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INTRODUCTION

Weight and bulk are extremely important factors to be considered in the design of foods for military operations involving transportation or storage of foods. Reduction up to 90% in the weight of foods carried to or by the combat soldier have been achieved by freeze-drying. These foods, because of their porous structures are fragile and bulky. The logistical advantages of compression, reducing volume by up to 90%, are readily apparent, not only for the combat soldier but also for underwater and surface naval vessels, aircraft and space vehicles. Significant savings would also be realized in packaging materials, storage space and transportation costs, which would redound beneficially upon the environment through reduced disposal requirements.

THE PROBLEM

Direct compression of freeze-dried foods results in fractures or powders. Optimum processing conditions for achieving compression without sacrificing quality and acceptability are not well defined. The effects of pressures up to 2000 pounds per square inch on the cell structures and the textural qualities of foods are not fully understood.

THE OBJECTIVE

The objective of these studies was the reduction of food weight and volume while maintaining overall quality, nutritional value, stability and acceptability. Three research and development approaches were pursued:

1. Reversible compression of foods for consumption only in a reconstituted state.

2. Nonreversible compression of foods for consumption only in the compressed state.

3. Dual purpose compression of foods for consumption either in the more dense form or after reconstitution to a familiar form.

REVIEW OF LITERATURE

The feasibility of compressing foods and subsequently restoring them was first recognized by Ishler (1). He indicated that successfully compressed freeze-dried cellular foods can be achieved by spraying with water to 5-13% moisture, compressing and redrying to less than 3% moisture.

These findings were later confirmed by Brockmann (2). Techniques have been remarkably improved in the past few years, the most notable studies being those of Mackenzie (3) and Rahman (4) relative to conditioning, compression pressure and dwell time procedures.

However, the texture (turgidity) of rehydrated products after compression is usually less firm than their counterparts due to the numerous treatments required before the compression of foods, namely blanching, freezing and freeze-drying. The physical properties that reflect the turgidity depend largely upon the structural arrangement and chemical composition of the cell walls. Since the intercellular cement is primarily composed of pectic substances (5,6,7) any agent or process which breaks down those substances can obviously bring about cell separation. Heating can cause breakdown of pectic substances in fruits and vegetables and ultimate separation of intact cells (8,9,10). Further processing such as freezing and freeze-drying can cause further changes to the cells. This was realized by Fennema (10) and Reeves (11) who indicated that freezing, especially slow freezing of fruit and other multicellular structures, often damages the tissue and ultimately the texture.

Nonreversibly compressed foods which can be eaten without rehydration, such as fruit bars and beef jerky bars, have also been successfully developed (12,13). In addition, reversibly compressed food bars were developed which can be eaten dry or rehydrated in either hot or cold water, requiring a maximum of 10 minutes to restore normal appearance and texture (14). These food bars were developed as prototype components for a potential seven-day strategic operations patrol ration packet.

EXPERIMENTAL PROCEDURE

1. Reversible Compression of Foods for Consumption in the Reconstituted State.

Materials preparation:

Carrots, peas and green beans were used as prototype foods to determine the effects of processing variables on the quality of compressed finished products. Freshly mature carrots of the Imperator variety were washed and peeled. They were then decorticated to separate the xylem tissue from the phloem portion which was used in these studies. The phloem portion was diced to 3/8 x 3/8 x 1/8 in. and divided into 8 lots. Each lot received one of the following treatments, and all treatments were replicated: a. Raw (no treatment). b. Blanched 3 min. in boiling water. c. Cooked 10 min. in boiling water. d. Frozen at 0°F. e. Frozen at -30°F. (blast freezing). f. Frozen at -320°F. (liquid nitrogen immersion). g. Frozen at 0°F. or -320°F., and then freeze-dried at platen temperature of 120°F. to a final moisture content less than 2 percent.

Peas and green beans were individually quick frozen (IQF) at -30°F. The seed coat of the peas was mechanically slit at several points. Frozen peas and green beans were then freeze-dried as above.

Compression:

The freeze-dried peas, carrots and green beans were compressed as follows:

1. Placticizing by subjecting to live steam for 5 min. or by spraying with water to 8-12% moisture.

2. Equilibrating.

3. Compressing at 1000, 1500 or 2000 psi to form bars 3 x 1 x ½ in. or discs approximately 3-3/4 in. diameter and ½ in. thick.

