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FUNDAMENTAL ASPECTS OF MEAT TEXTURE

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U. S. Army Natick Laboratories

Contract No. DA 19-129-QM-1844 (OI 5147)

August 1965



U. S. Army Materiel Command
U. S. ARMY NATICK LABORATORIES
Natick, Massachusetts

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FOREWORD

The deterioration of the textural quality of meat which frequently accompanies dehydration presents a continuing problem in the introduction of light-weight, pre-cooked dehydrated meats in special military rations. Progress in improving textural quality depends inherently on the development of reliable objective methods for the evaluation of texture.

The purpose of the work described in this report was to obtain information on: (a) applicability of the Contractor's previously developed texture nomenclature to the description of the textural quality of pre-cooked freeze-dried meat; (b) merits and limitations of the modified G.F.-M.I.T. Texturometer as an objective instrument for meat texture evaluation; (c) comparison of this instrument with other methods of texture evaluation. In addition, the work included the writing of a critical review of literature on the methodology of texture measurement, to be published in the Advances of Food Research, Volume 14, 1965.

The Official investigator was Dr. D. DeFelice. His collaborators were Dr. Alina Szczesniak, Mrs. E. Farkas, Mr. D. Gardner, and Miss K. Sloman.

The U. S. Army Natick Laboratories Project Officer was Dr. John G. Kapsalis, and the Alternate Project Officer was Mr. Justin Tuomy, both of the Food Division.

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ABSTRACT

This report summarizes work done over a four year period on the suitability of the General Foods Texturometer (I) for meat texture description and its comparison with the Warner-Bratzler Tenderometer (II) and the Kramer Shear Press (III). Parameters of hardness, cohesiveness, elasticity, chewiness and water release measurable on I were found applicable to fresh and freeze-dehydrated meats (beef, pork, turkey, fish, comminuted meat). Correlations of I with panel and with II and III varied in significance depending on variables incorporated into the sample design and were related to the range of values covered. Implications of this observation are discussed. In general, all three instruments correlated highly significantly with sensory tenderness and with each other. However, they could not be considered good predictors of tenderness. None correlated consistently with sensory juiciness. Sensory overall texture ratings could be described in terms of tenderness and juiciness. When several parameters were combined, I was superior to the other instruments in that it could account for up to 90% variation in sensory overall texture. However, the nature of equations and contributions of individual parameters varied depending on sample set. All three instruments were able to differentiate between important sample processing variables incorporated into the experimental design. In general, I appeared to be the most, and II the least sensitive to defining these differences. Rehydration in salt solution gave tougher fibers, allowed more water to be absorbed intrafibrally and less liquid to be released on mechanical chewing. Microscopically, samples rehydrated in distilled water and held overnight were the closest to freshly cooked meat. II is most susceptible to errors caused by non-muscle portions of the meat. I showed the lowest coefficient of variation and unexplained error. Due to the heterogeneity of the tested samples, it was not possible to single out one of the evaluated instruments as being definitely superior. It is recommended that the combined use of I and III be considered for research on meat texture. This and other recommendations stemming from the completed work are discussed in detail.

SUMMARY

The objective of this work was to define the suitability for meat texture description of the General Foods Texturometer and to compare this instrument with the Warner-Bratzler Tenderometer and the Kramer Shear Press. The contract was divided into three phases with different specific objectives. A total of 122 samples were evaluated using the three instruments and additional 115 samples were tested on the Texturometer only. Precooked freeze-dehydrated sliced beef was of primary concern. Fresh meat, and dehydrated pork, turkey and miscellaneous dried meats were also tested. The sponsor supplied dehydrated meat samples and sensory evaluation data in Phases II and III. General Foods texture profile panel was used in Phase I.

The Texturometer simulates the chewing motion of the human mouth and records the information in terms of several mechanical parameters (hardness, cohesiveness, elasticity and chewiness were found applicable to meats). Techniques for measuring the release of water and of fat were also worked out. Knowledge of textural parameters developed previously by General Foods Research was applied to the description of meat texture. The Texturometer was found to be highly suitable for meat work. It described meat texture in a manner which was accurate, logical and agreed with sponsor's previous experience with the tested samples. It also correlated highly with the sensory evaluation by the trained texture profile panel and with a number of chemical, physical and sensory tests performed by the sponsor.

Correlations obtained in Phase II and III between the Texturometer, the Kramer Shear Press, the Warner-Bratzler Tenderometer and a "consumer" panel were found to vary from one series of samples to another and to depend on the range of values covered as well as the sensitivity of the panel. The former, in turn, depended on the variables built into the experimental designs and the quality of meat samples. The Texturometer was found to be superior to the other two instruments in correlation with sensory tenderness ($r = -.91$) when the meat samples were replicated over four animals, four precooking levels (45 - 180 min.) were used and sensory evaluation was replicated four times over each judge. None of the instruments stood out as being superior in correlation with sensory tenderness when the samples were replicated over the judges. Combining the correlations with panel tenderness over these samples, gave the following r values for the three instruments: Texturometer $-.67$, KSP $-.77$, WB $-.76$. Although all of these correlations are significant at the 99.9% level, none of the three instruments can be considered a good predictor of sensory tenderness.

None of the three instruments correlated consistently with panel juiciness, although the Warner-Bratzler Tenderometer showed occasional correlations. No correlations were found between sensory tenderness and sensory juiciness. Panel ratings for overall texture could be statistically explained by tenderness and juiciness ratings, with the relative importance of these two parameters varying from sample set to sample set. The three instruments correlated significantly with panel overall texture, the quality of correlations again being dependent on sample type. None were good predictors of sensory overall texture ratings.

However, when several Texturometer parameters were combined, the instrument could account for up to 90% of variation in panel ratings. The relative importance of the Texturometer parameters and the quality of this relationship, again, varied depending on sample type.

All three instruments were able to differentiate between the important sample and processing variables incorporated into the experimental designs. In general, the Texturometer appeared to be the most, and the Warner-Bratzler Tenderometer the least sensitive in this respect. Length of precooking time, meat grade, animals, etc. were found to be important variables affecting meat texture. Data for the Warner-Bratzler Tenderometer were found to be the most subject to variations due to the presence of non-muscle portions in the meat samples.

The manner in which precooked freeze-dehydrated beef is rehydrated was found to have a significant effect on the microscopic appearance and textural characteristics of meat. Rehydration in a salt solution toughened the fibers and allowed more water to be bound tightly in the intrafibrillar spaces. None of the rehydration procedures tested regenerated the microscopic appearance of fresh meat. Rehydration in cold distilled water for 20 minutes followed by overnight equilibration in the refrigerator appeared to be the best of the four methods evaluated.

The three instruments were highly correlated with each other. The quality of these correlations varied between the individual sets of samples and, in general, appeared to be related to the range of values covered. High correlations were also obtained among the mechanical parameters of texture measured on the Texturometer and among the parameters related to water release. Only occasional correlations were obtained between the two groups of measurements.

The report discusses the obtained results in terms of meat heterogeneity, reliability of objective measurements, and reliability of sensory evaluations, and relates them to findings of other researchers in the field. The possible use of the three instruments in a sampling plan for quality control of precooked freeze-dehydrated meat is also described.

Based on the obtained data and comparing the individual merits of the three instruments, it is not possible to select one as being definitely superior. It is recommended that both the General Foods Texturometer and the Kramer Shear Press be used in research on meat texture.

INTRODUCTION

Meat tenderness has been the subject of numerous investigations. Because of its economic importance and its direct effect on acceptance, meat tenderness attracted the attention of husbandmen, nutritionists, biochemists, histologists, enzymologists, food technologists, home economists and others interested in contributing to the knowledge in this field. Attention of the scientists and technologists has been directed to three main areas: what is tenderness?, how can tenderness be produced in meat (either on the hoof or through post-mortem treatments)?, how can tenderness be measured and described objectively?

Research on methods of measurements has been very extensive. Various chemical, histological, enzymatic, physical and sensory methods were developed and used with varying degrees of success. In the area of physical methods, over twenty different instruments were constructed and used for basic and applied research. None of them, however, gave the consistently high agreements with the sensory perception of tenderness which were sought. Of these instruments, the Warner-Bratzler Shear, developed over 30 years ago, is the most widely used. In the last few years, the Kramer Shear Press has been gaining in popularity.

Recently, the General Foods research has developed an organized texture nomenclature dividing the complex concept of texture into primary and secondary parameters which could be defined rheologically and which could be related to popular terminology. This nomenclature was then applied to the development of sensory texture profiling and to the interpretation of recorded patterns obtained from an instrument. This instrument, the General Foods Texturometer, is a modification of the M.I.T. Denture Tenderometer and simulates the chewing motion of the human mouth.

The objective of this research contract was to investigate the applicability of the General Foods Texturometer to meat research, especially to the textural measurements on precooked freeze-dehydrated meat slices of interest to the military. The contract work was divided into three phases with the following specific objectives:

Phase I - To determine the feasibility of using the Texturometer as an objective tool for measuring the texture of precooked freeze-dehydrated meats, and to make an extensive survey of the literature on methods of meat texture evaluation.

Phase II - To compare and correlate the Warner-Bratzler Shear, the Kramer Shear Press and the General Foods Texturometer from the standpoint of their usefulness in evaluating the texture of fresh and freeze-dehydrated sliced beef.

Phase III - To extend the above comparisons and correlations to other meat types.

The results of these experimental investigations were reported in detail and discussed in 10 quarterly reports. In addition, at the request of the Project Officer, the work accomplished within Phase I was presented at the 15th annual meeting of the American Meat Institute Foundation (1) and the survey of the literature was made the basis of a review on meat texture prepared for the Advances in Food Research (2).

This report summarizes and inter-relates all of the experimental work done under this research contract. For clarity, each phase will be discussed separately. Due to the magnitude of the work, only the most important points will be discussed here and the reader interested in details is referred to the individual quarterly reports.

THE PROBLEM OF MEAT TENDERNESS

Tenderness may be defined as that characteristic of meat which determines the ease with which the meat can be chewed and swallowed. Tenderness can be affected by many pre- and post-slaughter factors (2). Heredity and age of the animal, amount of connective tissue, marbling and muscle characteristics such as fiber size, extensibility, etc. are among the main pre-slaughter factors identified by research. Biochemistry of rigor mortis, changes on aging and storage, type of cooking, enzyme treatment, etc. influence the tenderness of meat in the post-slaughter phase. Although extensive work has been done on factors affecting tenderness, it has not yet yielded a conclusive answer to what is the physico-chemical difference between tough and tender meat. It seems logical to postulate that a number of different factors are involved and that their interplay, rather than the action of any one single factor, is at the base of the problem.

Various workers have related tenderness to fineness of muscle fibers, density of sarcoplasm, shape of muscle cells, water binding, blood patterns and even hair density and diameter. In the area of instrumental measurements, tenderness has been related to the resistance of meat to shearing, biting, mincing, compression, torque, penetration, stretching and other similar forces.

Since the exact differences between tender and tough meat are not known, methods used in meat research attempt to 1) measure the overall meat characteristics under conditions which are purely empirical or which attempt to simulate conditions of actual consumption, and 2) measure individual

chemical or physical attributes shown to affect tenderness. In all this work difficulties have been encountered due to the heterogeneity of the test material and the questionable reliability of sensory panels used for correlation studies. Meat not only varies in tenderness from animal to animal, from one side of the animal to another, from muscle to muscle, but also within a muscle (2). Methods used for meat evaluation are destructive in nature and, thus, identical samples cannot be used to compare methods, or to define the basic errors involved in measurements.

Although sensory evaluation is used as the ultimate judge of tenderness, practically no information is available on how a human being chews the meat and judges its tenderness. In most cases the sensory evaluation is standardized by the use of anchored scales, by counting the number of chews required for mastication, etc. Even these techniques are not devoid of errors inherent in the subjectivity of human senses. For example, it is difficult to control the force of chewing and the panel may chew the meat differently depending upon whether it is tough or tender. The determination of the end point can also lead to error, especially if the tested meat contains much connective tissue. More recent research on sensory methodology tends to recognize that tenderness may be a composite of several parameters and that more meaningful results may be obtained by considering several qualities. Cover's pioneering work on the six components of sensory tenderness represents a significant contribution to this field (3).

METHODOLOGY

Of the three instruments used for this work, the Kramer Shear Press and the Warner-Bratzler Shear can be purchased from suppliers, while the Texturometer is not, at the present time, commercially available. A brief description of the design and action of each one of these instruments will be presented in this section of the report.

Description of the Instruments

Warner-Bratzler Shear - This apparatus is based on the principle of shear. It was first described by Warner in 1927 and subsequently modified by Bratzler in 1932 and 1933. It consists of a one inch thick blade equipped with a triangular hole in which is placed the sample of meat to be tested. Usually, the sample has a cylindrical shape and is obtained from the test material using an instrument similar to a cork-borer. When sliced meat is used, the slices can be stacked up to the desired height and placed in the hole in this fashion. The blade is

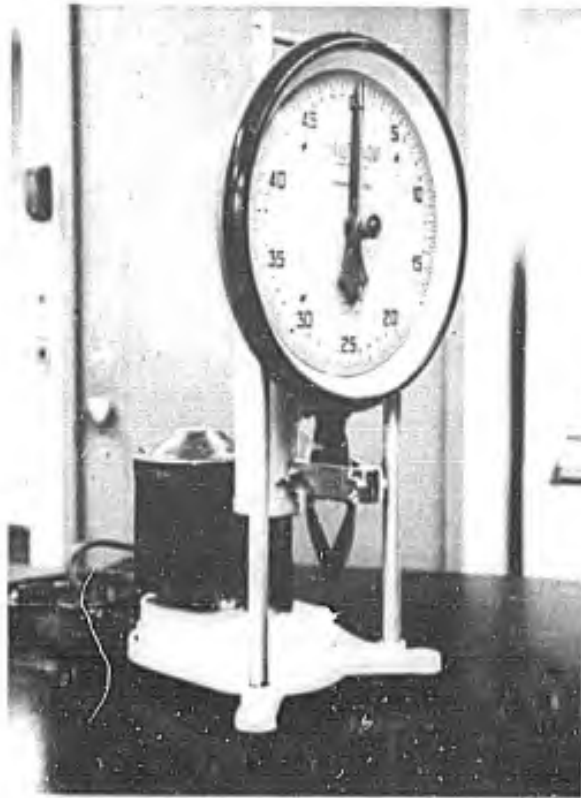


Figure 1 - Warner-Bratzler Shear

then led through a narrow slit between shear bars at a constant rate of pressure and the amount of force required to shear the sample is measured on the dynamometer scale. The greater the force, the tougher the meat.

The Warner-Bratzler Tenderometer, as it is also known, has been used extensively in measuring the tenderness of meat and there are over 45 literature references available on its correlations with sensory ratings. Of these, about 2/3 reported good to very good agreement and the remainder indicated that the correlation was borderline to poor. This variability may be influenced by many factors including the reliability of the taste panel, the tenderness range covered, and the definition of measured parameters. Blade dullness has been claimed to be a factor in the precision of the device. Several latest papers expressed the view that shear strength and tenderness may not be the same property of meat, and that what is termed "tenderness" in sensory tests may be composed of several different parameters.

