TEXTURE OF PRE-COOKED, FREEZE-DRIED BEEF

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ABSTRACT

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By

Gary Thomas Blair

Tenderness is said to be one of the most important quality factors affecting the acceptability of meat. Loss of tenderness has been identified as one of the principal factors contributing to poor palatability of freeze-dried beef.

In the present study, processing variables other than the freeze-drying step, notably freezing rate and rehydration temperature, were shown to affect tenderness. Choice grade pre-cooked beef steaks and 1/2-inch diameter beef cylinders were frozen at two freezing rates (0.005 cm/min and 0.1 cm/min), freeze-dried at 110°F plate temperature, and rehydrated at two different temperatures (100°F and 200°F) in a factorial design. Pre-cooking means heating in water to a center temperature of 165°F. Shear force was measured by Warner-Bratzler Shear and the Instron Universal Testing Machine, depending on the form of the meat samples.

In general, the toughest beef was that rehydrated at 200°F; shear values were nearly double those of samples rehydrated at 100°F. A lesser effect was associated with the rate of freezing. Slow frozen (0.005 cm/min) samples were less tough than fast frozen samples (0.1 cm/min) at the same rehydration temperatures. The correlation coefficient between the Instron and the Warner-Bratzler Shear values was 0.98.

Moisture content of the rehydrated samples may be the real index of tenderness, because it was found that shear force increased with lower moisture content. The correlation coefficient for this effect was -0.95. Low moisture content may be the result of a combination of freezing rate and rehydration temperature, with rehydration at temperatures below 150°F giving higher moisture uptake and lower shear values than samples rehydrated above 150°F.

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To my loving parents

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INTRODUCTION AND REVIEW OF LITERATURE

Texture Parameters

One of the important quality factors in foods is their mouthfeel or texture. The property of texture has been studied for many years, and a substantial part of this effort has consisted of a search for objective methods for measuring texture. One of the most urgent problems in texture technology is the development of a rational system of nomenclature for describing and translating textural qualities into precisely defined, measurable properties. A comprehensive study and classification of textural characteristics was undertaken by Alina Szczesniak and co-workers in 1962 (Szczesniak, 1963).

Szczesniak grouped texture into three main classes:

(1) Mechanical characteristics

(2) Geometrical characteristics

(3) Other characteristics (referring mainly to moisture and fat content of the food)

Mechanical characteristics are manifested by the reaction of the food to mechanical stresses. Organoleptically, these characteristics are measured by pressures exerted on the teeth, tongue, and roof of the mouth during eating.

Collectively, these stimuli are the biting forces required to masticate the food. Geometric characteristics refer to the arrangement of the food constituents, and are usually sensed visually because they are reflected mainly in the appearance of the food product. The "other characteristics" include mouthfeel factors that cannot be easily resolved on the basis of mechanical or geometric properties.

Mechanical Characteristics.--Mechanical characteristics are the most important in determining how the food reacts in the mouth. These characteristics can be divided into five basic parameters (Szczesniak, 1963):

(A) Hardness--the force necessary to attain a given deformation.

(B) Cohesiveness--the strength of the internal bonds making up the body of the product.

(C) Viscosity--the rate of flow per unit force.

(D) Elasticity--the rate at which a deformed material goes back to its original condition after the deforming force is removed.

(E) Adhesiveness--the work necessary to overcome the attractive forces between the surface of the food and the surface of other materials with which the food comes in contact (e.g., tongue, teeth, palate, etc.).

The first four characteristics refer to forces of attraction acting between food particles and opposing disintegration; whereas, adhesiveness relates to surface properties.

It is possible to characterize food texture in terms of three secondary parameters related to cohesiveness in order to make the characterization as meaningful as possible to those accustomed to popular terminology and at the same time keeping the characterization in agreement with basic rheological properties. The three secondary parameters are (Szczesniak, 1963):

(B-1) Brittleness--the force with which the material fractures. It is related to the primary parameters of hardness and cohesiveness. In brittle materials, cohesiveness is low and hardness can vary from low to high. Brittle materials, especially when possessing a substantial degree of hardness, often produce sound effects on mastication (e.g., celery, toasted bread).

(B-2) Chewiness--the energy required to masticate a solid food product to a state ready for swallowing. It is related to the primary parameters of hardness, cohesiveness, and elasticity.

(B-3) Gumminess--the energy required to disintegrate a semi-solid food product to a state ready for swallowing. It is related to the primary parameters of hardness and cohesiveness.

The classes of texture characteristics called "geometric" and "other" refer, generally, to size, shape, orientation in the mouth, and the influence of such product ingredients as moisture and fat.

From this table one can see that combinations of several parameters result in the characteristic texture which we derive from foods. When one wishes to use objective methods to determine a particular texture parameter he is really measuring the sum of a variety of parameters. Thus, when one wishes to determine the "tenderness" of meat, he is really measuring functions of hardness, cohesiveness, and elasticity, all of which contribute when one tries to compare mechanical measurements of shearing force and the sensations involved to a taste panel member when he is asked to evaluate tenderness.

Objective Measurement of Tenderness

Palatability studies provide ideas of what consumers may like or dislike, but a given panel of taste testers reflects only the likes and dislikes of that particular panel. Therefore, it is important to have an objective method to determine the tenderness of a particular product to use as a basis for comparison with taste panels.

All the objective methods which have been used have, as their primary purpose, the approximation of the

Table 1.--Relations between textural parameters and popular nomenclature (Szczesniak, 1963).

MECHANICAL CHARACTERISTICS		
Primary Parameters	Secondary Parameters	Popular Terms
Hardness		Soft→Firm→Hard
Cohesiveness	Brittleness	Crumbly→Crunchy→Brittle
	Chewiness	Tender→Chewy→Tough
	Gumminess	Short→Mealy→Pasty→Gummy
Viscosity		Thin→Viscous
Elasticity		Plastic→Elastic
Adhesiveness		Sticky→Tacky→Gooey
GEOMETRICAL CHARACTERISTICS		
Class		Examples
Particle Size and Shape		Gritty, Grainy, Coarse, etc.
Particle Shape and Orientation		Fibrous, Cellular, Crystalline, etc.
OTHER CHARACTERISTICS		
Primary Parameters	Secondary Parameters	Popular Terms
Moisture content		Dry→Moist→Wet→Watery
Fat content	Oiliness	Oily
	Greasiness	Greasy

experiences of a person chewing a piece of the product. Chewing a piece of meat involves the acts of cutting, shearing, tearing, grinding, and squeezing. Since it would be difficult to design an instrument which could approximate all these parameters simultaneously, most of the instruments have been based upon only one of the above mechanical acts. These objective measurements are also complicated by the fact that meat is not a homogeneous material. Therefore, it is difficult to evaluate or calibrate an instrument by using meat samples. Moreover, this makes sample selection a very important aspect in any study of meat tenderness. An excellent review of the mechanical methods of measuring tenderness was prepared by Schultz (1957), from which the following are taken.

Lehman's Mechanical Device.--One of the earliest recorded uses of mechanical means for determining the tenderness of meat is that of Lehman in 1907. He developed two instruments, one which measured breaking strength, and the other, which consisted of a shear arrangement connected to a weighing pan by a lever, to determine shear force. Shear force measurement was accomplished by adding weights to the weighing pan until the shear severed the meat.

The Warner-Bratzler Shear.--In 1928 Warner reported briefly to the American Society of Animal Production that a shearing device showing promise as a means of measuring tenderness of meat was under development. In 1932 Black, Warner, and Wilson gave a report on the use of the instrument in studies of beef from different classes and grades of animals. The machine measured the amount of force necessary to shear through a sample of meat of given diameter. The machine was improved and modified by L. J. Bratzler in 1932. As described by Bratzler,

> The standardized, or revised, machine uses a shearing blade 0.04 inches in thickness. The opening in the blade is made by circumscribing an equilateral triangle about a circle one inch in diameter. The cutting or shearing edge of the opening is rounded or dulled to the radius of a circle of 0.02 inch. As most of the machines are motor driven, a shearing speed of 9 inches per minute is used. While the amount of force necessary to shear the sample is recorded on a dead hand spring dynomometer, I can see no reason why any similar recording device in pounds cannot be used. (Bratzler, 1949)

<u>The Cutting Gauge of Tressler, Birdseye, and Murray</u>.--In 1932 Tressler, Birdseye, and Murray described an instrument that they designed to determine the pressure required to cut or puncture pieces of meat. The instrument consisted of a Schrader tire-pressure gauge having a blunt penetrating instrument inserted in it. In using the cutting gauge, a sample of meat 3 inches square and 1 inch thick was clamped at its periphery. As the cutting instrument was passed through the meat, it was free to perforate without obstruction. Eight readings were taken on each sample. The pressure gauge was calibrated so that the readings could be converted to pounds.

The Penetrometer of Tressler, Birdseye, and Murray. --In 1932 this group also described a penetrometer which was "more satisfactory" than the cutting gauge. The original penetrometer consisted of a needle 1-3/8 inches long, 0.15 inches in diameter, and rounded at the point to a radius of 0.07 inches. The meat sample was held in a one-inch deep container which was 1.5 inches in diameter and covered with a plate having a 3/8 inch hole in the center. In operating the penetrometer, the needlepoint was brought to rest in the vertical position on top of the meat. A 255-gram weight was then placed over the needle and held for 15 seconds at which time a reading of the distance of penetration in millimeters was recorded. The distance of penetration was recorded on a dial geared to the movement of the needle.

The Child-Satorius Shear.--In 1938, Satorius and Child reported some tenderness measurements using an instrument which recorded the number of pounds force on a gauge as shearing bars were pulled across a dull blade with a triangular opening through which the meat sample was inserted.

The Volodkevich Tenderness Instrument.--Volodkevich, working in Germany in 1938, described an instrument consisting of two metal wedges or artificial teeth. This instrument was subsequently improved by Krumbholz and Volodkevich. In the original device the meat sample was placed between the two wedges, one of which was stationary, the other movable by mechanical means. The movement of the wedge was recorded on a revolving drum, thus giving a continuous recording of the exertion of pressure on the meat sample. The slope of the curve and the area under the curve on the graph were used to interpret the tenderness characteristics of the sample.