4. Redrying to approximately 2 percent moisture.

Test Procedures

a. Compression ratio: To determine compression ratios, the dehydrated vegetables were compressed at 1500 psi into discs approximately 3-3/4 in. diameter, so that they would fit into a No. 2½ can. The compressed discs required to fill the can, leaving approximately ¼ in. headspace, were weighed. Uncompressed freeze-dried product of equivalent weight to that of the compressed was packed loosely in No. 2½ cans leaving approximately ¼ in. headspace. The number of cans utilized to pack the loose product gave the compression or packaging ratio.

b. Bulk density: Bulk density was measured by dividing the weight of product by its respective volume to yield grams per cubic centimeter. Calculated compression ratio was then determined by dividing the bulk density of the compressed product by that of the uncompressed.

c. Water holding capacity: Water holding capacity was measured by placing the carrot dice in a small cornical shaped screen that fit snugly inside a centrifuge cup (Fig. 1), and then centrifuging for 10 minutes at 500, 1000, 1500, 2000 and 2500 rpm respectively. The liquid extracted from the carrots into the centrifuge cup was weighed and the weight loss of the carrots calculated.

d. Texture: Texture was measured with the Allo-Kramer Shear Press using the 5000-pound ring with a 30 sec. downstroke. In addition, texture was evaluated by a technological taste panel of 10 trained judges using a 9-point scale ranging from 1 = extremely poor to 9 = excellent (15).

e. Histological studies: Carrot dice or peas were fixed in FAA (Formalin-Acetic acid-alcohol) and dehydrated with a series of solutions of ethanol and butanol. They were then embedded in parafin, cut to 10-12 micron ribbons, mounted on slides and stained with Hematoxylin and Safranin. Microscopic examinations were made on these slides and photomicrographs were taken.

2. <u>Nonreversible Compression of Foods for Consumption Only in the Compressed State</u>.

Material: Food ingredients used during the course of these studies such as dates, figs, maraschino cherries, golden raisins, sesame and nuts were locally purchased. During preliminary work products such as apricots, prunes and brown raisins were also studied, but were found to discolor excessively during storage at 100°F. The dates, figs, and maraschino cherries were chopped into pieces of approximately $\frac{1}{4}$ in. All fruits were dehydrated to a moisture range of 7-14% since it was impractical to compress fruits with their original moisture of 15 to 35 percent due to excessive extrusion of pulp. Moisture content below 7% resulted in excessively hard bars. Two percent lecithin was added before compression on a Carver Press using approximately 200 psi.

Bulk density was measured as indicated previously. Texture was measured by the Instron Universal Testing Apparatus, Floor Model TT-DM with a 500 Kg cell. The samples were penetrated to 50% of initial thickness at a speed of 2 cm/min. using a cylindrical 0.75 cm punch. Results were expressed as (1) firmness, which is the force at 50% penetration (2) toughness, which is the work expended for a 50% penetration, and (3) maximum force in Kg, which is used as an empirical measurement of "hardness".

The caloric value was determined by the Parr Oxygen Bomb Calorimeter. Moisture content was determined in accordance with the A.O.A.C. method using vacuum.

3. <u>Dual Purpose Compression of Foods for Consumption Either in the More Dense Form or After Reconstitution to a Familiar Form</u>.

Products such as beef noodle soup, kidney bean salad, cherry, and cornflakes were formulated, freeze-dried, and then compressed and packaged (14). Compression forces of approximately 200 psi for the corn flakes, 150 psi for the soup, and 1000 psi for the function of freezing temperature was in the same relative order as the measured changes in texture and water holding capacity. Only slight additional damage to cell structure occurs during freeze-drying and compression. No such tissue disruption is seen as a result of either blanching or cooking of fresh, raw carrots (Fig 6 A,B,C).

Table 1 shows that neither conditioning moisture level nor compression force affected the rehydration ratio and the texture of compressed peas as measured by the shear press or by a technological panel. Figure 7 shows no apparent difference in cell separation or disruption of cell walls in peas compressed at 1000, 1500 or 2000 psi compared to uncompressed peas. Results shown in table 2 indicate that compression ratio as determined by actual filling of cans, is slightly lower than that calculated from the bulk densities. This is due to the allowances given to headspace, the space between the compressed discs and the can wall needed to facilitate packing and unpacking of the product, and space between the discs due to uneven surfaces caused by relaxation of the product after compression. Figure 8 shows the practical compression ratios of 4:1, 14:1 and 16:1 for peas, carrots and green beans.

