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Compression of Rehydratable Vegetables and Cereals

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Annual Report
February 1977 - January 1978

Prepared by:
E.E. Burns
Horticultural Sciences Department
Texas A&M University
College Station, Texas 77843

TEXAS A&M UNIVERSITY
COLLEGE STATION, TEXAS 77843
AC 713-845-3341

Department of
Horticultural Sciences

May 31, 1978

Dr. Malcolm C. Smith
Head, Food Development Group
NASA/JSC (DE-5)
Houston, Texas 77058

RE: NAS9-12434

Dear Dr. Smith:

The annual progress report for the period of February 1977 to January 1978 is herewith submitted. The histological work has given excellent insight into the mechanisms of compression and rehydration. The storage studies have yielded guidance as concerns temperature/time regimes and resultant product effects.

We now look forward to the tasks concerning utilization of antioxidants and nutritive value.

Sincerely,

E.E. Burns

E.E. Burns, Professor
Food Science and Technology
Adriance Laboratory

EEB/kep
cc Dr. W.S. Barham, Head, Dept. of Horticultural Sciences
Dr. Neville P. Clarke, Director, Texas Ag. Exp. Sta.
J.H. Goldstein, R&T Procurement Branch, NASA
Francis M. Lucas, ONR Resident Rep., Austin, Texas

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I. JUSTIFICATION

Freeze drying has the advantage over other commercial preservation methods of being able to more effectively retain the natural flavor and texture of the original product. In addition, it eliminates the weight of water from the processed product, a factor of importance where transportation is involved. However, volume reduction is practically nil; and therefore, successful methods of compression are needed. Potential volume savings may be as high as 16-1. Creation of successful freeze-dried compressed products has significant impact where drastic food volume and weight reduction are a necessity.

Characteristics of freeze-dried compressed carrots, such as rehydration, volatile retention, and texture, have been studied. A need exists to identify those treatments which will produce a product with acceptable storage stability under varied conditions of storage and have acceptable food quality. This relates to objective measurements and subjective organoleptic evaluations. Limits of quality and acceptability for each quality factor can thus be objectively and subjectively identified.

There is a need to determine the histological changes that occur as a function of compression and relate these to textural quality evaluation. Since optimum utility requires that products be stored under a variety of conditions, a need also exists to determine the effects of storage temperature on the quality of freeze-dried compressed carrot bars. The ultimate goal would be that of obtaining a product of optimum quality in terms of rehydration characteristics, organoleptic properties and storage attributes.

II. HISTORICAL

FREEZE-DRYING. Freeze-drying is a commercially established process in the food industry. Freeze-drying produces the highest quality preserved product obtainable. However, the bulkiness of freeze-dried foods has presented a storage and transportation problem.

In terms of product quality, freeze drying is generally superior to other methods of food preservation. Reasons for the high quality of freeze-dried products include rigidity of the frozen material, low processing temperatures, lack of a liquid state, and the reduction of transfer rates which control the loss of flavor and aroma (King, 1971).

Freeze-drying can produce foods that are shelf stable, light in weight, and have good color and flavor when rehydrated. Foods produced by freeze-drying have less weight and a preserved flavor and structure; but volume in terms of packaging, transportation and storage is not changed. In an effort to alleviate this problem, different methods of compressing the freeze-dried product have been developed to eliminate most of the void spaces (King, 1971, Brockman, 1974). Two major advantages are: 75-94% volume reduction and 60-90% weight reduction (Rahman, 1969).

In spite of the many advantages of compressed freeze-dried foods, some problems do exist. Methods of plasticization involve procedures which are costly and require extensive equipment use. Texture of reconstituted products is still not comparable with foods processed by other methods.

COMPRESSION. The advantages of compression include a 75-94% volume reduction which benefits transportation and storage requirements. Other advantages are a 60-90% weight reduction resulting from moisture removed during dehydration, and lower freight costs along with added convenience due to volume reduction. There is also a reduction in the amount of packaging materials required, and an increase in stability and shelf life. Freeze-dried foods have an average bulk density of 0.3 g/cc. With existing technology, it should be possible to compress most foods to a bulk density of 0.9 g/cc without hampering reversibility (Brockman, 1966).

The basic technique for producing compressed foods is to dry the product to about 2% moisture, plasticize the product by the addition of water, compress into bars or disks, redry to about 2% moisture, and then package. Several innovations to the basic procedure have recently been developed. One involves simultaneous freeze drying and compression. Another method entails drying the food to 10-28% moisture, compressing, then drying to about 5% moisture and packaging. Still another method involves freeze drying to 10-30% moisture, equilibrating the moisture with microwave energy for upwards of one minute and then compressing and drying to about 3% moisture and packaging. The compression pressures used in these techniques range from 100-3000 pounds per square inch depending on product characteristics.

In spite of the many advantages and high quality of freeze-dried vegetables, the reduction of bulk by compression presents numerous problems with certain products. Compressed vegetable tissue undergoes irreversible changes in original properties. These changes most often manifest themselves as losses in texture and unacceptable rehydration times. In most cases, the length of time required for rehydration is directly proportional to the pressure and dwell time utilized during the compression phase (Lampri, 1967).

The reduction in bulk of freeze-dried products by compression can cause problems of fragmentation in certain products. Ishler (1965) determined that direct compression without the aid of plasticizing agents resulted in fracturing to the point of causing powders when high pressures were used. Upon rehydration, unplasticized bars attained an unacceptable puree consistency. However, when properly preconditioned, freeze-dried foods can be compressed with little to no fragmentation (Hamdy, 1962). Treatments used to reduce the fragmentation, other than added moisture or micro-wave treatments, include spraying the product with glycerine or propylene glycol prior to compression. These chemicals act as plasticizing agents, allowing the cell walls to be compressed without serious fragmentation.

<u>PLASTICIZATION</u>. Plasticization with heat was first used by Proctor and Sluder in 1943 in an effort to prevent the severe fracturing that resulted from compression of dehydrated products. It was determined that plasticization should be carried out at an optimum high temperature to reduce fragmentation. The use of added moisture was deleterious because of the problems of removal after compression.

Investigations by Gooding (1957) at Aberdeen, determined that dehydrated cabbage should be humidified to 8% prior to compression. Processes developed to remove this added moisture were elaborate and resulted in some deterioration in quality. Further investigations showed that cabbage with 4% moisture at 140-150°F became moderately plastic thus eliminating the humidification and redrying steps.

Studies by Ishler in 1965 on methods to control fragmentation showed that freeze-dried foods should be plasticized at the 5-20% moisture level prior to compression. Three methods of obtaining specific moisture levels were evaluated: 1) addition of water by atomized spray, 2) stopping the freeze drying process at a specific moisture level, and 3) humidification to a specific moisture level. Addition of water by spray was the chosen method because stopping the freeze drying process at a desired moisture was difficult and humidification required several hours.

Methods developed by Rahman et al. (1969) at the U.S. Army Natick Laboratories included subjecting vegetables to live steam for 5 minutes prior to compression. In related research, Rahman et al. (1970) found that blueberries and cherries became thermoplastic when heated for 10 minutes at 200°F. Recent work by Rahman (1976) indicate microwave radiation is an effective method of thermal plasticization.

Considering all quality attributes, the optimum pre-compression equilibration conditions for carrot slices are 7% moisture and 90°F (Rushing, 1975). MacPhearson (1973) found that carrot slices compressed at 170 pounds per square inch had improved rehydration and shedding times. In most cases, the rehydration and shedding times have been found to be directly proportional to the compression pressure and dwell times.

REHYDRATION. One of the goals of freeze-drying food is an end product that is indistinguishable from the cooked fresh food. To insure a foodstuff of satisfactory eating quality, it is essential that proper water uptake occur (Hanson, 1961). The most widely used method for measuring water absorption is the rehydration ratio. This ratio has been defined by Simpson et al. (1955) as the weight of the rehydrated sample divided by the initial weight. Measurement of water uptake requires that the sample be immersed for a specific time in water at a specified temperature and then drained, blotted free of excess water and weighed.

Temperature of water used for rehydration is important. Foods containing a high percentage of protein are rehydrated with cold water to prevent coagulation and toughening. Freeze-dried vegetables are rehydrated in boiling water (Hanson, 1961).

Rehydration of some freeze-dried foods is often difficult. Research by Gane and Wagner (1958) determined two important factors in vegetable rehydration: heating reduces cell swelling power and/or elasticity and destroys the cell wall osmotic properties.

Working with carrots, Rushing (1975) determined that the interaction of moisture and temperature had a profound effect upon bar rehydration. Improved shedding and rehydration times for carrots as obtained by MacPhearson (1973) by compression at 170 psi. In general, the shedding and rehydration times are directly proportional to the pressure and dwell time (MacPhearson, 1973, Rushing, 1975).