The Winkler Device.--This instrument, reported by Winkler in 1939, was similar to the Volodkevich instrument and measured the force as work per unit thickness of sample. It recorded curves which permitted analysis of the slope of the curve as a means of interpreting tenderness of the sample. The area under the curve could be used to determine the amount of work required in the operation.

Motorized Christel Texturemeter.--In 1955 Miyada and Tappel described the use of a Christel Texturemeter modified by attachment of an electric motor and reduction gears. The total work and maximum shear force required to force shearing prongs through a cylindrical sample of meat were recorded. Work diagrams were obtained by plotting the recorded data in pounds of force as a function of distance measurements. Maximum shear readings were obtained by finding the crest of the force-distance diagram. The area under the curve represented the total work involved.

The Motorized Food Grinder as a Tenderometer.--Miyada and Tappel also reported in 1955 the results in which a food grinder was used to measure tenderness. The motor of the food grinder was wired in series with an A. C. ammeter. By recording the ampere readings at five second intervals, it was possible to plot power consumption in watts as a function of time, thereby representing the total energy expended in grinding the sample. Theoretically, it was stated, increased toughness of meat would produce a corresponding increase in electric current consumption by the grinder.

Recording Strain-Gage Tenderometer.--Since the previously mentioned mechanical texture measurements tried to record some of the parameters involved in chewing a food product, it is not surprising that a device using artificial dentures would be used to simulate the chewing process. In 1955 Proctor, and his students at the Massachusetts Institute of Technology used an adaptation of the Volodkevich apparatus. The Tenderometer consisted of a set of human dentures. The upper denture was attached to a mechanical masticator (Honau articulator) and was moved by a driving motor; whereas, the lower denture was stationary. The force exerted by the chewing action was measured by two strain gauges located in the driving arm of the upper jaw. The changes in resistance due to deformations in the strain gauges were represented as a picture on the screen of a cathode-ray oscilloscope. Tenderness of the food was represented by the maximum deflection in millimeters from a zero line calibrated in terms of force.

The General Foods Textureometer is a modification of Proctor's Denture Tenderometer and in the interpretation of the data it uses Szczesniak's familiar classification of textural parameters (Szczesniak, 1961-1964). The instrument includes a Honau dental articulator (driven by a variable-speed motor), a variable-voltage power supply, a Wheatstone bridge circuit, and a fast speed recorder with balancing potentiometer. The General Foods Textureometer differs from Proctor's instrument in that the dentures were replaced with a punch and sample-holding plate, the strain-gauge sensing unit removed from the articulator arm and relocated on the stationary bottom plate, and the oscilloscope replaced by a fast-speed recorder.

The Kramer Shear-Press.--In 1951, Kramer, Aamlid, Guyer, and Rogers described a new tenderness-measuring instrument which utilized hydraulic pressure to force a series of metal plates downward through the product held in a metal box. The pressure required to plunge through the product was determined by measuring the pressure of the hydraulic fluid. In a recent refinement of this Shear-Press, called the Lee-Kramer Shear Press, a sensitive dial mechanical pressure indicator which registers through a proving ring is placed between the hydraulically operated piston and plunger plates, thus providing a more direct measure of force against the product being tested. A still later modification by Decker utilized a transducer in conjunction with a mechanical pressure gauge, which, when connected through an amplifier to a recording device, results in a continuous chart recording of pressure as the plunger plates traverse through the product. The recorder provides a force-time curve which can be used to measure the total work required to penetrate the product. Many applications of the recording Shear-Press have been discovered using attachments other than the plunger plates. Flat plate plungers with a stationary plate can be used to study the compression characteristics of foods. The Warner-Bratzler Shearing Device can be adapted to the Shear-Press to provide a comparison of values between the Shear Recorder and the Warner-Bratzler dynamometer. A chewing attachment similar to the Strain Gauge Tenderometers can be fitted to the Kramer Shear as a basis for comparing the two devices (Hartman, Isenberg, Ang, 1963).

In 1966 M. C. Bourne et al. reported on the use of an Instron Universal Testing Machine to test the tenderness of various foods. Briefly, the machine consists of two parts: (a) The drive mechanism which moves a crosshead in a vertical direction by means of twin lead screws at selected speeds in the range 0.05 to 50 cm/min; and (b) the load sensor and recording system which consists of electric bonded-wire strain gauges whose output is fed to a strip chart recorder. A full-scale deflection of the recorder pen over the load range of 2 g to 5,000 kg may be obtained by the use of a sensitivity selector switch on the machine and the appropriate load cell. The time axis of the chart is either a direct measure of or a simple multiple of the movement of the crosshead, depending upon the change gears used. This important attribute of the machine arises from the fact that both the recorder chart and moving crosshead are synchronously driven from the same power supply. The versatility of the Instron has been proven by the fact that any instrument that uses a linear motion in measuring food tenderness can be duplicated with a single universal testing machine (UTM) which has been fitted with the particular probe or shearing device, as demonstrated by Kulwich (1963), who obtained excellent correlation with taste panel and Warner-Bratzler Shear results. Similarly, the toughness-firmness of frankfurters was measured by a UTM fitted with probes resembling human molars and incisors. (This machine was the prototype for a specific instrument, the carbide penetrometer, which was built to perform frankfurter puncture tests.) The Warner-Bratzler Shear, Shear-Press, and numerous other tenderness-measuring devices have been used with the Instron. The force curve obtained from the Instron tests provides peak shear values and the force-displacement curve. The work required in shearing or puncturing can be obtained mathematically from the force curve or by the use of an integrator which can be fitted to the Instron and gives a numerical value for the work which is a function of the chart speed, load range, and force required to shear, puncture, or compress the product.

In considering the various tenderness devices, it must be emphasized that no specific device can be determined to be more accurate than another. But what must be considered are the ease of application, application to a particular type and form of product, and the convenience in obtaining the desired results.

Freeze-Dried Foods

Freeze-dried foods have been on the American market for about 10 years. Few of them, however, have been on grocery shelves as individual items. Some have been available in soups, others in stews. A number are available in sporting good stores for campers, hunters, fishermen, and others interested in foods that fill a convenience function. Kermit Bird, an economist with the United States Department of Agriculture Economic Research Service, has done an extensive study on the economic, marketing, and palatability considerations of freeze-dried foods.

Freeze-drying is the removal of moisture from frozen food through a combination of vacuum and heat without allowing the frozen food to melt. The major processing steps involved in freeze-drying include:

(1) Food Preparation--This may include cooking, eliminating unedible portions such as bone, fat, and skins. Also involved is getting the right particle size by slicing, dicing, powdering, or making into a syrup or slurry. Large or irregular sized pieces are difficult to freeze-dry.

(2) Freezing--Almost always food to be freeze-dried is frozen outside the drying cabinets. For some foods it is possible to vacuum freeze or plate freeze inside the drying chamber.

(3) Drying--Most commonly, frozen foods are placed on trays which are then inserted on racks in the drying cabinet. Cabinets are designed so that heat is close to each food particle. At the same time as heating, pressure within the cabinet is lowered to one millimeter or less, Hg., absolute. Temperatures may be 250°F at the beginning of the drying cycle and taper down to 110°F so the product does not burn. Drying usually takes 8-30 hours, with the final product being about 2% moisture. The cabinet can be back-flushed with nitrogen or other gases to prevent re-entry of oxygen or moisture into the dried food.

(4) Packaging--The food should be placed in an airtight, moisture-proof, light-proof package. Generally, packages are nitrogen-gassed to prevent

oxidation during storage. This is particularly important for products like meat which are high in fat.

Freeze-drying of foods on a commercial basis started in this country around 1960-1961. During 1959 the Thomas J. Lipton Company began market testing dried soups containing freeze-dried chicken and other soup ingredients. In Europe the first commercial freeze-drying operation was H. Hartog's Fakrieken, Oss, Netherlands, in 1955. In 1964 the first continuous freeze-drier began operation in Dahlenberg, Germany (Bird, 1964).

In 1962 the freeze-drying industry was about 6-1/2 million pounds. (This is in terms of input in frozen foods.) In 1963, there were over 11 million pounds of frozen foods dried, and in 1964 19 million pounds of food freeze-dried. By 1970, it is anticipated that about 250 million pounds of frozen food will be dried using the freeze-drying method. (Bird, 1964)

The major market outlets for freeze-dried foods will probably be in the following areas:

(A) The Remanufacturing Market--This area probably has the greatest future. At present, it uses more freeze-dried foods than any other outlet. Soups, stews, puddings, prepared meals, desserts, cereals and many other items will be the most popular foods to use freeze drying. Most freeze-dried foods going through this intermediate stage market will be mixed or blended with non freeze-dried items. If other items in the food must be dried, they will probably be dried using cheaper, more conventional methods.

(B) Coffee and Tea--Freeze-dried coffee now on the market appears to rival spray-dried coffee in popularity. These items may be sold at retail, to institutions, and to the Armed Forces.

(C) The Armed Forces--High-quality dried items have great value as emergency rations and combat foods. At present, about 59 different freeze-dried foods are being used in the services. Of these, 37 are rehydrated in the usual manner and the remaining 22 are saliva-wetted for rehydration (Bird, 1964). The expanding space exploration program has brought freeze-dried foods to the forefront as necessary items on prolonged flights.

(D) Retail Grocery Sales--Sales in this area have been disappointing, but the success of freeze-dried coffee and other freeze-dried products is encouraging in regard to consumer acceptance of freeze-dried foods.

(E) Institutional Sales and Specialized Sales--These areas do not appear to be large outlets for freeze-dried foods.

Specialized sales such as for campers, sportsmen, etc., are too small to justify the high costs of production and sales of freeze-dried foods. Institutions demand uniformly high quality products and, except for a few items, present freeze-dried foods do not meet this rigid requirement. Freeze-drying needs more cost reduction and quality developmental work before it will be ready for these markets.