The compression ratios of fruit bars which can be eaten as is such as date, raisin, date cherry ranged from 2:1 to 3:1. (Table 3). The caloric value of the four bars ranged between 3.7 and 4.6 cal. per gram. The uncompressed products ranged between 1.6 and 2.8 cal. per cc whereas in the compressed product the range was significantly increased to between 5.0 and 5.8 calories per cc. Table 4 indicates that the addition of the emulsifier, lecithin, significantly improved the texture of the bars as determined by the Instron Universal Testing Apparatus.

Test results for compressed bars which can be eaten as is or rehydrated to a familiar food such as beef noodle soup, kidney bean salad, cherry, and corn flakes are shown in Table 5. Quality characteristics of such bars as determined by technological panels as well as by objective means, in the dry or the rehydrated form are considered satisfactory.

CONCLUSION

Three research and development approaches for the production of compressed foods have been described. Results indicate that such compressed foods can be successfully produced without appreciably sacrificing their overall quality. Reduction in volume ranging from 4 to 16 fold have been achieved. For example, a truckload of freeze-dried, compressed green beans contains as much food as 16 truckloads of the uncompressed. This is extremely significant in terms of savings in packaging material and logistical advantages of reduced handling, storage and transportation. In addition, environmental improvement due to a lowered waste disposal requirement will result.

other two were used. The following tests were made on the compressed bars:

a. Drop test: A 5/8-inch diameter steel ball guided by 3/4-inch diameter glass tubing was dropped a distance of 26 inches onto the bar resting upon a hard, flat surface. The number of drops necessary to cause a break and the type of break were used for the evaluation of hardness and brittleness.

b. Break score: Evaluation of break at end of drop test: 5 - very clean break, 4 - clean break, 3 - some shattering, 2 - very much shattering, 1 - disintegrated.

c. Technological panel evaluations were conducted by ten members using the 9-point scale previously described.

The results of these studies were statistically analyzed and the least significant difference was determined as applicable.

RESULTS AND DISCUSSION

Effects of blanching, cooking, freezing, freeze-drying and compression on the water holding capacity of carrots, as determined by the weight loss upon centrifugation are shown in figure 2. Weight loss of carrots at 5 centrifugal speeds ranging from 500-2500 rpm increased with the following treatments: (1) fresh; (2) blanching; (3) cooking for 10 min; (4) freezing raw carrots at -30°F. and then thawing; (5) freeze-drying, compressing and then rehydrating. The figure indicates that freezing raw carrots results in a greater weight loss than does heating. The weight loss of freeze-dried carrots compressed at 1500 psi and then rehydrated was only slightly higher than the uncompressed freeze-dried carrots. Weight loss resulting from centrifugation was least for carrots frozen at -320°F. followed by freezing at 0°F. and at -30°F. respectively (Fig. 3). Therefore, freezing temperature appears to be the major factor affecting the water holding capacity of carrots.

The texture of raw carrots became increasingly soft from blanching to cooking and from freezing and thawing to freeze-drying and rehydration. When freeze-dried raw carrots were compressed at 1500 psi and then rehydrated, the texture was only slightly softer than uncompressed controls.

Firmness of frozen and thawed carrots, measured by the shear press was highest when frozen at -320°F., less at 0°F. and lowest at -30°F. This relationship persisted through freeze-drying and compression (Fig. 4) and was similar to the effect of freezing temperature upon water holding capacity (Fig. 3). Structural changes in the cells of the carrot tissue appear to be related to both the softening and loss of water holding capacity. Figure 5 shows the physical changes - cell separation and disruption of cell walls - which occur during freezing and as a result of subsequent freeze-drying and compression. The extent of these changes as a

As a result of these findings procurement specifications were prepared for compressed peas, green beans, spinach and onions. Limited quantities of compressed peas were commercially produced and tested nationwide by the Military services during 1969 and 1970. They were highly accepted by the four services comparing favorably with the canned or the frozen product, and were recommended for inclusion in the current feeding system. Accordingly in 1971, limited quantities of compressed green beans, spinach and onions were commercially produced in accordance with our specifications to be tested by the Military services in the near future.

The fact that a segment of the food industry, due to the help and encouragement of the U.S. Army is geared toward the production of compressed foods is a significant step toward the success of the food compression program which was initiated and pursued by the Military through inhouse as well as contract research.