Inherent raw material characteristics such as total sugar content and cellulose content, plus stage of maturity, all have an effect on the rehydration rate of compressed freeze-dried carrots. Bennett (1976) found that the rehydration rates decreased as the maturity of the raw product increased and as the total sugar content increased. He also showed that as cellulose content increased so did the rehydration rate. As previously mentioned, the rehydration rate can also be increased by pre-processing treatments such as 24 hour soaks in distilled water and also in salt solutions; whereas sucrose solutions have the opposite effect. In an effort to decrease the time required for rehydration, Haas et al. (1974) conducted investigations incorporating commercial surfactants into the water used as a rehydration media for selected freeze-dried products.

The rehydration ratio, like the rehydration rate, is also affected by the temperature of the water of reconstitution. Curry (1974) found that optimum rehydration ratios were obtained at a temperature of 33°C. with 3/4 inch thick slices. Longan (1973) also found an inverse relationship between thickness of carrot slices and rehydration ratios. He also showed that an increased rate of freezing created less cell disruption which resulted in decreased uptake of water on rehydration. Bennett (1976) showed that carrot maturity was inversely correlated with rehydration ratios. Curry (1974) investigating the effects of plasticizing methods discovered that stopping the freeze drier at the level of moisture desired for compression resulted in higher rehydration ratios than the surface spray equilibration method. He also found that as cooking time increased, rehydration ratios also significantly increased, becoming optimum at 8 minutes for 3/8 inch carrot slices.

TEXTURE. Due to the combined effect of blanching and freezing, freeze-dried vegetables sometimes possess a less firm texture than their fresh counterparts. The rate of freezing is recognized as a critical factor in tissue damage. With rapid freezing ice crystals are small; however, as the rate of freezing is reduced the size of the ice crystals increase and severe damage to the cell structure is experienced due to the penetrating of cell walls by ice crystals.

Although rehydration of compressed foods can be macroscopically observed, the actual mechanisms of rehydration and their effects on texture can only be observed at the cellular level.

Histological observation of freeze-dried compressed carrot tissue can be accomplished with the scanning electron microscope which offers several advantages. First, the sample can be observed in the freeze-dried state because no imbedding process is used. A second advantage is the three dimensional quality which allows a sense of reality to the object being viewed (Everhart and Hayes, 1973). Since all forms of microscopy supply different kinds of information, they compliment one another rather than compete. Each type has unique characteristics that can provide valuable information about the microstructure of biological materials (Curry, 1974).

STORAGE. Each food system has, under the best of conditions, a maximum storage life. This potential may be conserved by judicious selection and application of conditions of processing, packaging, and storage which will protect and prolong the retention of desirable qualities in both the product and its package. Comprehensive storage studies conducted by Cecil and Woodruff (1962) determines that the most important factor affecting the length of storage life of preserved foods was the reduction of storage temperatures (Desrosier, 1970). Each of the qualities of appearance, aroma, color, texture, flavor, acidity, drained weight , and vitamins responded favorably to refrigeration.

With increasing temperatures, the storage life of dehydrated foods is reduced by development of a brown discoloration which is largely the result of the Maillard reaction. In those cases where reducing sugars are the limiting reactants, browning would be prevented by their removal. Eggs may be stabilized by treatment with glucose oxidase before dehydration (Hanson, 1971).

Upon extended periods of storage, dehydrated vegetables tend to alter in color and flavor, and in some cases become unfit for human consumption. Such alterations in flavor, appearance, and odor are most frequently the result of oxidation of different substances present in the vegetables. Hence it has become standard practice in the food industry to treat dried vegetables with various antioxidants (Pintauro, 1974). The reason low moisture foods are subject to oxidation is not fully understood. Uri (1956) suggested that it may be associated with the catalytic effect of heavy salts or the free radical chain reaction essential to the developement of oxidative rancidity.

Several other factors including method of blanch, method of dehydration, moisture and sugar content can also have a profound effect on storage life. Concerning blanching, it has been found that as the concentration of solutes leached into the blanch water increases, the likelihood of browning is increased. The problem does not arise when steam scalding is used. If oxidation can be prevented, the lower the moisture of the dehydrated product, the longer the storage life at high temperature.

BROWNING. It is important to avoid browning in processed vegetables. The chief cause of browning is considered to be the reaction between reducing sugars and amino acids. Using model systems of glucose and amino acids, Lewis et al. (1949) found that nonenzymatic browning and carbon dioxide production occur at similar rates. In model systems, sugars react in the following order of decreasing activity with respect to browning: xylose, arabinose, galactose, mannose, glucose, lactose, and maltose. Sucrose shows no tendency to brown (Pomeranz et al., 1962).

OXYGEN. Atmospheric oxygen is capable of affecting the nutritive value of foods. In general the effects are detrimental and it is desirable to maintain certain types of foods at a low oxygen tension, or at least to prevent a continuous supply of oxygen into the package. The reactions due to atmospheric oxygen include the oxidation of fats and oils, deterioration of the biological value of proteins, and the destruction of some vitamins. The headspace gas and other gases dissolved in the food may contain free oxygen. Within a few days of packing, free oxygen is used up to produce anaerobic conditions.

NUTRITIONAL VALUE. Tressler (1958) discussed the major factors influencing retention of nutrients in dehydrated fruits and vegetables during production and storage. Storage at refrigerated temperatures is favorable to flavor, color, and vitamin retention. Packaging under nitrogen or carbon dioxide assists in conserving ascorbic acid and carotene. However, moisture content is a major factor affecting stability at 70°F or higher. Use of an inpackage dessicant to bring moisture content to 1% or lower should permit storage of dehydrated fruits and vegetables for 6 months at 70-100°F. without significant losses of vitamins.

There seems to be little information concerning the effects of compression on the retention of nutrients in freeze dried foods. The freeze drying process will certainly cause some loss of water soluble vitamins. The exclusion of oxygen during compression and packaging should enhance retention of the fat soluble vitamins during storage. However, much work remains to be done in this area.

III. EXPERIMENTAL

HISTOLOGY. This study determined the histological changes which occur as a function of compression. Specifically, the study was designed to compare a product compressed at 48% moisture with that produced by compression at 12% moisture.

Carrots of the Imperator 58 variety were obtained from Van de Walle Farms, San Antonio, Texas. The carrots were harvested the day prior to arrival at Adriance Laboratory, Texas A&M University. Samples were stored at 1.7°C. until processing.

Carrots were peeled, trimmed and cubed using an Economy Vegetable Cuber, manufactured by the H.G.W. Young Co., Philadelphia, Pennsylvania. The apparatus was equipped with a 3/8" die. After cubing, the sample was sieved through a 7/16" screen to remove fines. The carrots were then steam blanched for three (3) minutes and forty-five (45) seconds to a negative catalase-peroxidase end point. The sample was immediately frozen by immersing in LN_2, sealed in polyethylene freezer bags and stored at -29°C. until freeze-drying.

Freeze-drying was accomplished using a model REPP sublimator, manufactured by the Virtis Company, Gardner, New York. The samples were freeze dried using a condenser temperature of -50°C. and a shelf temperature of 10°C. The freeze dryer was stopped at intervals to obtain samples at the two moisture levels. The samples were resealed in polyethylene freezer bags and stored at -40°C. until plasticization and compression.

Moisture content was determined upon removal from the freeze dryer and after microwave treatment by the vacuum oven method of Pomeranz and Meloan (1971).

Carrot dices were freeze dried to two moisture levels: 12% and 48%. Sixteen (16) gram samples were plasticized with a 40 second microwave exposure in a Litton 420 Microwave oven. After 15 seconds equilibration, the dices were quickly loaded into a 1 x 3 inch compression cell. Compression was accomplished using a LOCAP testing machine manufactured by Tinius Olsen, Willow Grove, Pa. with force and dwell controlled manually. Ten bars of each moisture level were prepared utilizing a compression force of 500 psi with a 20 second dwell time. After compression, the bars were freeze dried to a final moisture level of 2.5%.

Evaluation of the samples included determination of rehydration ratios, histological examination and evaluation of sensory texture characteristics.

Rehydration ratios of the freeze-dried compressed bars were determined after 10, 20, and 30 minutes. Each bar was placed in a 600 ml beaker containing 250 ml of water at 60°C. After the allotted time the sample was removed from the beaker, allowed to drain and weighed. Rehydration ratios were calculated by dividing the rehydrated weight by the initial freeze dried weight.

Histological examination of freeze-dried compressed carrot tissue was conducted utilizing a JSM-U3 scanning electron microscope, manufactured by the Japanese Electron Optical Laboratory. Tissues were examined in the compressed state and after rehydration. Samples were coated with 50-100 NM carbon, followed with 150-200 NM of 40% paladium/60% gold alloy. This preparation was necessary to prevent surface charging of the sample material, thus allowing quality pictures.