The potentially high organoleptic and nutritional qualities of freeze-dried foods are limited by several chemical and physical deteriorative reactions. These reactions may occur during processing, others in storage, and are strongly influenced by factors such as temperature, moisture content, and the presence of oxygen. Much research has been undertaken to solve these undesirable changes; however, some difficult problems remain to be solved. Some reactions which still are inadequately understood are: (1) loss of flavor compounds, (2) nonenzymatic browning at very low water contents, (3) reactions due to lipid oxidation, (4) loss of pleasing appearance, and (5) changes in tenderness characteristics.

A major defect of freeze-dried foods is a decrease in tenderness often associated with decreased water-holding capacity. These changes are related to increased aggregation of polymeric constituents (Karel, 1968).

In fruits and vegetables, dehydration can result in increased crystallinity of the cellulose in the cell walls (Sterling and Shimaju, 1961). It is not known if this phenomenon is responsible for undesirable texture characteristics in dried vegetables, but it is known that random scission of the cellulose chains by suitable agents counteracts some of the effects of increased crystallinity and is also effective in improving texture. Cellulose is susceptible to scission by ionizing irradiation (Bovey, 1958), in addition to the ability of irradiation to soften vegetable and plant tissues (Maxie and Sommer, 1965). Therefore, the application of irradiation to improve tenderness of dehydrated foods of plant origin is a logical extension of researchers' findings.

The loss of tenderness in meats and fish is less understood than similar events in plant materials and is often difficult to correct. Palatability tests of freeze-dried meats were conducted by the U.S.D.A. Economic Research Service (Bird, 1965). The results of these tests showed that the greatest drawback of freeze-dried meats was loss in flavor, followed closely by tenderness and appearance. Many freeze-dried meats were considered tough, and probably some of this characteristic resulted from lack of complete rehydration (Bird, 1965).

In the palatability tests on beef, seven beef items were tested. These were diced beef, sliced beef with gravy, Swiss steak, beef steaks, beef stew, hamburger patties, and beef noodle soup. All these products were cooked, frozen, then dried. Comparison products were frozen for the sliced beef with gravy, hamburger patties, steaks, and Swiss steak. The comparisons were canned for diced beef, beef stew, and soup.

Freeze-dried beef dice were inferior to canned dice in general appearance, juciness, texture, and tenderness. Appearance and flavor scores were similar. Comments on the freeze-dried beef dice described the meat as "dry," "lacking in flavor," "tough," "fibrous," "stringy," and "poor in color." Comparison scores for freeze-dried beef slices were also low, for all taste characteristics. Comments were similar to those made about freeze-dried beef dice with the additional comment that the beef "looked like leather."

Freeze-dried Swiss steak received low palatability scores almost identical to frozen Swiss steak. Adverse comments included "fibrous and stringy," "dry," "off-flavor." Freeze-dried beef steak received lower scores than frozen steaks with respect to tenderness and juciness. They were described as "watery or mushy," and "dry, yet oozing juice."

The freeze-dried beef stew was packaged in a pouch which included non freeze-dried items. There was little difference noted between dried and canned stews, but comments for the freeze-dried stew meat included "tough" and "off-flavored."

Freeze-dried hamburger samples compared favorably with frozen samples in all palatability characteristics except juiciness. Freeze-dried beef noodle soup was judged superior to canned beef noodle soup in general acceptance, appearance, flavor, and juiciness. The only adverse comments were that the freeze-dried meat was "tough."

The changes in tenderness may be due to one or all of the following events in actomyosin complex: (1) aggregation or cross-linking of undenatured protein, (2) denaturation of protein, followed by aggregation, (3) interaction of the native, or denatured proteins with lipids or carbohydrates (Karel, 1968).

The view that events causing loss of water-holding and change in tenderness occur in actomyosin appears well substantiated. Tenderness of meats may be directly related to the length of sarcomeres of the muscle fibrils (Marsh and Leet, 1966). It has been shown by Wismer-Pedersen (1965a), that the main features of hydration losses produced in freeze-dried pork are also produced by freeze-drying isolated pork muscle myofibrils. Dehydration reduced water binding at the isoelectric pH range and resulted in significant tenderness changes as measured with a Warner-Bratzler Shear (Wismer-Pedersen, 1965b).

Little is known on the molecular interactions causing decreased hydration. Connell (1957) suggested that some of the increased aggregation is due to intermolecular disulfide bridges. Khan and Van Den Berg (1965) found that tenderness changes correlated with decreased sulfhydryl content of chicken muscle kept in frozen storage. Hamm and Deatherage (1960) suggested the possible formation of electrostatic and hydrogen bonds between the chains of muscle proteins. These bonds are possible because of the sensitivity of rehydration and tenderness characteristics of muscle tissues in relation to the ionic environment during dehydration. MacKenzie and Luyet (1967) studied bovine muscles which were freeze-dried and then heated under controlled conditions. They found that myofibrillar proteins sustained a substantial solubility loss when dry tissues were exposed to 80°C for 24 hours. When the experiment was conducted at low temperatures freeze-drying alone produced no losses in solubility of myofibrillar proteins. The authors suggested that the decreased solubility results from cross-linking reactions between undenatured myosin molecules.

From the previous works cited it appears that internal cross-linking of actomyosin is responsible for tenderness changes during the freeze-drying process. It is possible that a suitable combination of processing techniques before and after freeze-drying may ameliorate some of these undesirable changes.

Processing Techniques and Tenderness of Meat

Tenderness of meat is influenced greatly by the processing techniques used. In reports by Wells et al. (1962), Sosebee et al. (1964), and Seltzer (1964) the general conclusion was that freeze-drying toughened chicken meat. Similar results with freeze-dried pork were reported by Tuomy and Helmer (1967). Bird (1965) states that U.S. Department of Agriculture taste panels have shown that freeze dehydrated pork, chicken, and beef were rated tougher than fresh-frozen samples.

Goldblith et al. (1963), Tuomy and Felder (1964), reported that temperature during the dehydration process is an important variable. High temperatures during drying are harmful, maybe because heat-denatured proteins have a greater tendency to crosslink. Even though denaturation in the dry state is retarded, conditions during freeze-drying can result in significant concentrations of liquid water. These local concentrations are due either to non-frozen water when temperatures of the "frozen zone" are above -25°C (Nemitz, 1964) or to the considerable amount of "bound" water retained in the "dry zone" after sublimation of most of the ice crystals (Fusi, 1965). In addition, even in completely dry muscle, high temperatures can result in aggregation (MacKenzie and Luyet, 1967). Because of this toughening effect, only very low drying temperatures can be used with the extended periods required for freeze-drying if one is to minimize the toughening effects. A 110°F platen temperature, as specified by Seltzer (1961), is considered safe.

Cooking the meat before or after freeze-drying tended to toughen the meat (Miller and May, 1965). This result agrees with the idea presented by Seltzer, 1961, that any additional heat beyond the temperature required for freeze-drying tends to toughen meat. Miller and May, 1965, also showed that cooking in boiling water to 190°F before freeze-drying made chicken meat less tough than chicken cooked similarly after freeze-drying, although both cooked samples were tougher than non-cooked freeze-dried samples.

Freezing rate studies by Dubois _et al_. (1940) described rapidly-frozen beef (-40°F) as having better all around quality, including palatability (a parameter of which is tenderness), than controls frozen at 0°F. Dubois _et al_. (1942) reported the same results with rapidly-frozen poultry (-40°F) when compared with conventionally frozen birds (-100°F). Miller and May, 1965, found confusing results when comparing rapid (-90°F) and slow (0°F) freezing, with both rates resulting in meat of about equal tenderness in both freeze-dried and non-freeze-dried groups. Freeze-drying experiments by N. E. Bengtsson (1967) with cooked beef comparing rapid freezing at 0.8 cm/hr to slow freezing at 0.06 cm/hr showed no improvement of drying rate or water uptake during rehydration as a result of larger ice crystals formed in slow freezing. A significant difference in appearance between the quick and slow frozen products was noted with the quick frozen product being brighter and fresher in color and superior in appearance. Similar results with poultry were reported by King et al. (1968). They stated that fast-frozen pieces of turkey breast meat maintained a whiter color than did pieces frozen more slowly.

Storage studies by Bengtsson (1967) showed that after 3 months storage, sensory panels favored quick frozen meat to slow-frozen meat for taste, tenderness and juiciness. After 6-8 months storage there was a statistically significant difference with panelists favoring quick frozen freeze-dried beef over slowly frozen freeze-dried beef. Storage studies by Miller and May, 1965, showed that -30°F storage temperatures resulted in significantly more tender meat than storage temperatures of -15°F and 0°F, but as time in frozen storage increased, tenderness decreased. Wills et al. (1948a,b) reporting on chicken, and Klose et al. (1950), reporting on turkey steaks, have found that the palatability of frozen meat was better with low than with higher storage temperatures.

All the previously mentioned studies point out that meat to be subsequently freeze-dried may require quite different cooking, freezing, and storage treatments from meat preserved by other means.

METHODS AND MATERIALS

The meat used for study was choice grade, top round of beef, major muscles _Semi membranosus_, _Adductor_, _Gracilis_. This meat was bought from Michigan State University Food Stores.

Preparation

Samples were prepared by cutting small steaks 1-1/2" x 3 x 1/2" and by coring cylinders 1/2" diam. x 1-3/4". These samples were precooked in a steam-heated 180°F water bath to an internal temperature of 165°F and immediately frozen. (Precooking to 165°F was determined as the average time for a thermocouple placed midway in a number of different samples to register 165°F. For steaks, this time was about 10 minutes. For cylinders this time was about 2 minutes.)

Processing

A. Freezing--Two freezing rates were studied, rapid freezing accomplished with nitrogen vapor, and slow freezing, achieved by natural cold air convection.