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Conditioning moisture %	Compression pressure psi	Shear press force lbs	Rehydration ratio	Average sensory scores for texture
0	0	285	4.2	6.3
8	1000	225	4.3	5.6
8	1500	219	4.3	5.8
8	2000	237	4.0	5.0
12	1000	275	4.0	5.7
12	1500	280	3.9	6.0
12	2000	250	3.9	6.3

Table 1 - Effect of Conditioning Moisture and Compression Force on Texture and Rehydration Ratio of Compressed Peas

Product	gms/cc Freeze Dried	gms/cc Compressed	Compression Ratio	
			Calculated from Bulk Densities	Measured by Actual Fill of Cans
Peas	0.216	.889	4.1	4
Carrots	0.036	0.530	14.7	14
Green Beans	0.038	0.615	16.3	16

Table 2 - Bulk Densities of Freeze Dried Vegetables before and after Compression

Fruit Bar	Uncompressed		Compressed		Compression Ratio	Calories per/gram
	Bulk density gm/cc	Calories per/cc	Bulk density gm/cc	Calories per/cc		
Date Cherry	0.43	1.6	1.32	5.0	3.0	3.8
Date Fig	0.49	2.1	1.26	5.5	2.6	4.4
Date Sesame	0.62	2.8	1.27	5.8	2.0	4.6
Raisins	0.57	2.0	1.54	5.7	2.7	3.7

Table 3 - Bulk Density and Caloric Value of Fruit Bars

Product	Firmness Kg/cm	Toughness Kg/cm	Maximum Force Kg/cm	Tech. Panel Ratings for Texture
Date bar treated with lecithin	5.1	3.9	5.6	6.2
Date bar without lecithin	6.9	5.1	7.4	4.6

Table 4 - Texture of Date Bars

Tests	Beef Noodle Soup	Kidney Bean Salad	Cherry	Corn Flake
Drop Test	7	1	3	2
Break Score	5	4	5	3
Moisture (%)	3.3	3.1	2-4	12.5
Panel Scores(Dry)				
Color	6.1	6.6	6.8	7.4
Odor	6.0	6.3	7.2	7.4
Flavor	5.6	6.1	6.7	6.9
Texture	5.7	5.8	6.2	5.7
Panel Scores(Rehy)				
Color	5.7	6.2	6.1	6.8
Odor	5.9	6.4	6.4	7.4
Flavor	5.0	6.1	5.3	7.1
Texture	5.6	5.3	5.3	6.7

Table 5 - Test Results for Compressed Bars

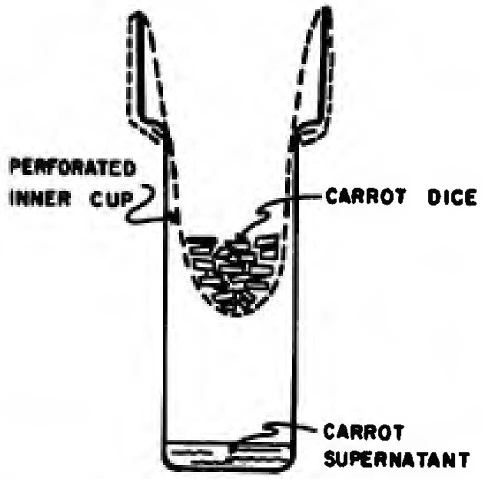

Fig. 1—Diagram of a centrifuge cup fitted with perforated inner cup for determining water holding capacity in carrots by means of centrifugation.

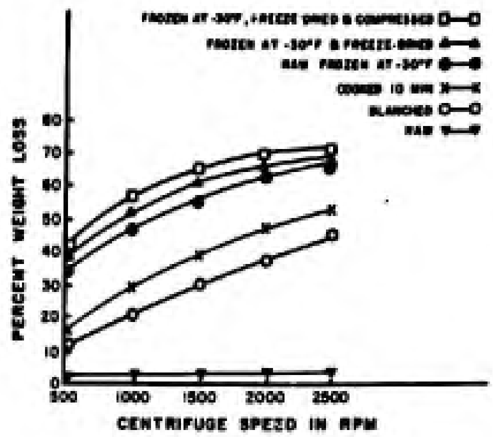

Fig. 2—Weight loss in carrots as affected by processing variables and measured by centrifugation.