Sensory evaluation of the texture characteristics of food is important because of the relationship to final product acceptance. The mechanical characteristics, describing the manner in which the food handles in the mouth include the following:

Hardness: the force necessary to attain a given deformation.

Cohesiveness: the strength of the internal bonds making up the body of the product.

Elasticity: the rate at which a deformed material goes back to its undeformed condition after the deforming force is removed.

Chewiness: the energy required to masticate a solid food product to a state ready for swallowing. It is a combination of the primary parameters of hardness, cohesiveness, and elasticity.

Sensory texture characteristics of carrot material similar to that for the histological studies were rated by a 7 member panel. A 9 point hedonic rating scale was used to define the descriptive terms of hardness, cohesiveness, elasticity and chewiness. A sample score sheet is shown in Figure 1.

FIGURE 1.

Score sheet for rehydrated freeze-dried and compressed carrots.

DESCRIPTION	SAMPLE NUMBER	SAMPLE RANKING								
		MOST		MORE		SAME		LESS		LEAST
		9	8	7	6	5	4	3	2	1
HARDNESS										
COHESIVENESS										
ELASTICITY										
CHEWINESS										

Results. The relationship between precompression moisture and water uptake can best be understood by examination of both the rehydration ratios (Table 1) and the Photomicrographs 1 through 6. The sample which is compressed with low moisture results in one that has considerable structural damage from compaction and a lower initial water uptake capacity when compared to one compressed at 48% moisture (Table 1). A sample compressed with a high moisture content undergoes only slight structural damage and rehydrates quickly.

Final product texture is also related to the damage resulting from compression. This results in a product that when completely rehydrated, contains large structural voids filled with water. These voids do not exist in products compressed at a high moisture level. Thus, the high moisture product has increased firmness.

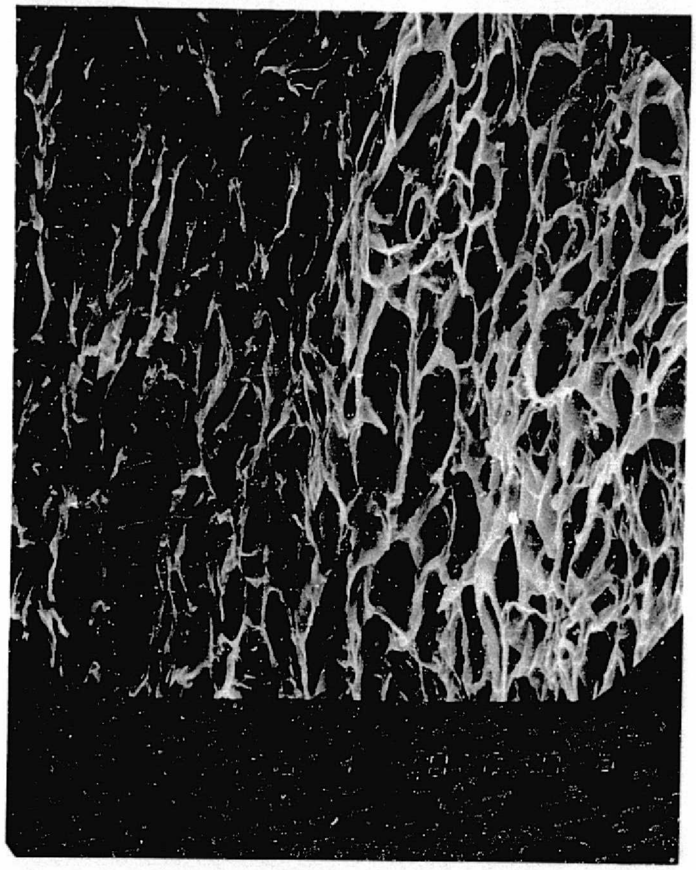
The scanning electron microscope was shown to be a useful tool for examination of freeze-dried food. Differences in rehydration and texture could easily be related to the processing methods studied. Cellular disruption as a result of compression at low moisture levels was found to be the main reason for rehydration and texture differences.

Results from the evaluation of the selected sensory characteristics of hardness, cohesiveness, elasticity and chewiness, as affected by moisture content are shown in Table 2. Products prepared at 48% moisture was rated above those produced at 12%. The product prepared from carrot cubes having 48% moisture compared favorably with a freshly cooked product in cohesiveness and elasticity, but was considered slightly harder and more chewy. The reduced scores for the product prepared at 12% moisture demonstrate the relationship of structural damage and water content to sensory textural quality. Sensory texture characteristics of rehydrated carrots determined that products compressed at a high moisture level were superior to those produced at a lower level.

TABLE 1.

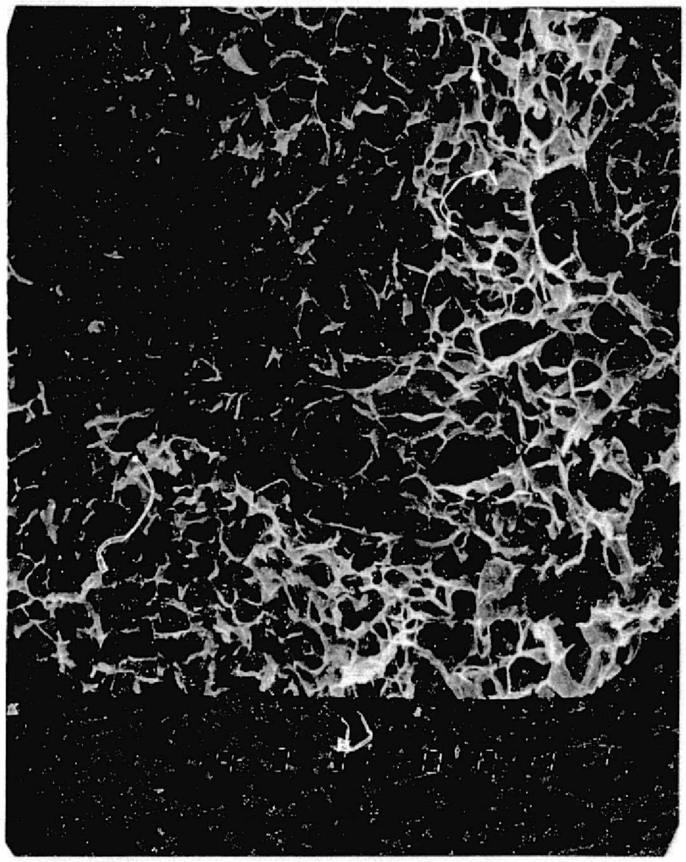
Rehydration ratios of freeze-dried compressed carrot bars as affected by moisture content.

Precompression Moisture %	Rehydration Ratio 10 minutes	Rehydration Ratio 20 minutes	Rehydration Ratio 30 minutes
12	3.40	6.31	7.45
48	5.96	6.68	7.01



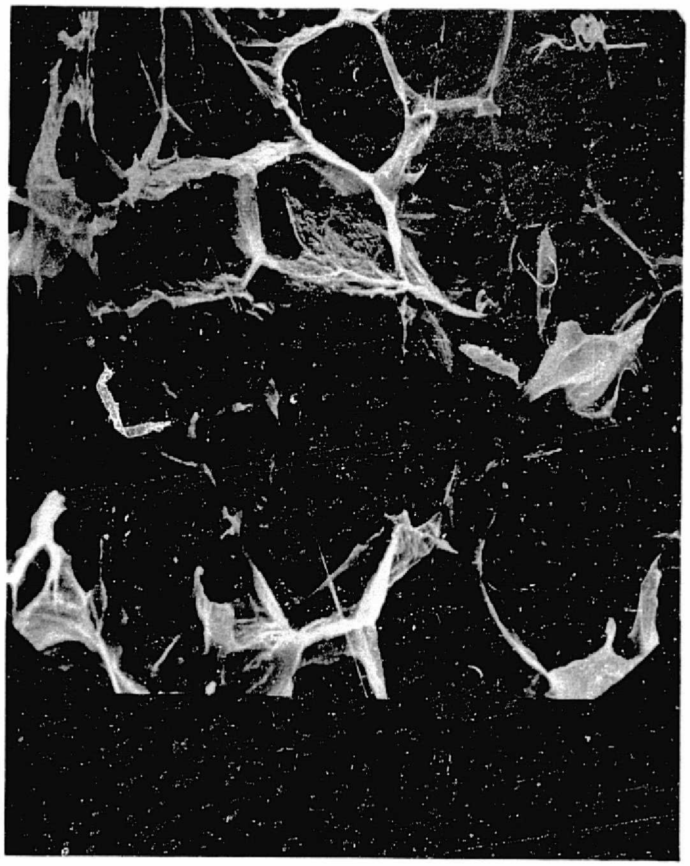
Photomicrograph 1: 100X

This shows the compression stage of carrot tissue compressed at a low moisture level (12%). It was found that compression at low moisture levels disrupts the cell structural integrity. This becomes apparent when low moisture compression tissue is rehydrated.