   1. Nitrogen Freezing--Nitrogen freezing was done in an Air Products Cryogenic Freezer, Model No.

CT-1818-12F. Nitrogen was forced by air at 3-10 lbs. pressure through a 3/8 inch diameter orifice into the freezing chamber where the nitrogen was channeled through copper tubing and expelled into the chamber through twelve 1/16" diameter holes. The nitrogen vapor was circulated in the chamber by a variable-speed fan. Chamber temperature was controlled by varying the rate at which liquid nitrogen was forced into the chamber.

For experimental work, the chamber temperature was regulated to -150°F and the sample frozen to -10°F internal temperature at an average freezing rate of 0.10 cm/min (half thickness divided by time required for a thermocouple placed midway into the product to register from 45 to -10°F. This is an average figure based on measurements for 3 different samples).

2. Convection Freezing--Convection freezing was accomplished in a Puffer-Hubbard upright freezer with a Honeywell temperature regulator, range -50 to 100°F. Freezing was done at a freezing temperature of -20°F. Cooling was continued until the warmest spot in the sample reached -10°F. To achieve a slow rate of

natural convection, the samples were placed on a wooden base and covered with a cardboard box. This process gave a freezing rate of about 0.005 cm/min. The pre-cook and freezing temperatures were recorded on a Honeywell 24 point (5 seconds between points) "Electronik 15" recording potentiometer (range -50°F to 250°F).

B. Freeze-Drying--Immediately after freezing, the samples were placed in a freeze-dryer, Virtis Sublimator Repp Model FFD 42WS with a compressor model Copeland 9TK1-0500-TFC and vacuum pump Model Hyvac 45. The freeze-drying chamber has 5 shelves, a condenser capacity of 50 lbs. water, and can achieve a vacuum of <5.0μHg.

The samples were freeze-dried at a plate temperature of 110°F at a vacuum of 5.0 μHg. Sample temperature during freeze-drying was recorded by measuring thermocouples connected to a Honeywell "Electronik 16" multipoint strip chart recorder. Vacuum was recorded on a Leeds and Northrup Speedomax W vacuum recorder (response time 5 sec full travel). Freeze-drying end point was determined to be when sample center temperature equalled plate temperature; i.e., about 24 hours.

C. Rehydration--After freeze-drying, samples were rehydrated in a steam-heated water bath. The temperature and steam inflow into the water bath were controlled by a Foxboro Temperature Controller. Rehydration time was 20 min, which was the time at which the samples rehydrate to an average of 95% of the extent to which they will ultimately rehydrate.

Tenderness and Rehydration

Various samples were "tagged" and weighed when raw, after precooking, after freeze-drying, and after rehydration. Weighing was accomplished on a top-loading Mettler balance. In this way, weight relationships and rehydration ratio data were obtained. In all cases rehydration was performed immediately after freeze-drying.

Tenderness values were obtained by using a Warner-Bratzler shear, and Instron Universal Testing Machine.

A. Warner-Bratzler Shear--Meat cores 1/2" x 1-3/4" were taken parallel with the direction of the majority of muscle fibers. The amount of force necessary to shear through the cylindrical meat sample of given diameter was determined by using a shearing blade 0.04 inches in thickness powered by a G.-R. Electric Mfg. Co. electric motor, at a blade speed of 0.38 cm/sec.

The opening in the shearing blade is made by circumscribing an equilateral triangle about a circle one inch in diameter. The cutting or shearing edge of the opening is rounded or dulled to the radius of a circle of 0.02 inches.

The amount of force necessary to shear the sample is recorded on a dead hand Chatillon spring dynamometer (50 lb. capacity).

B. Instron--An Instron Universal Testing Machine, Model TT-BM was used. The machine consists of two parts: (a) The drive mechanism which drives a moving crosshead in a vertical direction by means of twin lead screws at selected speeds of 0.05 to 50 cm/min; and (b) The load-sensing and recording system which consists of electric bonded-wire strain gauges whose output is fed to a strip-chart recorder. A sensitivity selector switch and several load cells make it possible to obtain full scale deflection of the recorder pen over the load range 2 g to 5,000 Kg. The time axis of the chart is either a direct measure of or a simple multiple of the movement of the crosshead, depending upon the change gears used.

An Instron Integrator was used to obtain the area under the force-distance curves generated by the pen recording the force necessary to shear the sample. The Integrator was connected to the recording pen and generated Integrator readings which were a function of the force-distance curves. By the use of a simple conversion formula the Integrator readings could be converted to the area under the force-distance curve (a measure of the work used to shear the sample).

The load cell was placed below the moving crosshead, with the shear blade being driven down through the sample by means of the twin lead screws at a speed of 20 cm/min (0.33 cm/sec).

The shear blades used were: (a) a metal blade 0.12 inches thick and 2.7 inches wide. The blade was moved through a guide housing (providing little friction) and sheared steak samples perpendicular to a majority of the muscle fibers; (b) a metal blade 0.12 inches thick and 2.7 inches wide similar to that described in (a), except that an equilateral triangle of side 1.22 inches was cut out such that it fit midway across the base of the shear blade. This blade is an approximation to the blade used in the Warner-Bratzler shear and was used to shear beef cylinders.

Note: The words texture and tenderness are often used interchangeably. However, since there is no universally accepted nomenclature to describe these stimulus-responses, peak shear force will be used in this study to represent tenderness.

EXPERIMENTAL RESULTS

Freezing Rates and Freezing Points

The samples frozen in a nitrogen vapor environment at -150°F gave a freezing rate of 0.1 cm/min. The samples frozen by natural cold air convection at -20°F froze at a rate of 0.005 cm/min. For the sake of simplicity we will call the freezing rate of 0.1 cm/min "fast" freezing and the freezing rate 0.005 cm/min "slow" freezing. The fast frozen samples reach -10°F in about 7.0 min.

Figures 1 and 2 show the freezing curves for the two types of freezing. An interesting observation from both these figures is the "freezing point" for cooked meat. Charm (1963) defines freezing point as the point on the freezing curve at which a sharp break, caused by a change of state occurs. Complex products such as meats do not necessarily show sharp breaks. As best as the writer can tell, both Figure 1 and 2 show breaks at about 18°F. Thus, in this experimental work the freezing point of choice top round of beef precooked to 165°F appears to be about 18°F.

Figure 3 shows the freezing curve for raw choice grade beef round. The sharp break representing the freezing point occurs on this curve at about 26°F. From these

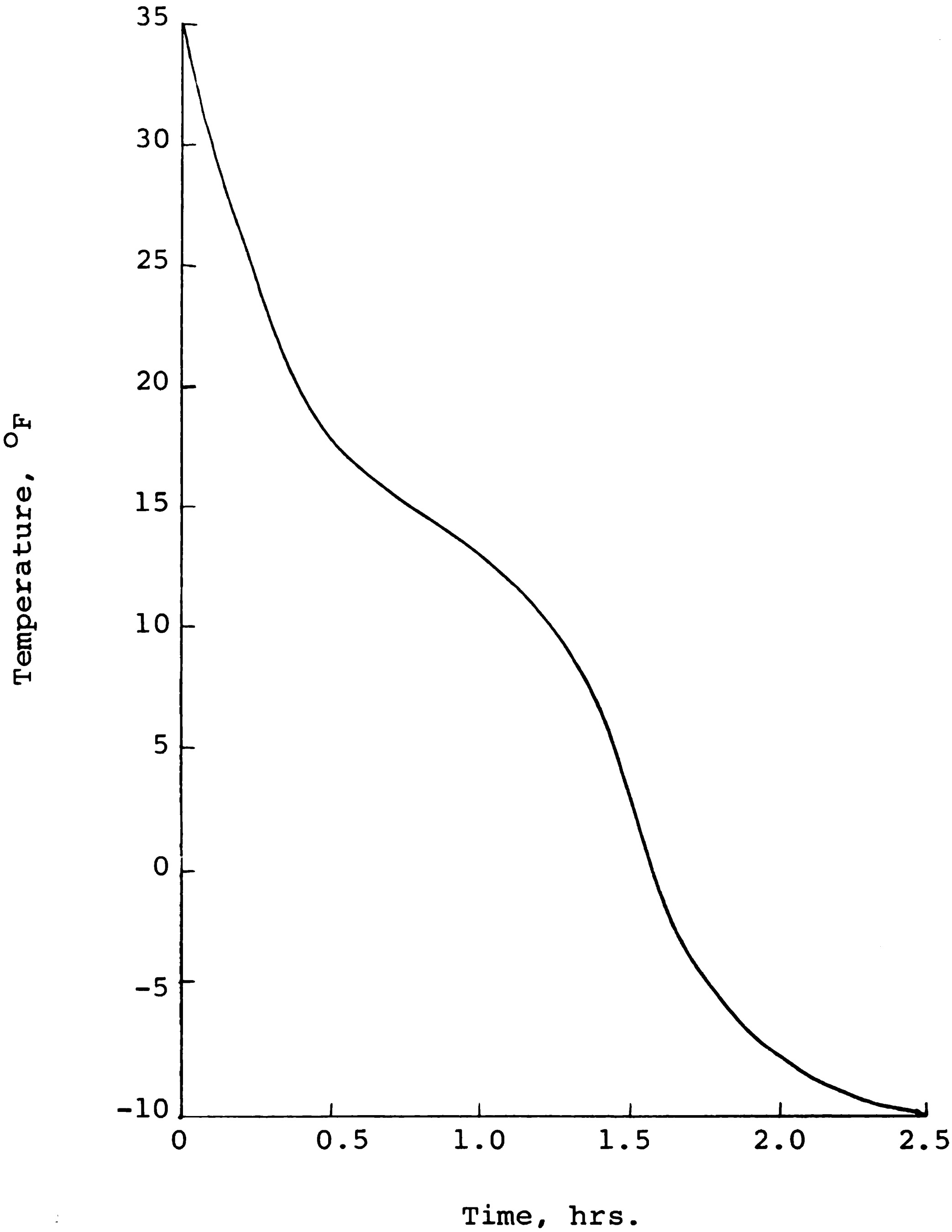

Figure 1.--Cold air convection freezing curve of precooked meat to -10^{O}F internal temperature.