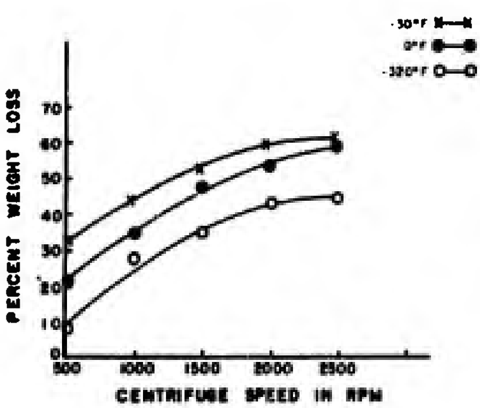

Fig. 3—Weight loss in carrots as affected by freezing temperature and determined by centrifugation.

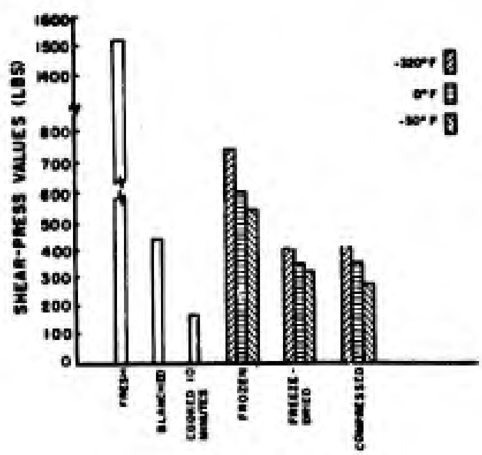

Fig. 4—Texture of carrots as affected by processing variables and measured by the Allo-Kramer shear press.

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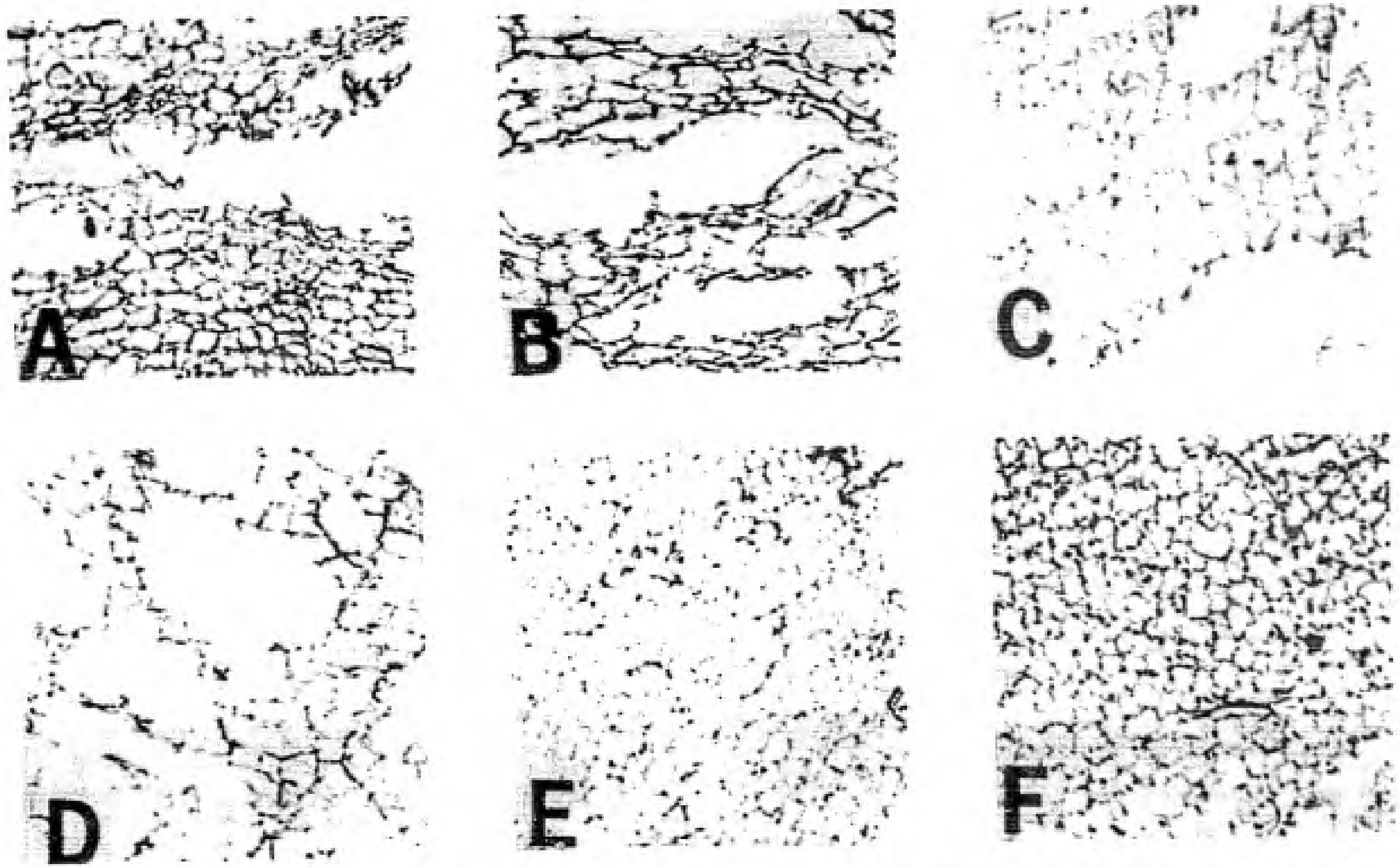