In spite of its recognized shortcomings, the Warner-Bratzler device is still the most widely used instrument for meat tenderness measurements in the U. S. A. It has been compared by workers in the field with several other instruments, including the Kramer Shear Press. Using fresh meat, these correlations were reported to be significant.

Using frankfurters as a "standard" meat sample, we have found during preliminary experimentation that the instrument does not show very excessive day-to-day variations. It was also determined that the sample is long enough for the proper operation of the blade. The suitable height of stacked sliced pieces was established at one-half inch (two one-quarter inch slices). When more slices were stacked, there was a danger of exceeding the maximum force readable on the dynamometer scale. Using the same cut of meat, very similar shear force values were obtained on cylindrical and square pieces indicating that the shape of the tested meat does not have a significant effect.

In the final procedure adopted, two slices 2-1/2" x 5/8" x 1/4" were stacked to a height of 1/2". Each sample was sheared three times in three different places. Thus, two samples of the indicated size gave six replicate readings.

Kramer Shear Press - In the form used for meat work, this instrument is also based on the principle of shear. It consists of shear bars which pass through a box having a corresponding number of slots. The test sample is placed over these slots and the force required to drive the shear bars through the slots is measured. The measurements can be taken as the maximum force (when the shear press is equipped with a proving ring dynamometer) or as the time-force relationship (when the unit is equipped with the electronic attachment and a chart recorder). A mechanical model equipped with a 3,000 lbs. proving ring dynamometer was used in our work. (Model SP-12 distributed by Allo Precision Metals Engineering, Inc.)

The Kramer Shear Press is a relatively new instrument, the earliest paper reporting its use on meat having been published in 1955. In general, good correlations were reported with panel evaluations. These, however, vary from laboratory to laboratory and may be influenced by a number of factors. The instrument is shown in Figure 2.

Our preliminary study indicated that the Kramer Shear Press does not show any excessive day-to-day variations provided the test conditions are carefully standardized. The following instrument conditions were used: cell-standard shearing cell (0.014" - 0.006" clearance between blades); ring size - 3,000 lbs.; compression - 220 lbs.; stroke time - 60 sec. The sample size was 2-1/2" x 2-1/2" x 1/4". It was derived either from one piece of meat or from two pieces layed side by side. The sample covered the entire bottom of the cell. The average weight of the samples was 25 gms. It varied somewhat from batch to batch depending on sample density. The stroke time of 60 sec. was selected because it showed the least variation in replicate samples. This selection was made on the basis of data obtained with 120, 60, 45, 30 and 18 sec. stroke time. With the unit available for this work, difficulties were encountered initially in keeping the stroke time constant over the period of measurements. This was overcome by using an oil in the piston exhibiting the least viscosity change with temperature and by constantly checking the stroke time with a stop-watch and, if necessary, adjusting the instrument setting accordingly. Readings were taken from the dynamometer ring dial and converted to pounds force per sample or pounds force per gram using the calibration curve for the ring. Four replicate measurements were made on each sample. The number of replicates was limited by the batch size of dehydrated meat. In early experiments, meat was sheared twice. Since some workers in the field claimed that the difference between the forces required for the first and the second pass through the cell might be indicative of the "mouth-melting quality of beef", it was thought of interest to obtain this additional piece of data. However, difficulties were encountered in returning the once-sheared meat to the shearing cell and the obtained data did not appear to add any new knowledge.

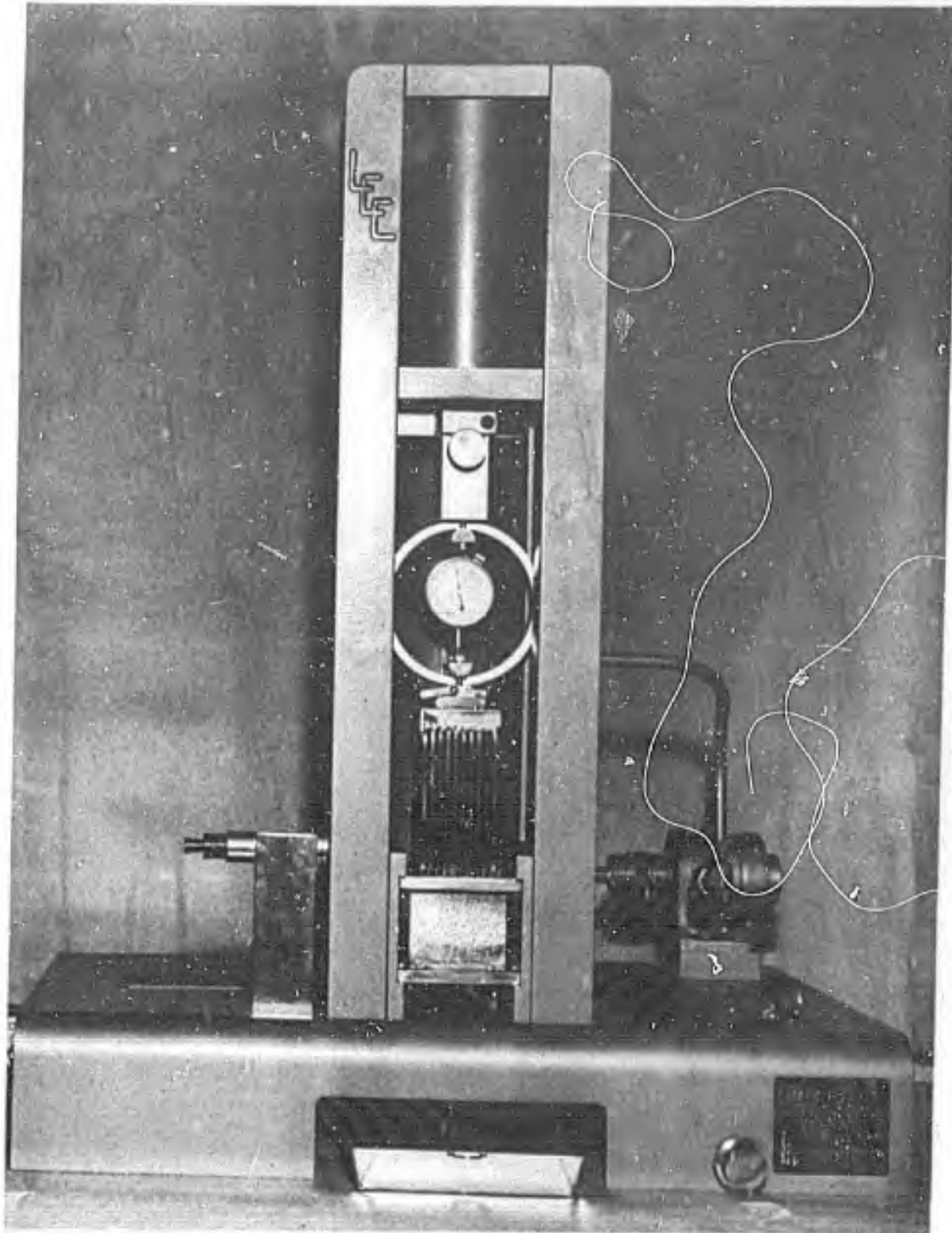


Figure 2 - Kramer Shear Press

Texturometer - The principle of this instrument is the simulation of the motions of mastication in the mouth with a mechanical chewing arrangement. The instrument used in this work was a modification by General Foods Research of the denture tenderometer developed earlier at the Massachusetts Institute of Technology (4,5). The main modifications introduced included replacement of dentures with a plunger and a plate, removal of the strain gage sensing unit from the articulator arm and redepositioning it on the plate support arm, provisions for several chewing speeds and substitution of a strip chart recorder for the oscilloscope. A full description of the Texturometer is available elsewhere (6).

In brief, the instrument consists of a mechanical masticator driven by a 1/15 horsepower 60 cycle motor, a variable voltage power supply, a Wheatstone Bridge circuit with a balancing potentiometer, and a fast speed recorder. The masticator is a modified Hanau dental articulator, the head and the lower arm of which are constructed in such a way that different sample-holding platforms and different type and shape plungers can be easily screwed into position. Two SR-4 500 ohm strain gages mounted on each side of the lower arm form two legs of the Wheatstone bridge and serve as sensing elements to detect the resistance of the food to forces exerted upon it. The test sample is placed on the platform resting on the lower arm of the masticator and the chewing forces are exerted through the up and down movements of the plunger mounted on the masticator head. Since the head is at an angle in relation to the platform, first the edge, then progressively larger areas, and eventually the entire surface of the plunger come in contact with the food as the plunger travels downward. The reverse situation occurs when the plunger travels upward. The side motion to which the food was subjected in the denture tenderometer due to the movement of the lower jaw (now replaced with the stationary platform) has been eliminated in the Texturometer. The chain-driven motor is equipped with a system of two pairs of tooth gears to permit articulation at different speeds. The recorder is a Leeds and Northrup Speedomax Model G, 1/4 second pen response, chart travel 60 inches per minute.

Figure 3 shows the photograph of the Texturometer. Design features of the instrument and operating instructions are included in the Appendix.

The conditions used for meats were as follows: The articulator speed for set for 24 chews per minute and a flat surface brass plunger, 3/8" in height and 6/8" in diameter was used. The height of the plunger was extended with two washers, 5/32" high, to facilitate the adjustment

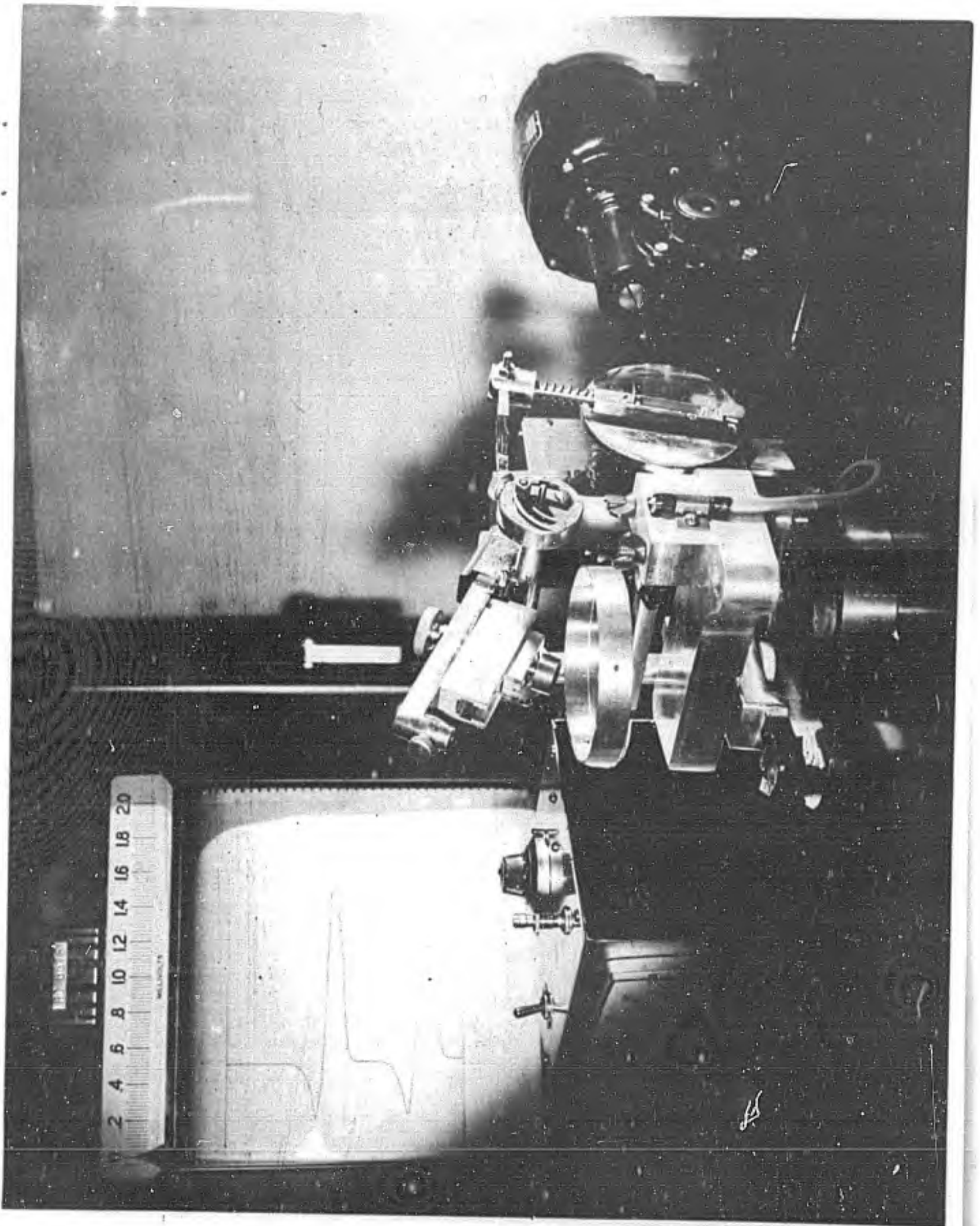


Figure 3 - General Foods Texturometer

of clearance without the necessity of excessive raising of the platform. The clearance (i.e. the distance between the platform and the plunger in its lowest position) was set at 0.057". The described brass plunger was selected from a number of variously shaped plungers as giving the most reproducible results and the greatest differentiation between samples. Meat was cut in cubes, 1" x 1" in surface area and 1/2" or 1" high. In phases I and II of this work, the two sample heights were used to measure different textural parameters. It was later found, that all the desired parameters could be obtained from readings on one sample size. Thus, in Phase III only samples 1/2" high were used. This simplified the measurements and reduced the quantity of meat required. The sample was placed in the center of a brass platform, 3" inside diameter, and the plunger was allowed to act on it for two consecutive chews. Five replicates were measured for each sample. Since the readings are proportional to sample height, all the values given in this report were equalized to the 1/2" sample height.

The precision of Texturometer measurements was checked out using a piece of foam rubber (weatherstripping) as a standard material. Based on these results, hardness could be determined with a precision of 0.045%, cohesiveness 2.64%, elasticity 1.27%, and chewiness 2.98%. Errors greater than this can be attributed to sample heterogeneity.

Texture Nomenclature

Most of the Texturometer methodology used in this work was developed previously by General Foods Research (6,7,8,9) and only some modifications were required to adapt it to the measurements of meat texture.

Previous General Foods Research on texture developed an organized texture nomenclature which grouped textural parameters into mechanical, geometrical, and other characteristics (mostly water and fat content). The mechanical characteristics are divided into five primary parameters:

- a) Hardness - defined as the force needed to attain a given deformation
- b) Cohesiveness - defined as the strength of internal bonds making up the body of the product
- c) Viscosity - defined as the rate of flow per unit force
- d) Elasticity - defined as the rate at which a deformed material goes back to its undeformed condition after the deforming force is removed

- e) Adhesiveness - defined as 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

The first four characteristics are related to forces of attraction acting between particles of food and opposing disintegration, while adhesiveness is related to surface properties.