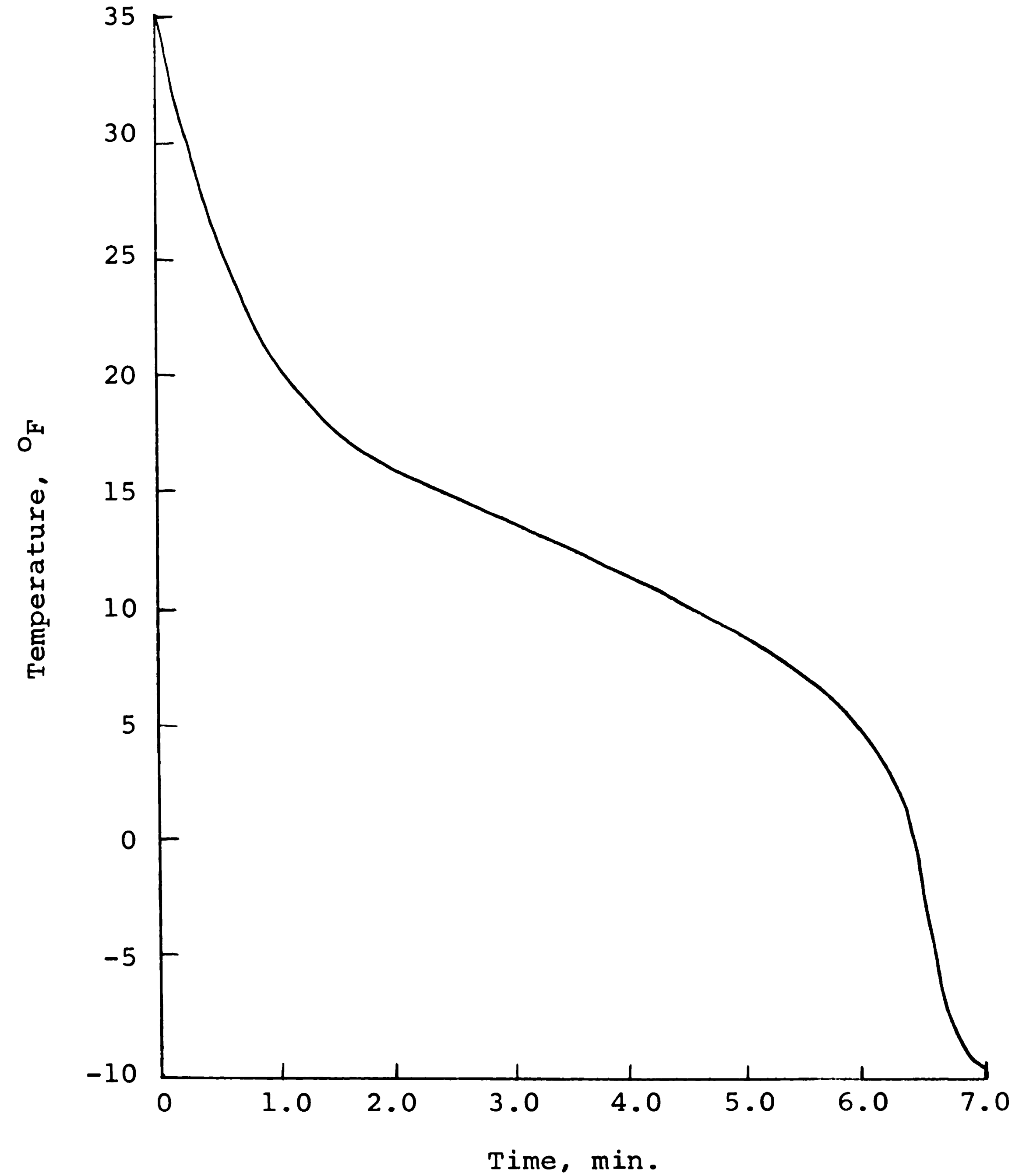

Figure 2.--Nitrogen vapor freezing curve of precooked meat to -10°F internal temperature.

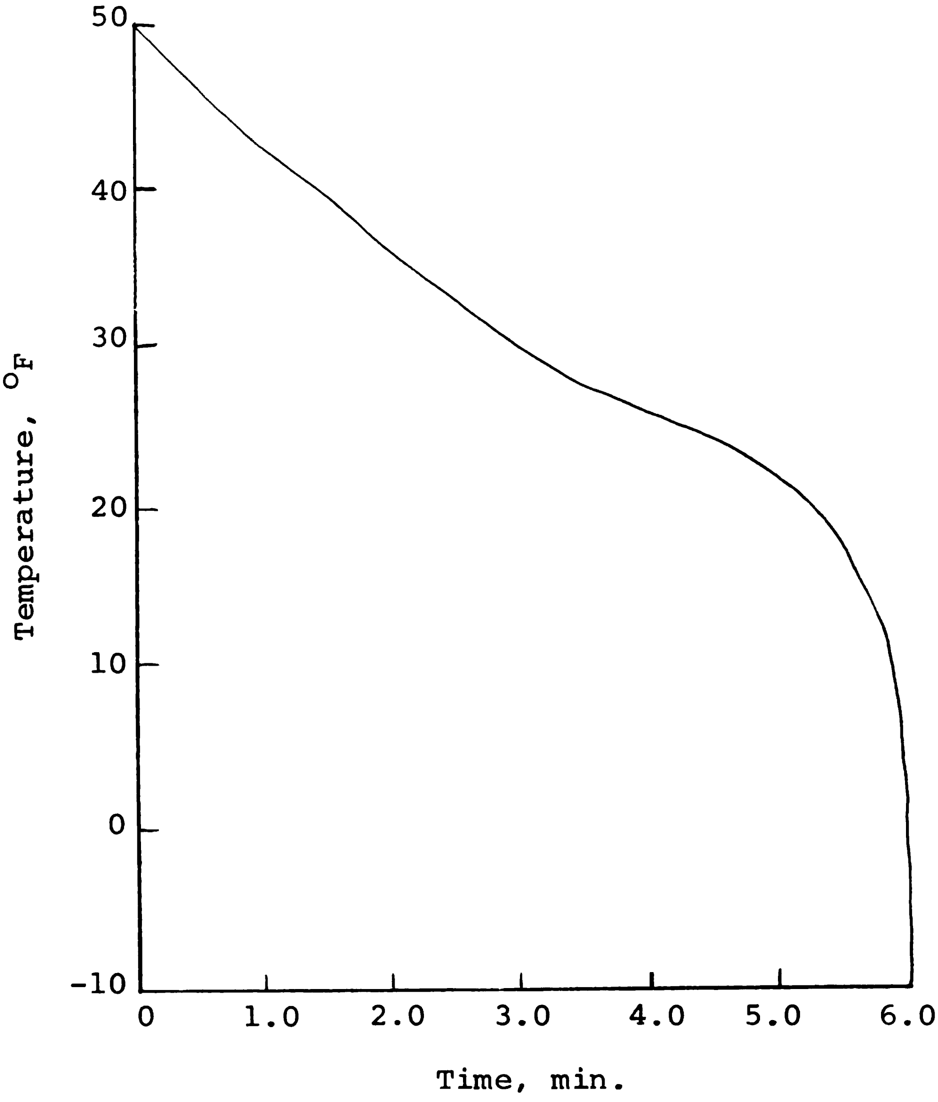

Figure 3.--Nitrogen vapor freezing curve of raw meat to -10°F internal temperature.

results it appears that cooking choice grade beef round to 165°F internal temperature lowers the freezing point about 8°F.

Processing Variables and Tenderness

Two processing variables, freezing rate and rehydration temperature, were each applied at two levels in a factorial experimental design. The processing variables were examined and compared for their effects on the peak force required to shear rehydrated, freeze-dried beef steaks. The values of the variables are shown in Table 2.

Table 2.--Processing variables affecting tenderness of freeze-dried beef.

Freezing Rate	Rehydration Temperature	Designation
0.005 cm/min	100°F	slow - 100
0.005 cm/min	200°F	slow - 200
0.1 cm/min	100°F	fast - 100
0.1 cm/min	200°F	fast - 200

Due to the variability among animals, the peak shear values (for identical treatments) will vary from animal to animal. The pattern shown in Table 3 consistently occurred, with slow freezing and 100°F rehydration being the least tough, and fast freezing at 200°F rehydration being the toughest.

Table 3.--Peak force, Kg., required to shear 1/2 inch thick rehydrated freeze-dried steaks (avg. of 12 measurements per treatment).

Rehydration temperature, °F	Freezing rate, cm/min		
	0.005	0.1	Avg.
100	42	52	47
200	70	109	90
Avg.	56	81	68

Table 4 shows the peak shear forces for another experiment, with the results being similar to those in Table 3.

Table 4.--Peak force, Kg., required to shear 1/2 inch thick rehydrated freeze-dried steaks (avg. of 20 measurements per treatment).

Rehydration temperature, °F	Freezing rate, cm/min		
	0.005	0.1	Avg.
100	36	76	56
200	69	124	96
Avg.	52	100	76

The results reported are all peak shear forces, but it should be noted that the energy required to shear the sample correlated well with peak shear forces. Therefore, the area under a force-displacement curve generated by shearing the sample could also be used for comparing the effect of processing variables on the tenderness of rehydrated freeze-dried beef.

Statistical analysis of the data presented in Tables 3 and 4 showed the following:*

Table 3. There was a 5% level of significant difference between freezing rates and a 1% level of significant difference between rehydration temperatures. A Duncan's Multiple Range Test was done with the results below.

Treatment	slow-100	fast-100	slow-200	fast-200
Mean Value, Kg. . .	42	52	70	109

α error: 5%
1%

Standard error of Mean = 11.1 Kg.