Fig 5 Cross sections of phloem region of carrots as affected by freezing temperature, freeze-drying and compression: All figures X 60. (A) Frozen at 0°F.; freeze-dried and rehydrated; (B) frozen at 0°F., freeze-dried, compressed and rehydrated; (C) frozen at -30°F. freeze-dried and rehydrated; (D) frozen at -30°F., freeze-dried, compressed and rehydrated; (E) frozen at -320°F., freeze-dried and rehydrated; (F) frozen at -320°F., freeze-dried, compressed and rehydrated.

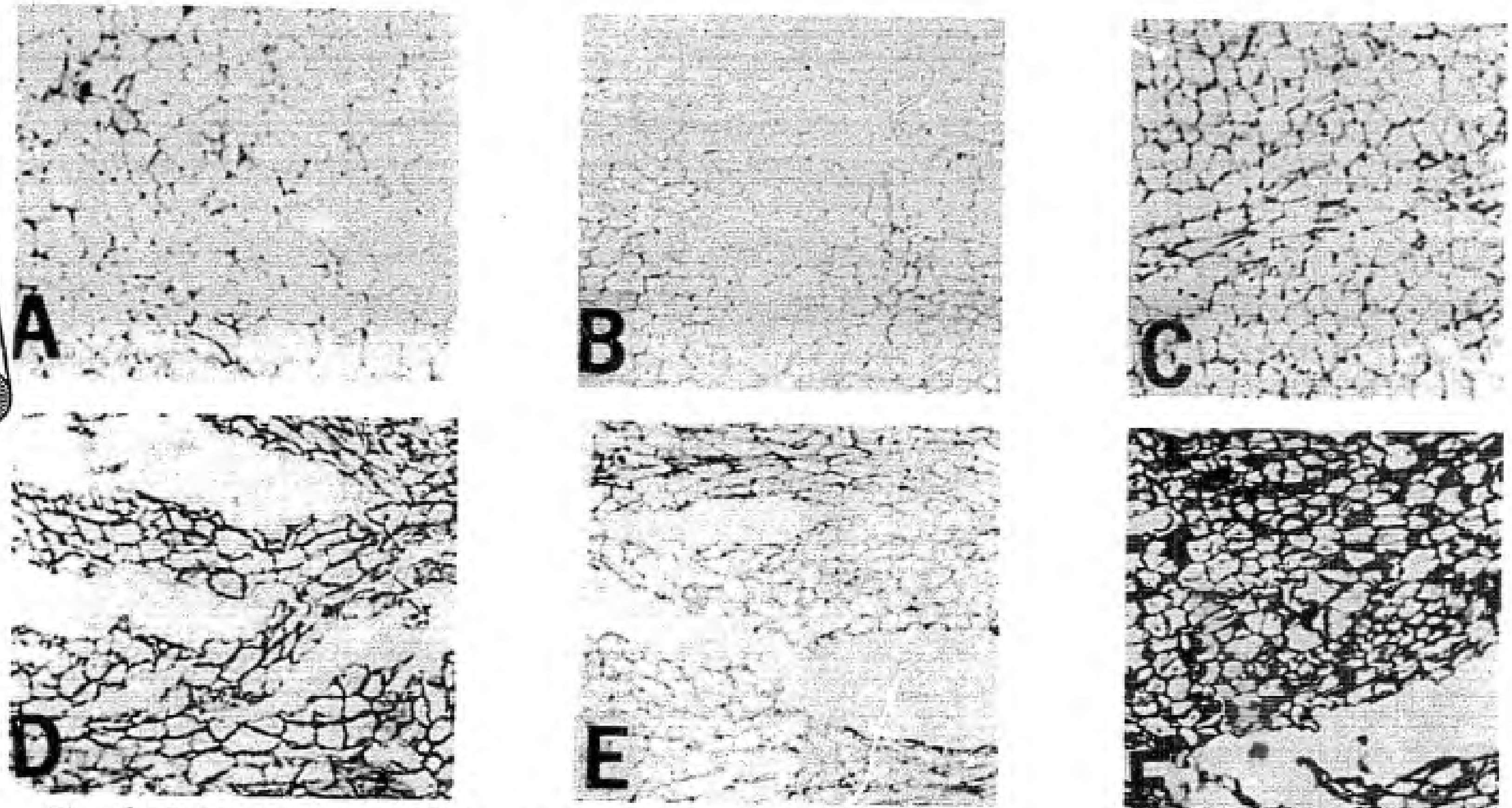

Fig. 6 Cross sections of phloem region of carrots as affected by the following treatments: All figures X 60. (A) Fresh (no treatment); (B) blanched; (C) cooked for 10 minutes; (D) frozen at 0^{o}F.; (E) freeze-dried and rehydrated; (F) F.D., compressed and rehydrated.