In addition to the five primary parameters, three secondary parameters have been set up:

- b-1) Brittleness - defined as the force with which the material fractures. It is related to the primary parameters of hardness and cohesiveness. In materials that fracture, cohesiveness is low and hardness can vary from low to high.
- b-2) Chewiness - defined as 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 - defined as the energy required to disintegrate a semisolid food product to a state ready for swallowing. It is related to the primary parameters of hardness and cohesiveness.

The geometrical characteristics do not lend themselves to clear-cut divisions. There are, however, two general groups of qualities:

- a) those related to size and shape of the particles, and
- b) those related to shape and orientation

The last group of characteristics comprises mouthfeel qualities related to the perception of moisture and fat content. These qualities may also be considered to be concerned with lubricating properties of the product. In the case of moisture, the total amount of water present and the rate at which the moisture is released from a product are important. In the case of the fat content, the total amount of fat and its melting point, as related to mouth coating properties, should be taken into consideration.

Popular nomenclature comprises terms which actually denote degrees of intensity of the various characteristics. Figure 4 shows the relationship between the defined textural parameters and popular nomenclature.

Figure 4

Relationship Between Textural Parameters
and Popular Nomenclature

MECHANICAL CHARACTERISTICS

<u>Primary Parameters</u>	<u>Secondary Parameters</u>	<u>Popular Terms</u>
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→Goey

GEOMETRICAL CHARACTERISTICS

<u>Class</u>	<u>Examples</u>
PARTICLE SIZE AND SHAPE	Gritty, Grainy, Coarse, etc.
PARTICLE SHAPE & ORIENTATION	Fibrous, Cellular, Crystalline, etc.

OTHER CHARACTERISTICS

<u>Primary Parameters</u>	<u>Secondary Parameters</u>	<u>Popular Terms</u>
MOISTURE CONTENT		Dry-Moist-Wet-Watery
FAT CONTENT	Oiliness	Oily
	Greasiness	Greasy

Based on the above classification of textural parameters, standard scales were set up covering the entire intensity range of these characteristics found in food products. Each point on the scale is represented by a food product selected on the basis of availability, familiarity, constancy of textural characteristics, freedom from interfering characteristics and minimum preparation necessary to ready the product for consumption. The foods were selected by a panel followed by objective measurements of the textural parameter under consideration. Elasticity and cohesiveness are difficult to perceive as such organoleptically and their evaluation is included in rating for other parameters. Although scales for elasticity and cohesiveness were set up originally, they were not serving a practical purpose and were excluded from the final set of scales (8). In setting up the standard scales, attempts were made to select reference foods in such a way that approximately equal differences in intensity of the textural parameters under consideration existed from point to point.

The quantitative evaluation of texture of any food is thus based on standard rating scales of hardness, brittleness, chewiness, gumminess, viscosity, and adhesiveness. Viscosity was measured objectively with the Brookfield viscometer, using a selected set of standard conditions, while the intensity of other parameters was measured with the Texturometer. A good agreement between the sensory and the objective evaluation was obtained on these scales. This indicated that the instrument and the trained panel perceived and quantified in the same manner the various textural characteristics present in foods selected for their homogeneity.

Interpretation of Texturometer Curves

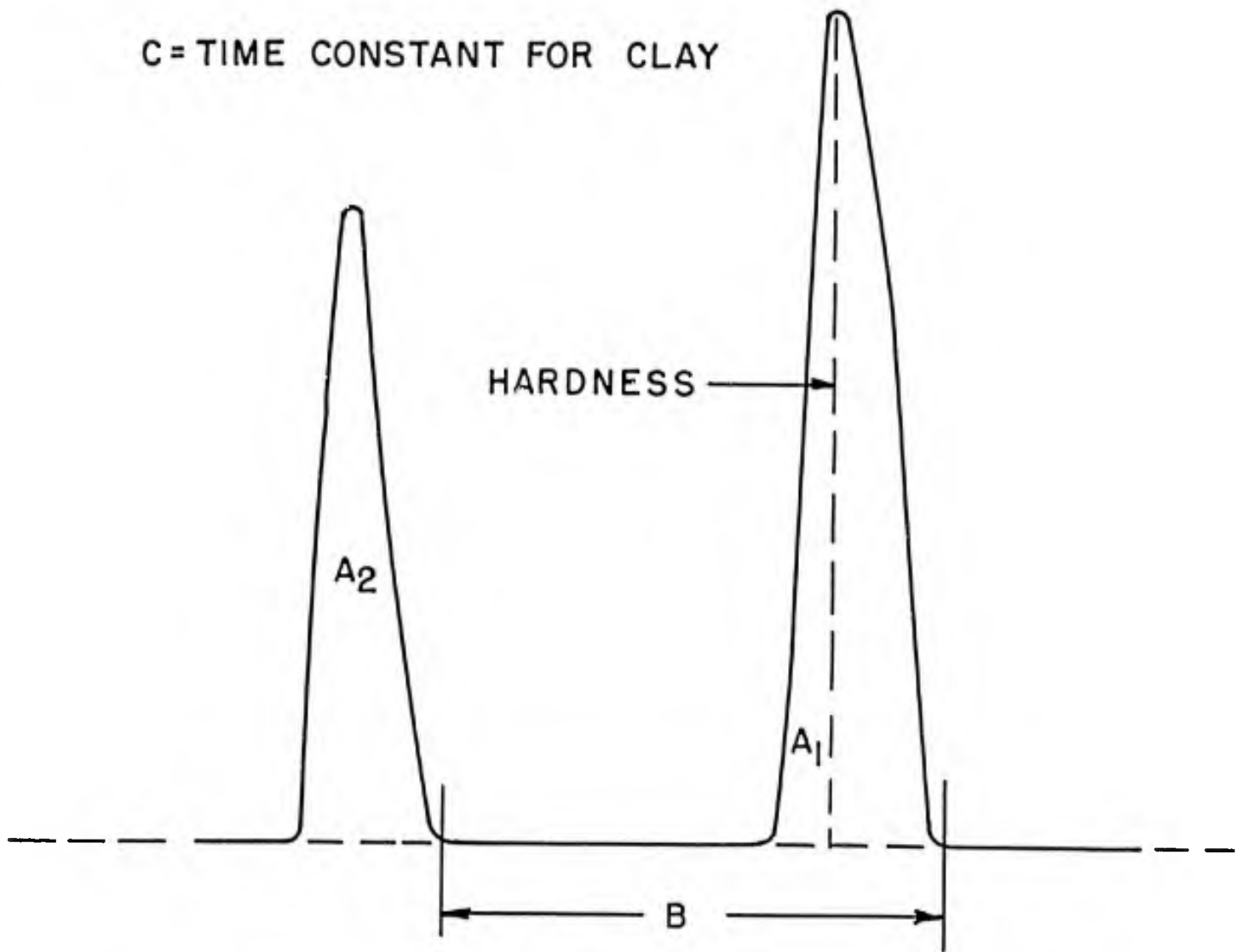
Figure 5 illustrates a typical Texturometer curve for meat. The pattern is traced by the recording pen from right to left and thus the peak on the right (A₁) depicts the first chew and the peak on the left (A₂) depicts the second chew. Any desired number of chews may be obtained with the instrument, but experience indicated that the first two chews are sufficient for calculating the desired parameters.

The recorded curves are typical for the food being tested and differ from food to food, both qualitatively and quantitatively. For example, foods showing crispness or brittleness will exhibit breaks in the otherwise smooth "chew" peaks. Adhesive foods will register negative peaks below the base line due to the fact that the food sticks to the platform and the plunger and exerts a pulling force on the upward movement of the plunger. The higher the intensity of a given textural parameter, the greater the pen

$$\text{COHESIVENESS} = \frac{A_2}{A_1}$$

$$\text{ELASTICITY} = C - B$$

C = TIME CONSTANT FOR CLAY



A TYPICAL TEXTUROMETER CURVE FOR MEAT

Figure 5

deflection. The scale range is adjusted by manipulating the voltage across the strain gages. The harder the food to be tested, the lower the voltage. The final results are reported in chart units per 1 volt impact.

The following parameters were found to be applicable to meats: hardness, cohesiveness, elasticity and chewiness.

Hardness data are obtained by reading the height of the first peak.

Cohesiveness is expressed as the ratio of the areas under the two peaks, i.e. the ratio of the work done in compressing a sample during the second and the first chew (A_2/A_1). The smaller the second peak, the more structural breakdown occurred during the first chew and the less cohesive the material.

Elasticity is measured as the time function and is expressed as the distance of plunger travel (B) subtracted from the same value for clay (C), which has extremely small recovery.

Chewiness is expressed as the product of hardness, cohesiveness and elasticity. Initially, a sample height of 1/2" was used for measuring hardness and cohesiveness, and a sample height of 1" was used for elasticity. It was found in Phase II of the work, that all the parameters could be measured on the same sample height.

Additional Techniques Developed for Meat

In the preliminary work, the texture profile panel identified hardness, chewiness and juiciness as the important textural parameters of fresh meat and the rate of water release as an outstanding parameter differentiating between fresh and dehydrated meats. Consequently Texturometer methods were developed for measuring these qualities:

Juiciness was measured by placing a piece of Whatman No. 41 filter paper (7 cm in diameter) over and one under the 1/2" high sample of meat. Three chews were taken on each sample and the wetted areas on the two filter papers were totalled and used as a measure of juiciness. The determination of the area boundary was facilitated by pre-treating the filter papers with a 5% CuSO_4 solution and drying at 130°C. With this technique, the wet area became a permanent light blue and could be measured after the water had evaporated. The area was measured with a planimeter or by comparison with standard circles drawn with areas ranging from 0.5 to 5.5 sq. inches at 0.5 sq. inch intervals.

Rate of Water Release used essentially the same technique as above, except that fresh filter papers were used for each chew and the meat was chewed a total of four times. In this manner, a measure of the liquid squeezed out on each chew was obtained. The wet areas on filter papers were measured and top and bottom areas for each chew were totalled. Samples which released water readily had relatively large areas for the first chew as compared to those obtained for the subsequent chews. Figure 6 shows a comparison in the rate of water release between two types of fresh meat and between fresh and rehydrated precooked freeze-dried beef.

The presence of the filter paper did affect the instrument readings for the mechanical parameters. Measurements of juiciness and of the rate of water release, thus, had to be made on a separate set of samples. Due to limitations in available sample size, only selected sample sets were subjected to these measurements.

Fat Release The same procedure as for juiciness was found to be suitable for determining the amount of fat released on chewing. In this case, the filter paper does not have to be impregnated with the copper sulfate solution. The fat area manifests itself by the translucency of the paper. Since most of the samples used in this investigation were lean cuts of beef, this measurement was not used beyond the point of demonstrating its feasibility.

Texture Profile Panel

This technique was developed by General Foods Research based on the organized texture nomenclature and the "order of appearance" principle of the Flavor Profile Method (9, 10). A texture profile is defined as the organoleptic analysis of the textural complex of a food in terms of its mechanical, geometrical, fat and moisture characteristics, the degree of each present and the order in which they appear from first bite through complete mastication. This analysis requires a panel of judges with prior knowledge of the texture classification system, the use of the standard rating scales and panel procedures regarding the mechanics of testing and sample control. Unlike flavor, where the order of appearance of notes cannot be anticipated, texture follows a definite pattern in the order in which the characteristics are perceived. These can be sub-divided into first bite, masticatory, and residual phases.

The first bite, or initial phase, encompasses the mechanical parameters of hardness, brittleness and viscosity, the parameter of moisture and fat content, and any geometrical characteristics which are observed initially.

WATER RELEASE

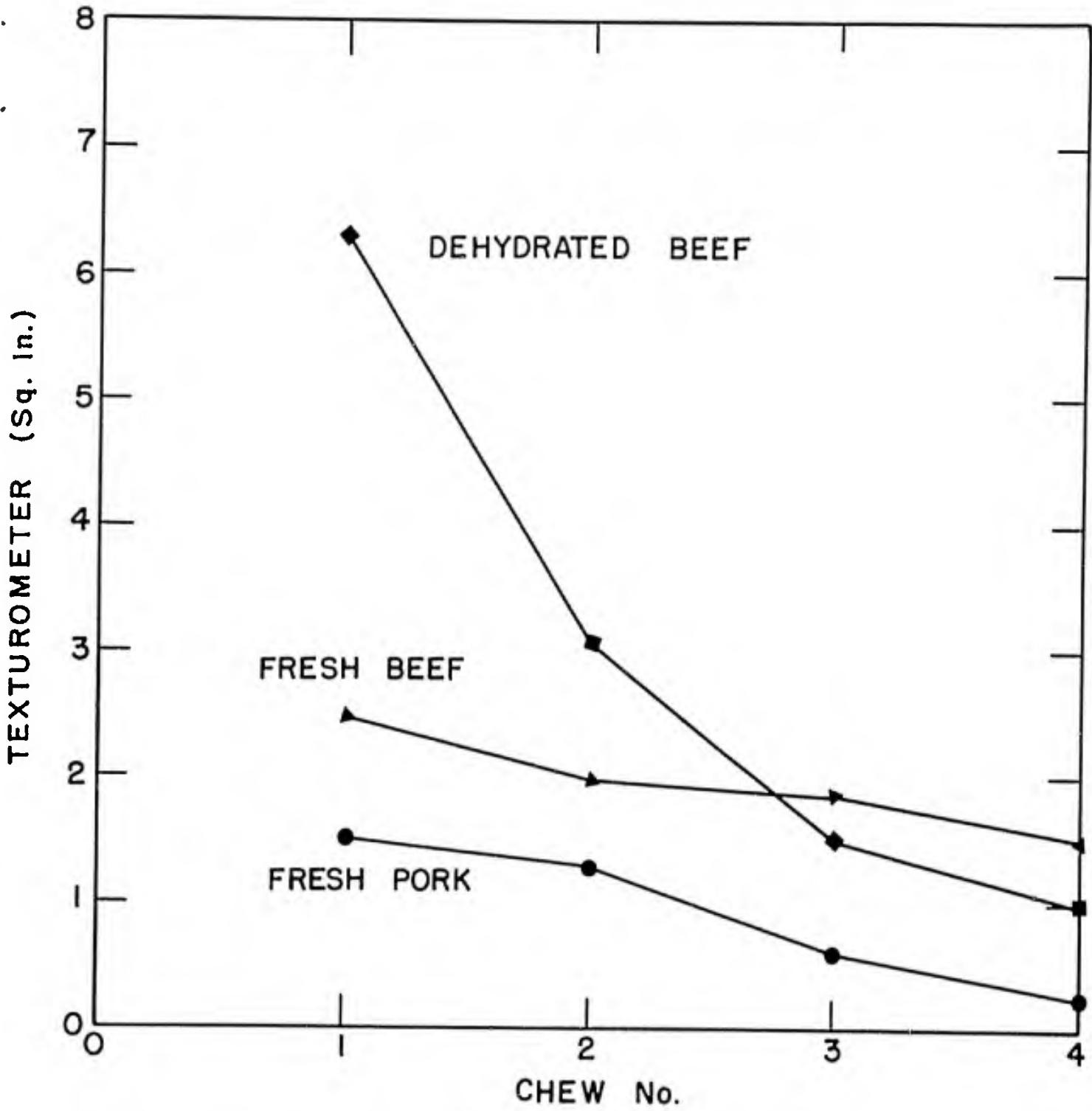


Figure 6

The second, or masticatory, phase encompasses the mechanical parameters of gumminess, chewiness and adhesiveness, and any geometrical characteristics which are observed during chewing.

