

## IMPROVEMENT OF THE TEXTURE OF DEHYDRATED CELERY BY GLYCEROL TREATMENT

### INTRODUCTION

DEHYDRATION is a reliable process for the preservation and reduction of weight of foods. The Armed Forces are expanding their usage of freeze-dried foods for these reasons. The high-water content plant products (celery, tomatoes, lettuce, etc.) primarily used for salads, do not withstand the freeze-drying process. They rehydrate to a mushy, unacceptable product due mostly to tissue damage during freezing. The purpose of this study was to develop a method of dehydrating celery so as to retain turgidity upon reconstitution. A process was sought which would reduce tissue damage and yield a product with good eating qualities.

#### Literature review

Dehydration, as well as freeze-drying techniques used in previous studies on celery, have failed to yield a product which, after rehydration, retains its textural qualities (Neubert et al., 1968; Schwimmer, 1969; Sullivan and Cording, 1969; Wilson, 1965). Upon examination of these processes, it became apparent that freezing and drying cause an irreversible damage to the celery tissue. Meryman (1966) points to the paradoxical situation that most labile biochemicals, even living organisms, can be stabilized by freeze-drying, but this success is not duplicated with food. Damage may occur during freezing, drying, storage and reconstitution. Such damage, which is cumulative,

becomes apparent when the rehydrated product is eaten. Blast freezing to  $-20^{\circ}\text{F}$ ., ordinarily used to freeze foods before freeze drying, causes severe damage. However, the freezing rate and the final temperature are important factors in minimizing damage to cells (Joslyn, 1966; Mazur, 1963; Mohr and Stein, 1969). Finkle (1971) believes that the large ice crystals which are formed at the intermediate sub-zero temperatures are responsible for tissue damage. The general belief is that in plant tissue intracellular ice crystals develop at slower freezing rates. This type of freezing dehydrates the cells, thereby enlarging the intracellular spaces. Ice crystal enlargement to many times the size of individual cells, disrupts cell membranes and middle lamellae, etc., causing textural changes (Finkle, 1971; Joslyn, 1966; Mazur, 1970; Meryman, 1966; Moore et al., 1969). Levitt (1966) hypothesized that freezing damage is due to the closeness of macromolecules caused by water loss during freezing. This compaction favors the formation of disulfide bonds which distort the product upon rehydration.

Freezing and desiccation damage are analogous in that both are attributed to water loss from vital positions in the cell (Finkle, 1971; Parker, 1969). While the importance of bound water, disulfide bonding, etc., are considered significant, there is less literature pertaining to mechanical damage in desiccation. The re-

quirements for protection, however, seem to be very similar, if not the same.

Most researchers agree that the best way to prevent freezing and desiccation damage is through the use of chemical additives. Manipulation of freezing rates and final temperatures may be important (Finkle, 1971; Moore et al., 1969), but are not satisfactory solutions by themselves. Most researchers agree that a useful protective agent must: preserve biochemical integrity of membranes, prevent water from freezing (formation of hydrogen bonds), permeate the cell membrane freely, prevent shrinkage below a minimum size, be a solvent for electrolytes, and be nontoxic (Finkle, 1971; Heber, 1968; Mazur, 1970; Meryman, 1966; Williams, 1969). These properties would also be effective in preventing damage according to other theories (Levitt, 1966; Parker, 1969). This was refined even further by the requirement that the additive must be edible and minimize any change in the organoleptic properties. Of the chemicals reviewed for use, glycerol seemed to be the most promising. It satisfied more of the above requirements than any other additive.

### EXPERIMENTAL

#### Preparation of dehydrated celery

Fresh California celery was locally procured and the outer stalks sliced into  $\frac{1}{4}$  in. cross-cut pieces. Equal quantities were soaked for 18 hr

Table 1—Experimental data on pretreated dehydrated celery

% Glycerol	Wt of celery after soak <sup>a</sup>	% Moisture after soak	After dehydration	Rehyd ratio <sup>b</sup>	% Yield <sup>c</sup>
100	—	40.1	4.0	3.1	54.8
90	89.5	—	—	2.7	54.0
80	104.0	46.2	4.1	2.9	47.0
70	115.5	36.0	—	2.8	63.5
60	129.0	32.0	3.8	3.0	61.2
50	153.3	52.0	—	2.8	62.1
40	184.2	63.0	3.5	3.1	67.3
30	172.6	67.5	—	3.4	59.7
20	189.0	76.8	3.7	4.0	55.2
10	180.5	85.6	—	6.2	48.1
0	300.0	95.5	1.7	12.1	35.2