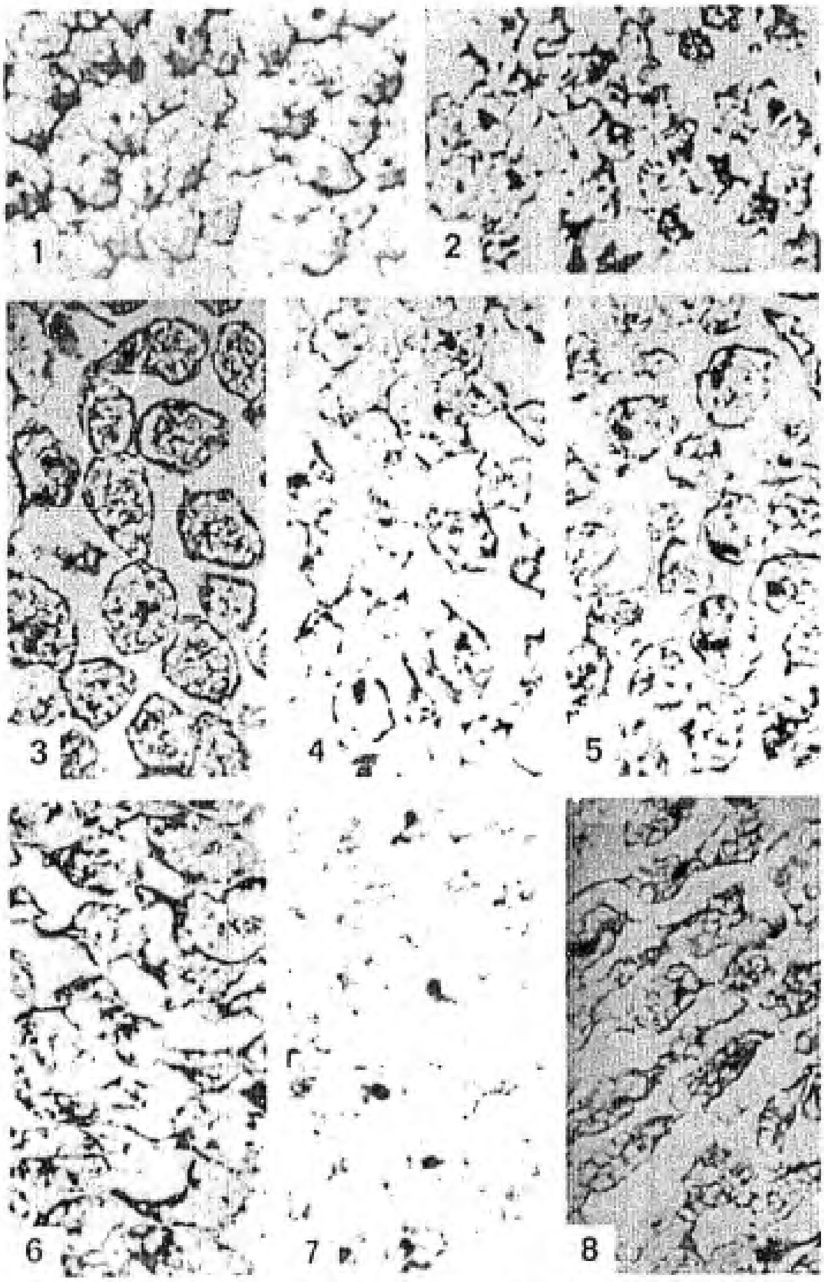

Fig. 7 Cross sections of fresh, freeze-dried rehydrated, and freeze-dried and compressed peas showing the effect of conditioning moisture (low) and compression pressure. All figures X100. 1, fresh; 2, freeze-dried and rehydrated, 3, 4, and 5, freeze-dried conditioned with 8% moisture and