The third, or residual, phase encompasses changes induced in the mechanical and geometrical characteristics through mastication.

An outline for sensory texture profiling is shown in Figure 7.

Panel definitions of the mechanical textural parameters sensed in the mouth are as follows:

Hardness - force required to penetrate a substance when placed between molar teeth.

Cohesiveness - extent of deformation, on the first bite, before fracturing.

Brittleness - ease or force with which a sample crumbles, cracks or shatters when placed between molar teeth.

Chewiness - length of time in seconds needed to masticate a sample at one chew per second.

Gumminess - measure of denseness of a semi-solid material as perceived in the mouth.

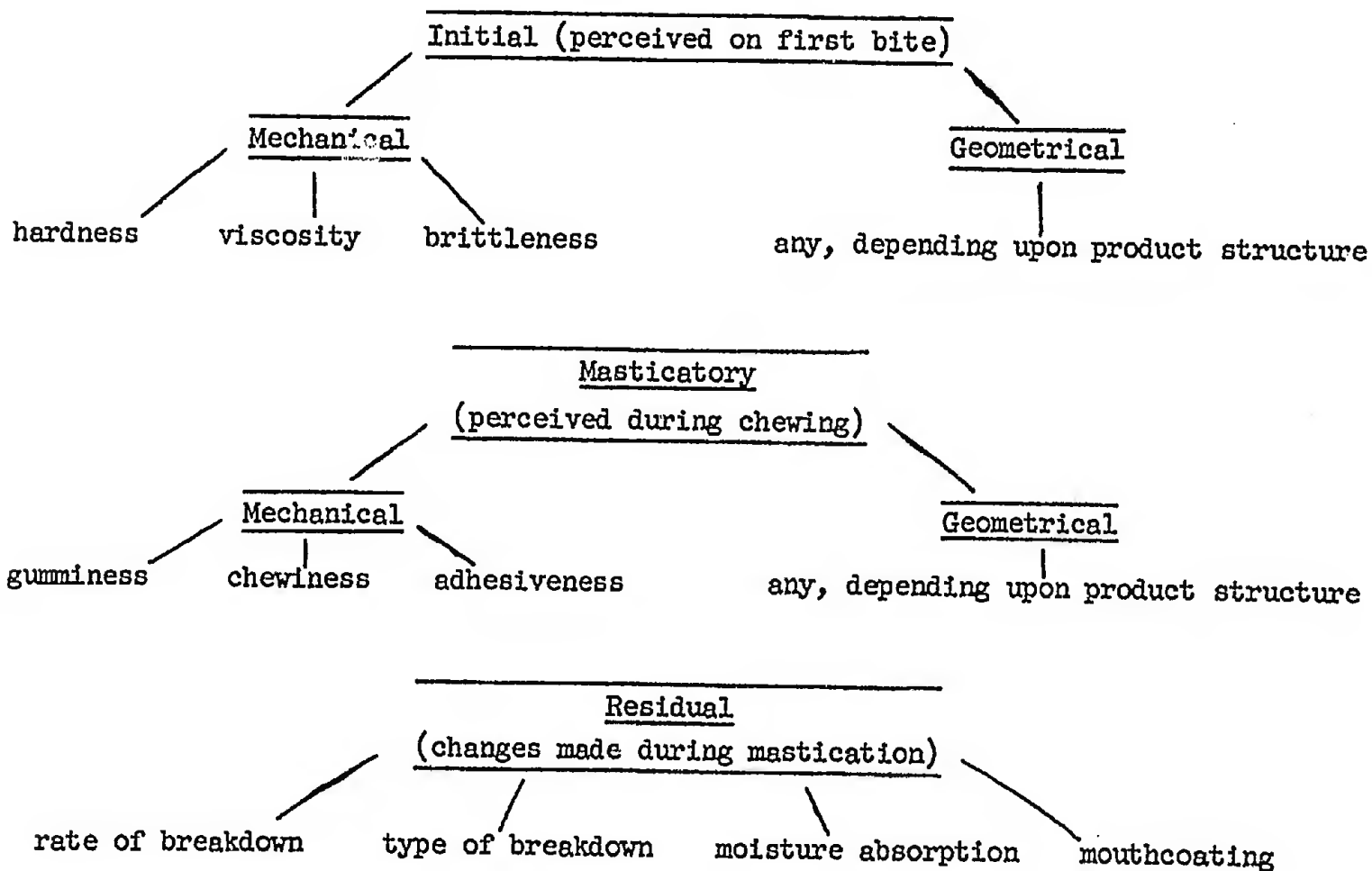
Viscosity - force required to draw a liquid or semi-solid from a spoon into the mouth and over the tongue.

Adhesiveness - force required to remove the material that adheres to the mouth (generally to the palate) during the normal eating process.

Six trained profilers participated in the panel evaluating meat samples. Cubes of meat were used cut to the same size as those used for Texturometer evaluation (1" x 1" x 1/2"). The panel members were thoroughly familiar with the classification and definition of textural parameters, standard scales and mechanics of profiling. They evaluated the test samples independently, followed by a round table discussion to clarify any possible significant discrepancies. The individual ratings were averaged to obtain the final value. Not more than three samples were used per session. Initially, two sessions were required per sample, but as the panel became more familiar with the texture of meat it was found that a single session could yield a satisfactory set of data.

Figure 7

Procedure for Sensory Texture Profiling



The General Foods texture profile panel was used in Phase I of this research. In Phases II and III, the work objectives called for correlating objective measurements with a panel of 24 consumers and a panel set up by the sponsor was employed.

"Consumer" Panel

In Phase II, a panel set up by the Food Acceptance Branch of the Armed Forces Food and Container Institute was used. With the first set of samples (Series 1) the panel was composed of forty people. Although the judges were selected from among the employees of the Institute, their background and type of work performed qualified them as "average" consumers. Each sample was tested four times by ten judges providing a total number of forty judgements per sample. Four samples were tested at one session. The rehydrated meat was rated using a nine-point scale shown in Figure 8. With this set of samples, the meat was rated for juiciness and tenderness (and in this order). In the next and subsequent series of samples, a rating for overall texture was included. The lowest point on the scales referred to extremely dry, extremely tough or extremely poor, and the highest point referred to extremely juicy, extremely tender or extremely good. The meat was rehydrated for panel work using a 20 min. soak in 80°F. distilled water and a 5 - 10 min. drain period. It was served immediately to the judges.

With the second series of samples in Phase II (Series 2), a panel of twenty-seven technologists was used, each testing four times. Six samples were served at one session and twenty-seven judgements per sample were obtained. Although supervised by the same personnel, this panel appeared to differ from the one employed earlier in Phase II in that it involved people experienced in food research and thus could be considered to be less similar to a consumer panel.

In Phase III, a panel set up by the Psychology Laboratories of the Pioneering Research Division of the U. S. Army Natick Laboratories was used. The panel was composed of twenty-four technologists. The meat was rehydrated and served and the panel work supervised by personnel different from that in Phase II of the contract work. Each sample was tested once by each judge, for a total of 24 individual judgements. Only one sample was presented to the judge at a time. The order of rating for the three qualities was randomized. Some judges were given a ballot for which the three parameters were listed in the order: tenderness, juiciness, overall texture, while other judges were given a ballot reading: juiciness, tenderness, overall texture.

Figure 8

OVERALL TEXTURE OF MEAT (2)

Name:

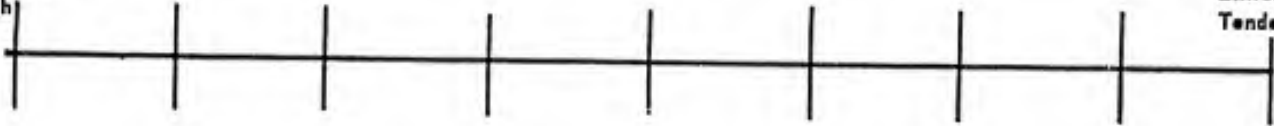
Date:

Sample Code

PART I

TENDERNESS

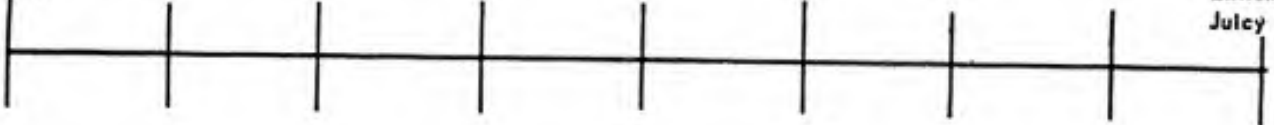
Extremely Tough



Extremely Tender

JUICINESS

Extremely Dry

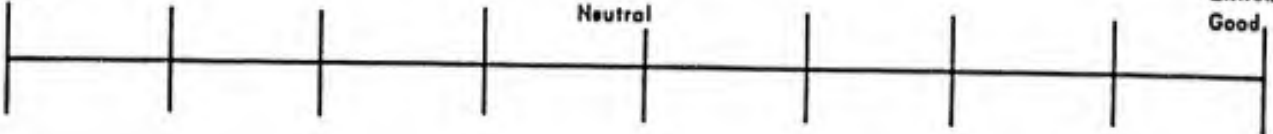


Extremely Juicy

PART II

OVERALL TEXTURE

Extremely Poor



Extremely Good

Comments:

1

2

3

4

5

6

7

8

9

Tested Meat Description

Fresh, commercial freeze-dehydrated and experimental freeze-dehydrated meat was tested within this work. Emphasis was placed on evaluation of precooked sliced dehydrated beef prepared especially for this investigation. In Phase I and II, the meat was processed by members of the Quartermaster Food and Containers Institute. Due to the move of the Institute to Natick, Mass., samples evaluated in Phase III were processed under a subcontract by Swift and Co. The meat was received packed under vacuum in tin cans and was kept at 35° - 40°F. until ready to use. Unless otherwise stated, the meat was trimmed of fat, tendons, gristle, etc. prior to dehydration.

In addition to sliced beef, measurements were also made on dehydrated pork, turkey, fish and ground meat. Except for special circumstances, each series of samples represented a statistical design incorporating variables deemed to be important in effecting texture. The effects of cooking time, meat grade, animal and side variation, state of meat prior to freezing, conditions of freezing and of dehydration, etc. were included in the investigated variables. This was done in order to determine the ability of the three instruments to pick up textural variations attributable to these variables, and to obtain samples covering a suitable range of tenderness.

Fresh meat was purchased from a local butcher. The muscles were separated in the laboratory, cut into the desired size and evaluated after 1 - 3 days in the refrigerator. Freeze-dehydrated meat samples were usually several months old when tested. The method of rehydration varied somewhat from one set of samples to another. In early work, samples were soaked for 25 minutes in 1% NaCl at 180°F, drained for 5 minutes and evaluated after 1 - 1-1/2 hours. Later, the rehydrated samples were allowed to equilibrate overnight in the refrigerator. This was necessitated by the large number of samples in the set. In still later work, rehydration in 80°F. distilled water was employed to standardize the rehydration procedure with that used in panel work. The exact rehydration procedure used is explained in individual sections of this report dealing with specific sets of samples. The meat was evaluated objectively at 45° - 55°F.

EXPERIMENTAL RESULTS

Phase I

The objective of this phase of the work was to determine the feasibility of applying the Texturometer to objective measurements of textural characteristics of precooked freeze-dehydrated meat and to correlate these results with sensory evaluation by the General Foods texture profile panel. A further objective was to identify important textural parameters of meat measurable with the Texturometer and to define any existing shortcomings of the instrument.

1. Preliminary Tests

Fresh roast pork, roast beef, boiled chicken and precooked freeze-dried sliced beef were used for the initial tests. An encouraging good qualitative agreement was obtained between the Texturometer and the trained texture profile panel indicating that the instrument was able to detect and record the intensity of hardness and chewiness of meat similar to that felt in the mouth. Table I illustrates differences in textural characteristics of different fresh meat types found by the Texturometer. On practice dehydrated meat, considerable can to can variation was found by the Texturometer. This does not appear to be unusual in view of the heterogeneity of meat discussed in the Introduction.

Table I

Texturometer Evaluation of Fresh Meat

<u>Meat Type</u>	<u>Texturometer Parameters</u>			
	<u>Hardness</u>	<u>Cohesiveness</u>	<u>Elasticity</u>	<u>Chewiness</u>
Roast Pork (6)	81.3	0.54	3.2	149
Roast Beef (4)	91.2	0.80	5.7	416
Boiled Chicken (1)	74.0	0.54	4.6	188

The numbers in parenthesis indicate the number of individual roasts (or birds) evaluated and averaged.

As described in the section on sensory texture profiling, the panel can describe the geometrical characteristics of foods in addition to the mechanical characteristics and those related to moisture and fat content. Texturometer measurements are limited to the latter two groups of parameters and do not include the geometrical characteristics. It was, therefore, of interest to determine the importance of the geometrical characteristics in the overall evaluation of meat texture.

In its initial work, the panel included the description of the fibers and of the binder in the overall texture profile on meats. The fibers were described in terms of their size, number and mechanical characteristics as perceived in the mouth. The binder was described in terms of its mechanical characteristics. Early in this work it was found that the mechanical parameters of the binder were almost equal in intensity to those exhibited by the entire meat sample. With regards to the fiber description, it was found that large differences existed between different meat types and that differences among samples within a given meat type were very small and often negligible.

Fresh pork was characterized by thin, fragile fibers whereas fresh beef had thicker, stringy somewhat less numerous, fibers which tended to ball-up and were difficult to swallow. Great differences in fiber characteristics were also found between fresh and dehydrated meats. Dehydrated pork had fibers which were rubbery and stringy as compared to the fragile character of the fresh pork fibers. They also appeared to be larger in size. Similarly, dehydrated beef had fibers which, on the whole, were considerably more tough than those present in fresh beef. A close examination, however, of the differences between fresh meats and dehydrated meats in the mechanical parameters of the overall sample indicated that these do reflect the fiber characteristics and that the separate evaluation of the geometrical characteristics may not be contributing anything of practical significance. In future work, however, this point should be rechecked with a consumer panel.

The difference in the fiber character may be an important clue to the biochemical and biophysical changes introduced into the muscle structure by dehydration, and may yield an answer to the causes of differences in mechanical parameters registered by objective measurements.

2. Effect of Cooking Time on Texture of Freeze-Dehydrated Sliced Beef

Following the preliminary tests, a variety of dehydrated meat samples supplied by the sponsor were evaluated by the Texturometer and by the trained texture panel, except when the quantity of the meat was not sufficient for sensory testing. The samples were rehydrated for 25 minutes in 1% NaCl at 180°F., drained for 5 minutes and tested within 1 - 1-1/2 hours.