Table 4. There was a 1% level of significant difference between freezing rates and a 1% level of significant difference between rehydration temperatures. A Duncan's Multiple Range Test was done with the results below.

Treatment	slow-100	slow-200	fast-100	fast-200
Mean Value, Kg. . .	36	69	76	124

α error: 5%
1%

Standard error of Mean = 9.6 Kg.

*See Appendix for statistical analyses.

The results from both Tables 3 and 4 showed that rehydrated freeze-dried samples slow frozen and rehydrated at 100°F were significantly different from samples fast frozen and rehydrated at 200°F. The internal differences between the treatments showed that samples slow frozen and rehydrated at 200°F were not statistically different from samples fast frozen and rehydrated at 100°F.

Correlation of Instron and Warner-Bratzler Shear

In comparing the Instron and Warner-Bratzler Shear, 1/2 inch rehydrated freeze-dried beef cores were sheared by each instrument (different cores on each instrument but from the same roast), and the amount of force (in Kg.) required to shear the samples was recorded. Results are shown in Tables 5 and 6.*

Table 5.--Instron peak shear values, Kg., required to shear 1/2" diameter rehydrated freeze-dried beef cylinders (avg. of 15 measurements per treatment).

Rehydration temperature, °F	Freezing rate, cm/min		
	0.005	0.1	Avg.
100	4.2	3.6	3.9
200	6.0	8.2	7.1
Avg.	5.1	5.9	5.5

*For analyses of variance, see Appendix.

Table 6.--Warner-Bratzler peak shear values, Kg., required to shear 1/2" diameter rehydrated freeze-dried beef cylinders (avg. of 15 measurements per treatment).

Rehydration temperature, °F	Freezing rate, cm/min		
	0.005	0.1	Avg.
100	3.5	3.4	3.4
200	4.4	5.1	4.8
Avg.	4.0	4.2	4.1

Separate analyses of variance for treatment effects showed no significant difference between freezing rates but significance at 1% for rehydration temperatures.

A Duncan's Multiple Range Test for the results shown in Tables 5 and 6 gave the following:

Table 5.

Treatment	fast-100	slow-100	slow-200	fast-200
Mean Value, Kg. . .	3.6	4.2	6.0	8.2

α error: 5%

1%

Standard error of Mean = 0.72 Kg.

Table 6.

Treatment	fast-100	slow-100	slow-200	fast-200
Mean Value, Kg. . .	3.4	3.5	4.4	5.1

α error: 5%

1%

Standard error of Mean = 0.34 Kg.

These results agree with those previously obtained from steaks in that freezing at 0.1 cm/min and rehydrating at 200°F has a significant effect on increasing the peak shear values of rehydrated freeze-dried beef.

The correlation between the peak shear values for the Instron and Warner-Bratzler samples was examined with the results shown in Table 7.*

Table 7.--Correlation parameters for 1/2" diameter rehydrated freeze-dried beef cylinders sheared by Instron and Warner-Bratzler Shear.

Correlation coefficient	$r = 0.98$
Slope of correlation curve	$m = 0.38$
Equation of correlation curve	$y = 0.38x + 2.01$
Standard error of estimate	$\sigma = 0.22$

The correlation curve is shown in Figure 4.

From the values shown previously it can be seen that the Instron equipped with a probe resembling the Warner-Bratzler blade agrees closely with the Warner-Bratzler Shear with regard to the peak force required to shear rehydrated freeze-dried beef cylinders. Both devices show the same pattern upon statistical analysis and a high correlation coefficient of $r = 0.98$.

*For determination of correlation, see Appendix.

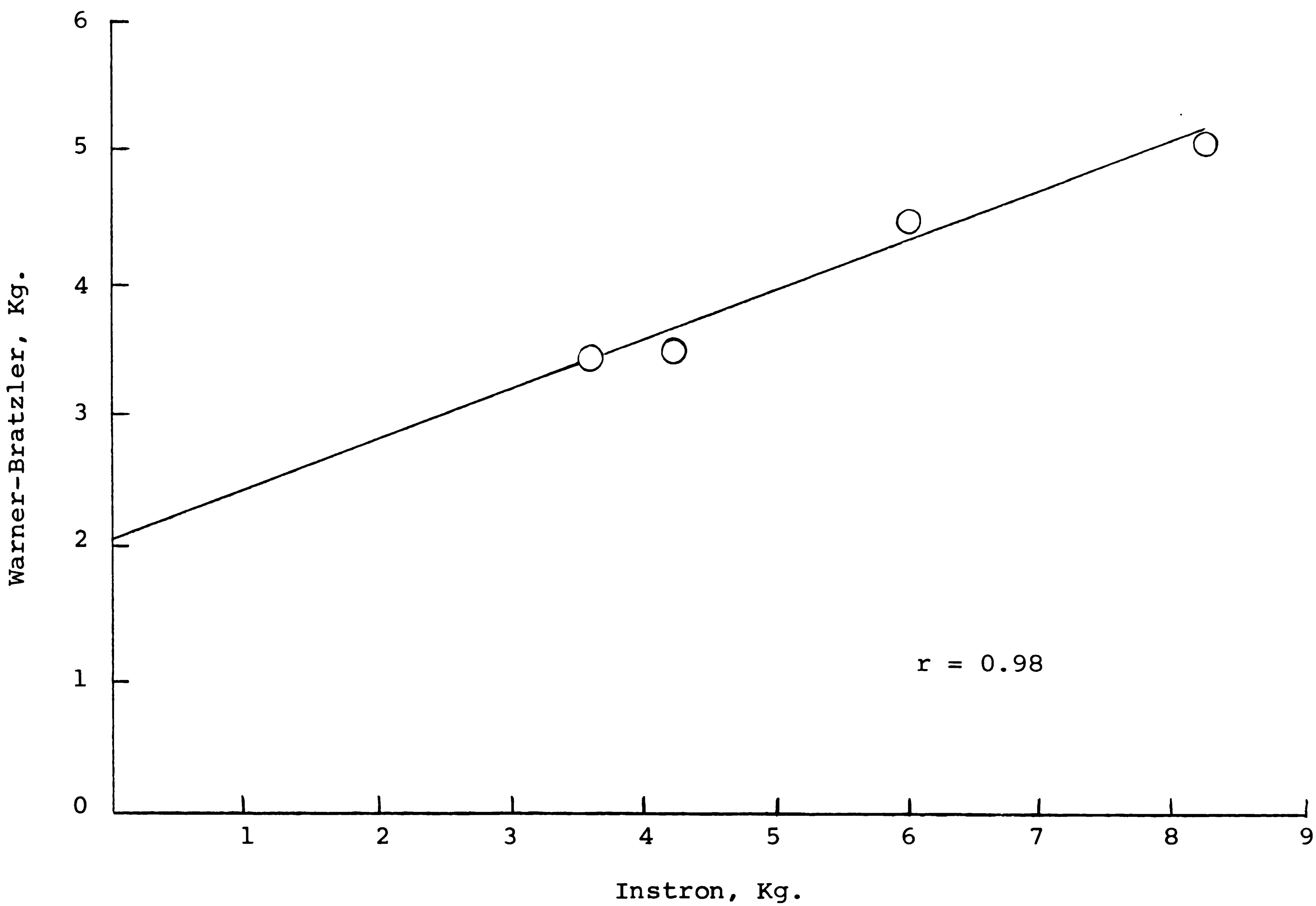

Figure 4.--Correlation of peak shear force, Kg., required to shear 1/2" diameter cylinders by Instron and Warner-Bratzler Shear.

Dry Basis Moisture Content and Tenderness

A factor which appears to be closely associated with shear force is the water uptake or rehydration ability of the freeze-dried samples. Processing variables did affect the ability of the samples to rehydrate. The fast and slow freezing rates discussed earlier and rehydration temperatures of 100°F and 200°F for 20 minutes were the parameters studied. Rehydration at 20 minutes represents the time at which the average rehydration of the samples is 95% of the extent to which they will ultimately rehydrate. The extent of rehydration was reported herein on a dry basis moisture content, Mr, the ratio of water to solids; that is, $Mr = \frac{\text{(rehydrated weight - dry weight)}}{\text{dry weight}}$ or wr - wd/wd. In this study the solids weight is assumed to be the weight after freeze-drying; that is, the removable water after freeze-drying = 0. This assumption is justified on the basis that the freeze-drying was done at a temperature similar to the vacuum oven temperature for AOAC (1965) moisture determination for beef and the vacuum during freeze-drying was much greater than that suggested by AOAC.

Figure 5 shows dry basis moisture content as a function of rehydration time for each of the combinations of variables. In this particular experiment the same four samples were removed periodically, weighed, and returned to the rehydration water bath.