<sup>a</sup>Original fresh celery, wt 300g

<sup>b</sup>Rehydrated wt/dry wt (inc glycerol)

<sup>c</sup>Rehydrated wt/original wt  $\times 100$

Table 2—Texture of freeze-dried vs. air-dried glycerated celery (technological panel analysis)<sup>a</sup>

% Glycerol treatment	Air dried	Freeze dried
0%	4.3	2.0
10%	5.2	5.0
20%	5.9	4.4
40%	6.1	5.4
60%	6.1	5.8
80%	5.9	5.4
Fresh celery (control)	7.5	7.5
LSD	0.8	1.3

<sup>a</sup>1—Extremely poor; 2—Very poor; 3—Poor; 4—Below fair, above poor; 5—Fair; 6—Below good, above fair; 7—Good; 8—Very good; 9—Excellent

in aqueous glycerol solutions of 0–100% (by volume) at 10% intervals. An excess of the glycerol solutions (2:1 by volume) was used for equilibration. This glycerol treatment is somewhat similar to osmotic dehydration as explained by Ponting et al. (1966).

Equal quantities representing each variable were freeze dried following commercial practices. It should be understood that glycerol treated samples underwent low temperature evaporative drying rather than true freeze-drying as the glycerol prevented freezing in most cases. At the same time, similar quantities were air dried in a bin drier with blowing air at 110°F for 16 hr. For rehydration, the samples were put in excess water (approximately 10 to 1 by weight of water to celery) and stored overnight at 40°F followed by two changes into fresh water. Weights and percentages of moisture (determined by weight loss after 16 hr at 70°C in a vacuum oven) were recorded before and after the various treatments to determine the direct effects of the processes. Percent glycerol in the rehydrated product was determined by the Perodate method (AOAC, 1970).

**Sensory evaluation**

Sensory evaluation panels of 15 members (food technologists) were used to determine the odor, flavor, texture, color and appearance qualities of the various rehydrated samples: ratings were on a qualified scale from 1 to 9 (extremely poor to excellent, Pilgrim and Peryam, 1958). No attempt was made in this study to correlate these tests with acceptability.

**Mechanical measurements**

The Allo-Kramer shear press has been used in this (Kapsalis et al., 1970a; Rahman et al., 1969) and other (Sullivan and Cording, 1969) laboratories to measure the texture of foods expressed as a maximum cutting-extrusion force. Freeze-dried celery was found to be spongy and tough (in sensory terms) upon rehydration, whereas fresh celery is crisp due to turgidity of the tissue. Preliminary studies indicated that the Kramer shear press did not adequately differentiate between the toughness and crispness that the technological panels indicated existed.

The Instron Universal Testing Apparatus (Kapsalis et al., 1970b) was used because it was capable of differentiating the textural changes. Fifteen replicates of each treatment were tested.

Celery slices ¼ in. thick were compressed to the rupture point, using a cylindrical, flat-surfaced anvil 57 mm in diameter moving at a speed of 1 cm/min. The force of compression

was recorded on a L/N ¼ sec recorder, the chart running at a constant speed of 30 cm/min. Two parameters were determined for these curves: (1) Toughness, defined as the work per