The length of cooking time was the first variable evaluated. As indicated in Table II, hardness and cohesiveness decreased significantly when the cooking time was extended from 2 to 3 hours. Elasticity and chewiness started decreasing after 75 minutes of cooking, while juiciness began to show an early decline with increasing time of cooking followed by a rise between 2 and 3 hours of cook. These data suggest that, all other factors being constant, shorter cooking times result in beef slices which rehydrate to a chewy, juicy product, while longer cooking times give a softer, less chewy and drier product. The general agreement between the panel and the Texturometer was good except in the case of the parameter of chewiness for the 3 hour sample.

3. Effect of Pretreatment on Texture of Precooked Freeze-Dehydrated Beef of Two Grades

The next series of freeze dehydrated sliced beef evaluated comprised 64 samples representing the following variables:

Meat Grade	State	Cooking Level		Type of Cook	Prefreeze Before Drying
		Water	Steam		
A - U.S. Good	1 - Fresh	C - 1 $\frac{1}{4}$ hrs.	C - 45 min.	3-Water cook	J-Slow
B - U.S. Canner cutter	2 - Frozen	D - 3 hrs.	D - 75 min.	4-Steam cook	K-Fast
		E - 4 $\frac{1}{2}$ hrs.	E - 120 min.		
		F - 7 $\frac{1}{2}$ hrs.	F - 180 min.		

Table II

Effect of Cooking Prior to Dehydration on Texture of
Freeze-Dehydrated Sliced Beef

(240°F. cook at 10 psi with a 15 mins. warm-up period)

Texturometer Parameters	Length of Cook			
	45 mins.	75 mins.	120 mins.	180 mins.
Hardness	141	137	137	115
Cohesivenss	0.88	0.88	0.83	0.65
Elasticity	5.5	5.6	4.9	3.8
Chewiness	683	675	557	284
Juiciness	5.1	4.2	1.65	2.7

The statistical evaluation of the Texturometer data indicated that, of all the processing variables evaluated, cooking time levels caused the greatest changes in the measured texture parameters. These effects paralleled those observed in the first series of samples when the cooking time was the only variable investigated. No differences were found between water and steam cooking (at parallel levels) and between slow or fast freezing prior to drying. These pairs of averages were thus pulled together for the summary of data shown in Table III.

The data show the following observations:

While hardness reaches a higher peak with the US Good Grade, the values also decrease faster as cooking time increases. Longer cooking has a greater influence on the US Good Grade than on the US Canner Cutter Grade. The decrease in hardness is most marked between the average for cooking level 3 (the 270 minutes of water cook and the 120 minutes of steam) and the average for cooking level 4 (the 450 minutes of water cook and the 180 minutes of steam cook).

The fresh US Good and frozen US Canner Cutter meats seem to respond the same to changes in cooking level as measured by the cohesiveness parameter. The frozen US Good grade meat starts higher at the short cooking times but decreases much faster than the other combinations with increased cooking. The results for fresh US Canner Cutter meat are relatively constant.

The decrease in elasticity with increased time of cooking is the same for each of the 4 combinations of the two meat grades and the two meat states. In general, elasticity is higher for frozen meat compared with fresh, and higher for US Canner Cutter than for US Good grade meat.

The results for all chewiness values shown for US Canner Cutter are 72 units higher than the corresponding values for US Good. It is seen that chewiness is higher for frozen meat at the shorter cooking times, but that chewiness for frozen meat decreases faster than for fresh meat as cooking time is increased.

There is a marked drop in juiciness from the shortest cooking time to the next shortest cooking time. The drop continues from level 2 to level 3 and then increases (particularly for fresh meat) at the longest cooking time. This is similar to the pattern shown by the data in Table II.

Table III

Effect of Pretreatment Variables on Texture of Precooked
Freeze-Dehydrated Sliced Beef

(pulled averages)

Texturometer Parameters	Cooking Level	Meat Grade			
		U.S. Good		U.S. Canner Cutter	
Hardness	1	125.7		117.1	
	2	126.4		123.6	
	3	119.0		121.8	
	4	103.5		112.1	
Cohesiveness		Fresh	Frozen	Fresh	Frozen
	1	.846	.902	.780	.836
	2	.845	.863	.823	.841
	3	.793	.775	.815	.797
Elasticity	1	5.3	5.8	5.8	6.2
	2	5.3	5.7	5.7	6.1
	3	4.9	5.3	5.3	5.7
	4	3.8	4.2	4.2	4.6
Chewiness	1	476	670	548	742
	2	514	633	586	705
	3	451	496	523	568
	4	290	260	362	332
Juiciness		State of Meat			
		Fresh		Frozen	
	1	6.3		7.2	
	2	4.5		4.8	
Water release (1st chew)	3	4.0		3.6	
	4	4.7		3.7	
		Average			
	1	5.6			
2	4.8				
3	4.0				
4	3.3				

Code: Cooking Level 1 = 175 mins. in water or 45 mins. in steam.
 2 = 180 mins. in water or 75 mins. in steam.
 3 = 270 mins. in water or 120 mins. in steam.
 4 = 450 mins. in water or 180 mins. in steam.

In analyzing the data for water release, only values for the first chew were considered because of the high correlation found in that series of samples between the four water release measurements. The response of water release to cooking level was completely linear, decreasing at the rate of 0.76 units for each increase in cooking time.

In summary, it may be stated that of all the processing variables evaluated in that series, cooking time caused the greatest changes in the measured texture parameters. The effect of cooking time was somewhat modified by the grade and the state of meat.

4. Effect of Drying Conditions on Texture of Precooked Freeze-Dehydrated Beef

In addition to the variables of meat state and grade, and variables in pre-processing, the effect of different drying conditions on textural parameters measurable on the Texturometer was also investigated.

Two series of samples were involved: precooked sliced beef, and raw sliced pork. The beef series involved 24 samples of US Canner Cutter "inside round" beef cooked in a steam retort at 10 psi for 2 hours and dehydrated under various conditions of plate temperature and vacuum. The samples also represented different types of prefreezing and different degrees of dehydration.

The obtained data (pulled averages) are summarized in Table IV.

The data was not analyzed for multiple correlations, except where stated. Plate temperature had some effect on hardness, chewiness and juiciness, with best results being shown by the plate temperature of 200°F. Vacuum affected juiciness and chewiness, with lower vacuum giving more tender and more juicy samples. The most significant effect on textural parameters was observed in the case of prefreezing vs. evaporative prefreezing, and, in the case of normal degree of drying vs. over-drying. A significant inter-relationship was also evident between these two sets of variables. The degree of drying had no effect on texture when combined with prefreezing, while it had a very significant effect when combined with evaporative prefreezing. Drying to a normal degree followed evaporative prefreezing, resulted in high intensities of all the evaluated parameters. The samples were hard, cohesive, elastic, chewy, and, surprisingly, juicy. Evaporative freezing seems to

Table IV

Effect of Drying Conditions on Texture of Freeze-Dehydrated Sliced Beef

(pulled averages)

<u>Variable</u>	<u>Texturometer Parameters</u>				
	<u>Hardness</u>	<u>Cohesiv.</u>	<u>Elast.</u>	<u>Chew.</u>	<u>Juic.</u>
Plate temperature 150°F.	119	0.76	4.7	428	2.8
" " 175°F.	122	0.77	4.5	440	3.5
" " 200°F.	113	0.77	4.7	410	3.5
Vacuum of 750 microns	115	0.77	4.6	416	3.6
" 2000 "	120	0.77	4.7	437	2.7
Prefrozen	114	0.74	4.4	377	2.6
Evaporative freezing	122	0.79	4.9	475	3.8
Normal degree of deh.	121	0.79	4.7	456	3.2
Over-dried	115	0.75	4.6	396	3.2
Prefrozen					
normal deg. of deh.	113	0.73	4.5	376	2.5
over-dried	115	0.75	4.4	378	2.7
Evaporative freezing					
normal deg. of deh.	128	0.84	5.0	536	3.8
over-dried	116	0.74	4.8	414	3.8

result in a higher degree of juiciness than prefreezing, and this is independent of the degree of drying. When samples subjected to evaporative freezing were overdried, the resulting intensity of the measured textural parameters was similar to the general average for the entire group of samples except for juiciness which was higher. This seems to indicate that overdrying is desirable when evaporative freezing is used.

5. Effect of Drying Conditions on Texture of Raw Freeze-Dehydrated Pork

The pork series involved twelve samples of pork loins in the 10 - 12 pound weight range. The chops were sliced 1/2 inch thick. The levels of process variables selected did not result in any very significant effects on textural parameters measured on the Texturometer. Frozen meat tended to yield harder and tougher rehydrated samples than fresh meat. This appears to agree with the observations made on beef where frozen meat, cooked for short periods of time, was found to give tougher samples on drying than fresh meat. The obtained data (pulled averages) are summarized in Table V.

The samples were prepared for evaluation by rehydrating for 30 mins. the contents of each can containing 1/2 lb. of material in 2-1/2 qts. of boiling water with 1% salt. This procedure was found to result in a more uniform rehydration and a less heterogenous texture than the procedure suggested by the sponsor which called for 20 min. rehydration in an excess of cold tap water containing 1 tsp. salt per quart, followed by deep fat frying for 3 mins. with an oil temperature of 350°F. The samples were eight months old at the time of the evaluation. They were tested by the panel and the Texturometer, the contents of each can being equally divided between the two tests. This minimized differences due to can-to-can variations, but did not eliminate differences related to variations within a can. Only boiled meat samples were used for sensory evaluation. Two raw samples were tested on the instrument. The objective evaluation indicated that raw meat was much softer, more tender and exuded more liquid under the plunger pressure than boiled meat.

Evaluation of the data for the effect of processing variables did not reveal any very significant influences of the processing conditions on the texture of the samples at the time they were tested. Frozen meat appeared to yield harder and tougher dried samples than fresh meat.

Table V

Effect of Drying Conditions on Texture of Freeze-Dehydrated Raw Pork

(pulled averages)

<u>Variable</u>	<u>Texturometer Parameters</u>				
	<u>Hardness</u>	<u>Cohesiv.</u>	<u>Elast.</u>	<u>Chew.</u>	<u>Juic.</u>
Frozen, thawed, fast freeze	129	0.84	5.8	629	1.3
Fresh, fast freeze	117	0.82	5.7	593	0.9
Fresh, slow freeze	118	0.81	5.4	528	2.0
Pressure during drying					
0.75 mm	125	0.82	5.3	557	1.5
2.0 mm	118	0.83	6.0	604	1.5
Plate temperature					
110° (contact)	121	0.83	5.4	563	1.0
150° (radiant)	122	0.82	5.9	597	2.1

6. Miscellaneous Commercial Freeze-Dehydrated Meat Types

Table VI shows Texturometer texture profiles of miscellaneous dehydrated meat samples obtained by the sponsor from commercial suppliers. The samples were tested after rehydration following supplier's directions. All the products, except two, were cooked prior to dehydration. The two raw products were beef steak Type I and fish squares from Wilson Co. Fish squares were rehydrated for 1-1/2 mins. in room temperature water, floured and deep fat fried. Beef steak was rehydrated and sauted in butter according to the directions of the supplier. The samples were also evaluated by the trained texture panel.

The tested samples represented wide ranges of textural characteristics. No unusual problems were encountered in their evaluation either by the Texturometer or the panel. Comminuted meat, in the form of meat balls, was characterized by low cohesiveness, low hardness, low chewiness and moderate juiciness. Fish was extremely low in hardness, cohesiveness, chewiness and elasticity and exhibited moderate juiciness. Of all the tested samples, the panel selected Wilson's Beef Steak Type I as having the best texture. The Texturometer indicated this sample to be low in hardness, cohesiveness and chewiness and moderate in juiciness. It was also observed that this sample was the most uniform in size and appearance.

7. Correlation Between the Texturometer and the Texture Profile Panel

Sensory and objective data obtained on 37 samples of beef and pork, both fresh and freeze-dehydrated, and on two samples of freeze-dehydrated fish were evaluated statistically for the degree of correlation. Table VII summarizes the calculated coefficients of variation.

All of these correlation coefficients are statistically significant at least at the 99% probability level. More significant correlations were obtained when sample type was considered as an additional variable and coefficients of multiple correlation were computed. This indicates that the strength of the relationship of Texturometer readings to trained panel ratings depends on meat type. This is a very important point and will be further discussed in later sections of this report.

Table VI

Textural Characteristics of Miscellaneous Freeze-Dehydrated Meats

<u>Meat Type</u>	<u>Sample Manufacturer</u>	<u>Hardness</u>	<u>Texturometer Parameters</u>			<u>Juic.</u>
			<u>Cohesiv.</u>	<u>Elast.</u>	<u>Chew.</u>	
Sliced Beef Type I	Liana, Inc.	109	0.74	4.7	376	1.5
Sliced Beef Type III	"	67	0.59	4.6	182	4.6
Sliced Beef lot 2 Type I	-	139	0.91	6.3	797	2.8
Sliced Beef lot 2 Type II	-	119	0.87	5.4	559	3.3
Sliced Beef lot 2A	Wilson Co.	122	0.86	6.3	661	6.6
Beef Steak Type I (new)	"	82	0.72	4.6	272	3.1
Pot Roast	Liana, Inc.	129	0.79	5.0	509	1.3
Beef Steak Swiss Style	"	80	0.54	3.2	138	1.1
Meat Balls Size A	"	5.5	0.54	5.0	146	3.0
Fish Patties	"	17	0.28	1.3	6	3.7
Fish Squares new Style 2, Species 3	Wilson Co.	16	0.29	2.1	9.7	3.0

Table VII

Correlation Between the Texturometer and the Panel

	<u>Correlation Coefficient</u>		
	<u>Meat & Fish</u> <u>Simple Correl.</u>	<u>Meat Only</u> <u>Simple Correl.</u>	<u>Multiple Correl.</u>
Hardness	0.892	0.772	0.807
Chewiness	0.694	0.645	0.735
Juiciness	0.560	0.550	0.784

It was of interest to find to what degree the heterogeneity of the tested meat samples contributed to the magnitude of the above correlations. This was done by calculating coefficients of variation for individual Texturometer readings and panel ratings within one sample. Twenty-six samples selected at random were used. The results indicated that these values ranged from 1% to 101% for the instrument and from 4% to 246% for sensory evaluation, depending upon the sample and the tested parameter. The mean coefficients of variation for replicate measurements were as follows: for the Texturometer - hardness 11.7%, cohesiveness 9.4%, elasticity 14.8%, chewiness 23.0%, and juiciness 25.6%; for the panel - hardness 10.4%, chewiness 22.1%, and juiciness 69.1%. This indicates that, for the entire group of the 26 samples analyzed, the panel and the instrument exhibited similar variations, except for the parameter of juiciness where the panel showed a significantly poorer agreement on replicate samples. This may explain the fact that the correlation between the Texturometer and the panel was the lowest in the case of the parameter of juiciness. The dependability of the coefficients of variation on sample type indicates that variability within the sample itself can account for much of the variation from the perfect linear relationship between the two types of measurement. It is also interesting to note that the above mean coefficients of variation for the Texturometer readings on meats are considerably higher than those obtained on a standard material, again indicating the appreciable textural heterogeneity of the tested meat samples.

