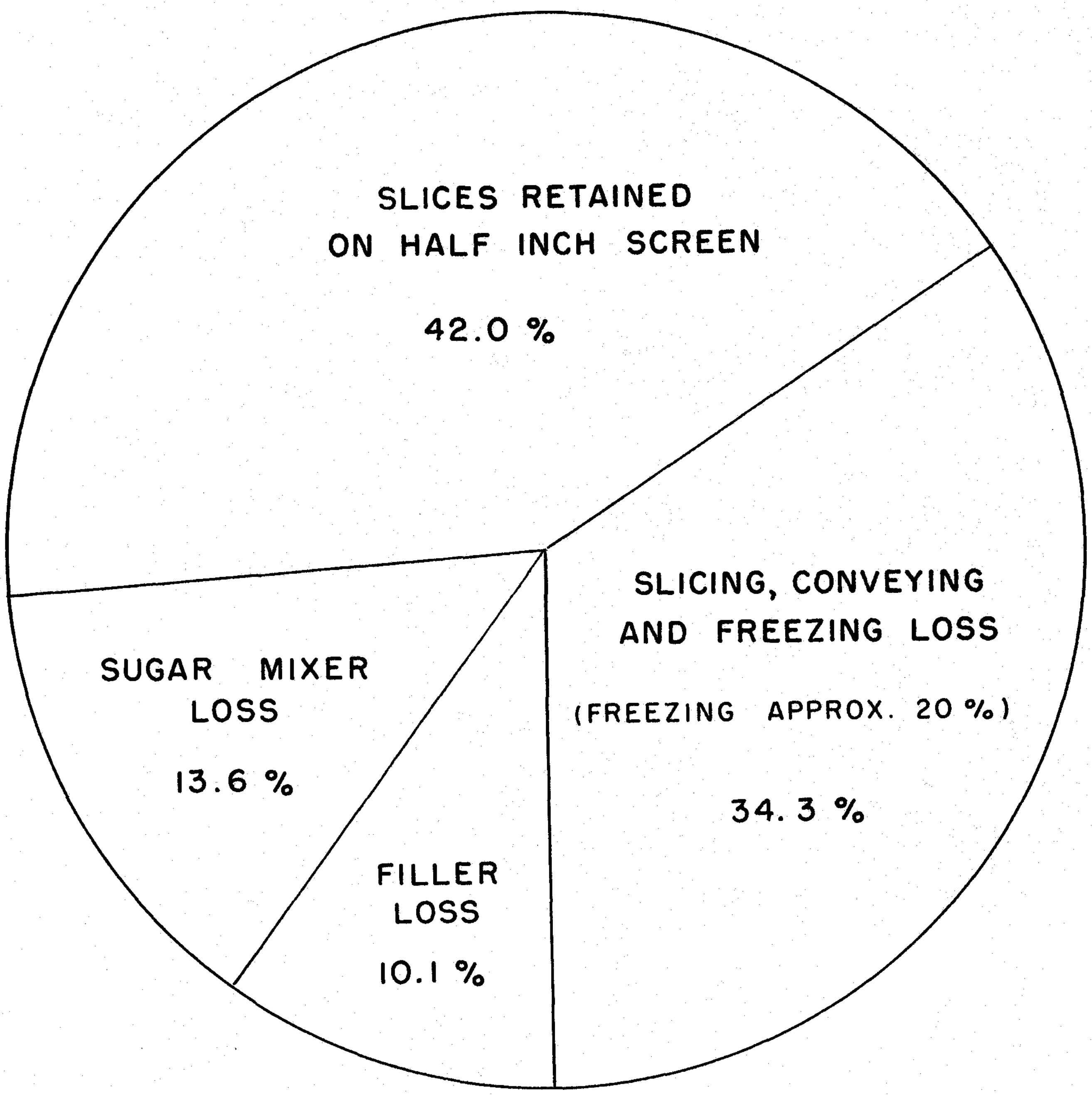

FIGURE 3. AVERAGE DISTRIBUTION OF SAMPLE WEIGHTS FOR FROZEN AND THAWED BERRIES FROM FOUR PLANTS

(1) developing firmer varieties by breeding; (2) harvest present varieties at optimum maturity, or when fruit reaches hard ripe stage; (3) that holding of fruit after harvest, even at optimum maturity, should be kept to a few hours; (4) that bruising the fruit during harvesting and handling should be kept to a minimum by constant surveillance of these operations; (5) that strawberry fields should not be over-irrigated or over-fertilized, a condition that can be detected by obervations; (6) that the present methods of slicing, mixing, conveying, filling and freezing be improved as much as possible without sacrificing efficiency of operations; (7) that equipment designers develop equipment capable of gentler treatment of the product during the mixing, conveying and filling operations; and (8) that commercial plants improve their present handling procedures in the plants to avoid bottlenecks and abuse of fresh and frozen fruits.

Many of the research findings have been applied by the commercial plants in order to improve the quality of frozen sliced strawberries. The research findings on the transmitted characters of varieties and selections have been introduced into the breeding program to speed-up the development of firmer varieties. Further experimental studies should be made on the polysaccharides in strawberries, especially those connected with cell-wall structure, in order to define more specifically the differences between varieties, and the changes taking place under variable conditions.

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