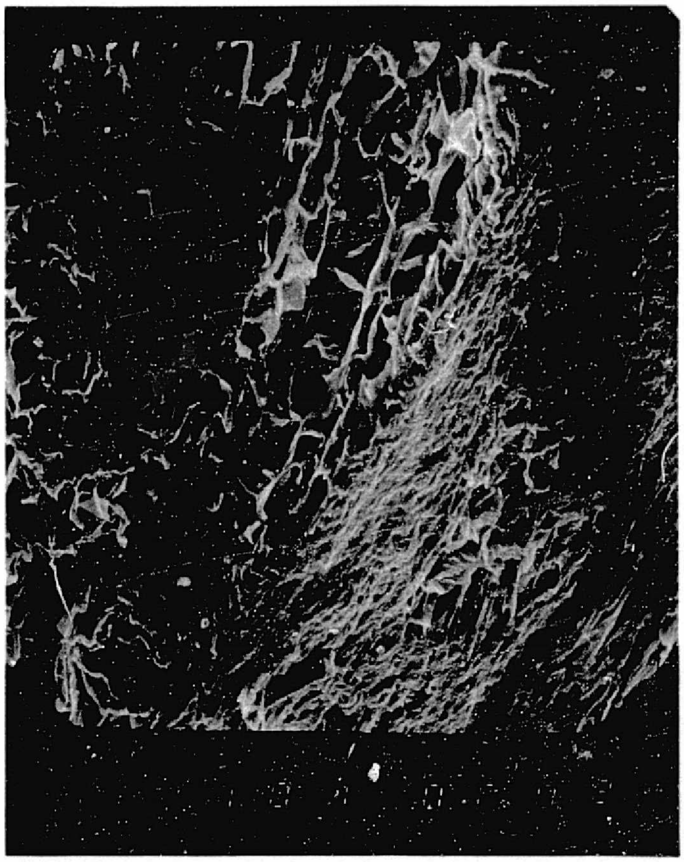
Photomicrograph 2: 75X

This picture shows the disruption that occurs when carrot tissue compressed at a low moisture level (12%) is rehydrated. The rehydration ratios show that this product has a slower and lower initial water uptake when compared to tissue compressed at a higher moisture level.

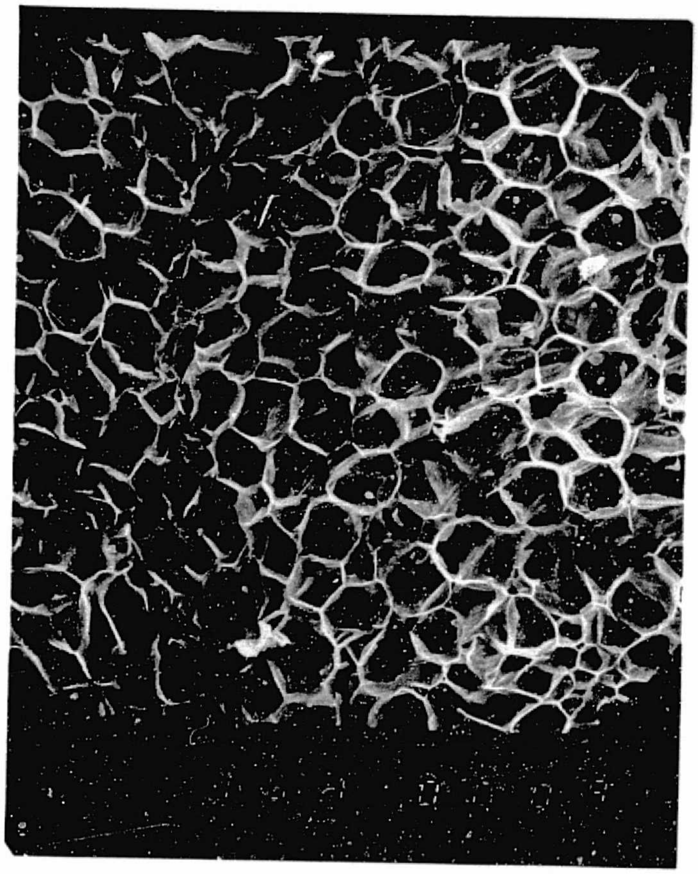


Photomicrograph 3: 450X

This shows the actual cellular disruption that occurs upon rehydration of carrot tissue compressed at a low moisture level (12%). The extensive structural damage caused to the cell by low moisture compression causes textural problems which affect organoleptic acceptance. Upon complete rehydration, the large voids where cells were ruptured are filled with water resulting in a softer mealier product.

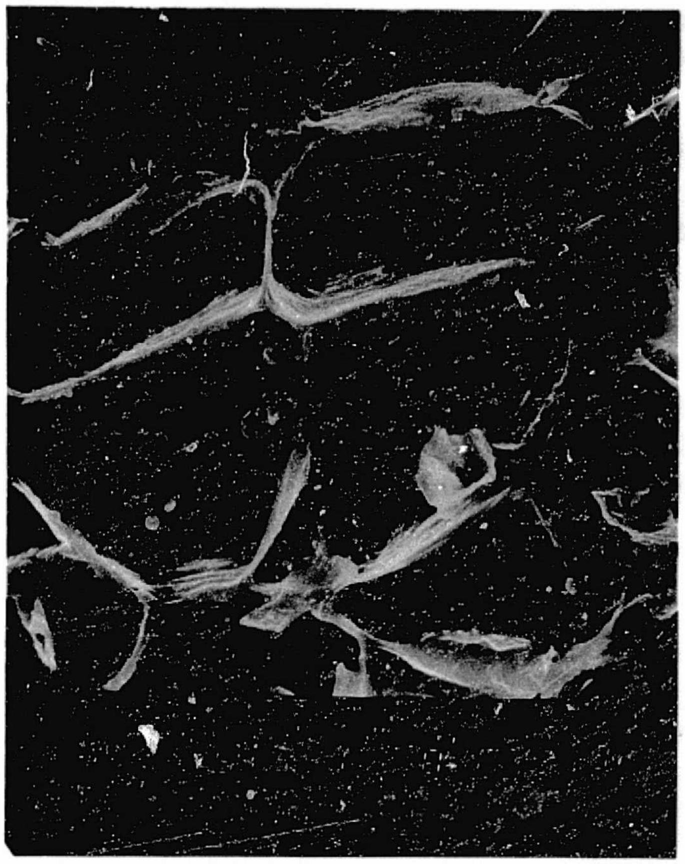


Photomicrograph 4: 100X
This picture shows the plastic surface that occurs with compression. This carrot tissue was compressed at a high moisture level of (48%). The external layer of over-compressed cells was reported by Curry (1974) and is considered a barrier to water during rehydration.



Photomicrograph 5: 100X

This is a rehydrated carrot dice with the cellular constituents still in place. The tissue was compressed at a high moisture level (48%). The rehydration ratio shows that this tissue compressed at a high moisture level rehydrates faster.



Photomicrograph 6: 500X

This is a close-up of rehydrated carrot tissue compressed at a high moisture level (48%) showing that very little cell disruption has occured. This product has a firmer texture than products compressed at lower moisture levels thus it scores higher organoleptically.

TABLE 2.

Sensory texture comparison of fresh cooked carrots with freeze-dried carrots compressed at two moisture levels.

Moisture Content (%)	Texture Description[a]			
	Hardness	Cohesiveness	Elasticity	Chewiness
12%	4.67	3.42	5.65	6.02
48%	7.25	4.57	4.15	3.76
Fresh Cooked	6.23	4.50	3.55	2.87

[a] Rated by a 7 member trained taste panel on a 9 point hedonic scale.

STORAGE. This study determined the effects of various storage temperatures on the quality of freeze dried compressed carrot bars.

Carrots were washed, peeled, blanched for 8 minutes in 5 times their weight of boiling distilled water. They were then chilled in ice water, drained, frozen and freeze-dried in a Virtis freeze drier for 48 hours to approximately 3% moisture content. The freeze dried carrots were spray plasticized to 8% moisture, equilibrated for 2 hours at 90°F. in a forced draft hot air oven, and compressed into 1 x 3 x 3/8 inch bars at 200 psi for 30 seconds.

The bars were then placed in #303 cans, sealed under vacuum, and stored at one of four temperatures, -20°F., 35°F., 70°F., or 110°F. After 9 months the bars were removed from the cans and evaluated as follows.