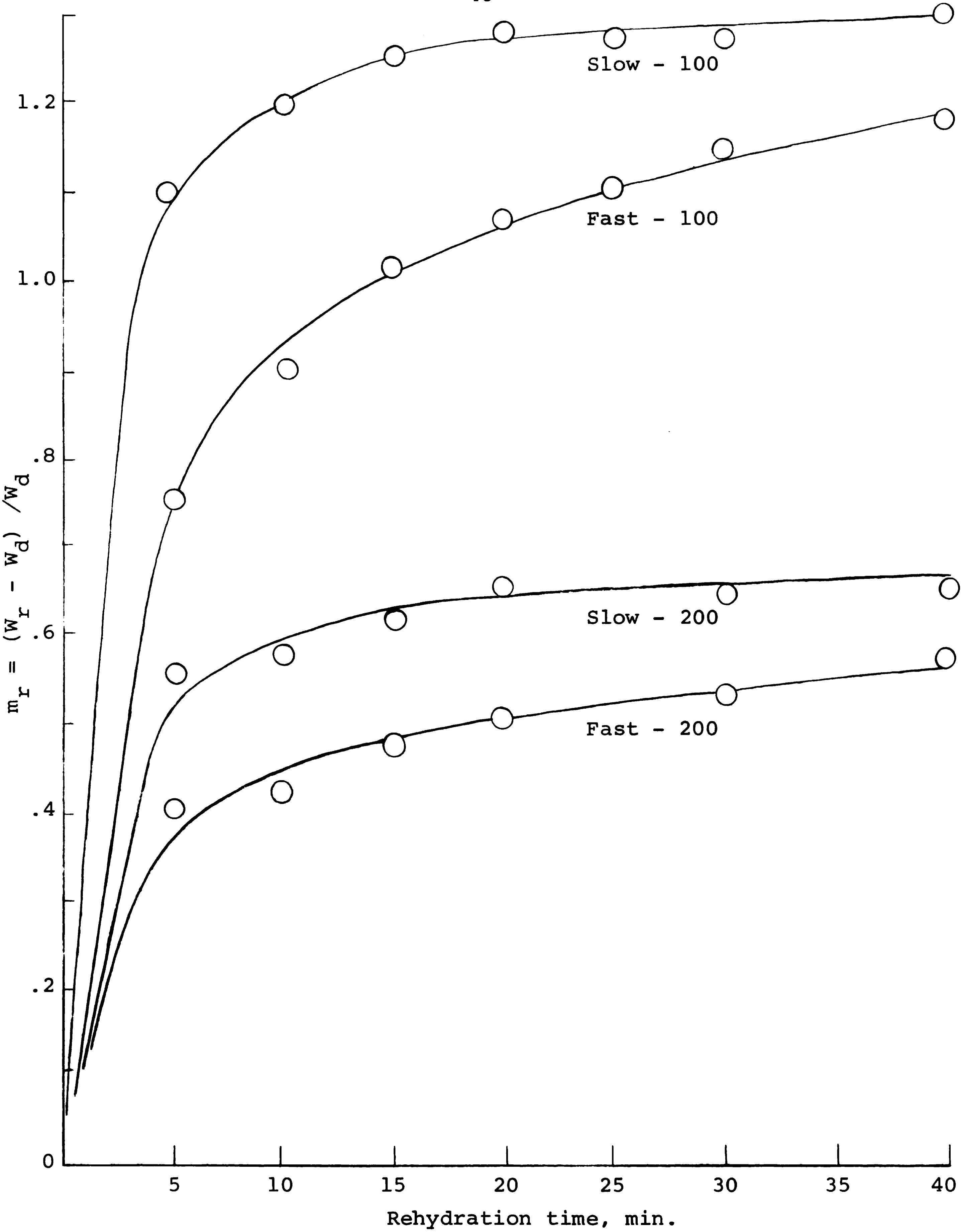

Figure 5.--Rehydration time and dry-basis moisture content of steaks.

Table 8 shows the average dry-basis moisture content for the samples in Figure 5.

Table 8.--Average dry-basis moisture content of four samples rehydrated at the 20-minute interval (data of Figure 5).

Rehydration temperature, °F	Freezing rate, cm/min		
	0.005	0.1	Avg.
100	1.28	1.08	1.18
200	0.64	.51	0.59
Avg.	0.96	0.79	0.88

Statistical analyses of these results showed a 5% level of significant difference between freezing rates and a 1% level of significant difference between rehydration temperatures in decreasing water uptake.* A Duncan's Multiple Range Test of the results in Table 8 showed:

Treatment	slow-100	fast-100	slow-200	fast-200
Mean Value	1.28	1.08	.64	.51

α error: 5%

1%

Standard error of Mean = 0.063

From these results it can be seen that rehydration temperature had the most effect in significantly reducing the extent of rehydration.

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*For analysis of variance, see Appendix.

Moisture content has also been correlated with shear values. Table 9 gives the average dry basis moisture content of the samples whose average peak shear values are shown in Table 3.*

Table 9.--Dry-basis moisture content of samples rehydrated for 20 minutes (avg. of four measurements per treatment).[a]

Rehydration temperature, °F	Freezing rate, cm/min		Avg.
	0.005	0.1	
100	1.09	0.93	1.01
200	0.65	0.51	0.58
Avg.	0.87	0.72	0.80

[a]Shear values for these steaks are given in Table 3.

Analysis of variance of the results in Table 9 showed the freezing rate to be significant at the 5% level and rehydration temperature to be significant at the 1% level in relation to decreasing moisture uptake during rehydration of the freeze-dried samples. These results are similar to those obtained for peak shear values of the samples in Table 3, and imply that the rehydration moisture content (as affected by processing variables) had an effect on the shear values of the samples.

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*For analysis of variance, see Appendix.

A Duncan's Multiple Range Test of the results in Table 9 showed:

	slow-100	fast-100	slow-200	fast-200
Treatment	slow-100	fast-100	slow-200	fast-200
Mean Value	1.09	.93	.65	.51

α error: 5%

1%

Standard error of Mean = 0.055

Again the results show that temperature of rehydration had the most significant effect in reducing the extent of rehydration.

Figure 6 shows graphically the relationship between average peak shear force and dry-basis moisture content for the samples examined in Tables 3 and 9. It can be seen that peak shear force increases greatly as the dry-basis moisture content of the rehydrated sample decreases.

The correlation between average dry-basis moisture content and average peak shear force of samples at each treatment was examined with the results shown in Table 10.*

It appears that the dry basis moisture content plays a significant role in the peak force required to shear rehydrated freeze-dried beef steaks, with an increase in the dry-basis moisture content correlating with a decrease in the peak force required to shear the sample.

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*For determination of correlation, see Appendix.

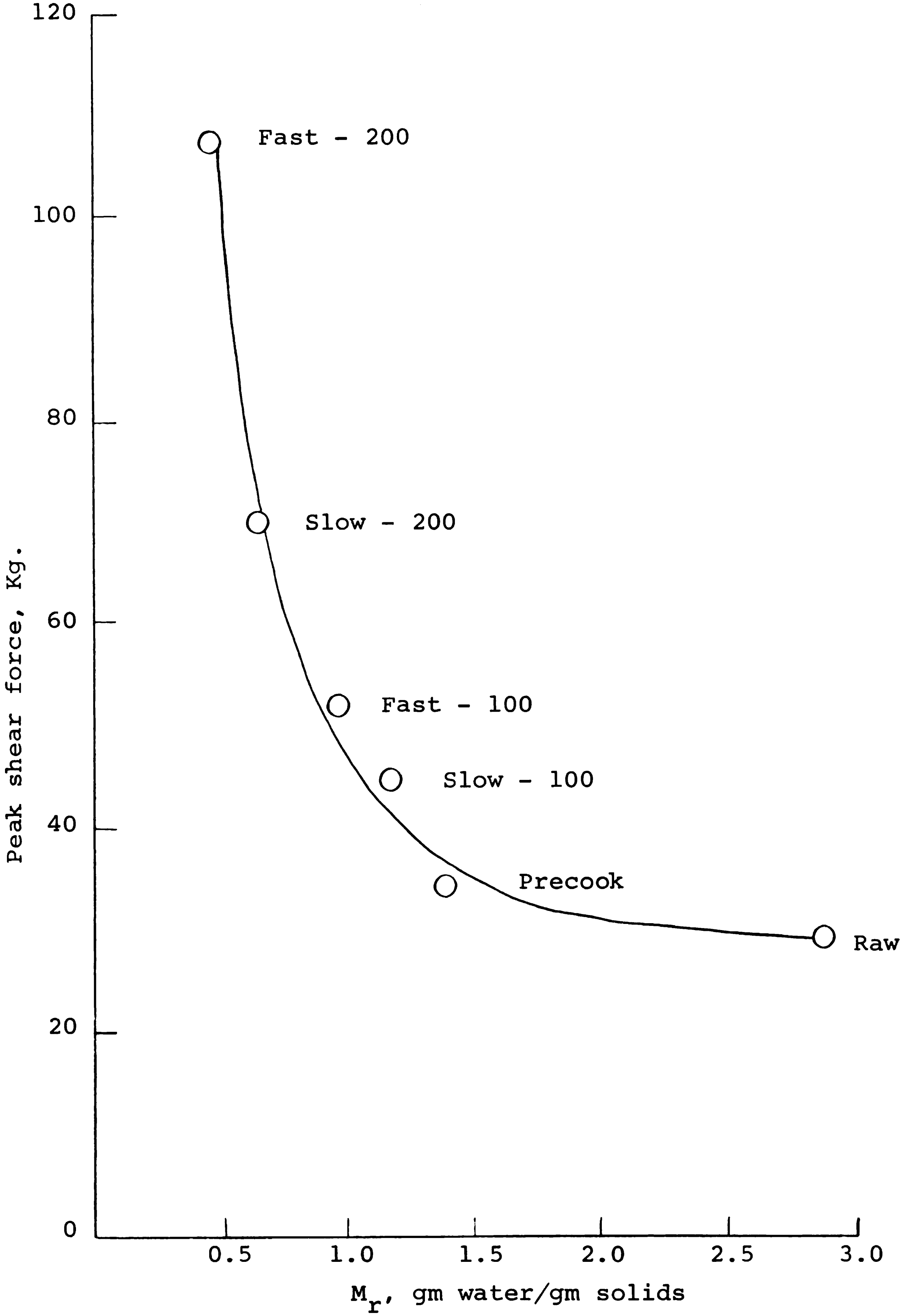

Figure 6.--Dry-basis moisture content and Kg. force required to shear steaks.

Table 10.--Correlation parameters of dry-basis moisture content and Kg. peak shear force for rehydrated freeze-dried beef steaks.

Correlation coefficient	r = -0.949
Slope of correlation curve	m = -0.008
Equation of correlation curve	y = -0.008x + 3.726
Standard error of estimate	σ = 0.117

Rehydration Temperature and Tenderness

Since it has been shown that rehydration at a temperature of 200°F caused a significant increase in shear force from samples rehydrated at 100°F, it may be conjectured that there is a temperature range where the toughening effect begins to manifest itself.

For evaluation, samples were pre-cooked and slow frozen in the conventional manner, then rehydrated at temperatures of 100, 125, 150, 175, and 200°F for 20 minutes.