8. Correlation of the Texturometer with Other Tests

The 64 samples of freeze-dehydrated sliced beef representing variables of meat grade, length and type of cooking, etc. (see Section 3 p. 25) were also subjected by the sponsor to 18 different chemical, physical and sensory tests. These data were made available to us for correlation with Texturometer values. The statistical analysis indicated that the textural parameters measured on the Texturometer were highly correlated with a number of measurements performed by the sponsor, especially those involving sensory tests. More than half of the fluctuations in Texturometer variables could be explained in terms of fluctuations in two of the subjective variables: cuttability and juiciness. Moreover, the derived equations showed that the Texturometer was measuring some differences in the samples that none of the 18 measurements reflected either simply or in combination as linear functions. Table VIII summarizes these results and shows those tests which exhibited the highest correlations with the Texturometer parameters. The reported values are coefficients of multiple correlation except in the case of elasticity which showed a simple linear relationship to cuttability. A coefficient of multiple correlation for Texturometer chewiness and sensory tenderness is included for additional information, although a higher correlation was obtained with a combination of texture-cuttability-juiciness ratings.

The only instrumental method of texture evaluation used by the sponsor in this set of data was the Kramer Shear Press. It was of interest to see how the Texturometer compared with the Shear Press in correlations with the other data (mostly organoleptic). This is shown in Table IX. The correlation coefficients for the Shear Press were supplied by the sponsor.

It will be noted that the coefficients of correlation are very similar when the chewiness parameter is considered. This suggested that the Texturometer may be at least as good as the Kramer Shear Press in describing the texture of meat in a manner correlatable with sensory evaluation.

Table VIII
Correlation Between the Texturometer and Certain Physical
and Chemical Tests

Texturometer Parameter	Related to	Coefficients of Correlation*
Hardness	Cuttability, juiciness	0.774
Cohesiveness	Rehydration ratio, cuttability, juiciness	0.860
Elasticity	Cuttability	-0.735 (S)
Chewiness	Texture, cuttability, juiciness	0.883
Chewiness	Tenderness	-0.775 (S)
Juiciness	Per cent fat, protein, cutta- bility, juiciness	0.768
Water release (1)	Sedimentation volume, juiciness	0.774
Water release (2)	Juiciness, cuttability	0.807
Water release (3)	Per cent water, juiciness, cuttability	0.877
Water release (4)	Per cent water, juiciness, cuttability	0.911

* All the correlations are significant at the 99% level or less.

The values represent coefficients of multiple correlation except those marked (S).

Table IX

Comparison Between the Texturometer and the Kramer Shear Press
(coefficients of correlation)

	<u>Shear Press</u>	<u>Texturometer Chewiness</u>
Texture MPB	-0.7447	-0.735
Cuttability	-0.8342	-0.831
Tenderness	-0.7610	-0.775
Residue	+0.7087	+0.714

9. Correlation Between Texturometer Parameters

High correlations were obtained among the mechanical parameters of texture measurable on the instrument and among the parameters of juiciness and water release. However, there were only sporadic and low correlations between the two groups of parameters. Of the mechanical parameters, elasticity showed the lowest correlations.

10. Synopsis

This phase of the contract has demonstrated that the Texturometer can be used to describe objectively the textural properties of both fresh and dehydrated meats in a manner that was in agreement with sample characteristics recognized by the meat experts at the sponsor's laboratory and by the General Foods trained texture profile panel. It has further shown that the instrument correlated highly with sensory evaluation by the texture profile panel and with a number of chemical, physical and sensory tests performed by the sponsor. Hardness, cohesiveness, elasticity, juiciness and the rate of liquid release were identified as the important textural parameters of meat measurable on the Texturometer. The techniques of measuring juiciness, rate of liquid release and fat release with the Texturometer were developed within this phase of the work.

Phase II

The objective of this phase of the work was to evaluate and compare the Texturometer, the Kramer Shear Press and the Warner-Bratzler Tenderometer from the standpoint of their usefulness in evaluating the texture of fresh and freeze-dehydrated sliced beef. The objective measurements were to be correlated with each other and with sensory evaluation by a consumer panel. Sensory testing was to be done by the sponsor. Another objective of this research was to define numerical values for good, poor and borderline meat texture, and to simplify Texturometer measurements.

1. Fresh Beef - Correlation Between Instruments

Choice grade beef was purchased on the open market and four muscles were separated and cooked in 1% salt solution for 2.5 hours. The muscles were: semitendinosus, semimembranosus, adductor and biceps femoris. The cooked meat was refrigerated for 3 days. It was then sliced 1/4" thick across the fibers, the slices were randomized and cut to the proper size for the three instruments. The experiment was replicated 4 times by using 4 carcasses from 4 animals.

Table X gives the summary of data averaged for the 4 animals. Only one measurement, maximum shear force in lbs., is indicated for the Kramer Shear Press. The obtained values indicate that semimembranosus and biceps femoris gave considerably more resistance to the disintegrating action of the instruments than semitendinosus and adductor. Parameters related to the water holding capacity showed that biceps femoris released the most and adductor the least liquid under the Texturometer's plunger. The magnitudes of the coefficients of variation for objective measurements were different for the four muscle, but no definite pattern could be seen. In general, adductor tended to show the greatest variations. When the three instruments were compared, Texturometer hardness showed the smallest coefficient of variation across all four muscles.

The data were subjected to the analysis of variance to obtain a measure of the ability of the three instruments to pick up animal and muscle differences. As indicated in Table XI, all the instrumental measurements showed a significant difference from muscle-to-muscle, and all - except two - showed a significant

Table X

Objective Texture Measurements on Four Fresh Boiled Beef Muscles

	Semitendinosus		Semimembranosus		Adductor		Biceps Femoris	
	av.	c.v.	av.	c.v.	av.	c.v.	av.	c.v.
WBT (lbs.)	4.49	0.205	6.42	0.169	5.31	0.258	8.91	0.197
KSP (lbs.)	216.0	0.091	380.3	0.191	276.6	0.330	396.9	0.195
Texturometer (i.u.)								
Hardness	73.0	0.072	84.3	0.055	74.5	0.056	90.8	0.078
Cohesiveness	0.624	0.090	0.682	0.075	0.586	0.085	0.736	0.135
Elasticity	6.95	0.135	7.25	0.165	6.75	0.340	8.65	0.229
Chewiness	185.3	0.223	230.3	0.186	168.6	0.379	331.6	0.234
Juiciness	2.37	0.149	2.36	0.086	1.96	0.143	2.90	0.157
Water Release 1	1.91	0.263	1.80	0.222	1.58	0.344	2.25	0.190
2	1.21	0.326	1.25	0.329	0.93	0.382	1.67	0.242
3	0.76	0.346	0.95	0.535	0.65	0.517	1.39	0.242
4	0.52	0.546	0.64	0.625	0.47	0.941	1.18	0.291

Table XI

Significant Effects Shown by Objective Measurements on Fresh Boiled Beef

(analysis of variance; indicated effects are significant at least at the 95% level)

	<u>Animals</u>	<u>Muscles</u>	<u>A x M</u>
Warner-Bratzler Tenderometer		*	*
Kramer Shear Press			
1st lb. force		*	*
2nd lb. force		*	*
1st lb. force/gm.		*	*
2nd lb. force/gm.		*	*
1st - 2nd lb. force	*	*	*
Texturometer			
Hardness	*	*	*
Cohesiveness	*	*	
Elasticity	*	*	
Chewiness	*	*	*
Juiciness		*	*
Water Release 1	*	*	*
2	*	*	*
3	*	*	*
4	*	*	*

animal-muscle interaction. This means that the texture of meat is not only influenced by the muscle type, but also by the carcass from which the muscle was obtained and that muscle variation is not the same from animal to animal. Since the meat was purchased in a store, the "animal" variation includes factors such as aging, storing, etc. (over which we had no control) in addition to the inherent differences among animals. The two measurements which did not pick up the animal-muscle interaction were Texturometer cohesiveness and elasticity. Of the three instruments evaluated, simple animal-to-animal differences were picked up only by the Texturometer.

The data were also used to determine correlations between the three instruments, among the Texturometer parameters, and among the different measurements obtained with the Kramer Shear Press. The results indicated that, for that particular series of samples, correlations significant at the 99% level existed between the Kramer Shear Press and the Warner-Bratzler Tenderometer, and between the Kramer Shear Press and all four of the mechanical parameters of texture measurable on the Texturometer. A correlation significant at the 95% level was found between the Warner-Bratzler Tenderometer and the parameter of cohesiveness. None of the other mechanical parameters measurable on the Texturometer correlated with the Warner-Bratzler Tenderometer. Texturometer parameters related to water holding did not show any pattern of correlation with other objective measurements. A summary of coefficients of linear correlation between the three instruments is presented in Table XII.

Since the weight of the samples was carefully controlled, perfect correlations (.99 and .98) were obtained between lb. force and lb. force/gm. on the Kramer Shear Press for both the first and the second pass. The difference between maximum forces on the first and the second pass exhibited a very high error and appeared to offer no advantage. This measurement was, therefore, abandoned in subsequent work.

2. Precooked Freeze-Dehydrated Sliced Beef - Correlation Between Instruments

In this phase of the contract, three sets of freeze-dehydrated samples were used to seek a correlation between the three instruments. In addition, a correlation between the three instruments and sensory evaluation conducted by the sponsor was calculated in the latter two sets.

Table XII

Summary of Coefficients of Linear Correlation Between the Three Instruments

(fresh boiled beef)

<u>Objective Measurements</u>	<u>r</u>
WB vs. KSP (lbs. force on 1st pass)	.69 **
WB vs. Texturometer hardness	.24
cohesiveness	.60 *
elasticity	.37
chewiness	.40
KSP vs. Texturometer hardness	.64 **
cohesiveness	.80 ***
elasticity	.62 **
chewiness	.74 ***

Note: The statistical significance of the correlation coefficients is denoted by one asterisk for the 95 per cent level, two asterisks for the 99 per cent level and three asterisks for the 99.9 per cent level.

In the first set, a statistical design based on two grades (US Good and US Canner Cutter), two states of meat (fresh and frozen) and three cooking times (45, 75, and 120 mins.) was used for a total of twelve samples. No differentiation was made between animals and muscles. The meat was rehydrated in 1% NaCl at 180°F. for 25 mins., drained, wrapped in aluminum foil and refrigerated overnight.

In the second set, semimembranosus muscle derived from 16 animals of the US Canner Cutter grade was used. The samples were randomized into 4 groups and each group was cooked for different periods of time (45, 75, 120 and 180 mins.). The meat was rehydrated in 1% NaCl at 180°F. for 1 hr., drained and evaluated within 1 - 1-1/2 hrs. after rehydration.

In the third series, semimembranosus and biceps femoris muscles derived from the same animal were used. Two grades and three cooking levels (45, 75 and 120 mins.) were incorporated into the experimental design. Each combination of variables was replicated over two animals for a total of 12 samples in each muscle type. In order to obtain the required amount of material, both sides of the animal were used. These samples were rehydrated in distilled water at 80°F. for 20 mins., drained for 5 mins. and evaluated within 1/2 - 1 hr after rehydration.

A summary of the obtained correlation coefficients is shown in Table XIII. All three instruments were highly correlated with each other, but the quality of the correlations varied between the three sets of samples. In general, correlations of lower significance level were found when only one muscle was used (second series). Correlations between the three instruments calculated for the three sets of dehydrated beef were essentially the same as those calculated for fresh boiled beef except for the Warner-Bratzler Tenderometer which showed a better correlation with the Texturometer when dehydrated meat was tested than when fresh meat was used. It is interesting to note that in the first two series, Texturometer parameters related to juiciness and liquid release, were significantly correlated with measurements of mechanical properties of meat by the Warner-Bratzler Tenderometer and the Kramer Shear Press. For an unexplained reason, in these two series of samples the two groups of Texturometer parameters were also highly correlated. This accounts for the above mentioned correlation. The correlations between the mechanical parameters

Table XIII

Summary of Coefficients of Linear Correlation Between the Three Instruments
(precooked freeze-dehydrated sliced beef)

	<u>1</u>	<u>2</u>	<u>3</u>
WB vs. KSP (lbs. force on 1st. pass)	.92 ***	.55 *	.78 ***
WB vs. Texturometer			
hardness	.88***	.74 **	.72 ***
cohesiveness	.84 ***	.76 **	.42 **
elasticity	.87 ***	.62 *	.44 **
chewiness	.93 ***	.73 **	.64 ***
juiciness	-.79 **	-.61 *	.11
water release 1	-.77 **	-.54 *	--
2	-.63 *	-.68 **	--
3	-.28	-.65 *	--
4	---	-.62 *	--
KSP vs. Texturometer			
hardness	.74 **	.70 **	.84 ***
cohesiveness	.73 *	.54 *	.43 **
elasticity	.79 **	.51 *	.62 ***
chewiness	.80 **	.61 *	.81 ***
juiciness	-.87 ***	-.57 *	.09
water release 1	-.68 *	-.70 **	--
2	-.63 *	-.64 *	--
3	-.37	-.66**	--
4	--	-.79 **	--

Sample Description:VariablesRehydration

1
(12 samples)

2 grades, 2 states of meat,
3 cooking times (no differentiation
between muscles and animals)

1% NaCl, 180°F.,
25 mins., overnight
holding

2
(16 samples)

semimembranous muscle, c & c grades,
4 cooking times, replicated over
4 animals

1% NaCl, 180°F.,
1 hr., evaluated
within 1-1 1/2 hr.

3
(24 samples)

semimembranous and biceps femoris,
2 grades, 3 cooking times,
replicated over 2 animals

distilled water,
80°F., 20 mins.,
evaluated within
1/2 - 1 hr.

of texture measurable on the Texturometer and those related to juiciness and liquid release were higher for the second series. This is also reflected in the correlations between the three instruments summarized in Table XIII. In the third series, only the parameter of juiciness was measured and the measurements of liquid release were omitted. Contrary to the first two series, juiciness did not correlate with the other instruments or with the mechanical parameters of texture measurable on the Texturometer.

3. Precooked Freeze-Dehydrated Sliced Beef - Correlation of the Instruments with Sensory Evaluation

As had been mentioned in the preceding section, the second and the third set of the freeze-dehydrated sliced beef samples were also evaluated by taste panels set up by the sponsor in the Chicago laboratories. These panels are described in detail on page 20. The two panels differed in three main respects:

Composition - clerical etc. help vs. technologists
Number of replicates - forty vs. twenty-seven
Number of samples presented at one time - four vs. six

Differences also existed between the two sets of dehydrated meat. The main differences were:

Number of replicates over the animals - four vs. two
Cooking levels - four vs. three (180 mins. cook was omitted in the second set)
Rehydration procedure - hot 1% NaCl vs. cold distilled water

In addition, the second set of samples comprised semimembranosus muscle as well as biceps femoris, while only the semimembranosus muscle was included in the first set.