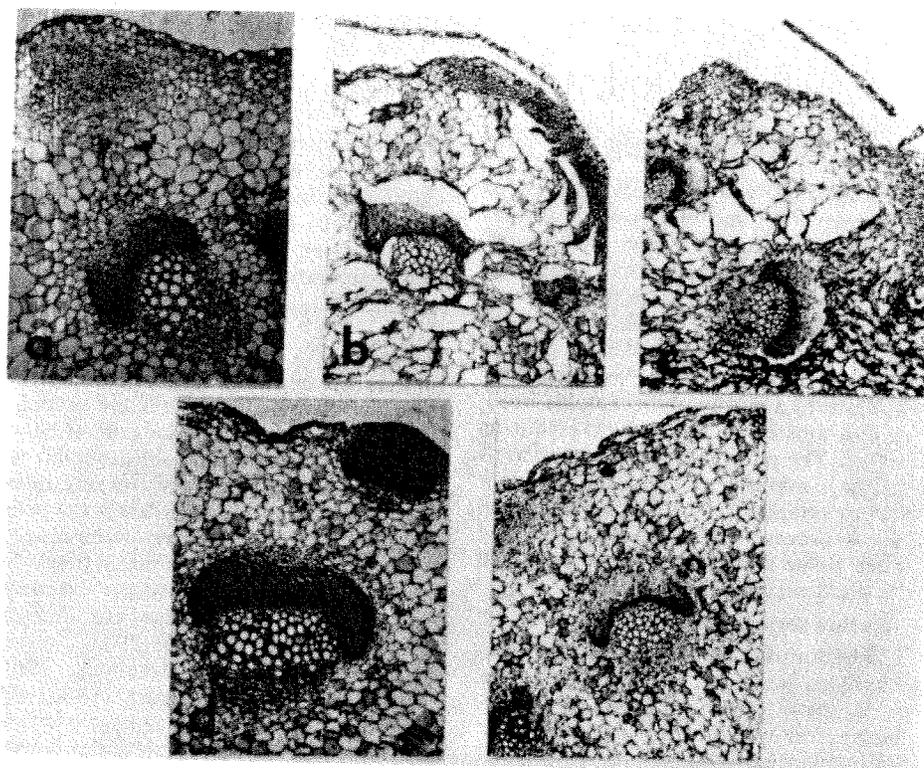


Fig. 1—Effects of glycerol on celery tissue: (a) Fresh celery; (b) Freeze-dried, rehydrated celery; (c) Air-dried, rehydrated celery; (d) 60% glycerated, freeze-dried, rehydrated celery; (e) 60% glycerated, air-dried, rehydrated celery. Magnification ≈ 25X.

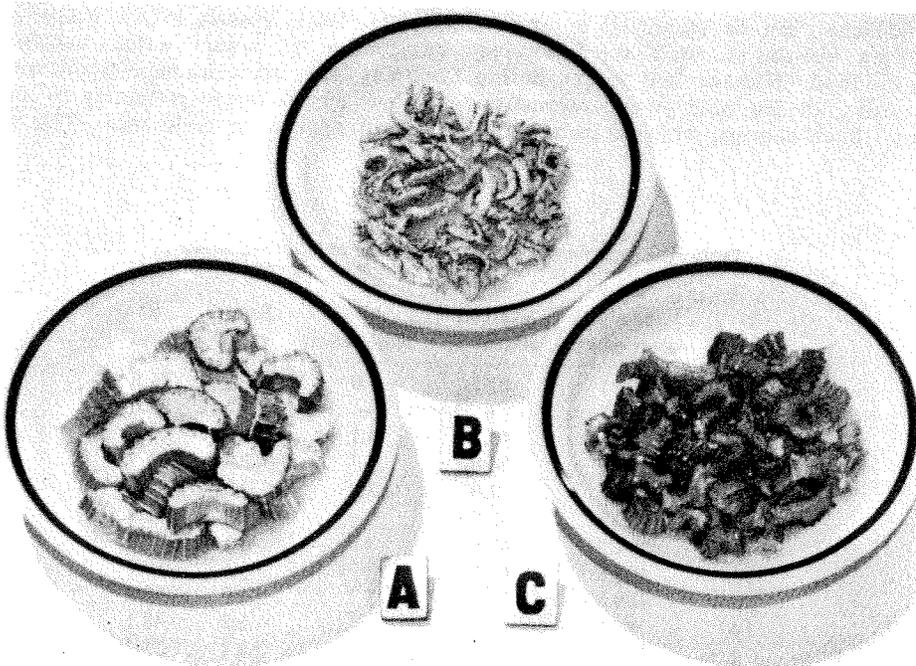


Fig. 2—Dehydrated celery: (a) Freeze dried; (b) Air dried; (c) Glycerated, air dried.

Table 3—Mechanical evaluation of celery texture

Treatment <sup>a</sup> (% Glycerol)	Apparent modulus of elasticity (kg/cm <sup>2</sup> )	Toughness (kg/cm <sup>2</sup> ) <sup>b</sup>
0% Fresh	59.8	1.91
0% FD	0.94	0.0043
0% AD	0.77	0.0078
20% AD	20.5	0.77
40% AD	19.3	0.51
60% AD	20.9	0.74
60% FD	12.8	0.40
80% AD	19.5	0.62
LSD	4.68	0.14
r	0.79	0.80

<sup>a</sup>AD = Air dried; FD = Freeze dried  
<sup>b</sup>kg cm/cm<sup>3</sup> = kg/cm<sup>2</sup>

unit volume necessary to compress the sample to its rupture point (Kapsalis et al., 1970b) and (2) Apparent modulus of elasticity, which is the firmness or rigidity of the product as indicated by the slope of the initial straight-line portion of the curve.