compressed under 1000, 1500, and 2000 psi respectively; 6, 7, and 8, freeze-dried conditioned with 12% moisture and compressed as above.

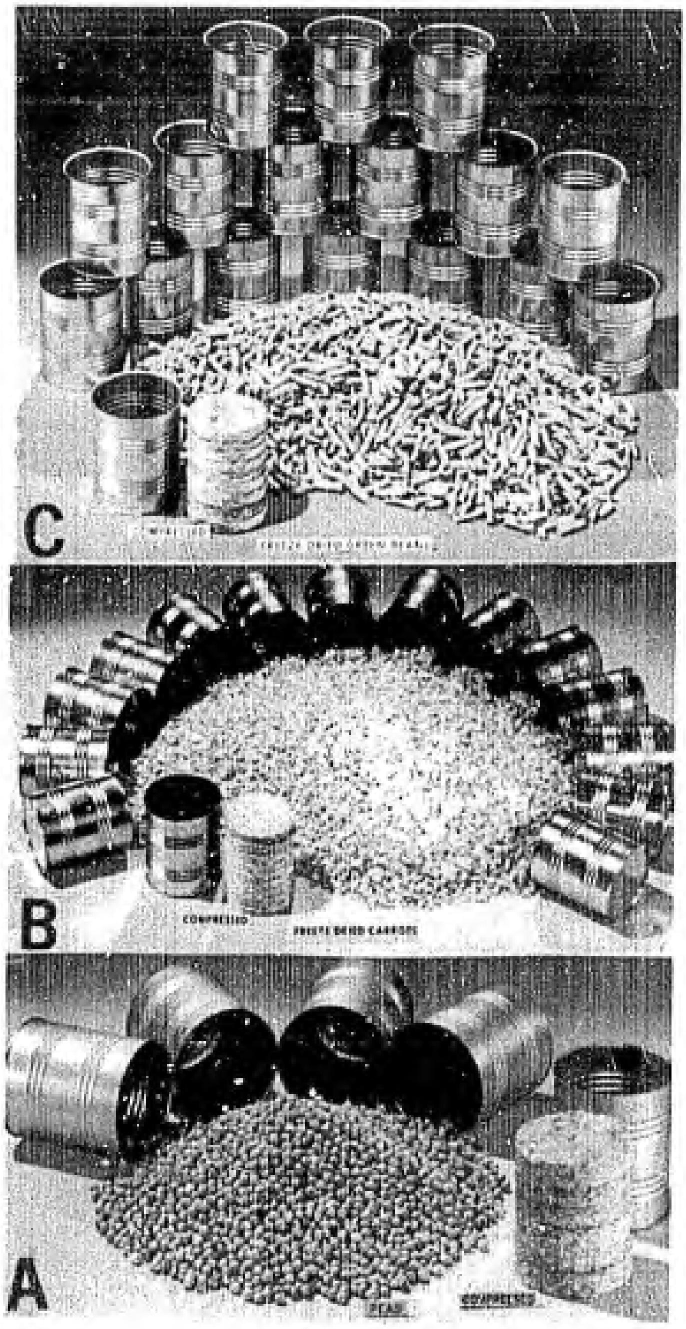

Fig. 8 Compression Ratios of 4:1 for peas (A), 14:1 for carrots (B) and 16:1 for green beans (C).

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