Differences in the panel were introduced by the sponsor. Differences in the meat samples were introduced by mutual agreement. The longest cooking time was omitted in order to keep down the total number of samples and because this cooking time often resulted in very fragile meat which was not suitable for evaluation. The rehydration procedure was changed in order to make it equal to that used for panel work. In the second series the panel evaluated the meat for overall texture in addition to tenderness and juiciness.

As will be seen from Table XIV, the Texturometer was exceptionally well correlated with sensory evaluation in the first series ($r=.91$ for hardness vs. tenderness, and $r=.88$ for chewiness vs. tenderness) and in that respect was superior to the other two instruments. The Warner-Bratzler Tenderometer showed the poorest correlation. In the second series, however, all three instruments were highly correlated with sensory tenderness. Numerically, the Texturometer showed the lowest correlation coefficients. With respect to panel overall texture, the Warner-Bratzler Tenderometer, the Kramer Shear Press and Texturometer hardness showed correlations significant at the 99.9% level, while Texturometer chewiness and elasticity correlated at 99 and 95% levels, respectively. Even there, however, the Texturometer showed the lowest numerical coefficient of correlation and, thus, could not be considered as good a predictor of sensory overall texture as the other two instruments.

What effect the indicated differences in the panel and in the samples had on the correlation, cannot be determined with certainty. These differences, however, are interesting to note. We shall return to this point in the Evaluation of Data section of the report. None of the objective measurements correlated with sensory juiciness, except the Warner-Bratzler Tenderometer in the first series. Why the shearing force should be related to juiciness, cannot be adequately explained by the data on hand. The Texturometer juiciness did not correlate with the sensory evaluation of juiciness, thus, indicating that the amount of liquid squeezed out by mechanical compression of the meat does not appear to be a good measure of sensory juiciness.

It will also be seen from Table XIV that the correlations between panel evaluation and objective measurements were dependent upon the muscle type. This dependency was influenced by the type of measurement, but followed few definite patterns. With panel overall texture, better correlations were obtained for semimembranosus muscle, except for the Warner-Bratzler Tenderometer which was more highly correlated for biceps femoris.

4. Precooked Freeze-Dehydrated Sliced Beef - Differentiation Between Processing and Sample Variables

Similarly to fresh beef evaluated within this phase of the contract, analysis of variance was performed on data obtained on dehydrated meat samples to determine the ability of the objective and sensory (whenever used) measurements to detect processing and other sample variables. The results are summarized in Table XV.

Table XIV

Correlation Between Sensory Ratings and the Three Instruments
(precooked freeze-dehydrated sliced beef)

	<u>Tenderness</u>	<u>Taste Panel</u>	
		<u>Juiciness</u>	<u>Overall Texture</u>
<u>Warner-Bratzler Tenderometer</u>			
Series 2, semimembranosus	-.62*	.60*	-
Series 3	-.72***	-.09	-.71***
semimembranosus	-.69*	.47	-.47
biceps femoris	-.71**	-.16	-.74**
<u>Kramer Shear Press (lbs force)</u>			
Series 2, semimembranosus	-.67**	.22	-
Series 3	-.76***	-.11	-.69***
semimembranosus	-.76**	.15	-.63*
biceps femoris	-.73**	.05	-.57
<u>Kramer Shear Press (lbs force/gm)</u>			
Series 2, semimembranosus	-.75***	.35	-
Series 3	-.78***	-.19	-.78***
semimembranosus	-.64*	.17	-.58*
biceps femoris	-.90***	-.01	-.78**
<u>Texturometer - hardness</u>			
Series 2, semimembranosus	-.91***	.10	-
Series 3	-.65***	-.09	-.64***
semimembranosus	-.58*	.05	-.58*
biceps femoris	-.69*	.30	-.44
- <u>cohesiveness</u>			
Series 2, semimembranosus	-.87***	.17	-
Series 3	-.59**	.37	-.34
semimembranosus	-.42	.50	-.24
biceps femoris	-.69*	.42	-.40
- <u>elasticity</u>			
Series 2, semimembranosus	-.76***	-.02	-
Series 3	-.70***	.26	-.44*
semimembranosus	-.73**	.32	-.58*
biceps femoris	-.65*	.43	-.28
- <u>chewiness</u>			
Series 2, semimembranosus	-.88***	.12	-
Series 3	-.77***	.09	-.61**
semimembranosus	-.72**	.20	-.66*
biceps femoris	-.75**	.30	-.48
- <u>juiciness</u>			
Series 2, semimembranosus	-.82***	-.37	-
Series 3	-.21	.22	-.03
semimembranosus	-.17	.02	-.17
biceps femoris	-.33	.27	-.11

Note: The statistical significance of the correlation coefficients is denoted by one asterisk for the 5% level, two asterisks for the 1% level and three asterisks for the 0.1% level.

Table XV

Ability of the Measurements to Differentiate Between
Processing and Sample Variables in Freeze-Dehydrated Beef

(analysis of variance, indicated effects are significant at least at the 95% level)

	Grade		Cook Time			GxCT	Condition	GxCT	Animal	Muscle
	1	3	1	2	3	1	1	1	2	3
Warner-Bratzler	x	x		x				x	x	x
Kramer Shear Press	x		x	x		x	x	x	x	x
Texturometer										
hardness	x		x	x				x	x	x
cohesiveness		x	x	x	x					
chewiness	x	x	x	x	x			x	x	x
juiciness	x	x	x	x				x	x	
Panel										
tenderness	-	x	-	x	x	-	-	-	x	x
juiciness	-	x	-	x	x	-	-	-	x	x
overall texture	-	x	-		x	-	-	-	-	x

Note: The numbers refer to sample series described in the text and in Table XIII.

It will be seen that the Kramer Shear Press (lbs. force on the first pass) and the Texturometer (chewiness) picked up the largest and the Warner-Bratzler Tenderometer the smallest number of variables. The difference between the instruments, however, was relatively small. The panel was able to distinguish different grades, cook times, muscles and animals.

As was the case with correlations with sensory evaluation, the ability of the objective measurements to pick up processing and other variables was influenced by sample type. For example, in the second series all measurements (including sensory) picked up variations due to cooking time length, in the first series all but the Warner-Bratzler Tenderometer picked them up, while in the third series only the panel and the Texturometer (chewiness and cohesiveness) showed the effect.

In series three, the two sides of the animal were kept separately throughout the objective measurements and were only combined for the final averages. Although the analysis of variance was not able to show that the objective measurements were able to pick up differences between the left and the right side of the animal, an examination of the actual data revealed that very large differences (two and three-fold) often existed in objective numbers for the two sides of the carcass. These differences, however, were not consistent for the sides nor for the instruments. This indicated that the right side was not always the more resistant to the disintegrating action of the instruments and that whatever differences existed between the two sides were not consistent from animal to animal.

5. Correlation Between Texturometer Parameters

With fresh meat, highly significant correlations were obtained within each group, mechanical parameters and those related to liquid release, but not between the two groups. With freeze-dehydrated beef, correlations were highly dependent on sample type. In all three series highly significant correlations were obtained within each of the two groups of parameters. In the first series some correlations between the two groups were obtained. In the second series, all the parameters were highly correlated with each other (99% level). In the third series, all the mechanical parameters except hardness correlated with juiciness for biceps femoris and none correlated with juiciness for semimembranosus.

6. Objective Definition of Good, Poor and Borderline Meat Texture

The freeze-dehydrated series of sliced beef comprising two muscles was also tested by the sponsor for overall acceptance. Table XVI summarizes correlations between panel overall acceptance and the three instruments.

Correlations with other sensory ratings are also included for comparison. It will be seen that the Texturometer parameters, as a group, correlated somewhat higher with acceptance ratings than either the Warner-Bratzler Tenderometer or the Kramer Shear Press. The parameter of chewiness showed the highest correlation coefficient, numerically, and could account for 52% of variations in sensory overall acceptance ratings as compared to 26% and 41%, respectively, for the other two instruments. Multiple correlations were not calculated. It will also be seen from Table XVI that sensory tenderness and overall texture, but not juiciness, were highly correlated with acceptance ratings.

On the basis of the obtained data, it was not possible to assign objective numbers to "good", "poor" and "borderline" meat texture. Similarly to the other sensory evaluations, acceptance ratings were based on the 0-9 scale. However, the sponsor did not have available sufficient information to describe good, poor and borderline meat texture in terms of acceptance ratings. Even if one assumes that ratings above 5.5 represent good, 4.7 - 5.4 borderline, 4.6 and below poor texture, it is not possible to assign objective numbers based on this limited quantity of tested samples because of tremendous fluctuations from sample to sample (including side-to-side variations). This is illustrated in Table XVII with some representative samples. In addition, the distribution of acceptance ratings was not very good to be used for this purpose: 39% in 5.5 - 6.0 range, 39% in 4.7 - 5.4 and 22% in 4.6 or less.

7. Synopsis

Work performed during the second phase of the contract indicated high correlations between the Warner-Bratzler Tenderometer, the Kramer Shear Press and the Texturometer, and the dependence of these correlations on sample type. The sample type also influenced the ability of the instruments to pick up processing and other variables incorporated into the experimental design, and the correlation between objective measurements and sensory evaluation. Two series of dehydrated sliced beef evaluated instrumentally and by the panel not only differed in sample type but also in the type of sensory evaluation. In one series, the Texturometer correlated very highly with sensory tenderness and, thus, appeared to be superior to the other two instruments. In the other series, all instruments showed highly significant correlations with sensory tenderness and none stood out as being superior in this respect.

Table XVI

Summary of Coefficients of Linear Correlation Between Panel
Overall Acceptance Ratings and Other Measurements
 (precooked freeze-dehydrated sliced beef)

<u>Objective Measurement</u>	<u>r</u>
Warner-Bratzler Tenderometer	-.51 *
Kramer Shear Press (lbs. force on 1st. pass)	-.64 ***
Texturometer hardness	-.56 **
cohesiveness	-.54 **
elasticity	-.68 ***
chewiness	-.72 ***
juiciness	-.60 **
Panel tenderness	.65 ***
juiciness	-.08
overall texture	.55 **

Note: The statistical significance of the correlation coefficients is denoted by one asterisk for the 95 percent level, two asterisks for the 99 percent level and three asterisks for the 99.9 percent level.

Table XVII

Comparison of Sensory Acceptance Ratings with Objective Measurements
(biceps femoris)

	<u>3.6</u>	<u>Acceptance Ratings</u>			
		<u>4.1</u>	<u>5.0</u>	<u>5.5</u>	<u>5.6</u>
WB					
right side	15.42	21.70	30.37	25.05	12.05
left side	14.98	20.58	10.30	20.80	9.55
KSP					
right side	463.8	888.8	628.9	548.8	540.0
left side	538.8	873.8	321.3	426.3	510.0
Texturometer hardness					
right side	103.5	129.9	108.1	105.3	94.2
left side	115.5	130.9	90.7	90.2	86.6
cohesiveness					
right side	.826	.886	.692	.650	.696
left side	.830	.852	.708	.560	.648
chewiness					
right side	464.5	635.70	313.7	188.7	297.2
left side	444.6	660.16	166.4	92.2	234.1
juiciness					
right side	7.12	4.12	5.98	1.84	2.50
left side	5.30	3.46	3.00	1.72	3.92

Phase III

The objective of this phase of the work was to extend the comparison of the three instruments to poorer cuts of beef and to other meat types such as pork and turkey. A further objective was to study the effect of rehydration procedure on objective measurements and to define the sensitivity of the instruments to the presence of gristle, fat, tendons, etc. in the untrimmed meat. In addition, some dehydrated raw meat samples were also evaluated to obtain some knowledge of the differences between raw and cooked meat measurable on the three instruments.

Meat samples used for this phase of the contract were prepared by Swift and Co. and not by the sponsor. The panel work was performed in Natick. Twenty-four panelists selected at random were used with no replication. Each sample was tested separately for a total of twenty-four individual judgements.

1. Effect of Rehydration Procedure

Trimmed semimembranosus muscle was used for this study. The design included two meat grades (US Good and US Canner Cutter) and three cooking times (45, 75 and 120 mins.). Each sample was prepared in duplicate for a total of twelve samples. Because of the quantity required, each sample comprised meat derived from several animals and no attempts were made to keep the animal factor separate.

The purpose of this study was three-fold. First, we wanted to check the possibility that differences in the rehydration procedure influenced the sample type-dependability of correlations between objective and sensory evaluations found in Phase II. Secondly, a study of the effect of the rehydration procedure on numerical values of the measured parameters, coefficients of variation and unexplained errors appeared to be in order. Thirdly, we wanted to find which of the several rehydration procedures regenerates best the microscopic appearance of fresh meat.

The following rehydration procedures were used:

- A) 1% NaCl, 180°F. for 1 hour, wrapped in aluminum foil and held overnight in the refrigerator
- B) 1% NaCl, 180°F. for 1 hour

- C) distilled water, 80°F, for 20 minutes
- D) distilled water, 80°F. for 20 minutes, wrapped in aluminum foil and held overnight in the refrigerator

The rehydration procedures were selected to check two variables:

- a) salt solution versus distilled water
- b) overnight equilibration versus no equilibration

The soaking times were selected to duplicate some of the conditions which were used in Phase II of the project.

Only one rehydration procedure was used for sensory evaluation of the samples. This procedure (C) involved the use of distilled water and soaking for 20 minutes.

- a) Microscopic Evaluation - Half of the samples were subjected to microscopic evaluation to obtain additional information on the effect of rehydration procedures. The samples examined represented all processing variables (two grades and four cooking times). Duplicates were not evaluated in order to keep the magnitude of the work within the budget boundaries.

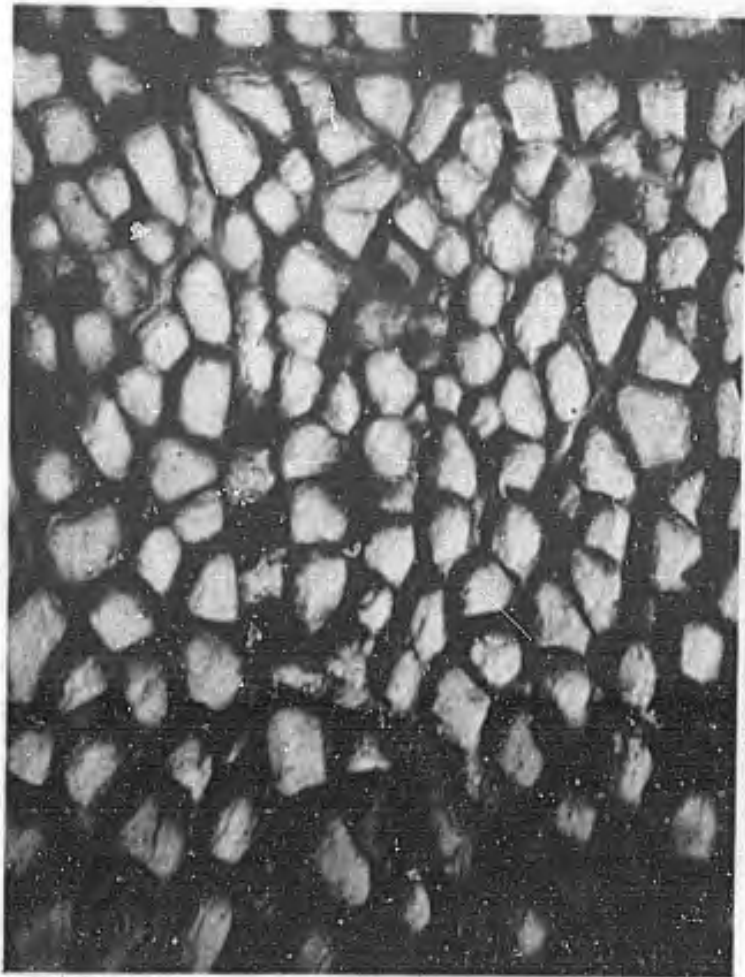
Rehydrated meat was quick-frozen in dry ice to stop any changes. Samples were stored at -20°C. until ready to use. They were sectioned at approximately 50 μ on a freezing microtome and examined at 150 magnification. Photomicrographs of suitable microscopic field were made, using Polaroid film, on both longitudinal and transverse sections. Staining of microscopic sections with eosin did not appear to offer any significant advantage to warrant the expenditure in time and mostly unstained sections were examined in this study. In general, transverse sections were more revealing than longitudinal sections. Evaluation included size of muscle fibers, interfibril spaces, smoothness or roughness in the fibers, resistance to the microtome blade and general fragility of the tissue.