Peak shear results for samples rehydrated at these temperatures are given in Table 11 and are shown graphically in Figure 7.

Table 11.--Peak shear force, Kg., of samples slow frozen and rehydrated at various temperatures (avg. of 10 measurements per treatment).

Rehydration Temp., °F . .	100	125	150	175	200
Kg. Peak Shear Force . .	41	37	47	64	80

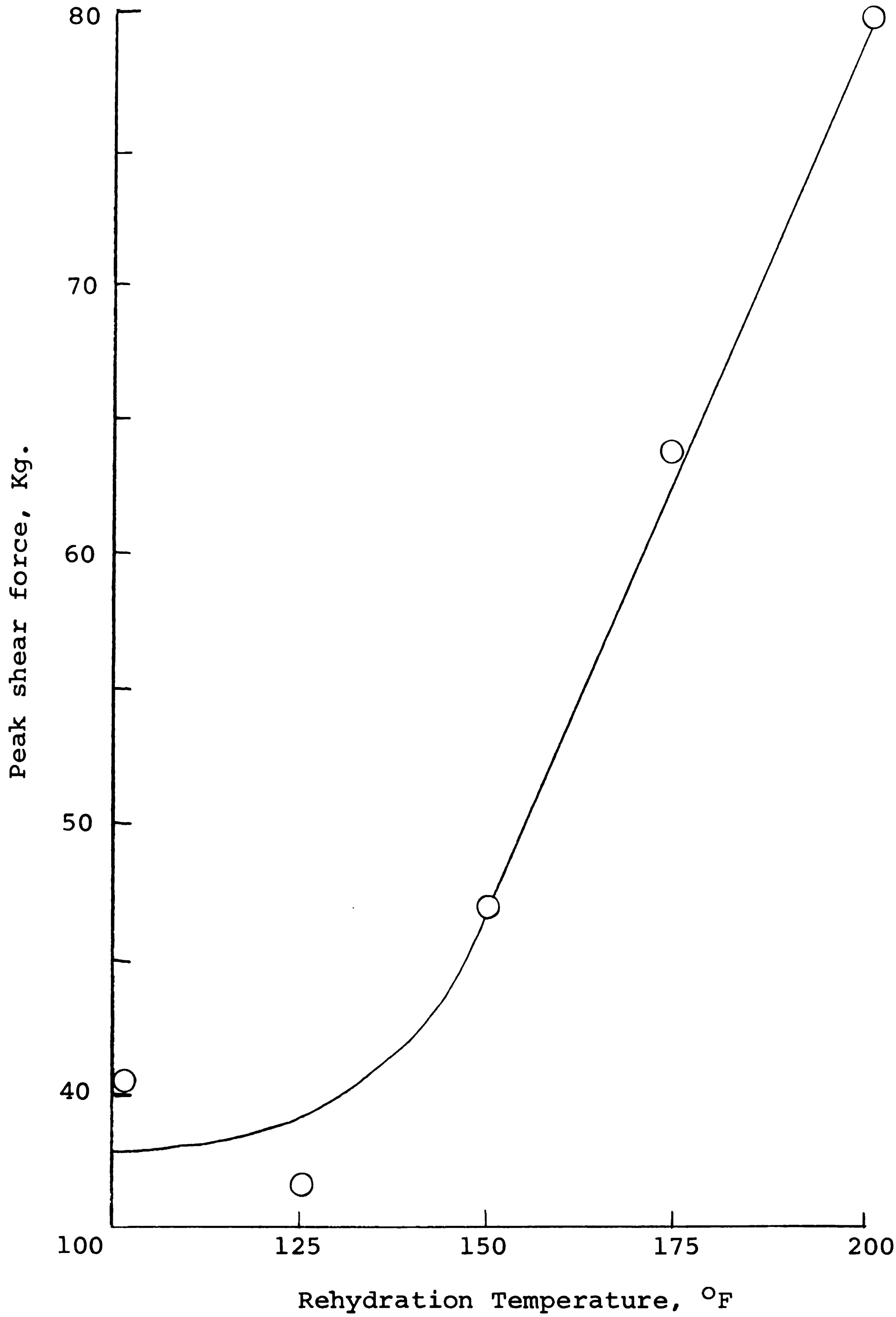

Figure 7.--Rehydration temperature and peak force required to shear steaks.

Analysis of variance of the results showed there was a 1% level of significant difference among the treatments.* A Duncan's Multiple Range Test of the treatment means in Table 11 was performed with the results shown below:

Rehydration Temp., °F . . .	125	100	150	175	200
Kg. Peak Shear Force . . .	37	41	47	64	80
α error: 5%					
1%					

Standard error of Mean = 8.05 Kg.

From these results it appears that the toughening effect occurs somewhere between 150°F and 175°F. It is possible that this toughening effect could be related to the pre-cook temperature of 165°F, but this is an area that needs further investigation. It may be implied that rehydration of freeze-dried beef steaks at temperatures below 150°F will be less detrimental to tenderness than rehydration above 150°F.

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*For analysis of variance, see Appendix.

SUMMARY AND CONCLUSIONS

In summarization, it can be said that freezing rate and rehydration temperature affect the tenderness (as measured by peak force required to shear the samples) of rehydrated freeze-dried beef. High rehydration temperature is the more significant factor in increasing shear force, and these results are highly correlated with both the Instron Universal Testing Machine equipped with a shear blade, and the Warner-Bratzler Shear. It appears that the force required to shear the samples is related to the ability of the samples to rehydrate, with precooked samples fast frozen (0.1 cm/min) and slow frozen (0.005 cm/min) and rehydrated at 200°F for 20 minutes, taking up less water (as measured by dry-basis moisture content) than similar samples slow frozen and fast frozen and rehydrated at 100°F for 20 minutes.

This temperature of rehydration effect seems to manifest itself between 150 and 175°F, for in this range significant toughening effects begin to occur. It is possible that the toughening effect in this temperature range is a function of the 165°F precooking temperature.

Sample variability presented a contrast between methods of analysis in that σ for shear force varied up to 30% of the mean value, whereas σ dry-basis moisture content varied only up to 10% of the mean value.

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APPENDIX

Freeze = freezing rate, Rehydration = rehydration temperature, * = significant at 5%, ** = significant at 1%.

1. Analysis of variance for data shown in Table 3.

Source of Variance	Degrees of Freedom	Sum of Squares	Mean Square	F
Total	47	96,122	-	-
Freeze	1	7,001	7,001	4.75*
Rehydration	1	21,688	21,688	14.72**
Interaction	1	2,586	2,586	1.75
Error	44	64,848	1,474	-

2. Analysis of variance for data shown in Table 4.

Source of Variance	Degrees of Freedom	Sum of Squares	Mean Square	F
Total	79	218,065	-	-
Freeze	1	44,916	44,916	24.50**
Rehydration	1	32,563	32,563	17.70**
Interaction	1	1,319	1,319	0.72
Error	76	139,267	1,832	-

3. Analysis of variance for data shown in Table 5.

Source of Variance	Degrees of Freedom	Sum of Squares	Mean Square	F
Total	59	626.6	-	-
Freeze	1	9.4	9.4	1.19
Rehydration	1	152.6	152.6	19.50**
Interaction	1	27.1	27.1	3.48
Error	56	437.5	7.8	-

4. Analysis of variance for data shown in Table 6.

Source of Variance	Degrees of Freedom	Sum of Squares	Mean Square	F
Total	59	127.9	-	-
Freeze	1	1.3	1.3	0.74
Rehydration	1	24.9	24.9	14.24**
Interaction	1	3.4	3.4	1.92
Error	56	98.3	1.8	-

5. Determination of correlation for results shown in Tables 5 and 6.

	(Instron) x	(Warner-Bratzler) y	x^2	y^2	xy
	3.6	3.4	13.0	11.6	12.2
	8.2	5.1	67.2	26.0	41.8
	4.2	3.5	17.6	12.2	14.7
	6.0	4.4	36.0	19.4	26.4
Σn	22.0	16.4	133.8	69.2	95.1
$\bar{n}$	5.5	4.1			

Correlation Coefficient

$r = +0.98$

Equation of linear correlation curve

$m = 0.38$

$y = \bar{y} + m(x - \bar{x}) = 0.38x + 2.01$

Standard error of estimate

$\sigma = 0.22$

6. Analysis of variance for data shown in Table 8.

Source of Variance	Degrees of Freedom	Sum of Squares	Mean Square	F
Total	15	1.76	-	-
Freeze	1	.12	.12	6.0*
Rehydration	1	1.45	1.45	72.5**
Interaction	1	0.00	0.00	0
Error	12	0.19	0.016	-

7. Analysis of variance for data shown in Table 9.

Source of Variance	Degrees of Freedom	Sum of Squares	Mean Square	F
Total	15	1.026	-	-
Freeze	1	0.101	0.101	8.29*
Rehydration	1	0.779	0.779	64.00**
Interaction	1	0.000	0.000	0
Error	12	0.146	0.012	-

8. Determination of correlation for data shown in Tables 3 and 9.

	Kg. shear force x	Dry-Basis Moisture y	x^2	y^2	xy
	42	1.09	1,764	1.19	45.78
	52	0.93	2,704	0.86	48.36
	70	0.65	4,900	0.42	45.50
	109	0.51	11,881	0.26	55.59
Σn	273	3.18	21,249	2.73	195.23
$\bar{n}$	68.2	0.80			

Correlation coefficient

$r = -0.949$

Equation of linear correlation curve

$m = -0.0083$

$y = \bar{y} + m(x - \bar{x}) = -0.008x + 3.726$

Standard error of estimate

$\sigma = 0.117$

9. Analysis of variance for data shown in Table 11.

Source of Variance	Degrees of Freedom	Sum of Squares	Mean Square	F
Total	49	39,946.2	-	-
Rehydration	4	13,113.0	3,278.2	5.06**
Samples	9	3,498.8	388.7	0.60
Error	36	23,334.4	648.1	-