Evaluation. Bars were rehydrated in 143°F. water. Bars were drained, and weighed at 10 minute intervals. Rehydrated carrots were then evaluated organoleptically by a trained panel using the evaluation sheet of Figure 2. Fifty grams of carrots were then tested in the Allo Kramer shear press, using the 13 blade multiple purpose shear compression cell. Then, 150 ml. water was added and the mixture was blended for 1 minute. The resultant puree was then evaluated in the Gardner Color Difference Meter using the Sweet Potato Color plate as the standard. Water holding capacity was measured by centrifuging 20 grams of rehydrated carrots for 10 minutes at 1000 rpm. The volume of water lost was then determined. Rehydration ratio was determined by dividing the weight of product after 30 minutes rehydration by the weight of the original dehydrated product.

Results. The results of these analyses are as follows.

FIGURE 2.
Taste panel evaluation sheet.

TECHNOLOGICAL EXAMINATION	
PRODUCT:	DATE
TESTERS NAME:	

COLOR									
ODOR									
FLAVOR									
TEXTURE									
APPEARANCE									
Sample Number	Extremely Poor	Very Poor	Poor	Below Fair Above Poor	Fair	Below Good Above Fair	Good	Very Good	Excellent

COLOR									
ODOR									
FLAVOR									
TEXTURE									
APPEARANCE									
Sample Number	Extremely Poor	Very Poor	Poor	Below Fair Above Poor	Fair	Below Good Above Fair	Good	Very Good	Excellent

COLOR									
ODOR									
FLAVOR									
TEXTURE									
APPEARANCE									
Sample Number	Extremely Poor	Very Poor	Poor	Below Fair Above Poor	Fair	Below Good Above Fair	Good	Very Good	Excellent

COLOR									
ODOR									
FLAVOR									
TEXTURE									
APPEARANCE									
Sample Number	Extremely Poor	Very Poor	Poor	Below Fair Above Poor	Fair	Below Good Above Fair	Good	Very Good	Excellent

COLOR									
ODOR									
FLAVOR									
TEXTURE									
APPEARANCE									
Sample Number	Extremely Poor	Very Poor	Poor	Below Fair Above Poor	Fair	Below Good Above Fair	Good	Very Good	Excellent

STSNL Form 685
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EDITION OF 28 AUG 69 WILL BE USED UNTIL EXHAUSTED.

Statistical Analysis. Computer analysis of the data using a general linear model procedure was conducted with a statistical model consisting of temperature as the independent variable and all other variables such as taste panel scores, Gardner color values, etc. as the dependent variables (Appendices II-XIII).

STATISTICAL MODEL

$$T = a + b_1(TPC) + b_2(TPO) + b_3(TPF) + b_4(TPT) + b_5(TPA) + b_6(GC'L') + b_7(GC'a') + b_8(GC'b') + b_9(GC'a'/'b') + b_{10}(RR) + b_{11}(WHC) + b_{12}(SH)$$

where:

T = temperature, °C.

a = a constant

b_{1-12} = response parameters

TPC = Taste panel color scores

TPO = Taste panel odor scores

TPF = Taste panel flavor scores

TPT = Taste panel texture scores

TPA = Taste panel appearance scores

GC'L' = Gardner Color Difference Meter 'L' values

GC'a' = Gardner Color Difference Meter 'a' values

GC'b' = Gardner Color Difference Meter 'b' values

GC'a'/'b' = Gardner Color Difference Meter 'a' values divided by Gardner Color Difference Meter 'b' values

RR = Rehydration ratios

WHC = Water holding capacities

SH = Shear values

Of these, taste panel color, odor, flavor, texture, and appearance scores, Gardner color 'b' and 'L' values and shear values were significant with temperature. Relative significance is shown in Table 3.

TABLE 3.

Level of significance of dependent variables from the statistical model

Level of significance	Dependent variable
0.5%	Gardner 'L' values Shear values
1.0%	Taste panel flavor scores Taste panel appearance scores
2.5%	Taste panel color scores Taste panel texture scores Gardner 'b' values
10%	Taste panel odor scores
Not significant	Gardner 'a' values Rehydration ratios Water holding capacity

A Duncan's multiple range test was then performed on those significant dependent variables with respect to temperature in order to effect means separation (Appendices XIV-XXI). Results are retabulated in Tables 4 and 5.

Significant Correlation. (Appendices XXII-XXIII). Temperature was most positively correlated with shear and most negatively correlated with taste panel appearance, flavor, color, and odor. Highest correlation was between taste panel color and flavor. Taste panel color was also most positively correlated with appearance, odor, texture, Gardner 'b' and 'L' values, and negatively correlated with shear. Taste panel odor was most positively correlated with appearance, color, flavor and texture and negatively correlated with shear. Taste panel flavor was most positively correlated with Gardner 'b' values, taste panel appearance and texture, and negatively correlated with shear values. Taste panel texture was most positively correlated with Gardner 'b' values and negatively correlated with shear. Taste panel acceptance was positively correlated with Gardner 'b' values and Gardner 'L' values and negatively correlated with shear.

Discussion of Results. The highly significant positive correlation of taste panel color and flavor values suggests that taste panel flavor scores could have been influenced by the color of the product as perceived by the panelists. The largest number of significant positive correlations between taste panel attributes and objective measurements involved Gardner 'b' values, which were positively correlated with all taste panel attributes. Taste panel color was most highly correlated with Gardner 'b' values, with taste panel texture a close second. Also, shear values correlated most highly negatively with each taste panel attribute. Rehydration ratio and water holding capacity were nonsignificantly correlated with any other variable. Gardner color difference meter values 'a', 'L', and a/b ratio were non-significantly correlated.

TABLE 4.

Separation of means of significant taste panel variables by storage temperature.

ATTRIBUTE	TASTE PANEL SCORE[α]			
	storage temperatures			
	-20°F.	35°F.	70°F.	110°F.
Color	6.8a	4.6a,b	5.6a,b,c	3.0c
Odor	6.2a	4.0b	4.1b	3.3b
Flavor	5.7a	3.5b	4.4a,b	2.1c
Texture	5.4a	3.8b	4.8a	3.7b
Appearance	7.2a	4.2b	4.9b,c	4.0c

Note: Means with the same letter are not significantly different.

α Taste panel scores ranging from 1 to 9, 1 being extremely poor, 9 being excellent.

TABLE 5.

Separation of significant Gardner Color Difference Meter and shear attributes by storage temperature.

ATTRIBUTE	VALUES			
	storage temperatures			
	-20°F.	35°F.	70°F.	110°F.
Gardner 'b'	29.3a	27.3b	28.7a	27.0b
Gardner 'L'	50.0a	50.1a	50.8a	46.7b
Shear[β]	220 c	246 b	250 a,b	263 a

Note: Means with the same letter are not significantly different.

[β] Force in pounds

No single characteristic can be relied upon to identify one storage temperature from another over the entire range of storage temperatures. However, at lower temperature ranges, taste panel odor, taste panel appearance, and shear appear to be the best indicators of differences in product quality due to different storage temperatures (Table 6). At high temperatures taste panel flavor and Gardner 'L' values appear best.

TABLE 6.

Significant differences in organoleptic, Gardner color and shear values of carrot ba.s stored at specified temperatures when compared to other storage temperatures.

SPECIFIED TEMPS.	COMPARISON TEMPS.	SIGNIFICANT DEPENDENT VARIABLES								
		TPC	TPO	TPF	TPT	TPA	GC 'b'	GC 'L'	SH	TOTAL
-20°F.	35°F.		+	+	+	+	+		+	6
	70°F.		+			+			+	3
	110°F.	+	+	+	+	+	+	+	+	8
			*			*			*	
35°F.	-20°F.		+	+	+	+	+		+	6
	70°F.				+		+			2
	110°F.	+		+		+		+	+	5
70°F.	-20°F.		+			+			+	3
	35°F.				+		+			2
	110°F.			+	+		+			3
110°F.	-20°F.	+	+	+	+	+	+	+	+	8
	35°F.	+		+		+		+	+	5
	70°F.			+	+		+	+		4
				*				*		

\+ the specified temperature is significantly different from the other temperature with respect to this variable.
* solely significantly different from the other temperatures with respect to this variable.