Upon inspection and as shown by sensory panel results, the conventional freeze-drying process had no advantage over air drying. Consequently, to keep the testing within reasonable limits, some samples were deleted from the mechanical tests. Fresh, freeze-dried, air-dried, 20, 40, 60 and 80% glycerol-air dried and 60% glycerol-freeze dried samples were tested.

#### Statistical analysis

Analysis of variance and least significant difference (LSD) were calculated for the toughness, apparent modulus of elasticity and panel ratings. The correlation coefficients between each of the two mechanical test methods and the subjective tests for textural properties were also calculated.

#### Histological studies

In order to determine the site of damage, as well as the effects of additives on the tissue, histological studies were also conducted. Attempts were made to obtain uniform samples

by using sections taken from the middle of outer stalks. The method included killing all samples in Nawashin Craf (chromic-acid type) fixative (Jensen, 1962; Sass, 1958), dehydrating with an ethanol-butanol series and embedding in tissue-mat. Sections of all samples were cut at  $21\mu$  on a lipshaw rotary microtome and stained in haematoxylin-safranin (Johansen, 1940). Photomicrographs were taken of all slides using a R and L type microscope fitted with a Polaroid camera.

## RESULTS & DISCUSSION

### Effects on moisture

As seen in Table 1, celery soaked in glycerol showed a noticeable loss of moisture. Higher moisture loss was exhibited in celery soaked in glycerol of higher concentrations. Additional dehydration reduced the samples to about 4% moisture. The rehydration ratio of celery dehydrated after soaking in glycerol solutions ranging between 30–60% was approximately 3:1, with an average yield of 63% from the fresh product. However, the rehydration ratio was significantly increased in celery with concentrations of glycerol less than 20%. Rehydration time, as in many air-dried products, is rather long compared with their freeze-dried counterparts; here, 18 hr (overnight) was used for convenience. Initial tests indicated that it can be reduced to approximately 2 hr when several changes in warm water (100°F) are used. The glycerol residue in the rehydrated product depends upon the method of rehydration. For example, it was approximately 1% for an overnight rehydration and 6% for the 2 hr rehydration.

### Sensory evaluation of texture

Results shown in Table 2 indicate significant difference in texture (as measured by a technological panel) between the dehydrated treated and untreated celery regardless of the method of dehydration.

### Instron tests

Both the toughness and the apparent modulus of elasticity as determined with the Instron, indicated the magnitude of textural differences among the samples (Table 3). The toughness of fresh celery had a value of  $1.91 \text{ Kg/cm}^2$ , while that of freeze-dried and air-dried were very poor,  $0.0043$  and  $0.0078 \text{ kg/cm}^2$ , respectively. However, the glycerated samples averaged about  $0.6 \text{ kg/cm}^2$  which is much closer to fresh celery than are the untreated samples. This property, when compared with the technological panel ratings, showed a significant correlation with an  $r$  value of  $0.80$ . The apparent modulus of elasticity ( $E_a$ ) also showed significant correlation with the panel ratings ( $r=0.79$ ). The  $E_a$  of fresh celery was  $59.8 \text{ kg/cm}^2$  whereas that of freeze-dried and air-dried unglycerated celery was  $0.94$  and  $0.77$ , respectively. The glycerol treatments definitely

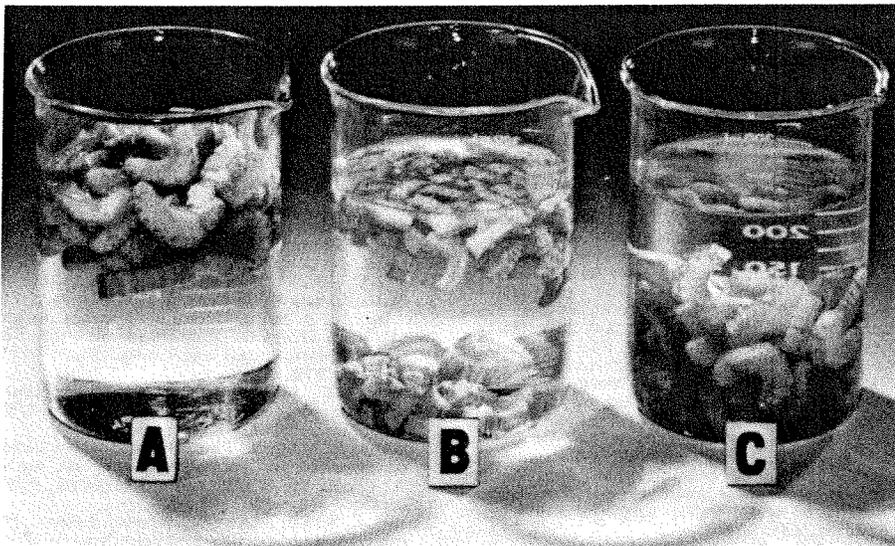


Fig. 3—Dehydrated celery, rehydrated: (a) Freeze dried; (b) Air dried; (c) Glycerated, air dried.