TPC = Taste panel color score means
TPO = Taste panel odor score means
TPF = Taste panel flavor score means
TPT = Taste panel texture score means
TPA = Taste panel appearance score means
GC'b' = Gardner color difference meter 'b' value means
GC'L' = Gardner color difference meter 'L' value means
SH = Shear value means

In general the -20°F. storage resulted in the best values in every instance. In six of the eight categories of significance storage at -20°F. gave significantly better results than the next storage temperature (35°F.). However, in three of these (taste panel flavor, texture, and Gardner 'b' value) the -20°F. values and the 70°F. values were not significantly different. In two categories, taste panel color and Gardner 'L' value, the -20°F., 35°F., and 70°F. results were not significantly different. The least number of differences was noted between 35°F. and 70°F. which differed significantly only in taste panel texture and Gardner 'b' values. The 110°F. scores were significantly different from 70°F. in taste panel flavor and texture, Gardner 'b' and 'L' values (not significantly different from 35°F. in taste panel texture and Gardner 'L' value).

IV. SUMMARY

Textural characteristics of food are extremely important to final product acceptance. In this study samples compressed at low moisture exhibited considerably more structural damage than those compressed at a higher moisture level. Samples compressed at high moisture rehydrated more quickly and the texture of the final product was more acceptable in terms of hardness, cohesiveness, elasticity and chewiness.

The organoleptic attributes as well as Gardner 'L' and 'b' values generally decreased for carrot bars as the temperature of storage increased. However the reverse was true for shear values which suggested increased toughening at elevated storage temperature. The most common differences in indicators of carrot quality between carrots stored at -20°F. and those stored at higher temperatures were found to be taste panel odor and acceptance scores and shear values. The most common differences between carrots stored at 110°F. and those stored at lower temperatures were taste panel flavor scores and Gardner 'L' values. Greatest number of significant changes in indicators of carrot quality occurred between -20°F. and 35°F. and between 70°F. and 110°F. Least differences in indicators of carrot quality were encountered at storage temperatures of 35°F. and 70°F.

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APPENDIX TABLES

Appendix I. Results of Analysis

Obs	Temp	TPC	TPO	TPF	TPT	TPA
1	1	34	32	27	27	37
2	1	34	30	30	27	35
3	2	23	17	17	17	20
4	2	23	23	18	21	22
5	3	25	18	19	24	26
6	3	31	23	25	24	23
7	4	18	20	11	19	18
8	4	12	13	10	18	12

Obs	Temp	GCA	GCB	GCAB	GCL	RR	WHC	SH
1	1	22.8	28.9	0.789	49.6	9.59	1.3	227
2	1	22.1	29.6	0.747	50.3	6.90	2.0	213
3	2	20.9	27.3	0.766	50.0	8.76	0.6	245
4	2	22.2	27.2	0.816	50.1	6.97	1.5	246
5	3	20.6	28.3	0.730	50.4	9.94	2.5	254
6	3	20.8	29.1	0.715	51.1	6.02	2.1	248
7	4	21.5	27.1	0.793	46.6	9.73	1.3	264
8	4	21.4	26.9	0.796	46.7	6.97	2.7	263

Appendix II.

GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: TPC

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	3	388.00000000	129.33333333	14.37	0.0131	0.915094	12.0000
ERROR	4	36.00000000	9.00000000		STD DEV		TPC MEAN
CORRECTED TOTAL	7	424.00000000			3.00000000		25.00000000

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE IV SS	F VALUE	PR > F
TEMP	3	388.00000000	14.37	0.0131	3	388.00000000	14.37	0.0131

OBSERVATION	OBSERVED VALUE	PREDICTED VALUE	RESIDUAL
1	34.00000000	34.00000000	0.00000000
2	34.00000000	34.00000000	0.00000000
3	23.00000000	23.00000000	0.00000000
4	[illegible].00000000	23.00000000	0.00000000
5	25.00000000	28.00000000	-3.00000000
6	31.00000000	28.00000000	3.00000000
7	18.00000000	15.00000000	3.00000000
8	12.00000000	15.00000000	-3.00000000

SUM OF RESIDUALS	0.00000000
SUM OF SQUARED RESIDUALS	36.00000000
SUM OF SQUARED RESIDUALS - ERROR SS	0.00000000
FIRST ORDER AUTOCORRELATION	-0.28867513
DURBIN-WATSON D	2.25000000

Appendix III.

GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: TPO

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	3	235.00000000	78.33333333	5.50	0.0666	0.804795	17.1587
ERROR	4	57.00000000	14.25000000		STD DEV		TPO MEAN
CORRECTED TOTAL	7	292.00000000			3.77491722		22.00000000

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE IV SS	F VALUE	PR > F
TEMP	3	235.00000000	5.50	0.0666	3	235.00000000	5.50	0.0666

OBSERVATION	OBSERVED VALUE	PREDICTED VALUE	RESIDUAL
1	32.00000000	31.00000000	1.00000000
2	30.00000000	31.00000000	-1.00000000
3	17.00000000	20.00000000	-3.00000000
4	23.00000000	20.00000000	3.00000000
5	18.00000000	20.50000000	-2.50000000
6	23.00000000	20.50000000	2.50000000
7	20.00000000	16.50000000	3.50000000
8	13.00000000	16.50000000	-3.50000000

SUM OF RESIDUALS	0.00000000
SUM OF SQUARED RESIDUALS	57.00000000
SUM OF SQUARED RESIDUALS - ERROR SS	-0.00000000
FIRST ORDER AUTOCORRELATION	-0.48441905
DURBIN-WATSON D	2.61342105

Appendix IV.

GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: TPF

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	3	344.37500000	114.79166667	19.54	0.0075	0.936120	12.3508
ERROR	4	23.50000000	5.87500000		STD DEV		TPF MEAN
CORRECTED TOTAL	7	367.87500000			2.42383993		19.62500000

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE IV SS	F VALUE	PR > F
TEMP	3	344.37500000	19.54	0.0075	3	344.37500000	19.54	0.0075

OBSERVATION	OBSERVED VALUE	PREDICTED VALUE	RESIDUAL
1	27.00000000	28.50000000	-1.50000000
2	30.00000000	28.50000000	1.50000000
3	17.00000000	17.50000000	-0.50000000
4	18.00000000	17.50000000	0.50000000
5	19.00000000	22.00000000	-3.00000000
6	25.00000000	22.00000000	3.00000000
7	11.00000000	10.50000000	0.50000000
8	10.00000000	10.50000000	-0.50000000

SUM OF RESIDUALS	0.00000000
SUM OF SQUARED RESIDUALS	23.50000000
SUM OF SQUARED RESIDUALS - ERROR SS	-0.00000000
FIRST ORDER AUTOCORRELATION	-0.56236601
DURBIN-WATSON D	2.95744681

GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: TPT

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	3	100.37500000	33.45833333	15.75	0.0111	0.921929	6.5886
ERROR	4	8.50000000	2.12500000		STD DEV		TPT MEAN
CORRECTED TOTAL	7	108.87500000			1.45773797		22.12500000

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE IV SS	F VALUE	PR > F
TEMP	3	100.37500000	15.75	0.0111	3	100.37500000	15.75	0.0111

OBSERVATION	OBSERVED VALUE	PREDICTED VALUE	RESIDUAL
1	27.00000000	27.00000000	0.00000000
2	27.00000000	27.00000000	0.00000000
3	17.00000000	19.00000000	-2.00000000
4	21.00000000	19.00000000	2.00000000
5	24.00000000	24.00000000	0.00000000
6	24.00000000	24.00000000	0.00000000
7	19.00000000	18.50000000	0.50000000
8	18.00000000	18.50000000	-0.50000000

SUM OF RESIDUALS	0.00000000
SUM OF SQUARED RESIDUALS	8.50000000
SUM OF SQUARED RESIDUALS - ERROR SS	0.00000000
FIRST ORDER AUTOCORRELATION	-0.50751922
DURBIN-WATSON D	2.97058824

Appendix VI.

S T A T I S T I C A L   A N A L Y S I S   S Y S T E M   15:15 MONDAY, FEBRUARY 27, 1978   6

GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: TPA

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	3	468.37500000	156.12500000	23.57	0.0053	0.946451	10.6690
ERROR	4	26.50000000	6.62500000		STD DEV		TPA MEAN
CORRECTED TOTAL	7	494.87500000			2.57390754		24.12500000

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE IV SS	F VALUE	PR > F
TEMP	3	468.37500000	23.57	0.0053	3	468.37500000	23.57	0.0053

OBSERVATION	OBSERVED VALUE	PREDICTED VALUE	RESIDUAL
1	37.00000000	36.00000000	1.00000000
2	35.00000000	36.00000000	-1.00000000
3	20.00000000	21.00000000	-1.00000000
4	22.00000000	21.00000000	1.00000000
5	26.00000000	24.50000000	1.50000000
6	23.00000000	24.50000000	-1.50000000
7	18.00000000	15.00000000	3.00000000
8	12.00000000	15.00000000	-3.00000000

SUM OF RESIDUALS	0.00000000
SUM OF SQUARED RESIDUALS	26.50000000
SUM OF SQUARED RESIDUALS - ERROR SS	-0.00000000
FIRST ORDER AUTOCORRELATION	-0.72190613
DURBIN-WATSON D	2.77358491

Appendix VII.

GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: GCA

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	3	3.08375000	1.02791667	3.69	0.1199	0.734445	2.4514
ERROR	4	1.11500000	0.27875000		STD DEV		GCA MEAN
CORRECTED TOTAL	7	4.19875000			0.52796780		21.53750000

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE IV SS	F VALUE	PR > F
TEMP	3	3.08375000	3.69	0.1199	3	3.08375000	3.69	0.1199

OBSERVATION	OBSERVED VALUE	PREDICTED VALUE	RESIDUAL
1	22.80000000	22.45000000	0.35000000
2	22.10000000	22.45000000	-0.35000000
3	20.90000000	21.55000000	-0.65000000
4	22.20000000	21.55000000	0.65000000
5	20.60000000	20.70000000	-0.10000000
6	[illegible].80000000	20.70000000	0.10000000
7	21.50000000	21.45000000	0.05000000
8	[illegible].40000000	21.45000000	-0.05000000

SUM OF RESIDUALS	0.00000000
SUM OF SQUARED RESIDUALS	1.11500000
SUM OF SQUARED RESIDUALS - ERROR SS	0.00000000
FIRST ORDER AUTOCORRELATION	-0.37114989
DURBIN-WATSON D	2.58744395

Appendix VIII.

GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: GCB

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	3	7.21000000	2.40333333	16.29	0.0105	0.924359	1.3692
ERROR	4	0.59000000	0.14750000		STD DEV		GCB MEAN
CORRECTED TOTAL	7	7.80000000			0.38405729		28.05000000

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE IV SS	F VALUE	PR > F
TEMP	3	7.21000000	16.29	0.0105	3	7.21000000	16.29	0.0105

OBSERVATION	OBSERVED VALUE	PREDICTED VALUE	RESIDUAL
1	28.90000000	29.25000000	-0.35000000
2	29.60000000	29.25000000	0.35000000
3	27.30000000	27.25000000	0.05000000
4	27.20000000	27.25000000	-0.05000000
5	28.30000000	28.70000000	-0.40000000
6	29.10000000	28.70000000	0.40000000
7	27.10000000	27.00000000	0.10000000
8	26.90000000	27.00000000	-0.10000000

SUM OF RESIDUALS	0.00000000
SUM OF SQUARED RESIDUALS	0.59000000
SUM OF SQUARED RESIDUALS - ERROR SS	-0.00000000
FIRST ORDER AUTOCORRELATION	-0.41769036
DURBIN-WATSON D	2.51271186

Appendix XIV.

DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE TPC

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

ALPHA LEVEL=.05   DF=4   MS=9

GROUPING		MEAN	N	TEMP
	A	34.000000	2	1
	A			
B	A	28.000000	2	3
B				
B	C	23.000000	2	2
	C			
	C	15.000000	2	4

Appendix XV.

DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE TPO

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

ALPHA LEVEL=.05   DF=4   MS=14.25

GROUPING	MEAN	N	TEMP
A	31.000000	2	1
B	20.500000	2	3
B			
B	20.000000	2	2
B			
B	16.500000	2	4

Appendix XVI.

DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE TPF

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

ALPHA LEVEL=.05   DF=4   MS=5.875

GROUPING		MEAN	N	TEMP
	A	28.500000	2	1
	A			
B	A	22.000000	2	3
B				
B		17.500000	2	2
	C	10.500000	2	4

Appendix XVII.

DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE TPT

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

ALPHA LEVEL=.05   DF=4   MS=2.125

GROUPING	MEAN	N	TEMP
A	27.000000	2	1
A			
A	24.000000	2	3
B	19.000000	2	2
B			
B	18.500000	2	4

Appendix XVIII.

DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE TPA

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

ALPHA LEVEL=.05 DF=4 MS=6.625

GROUPING		MEAN	N	TEMP
	A	36.000000	2	1
	B	24.500000	2	3
	B			
C	B	21.000000	2	2
C				
C		15.000000	2	4

Appendix IX.

GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: GCAB

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	3	0.00659500	0.00219833	3.91	0.1104	0.745703	3.0835
ERROR	4	0.00224900	0.00056225		STD DEV		GCAB MEAN
CORRECTED TOTAL	7	0.00884400			0.02371181		0.76900000

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE IV SS	F VALUE	PR > F
TEMP	3	0.00659500	3.91	0.1104	3	0.00659500	3.91	0.1104

OBSERVATION	OBSERVED VALUE	PREDICTED VALUE	RESIDUAL
1	0.78900000	0.76800000	0.02100000
2	0.74700000	0.76800000	-0.02100000
3	0.76600000	0.79100000	-0.02500000
4	0.81600000	0.79100000	0.02500000
5	0.73000000	0.72250000	0.00750000
6	0.71500000	0.72250000	-0.00750000
7	0.79300000	0.79450000	-0.00150000
8	0.79600000	0.79450000	0.00150000

SUM OF RESIDUALS	0.00000000
SUM OF SQUARED RESIDUALS	0.00224900
SUM OF SQUARED RESIDUALS - ERROR SS	-0.00000000
FIRST ORDER AUTOCORRELATION	-0.19883688
DURBIN-WATSON D	2.15929302

Appendix X.

GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: GCL

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	3	20.20000000	6.73333333	53.87	0.0011	0.975845	0.7164
ERROR	4	0.50000000	0.12500000		STD DEV		GCL MEAN
CORRECTED TOTAL	7	20.70000000			0.35355339		49.35000000

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE IV SS	F VALUE	PR > F
TEMP	3	20.20000000	53.87	0.0011	3	20.20000000	53.87	0.0011

OBSERVATION	OBSERVED VALUE	PREDICTED VALUE	RESIDUAL
1	49.60000000	49.95000000	-0.35000000
2	50.30000000	49.95000000	0.35000000
3	50.00000000	50.05000000	-0.05000000
4	50.10000000	50.05000000	0.05000000
5	50.40000000	50.75000000	-0.35000000
6	51.10000000	50.75000000	0.35000000
7	46.60000000	46.65000000	-0.05000000
8	46.70000000	46.65000000	0.05000000

SUM OF RESIDUALS	0.00000000
SUM OF SQUARED RESIDUALS	0.50000000
SUM OF SQUARED RESIDUALS - ERROR SS	-0.00000000
FIRST ORDER AUTOCORRELATION	-0.69302401
DURBIN-WATSON D	2.96000000

Appendix XI.

GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: RR

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	3	0.30550000	0.10183333	0.02	0.9941	0.017952	25.2037
ERROR	4	16.71210000	4.17802500		STD DEV		RR MEAN
CORRECTED TOTAL	7	17.01760000			2.04402177		8.11000000

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE IV SS	F VALUE	PR > F
TEMP	3	0.30550000	0.02	0.9941	3	0.30550000	0.02	0.9941

OBSERVATION	OBSERVED VALUE	PREDICTED VALUE	RESIDUAL
1	9.59000000	8.24500000	1.34500000
2	6.90000000	8.24500000	-1.34500000
3	8.76000000	7.86500000	0.89500000
4	6.97000000	7.86500000	-0.89500000
5	9.94000000	7.98000000	1.96000000
6	6.02000000	7.98000000	-1.96000000
7	9.73000000	8.35000000	1.38000000
8	6.97000000	8.35000000	-1.38000000

SUM OF RESIDUALS	0.00000000
SUM OF SQUARED RESIDUALS	16.71210000
SUM OF SQUARED RESIDUALS - ERROR SS	-0.00000000
FIRST ORDER AUTOCORRELATION	-0.94369112
DURBIN-WATSON D	3.45548585

Appendix XII.

GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: WHC

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	3	1.73000000	0.57666667	1.35	0.3774	0.502907	37.3620
ERROR	4	1.71000000	0.42750000		STD DEV		WHC MEAN
CORRECTED TOTAL	7	3.44000000			0.65383484		1.75000000

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE IV SS	F VALUE	PR > F
TEMP	3	1.73000000	1.35	0.3774	3	1.73000000	1.35	0.3774

OBSERVATION	OBSERVED VALUE	PREDICTED VALUE	RESIDUAL
1	1.30000000	1.65000000	-0.35000000
2	2.00000000	1.65000000	0.35000000
3	0.60000000	1.05000000	-0.45000000
4	1.50000000	1.05000000	0.45000000
5	2.50000000	2.30000000	0.20000000
6	2.10000000	2.30000000	-0.20000000
7	1.30000000	2.00000000	-0.70000000
8	2.70000000	2.00000000	0.70000000

SUM OF RESIDUALS	0.00000000
SUM OF SQUARED RESIDUALS	1.71000000
SUM OF SQUARED RESIDUALS - ERROR SS	-0.00000000
FIRST ORDER AUTOCORRELATION	-0.56227343
DURBIN-WATSON D	2.55701754

Appendix XIII.

GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: SH

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	3	6759.41375000	2253.13791667	27.10	0.0041	0.953099	1.9761
ERROR	4	332.62500000	83.15625000		STD DEV		SH MEAN
CORRECTED TOTAL	7	7092.03875000			9.11900488		461.46250000

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE IV SS	F VALUE	PR > F
TEMP	3	6759.41375000	27.10	0.0041	3	6759.41375000	27.10	0.0041

OBSERVATION	OBSERVED VALUE	PREDICTED VALUE	RESIDUAL
1	427.30000000	415.65000000	11.65000000
2	404.00000000	415.65000000	-11.65000000
3	461.90000000	462.20000000	-0.30000000
4	462.50000000	462.20000000	0.30000000
5	478.00000000	472.50000000	5.50000000
6	467.00000000	472.50000000	-5.50000000
7	496.00000000	495.50000000	0.50000000
8	495.00000000	495.50000000	-0.50000000

SUM OF RESIDUALS	0.00000000
SUM OF SQUARED RESIDUALS	332.62500000
SUM OF SQUARED RESIDUALS - ERROR SS	-0.00000000
FIRST ORDER AUTOCORRELATION	-0.64074545
DURBIN-WATSON D	2.57681323

Appendix XIX.

DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE GCB -

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DI ERENT.

ALPHA LEVEL=.05   DF=4   MS=0.1475

GROUPING	MEAN	N	TEMP
A	29.250000	2	1
A			
A	28.700000	2	3
B	27.250000	2	2
B			
B	27.000000	2	4

Appendix XX.

DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE GCL

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

ALPHA LEVEL=.05 DF=4 MS=0.125

GROUPING	MEAN	N.	TEMP
A	50.750000	2	3
A			
A	50.050000	2	2
A			
A	49.950000	2	1
B	46.650000	2	4

Appendix XXI.

DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE SH

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

ALPHA LEVEL=.05   DF=4   MS=83.1563

GROUPING		MEAN	N	TEMP
	A	495.500000	2	4
	A			
B	A	472.500000	2	3
B				
B		452.200000	2	2
	C	415.650000	2	1

Appendix XXII.

VARIABLE	N	MEAN	STD DEV	SUM	MINIMUM	MAXIMUM
TEMP	8	2.50000000	1.19522861	20.00000000	1.00000000	4.00000000
TPC	8	25.00000000	7.78276484	200.00000000	12.00000000	34.00000000
TPO	8	22.00000000	6.45865975	176.00000000	13.00000000	32.00000000
TPF	8	19.62500000	7.24938421	157.00000000	10.00000000	30.00000000
TPT	8	22.12500000	3.94380165	177.00000000	17.00000000	27.00000000
TPA	8	24.12500000	8.40811683	193.00000000	12.00000000	37.00000000
GCA	8	21.53750000	0.77448139	172.30000000	20.60000000	22.80000000
GCB	8	28.05000000	1.05559733	224.40000000	26.90000000	29.60000000
GCAB	8	0.76900000	0.03554474	6.15200000	0.71500000	0.81600000
GCL	8	49.35000000	1.71963451	394.80000000	46.60000000	51.10000000
RR	8	8.11000000	1.55919393	64.88000000	6.02000000	9.94000000
WHC	8	1.75000000	0.70101967	14.00000000	0.60000000	2.70000000
SH	8	461.46250000	31.82999203	3691.70000000	404.00000000	496.00000000

CORRELATION COEFFICIENTS / PROB > |R| UNDER HO:RHO=0 / N = 8

	TEMP	TPC	TPO	TPF	TPT	TPA	GCA	GCB	GCAB	GCL	RR	WHC	SH
TEMP	1.00000	-0.79858	-0.79575	-0.81612	-0.62128	-0.84580	-0.59416	-0.60011	0.03699	-0.63944	0.03296	0.39215	0.93820
	0.0000	0.0175	0.0182	0.0135	0.1001	0.0081	0.1204	0.1158	0.9307	0.0878	0.9382	0.3366	0.0006
TPC	-0.79858	1.00000	0.87250	0.97736	0.87035	0.91689	0.33181	0.91639	-0.49007	0.77067	-0.06651	-0.15972	-0.84892
	0.0175	0.0000	0.0047	0.0001	0.0049	0.0013	0.4220	0.0014	0.2176	0.0252	0.8757	0.7056	0.0077
TPO	-0.79575	0.87250	1.00000	0.85431	0.84127	0.91283	0.72255	0.75643	-0.06409	0.44375	-0.02355	-0.23033	-0.85751
	0.0182	0.0047	0.0000	0.0069	0.0088	0.0015	0.0429	0.0298	0.8802	0.2707	0.9559	0.5832	0.0065
TPF	-0.81612	0.97736	0.85431	1.00000	0.88629	0.90086	0.35654	0.94181	-0.48898	0.76492	-0.21321	-0.03233	-0.89907
	0.0135	0.0001	0.0069	0.0000	0.0034	0.0023	0.3860	0.0005	0.2188	0.0270	0.6122	0.9394	0.0024
TPT	-0.62128	0.87035	0.84127	0.88629	1.00000	0.90417	0.41918	0.91450	-0.41579	0.55716	-0.03671	0.24544	-0.74536
	0.1001	0.0049	0.0088	0.0034	0.0000	0.0020	0.3012	0.0015	0.3056	0.1514	0.9312	0.5579	0.0338
TPA	-0.84580	0.91689	0.91283	0.90086	0.90417	1.00000	0.53885	0.83294	-0.26577	0.57552	0.16694	-0.13451	-0.88724
	0.0081	0.0013	0.0015	0.0023	0.0020	0.0000	0.1682	0.0102	0.5247	0.1355	0.6928	0.7508	0.0033
GCA	-0.59416	0.33181	0.72255	0.35654	0.41918	0.53885	1.00000	0.18260	0.61079	-0.09386	-0.00710	-0.24602	-0.58262
	0.1204	0.4220	0.0429	0.3860	0.3012	0.1682	0.0000	0.6652	0.1077	0.8251	0.9867	0.5570	0.1296

Appendix XXIII.

CORRELATION COEFFICIENTS / PROB > |R| UNDER HO:RHO=0 / N = 8

	TEMP	TPI	TPO	TPF	TPT	TPA	GCA	GCB	GCAB	GCL	RR	WHC	SH
GCB	-0.60311	0.91639	0.75643	0.94181	0.91450	0.83294	0.18260	1.00000	-0.66668	0.65477	-0.18236	0.18726	-0.76848
	0.1158	0.0014	0.0298	0.0005	0.0015	0.0102	0.6652	0.0000	0.0710	0.0781	0.6656	0.6570	0.0259
GCAB	0.03699	-0.49007	-0.06409	-0.48898	-0.41579	-0.26577	0.61079	-0.66668	1.00000	-0.59738	0.12960	-0.32163	0.17915
	0.9307	0.2176	0.8802	0.2188	0.3056	0.5247	0.1077	0.0710	0.0000	0.1179	0.7597	0.4372	0.6712
GCL	-0.63944	0.77067	0.44375	0.76492	0.55716	0.57552	-0.09386	0.65477	-0.59738	1.00000	-0.23347	-0.08177	-0.57122
	0.0878	0.0252	0.2707	0.0270	0.1514	0.1355	0.8251	0.0781	0.1179	0.0000	0.5779	0.8474	0.1391
RR	0.03296	-0.06651	-0.02355	-0.21321	-0.03671	0.16694	-0.00710	-0.18236	0.12960	-0.23347	1.00000	-0.34008	0.15682
	0.9382	0.8757	0.9559	0.6122	0.9312	0.6928	0.9867	0.6656	0.7597	0.5779	0.0000	0.4098	0.7108
WHC	0.39215	-0.15972	-0.23033	-0.03233	0.24544	-0.13451	-0.24602	0.18726	-0.32163	-0.08177	-0.34008	1.00000	0.19786
	0.3366	0.7056	0.5832	0.9394	0.5579	0.7508	0.5570	0.6570	0.4372	0.8474	0.4098	0.0000	0.6386
SH	0.93820	-0.84892	-0.85751	-0.89907	-0.74536	-0.88724	-0.58262	-0.76848	0.17915	-0.57122	0.15682	0.19786	1.00000
	0.0006	0.0077	0.0065	0.0024	0.0338	0.0033	0.1296	0.0259	0.6712	0.1391	0.7108	0.6386	0.0000