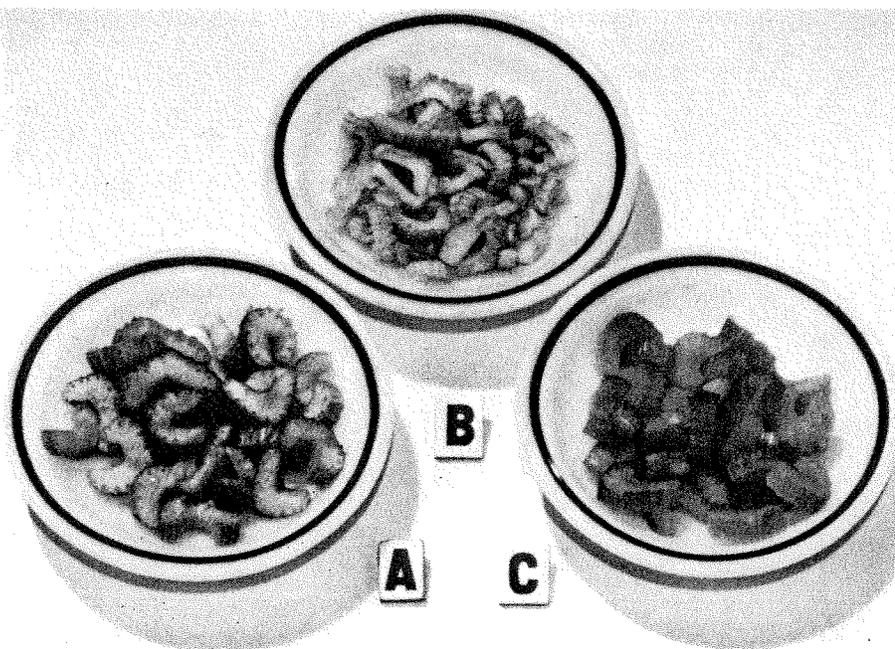


Fig. 4—Dehydrated celery, rehydrated: (a) Freeze dried; (b) Air dried; (c) Glycerated, air dried.

improved the texture as indicated by an average value of 21.5.

The results obtained from the Instron Universal Testing Apparatus and their correlation with the sensory evaluations of texture point out the applicability of this apparatus to predicting the textural properties of fresh, freeze-dried or treated celery.

#### Histological investigations

The effects of the various treatments on the tissue and cell structure of the rehydrated celery are shown in Figure 1.

Photomicrographs of fresh, untreated celery (Fig. 1a) show polyhedron-shaped cells with organized nuclei, and the collenchyma, parenchyma, epidermis and vascular bundles all intact. Figures 1b and 1c show the effect of freeze-drying and air-drying, respectively, where large crevices are visible and tissue is significantly disrupted. The epidermis has separated and large crevices appear in the collenchyma, parenchyma and vascular bundles. 60% glycerol treatment with a subsequent freeze-drying-like process (Fig. 1d) and air-drying (Fig. 1e) protects the tissues as evidenced by absence of major tissue damage and disruption of the cell walls. Appearance is similar to fresh celery, although the epidermis and some of the cell walls seem to be partially distorted.

Figure 2 shows the differences among the samples in the dehydrated state. The freeze-dried samples (2a) hold their original shape but are very fragile; the air-dried (2b) are highly shriveled and hard; the glycerated air-dried (2c) are partly shriveled but soft and flexible and take on a darker (green) color.

While rehydrating (Fig. 3), the samples show obvious differences. The freeze-dried celery (3a) floats as it takes up water like a sponge, with a lot of air still present within the tissue. The air-dried celery (3b) rehydrates poorly and remains partly shriveled, some air also remaining in the tissue. The glycerated, air-dried celery (3c) remains in phase with the water, has little or no air in the tissues and returns to its original shape.

The fully rehydrated samples are seen in Figure 4. Therefore, it is concluded that fresh celery treated with glycerol can be successfully air dried to approximately 4% moisture and subsequently rehydrated to have textural characteristics that approach fresh celery.

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