Prior to the examination of dehydrated meat involved in this study, a preliminary evaluation of rehydration time was made on an old sample of commercial freeze-dried precooked sliced beef

(Type 1) processed by Liana Inc. and kept at 35°F. for about 1 - 1/2 years. The meat was rehydrated in distilled water for 5 minutes, 1 hour and 1 hour with overnight equilibration. Its microscopic appearance was compared with that of raw beef, fresh cooked beef, and unrehydrated precooked beef. Fiber diameter measurements and observations on interfibril spaces, protein coagulation and overall appearance indicated that samples equilibrated overnight most closely resembled fresh cooked meat. The following changes were noted to be connected with increasing rehydration time: reduction in size of interfibril spaces, increase in fiber diameter, more visible coagulated protein.

The microscopic evaluation of the twelve samples representing the main subject of this section of the report showed that, in general, rehydration in 1% NaCl appeared to toughen the meat fibers, while at the same time allowing more water to be absorbed intrafibrally than did rehydration in distilled water. Samples rehydrated according to procedures A and B contained fibers which were generally larger in diameter, more irregular and offered more resistance to microtome cutting than did meats from groups C and D. Overnight equilibration made the meat fibers rehydrated in the salt solution tougher, rougher and larger. The diameter of these fibers appeared to be larger than that in fresh cooked meat. Samples rehydrated in distilled water became, on overnight equilibration, more regular, smoother, softer and-- overall-- more like fresh cooked meat. Selected photomicrographs illustrating these observations are shown in Figures 9A, 9B, 9C and 9D. It should be noted, however, that none of the evaluated rehydration procedures duplicated the appearance of fresh cooked beef.

- b) Water Release - The conclusion drawn from the microscopic evaluation of samples that rehydration in the sodium chloride solution makes for greater water binding was confirmed by Texturometer measurements of water released on consecutive chews. It will be seen from Figure 10 (and Table XVIII) that samples rehydrated in distilled water exuded drastically more liquid than those rehydrated in 1% NaCl. Overnight equilibration had a significant decreasing effect on liquid released from samples rehydrated in distilled water while it had no effect on samples rehydrated in the salt solution. Total water uptake on rehydration was not measured and, thus, the obtained results have to be expressed in absolute rather than in relative terms.



a



b

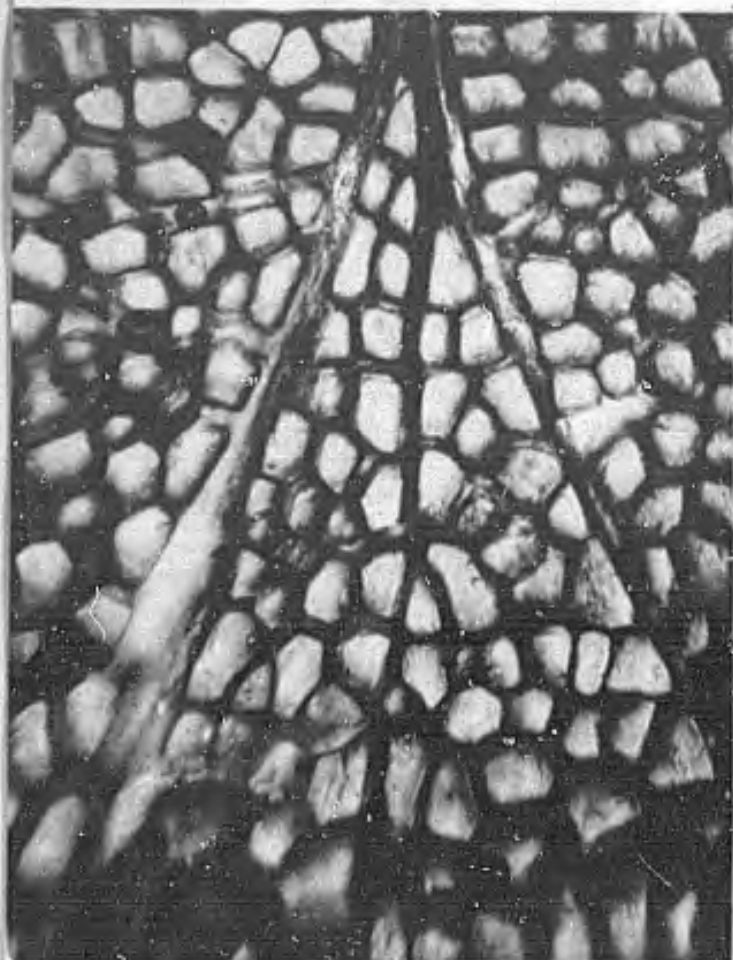
Figure 9A

Photomicrographs of precooked freeze-dried beef rehydrated in 1% NaCl
(1 hour with overnight equilibration)

a - Transverse section showing large
fiber diameters, reduced interfibrillar
spaces.

b - longitudinal section showing large,
rough fibers.

150 X



a



b

Figure 9B

Photomicrographs of precooked freeze-dried beef rehydrated in 1% NaCl
(1 hour with no overnight equilibration)

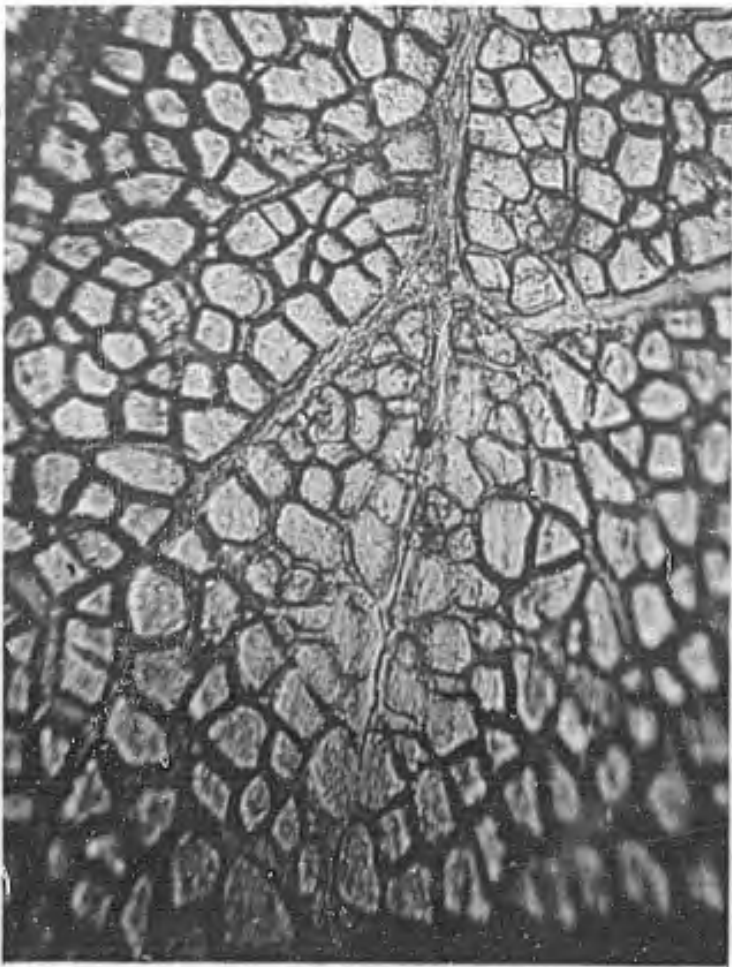
a - transverse section showing fiber diameters smaller than in A, larger interfibrillar spaces.

b - longitudinal section showing smaller, smoother fibers than in A.

150 X

T-100 No. 11

-58-



a



b

Figure 9C

Photomicrographs of precooked freeze-dried beef rehydrated in distilled water
(20 minutes with no overnight equilibration)

a - transverse section showing fiber diameters smaller than in A or B, larger interfibril spaces.

b - longitudinal section showing smaller, smoother, less swollen fibers than in A or B.

150 X

T-100 No. 11

-59-



a



b

Figure 9D

Photomicrographs of precooked freeze-dried beef rehydrated in
distilled water
(20 minutes with overnight equilibration)

a - transverse section showing fiber
diameters larger than in C, but
smaller than in A or B.

b - longitudinal section showing the
smoothest fibers of the series.

150 X

T-100 No. 11

-60-

Data shown in Figure 10 were averaged across the two grades and the three cooking times. The effect of these variables on water release, as related to the rehydration procedure, is illustrated in Figure 11 (A through D). Statistically, there was no apparent consistent relationship between cooking time and water release for procedures A and B (1% NaCl) at either grade. It is interesting to note, however, that, in general, the longest cooking time (120 minutes) resulted in the greatest release of water, except for US Good grade and procedure A where the 75 minutes cooking time gave the highest values. Rehydration in distilled water (procedures C and D) showed a statistically significant (95% level) correlation between water release and cooking time, with values decreasing as the cooking time increased. The grade effect was not statistically significant. In general, however, the Canner Cutter grade tended to release more water than the US Good grade except for 120 minutes cooking time where the opposite was true.

- c) Numerical Values for the Mechanical Parameters of Texture - Table XVIII summarizes the effects of the four rehydration procedures on objective measurements performed with the three instruments and their statistical significance (95% level). Differences due to rehydration in the salt solution versus distilled water were picked up by the Warner-Bratzler Tenderometer, the Texturometer hardness and by water release values. The Texturometer indicated that the samples rehydrated in 1% NaCl were harder than those rehydrated in distilled water. The Warner-Bratzler Tenderometer, however, showed lower values for samples rehydrated in the salt solution. Microscopic evaluation of meat agrees with the Texturometer measurements in that the samples subjected to rehydration procedures A + B (1% NaCl) showed tougher, larger and more irregular fibers which offered more resistance to microtome cutting.

Differences due to overnight equilibration were picked up by the Kramer Shear Press and the Texturometer cohesiveness. In both cases, overnight equilibration resulted in lower values i.e. samples required less force to shear and were less cohesive. Texturometer elasticity and chewiness showed no particular patterns due to the rehydration procedure.

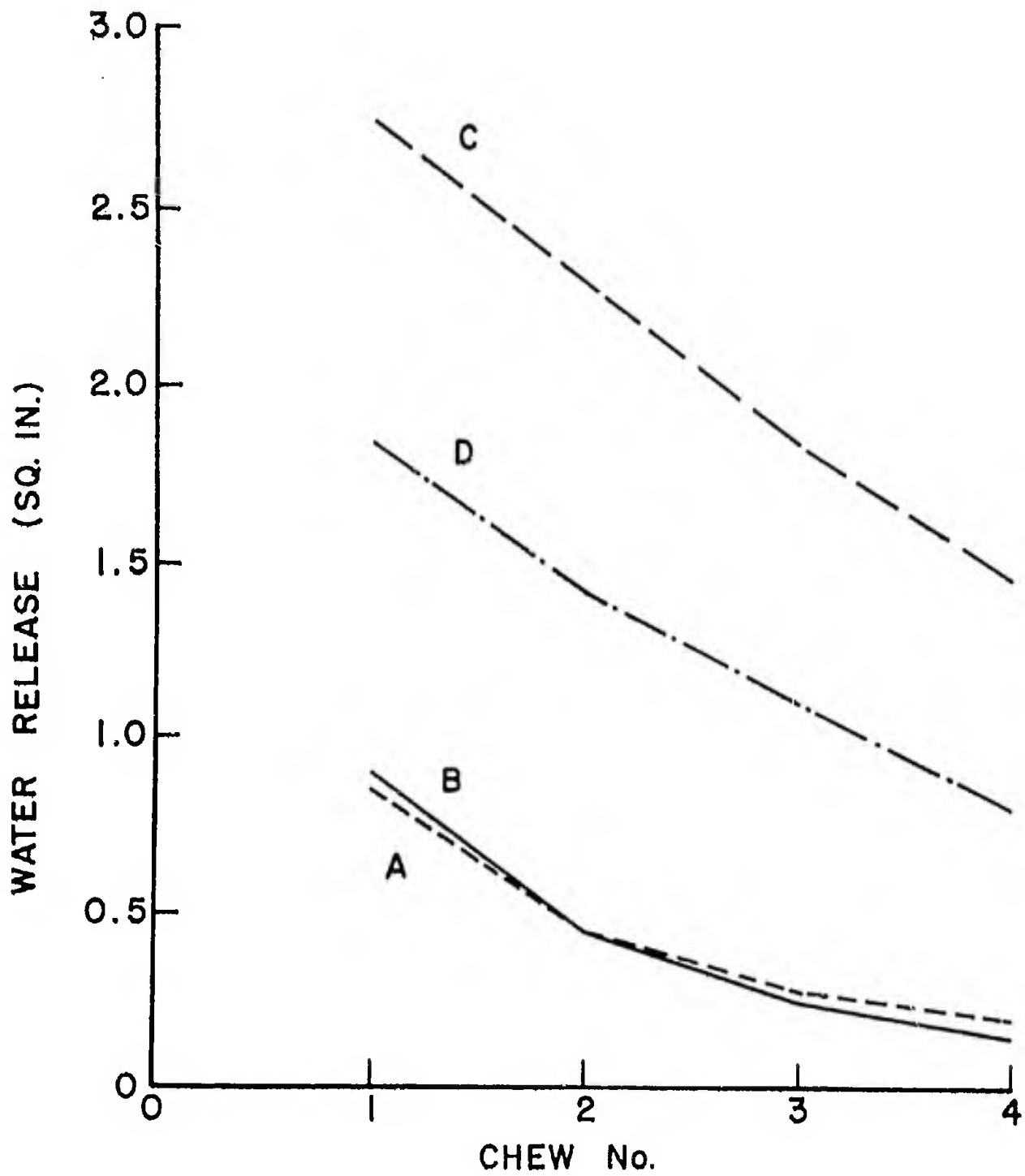
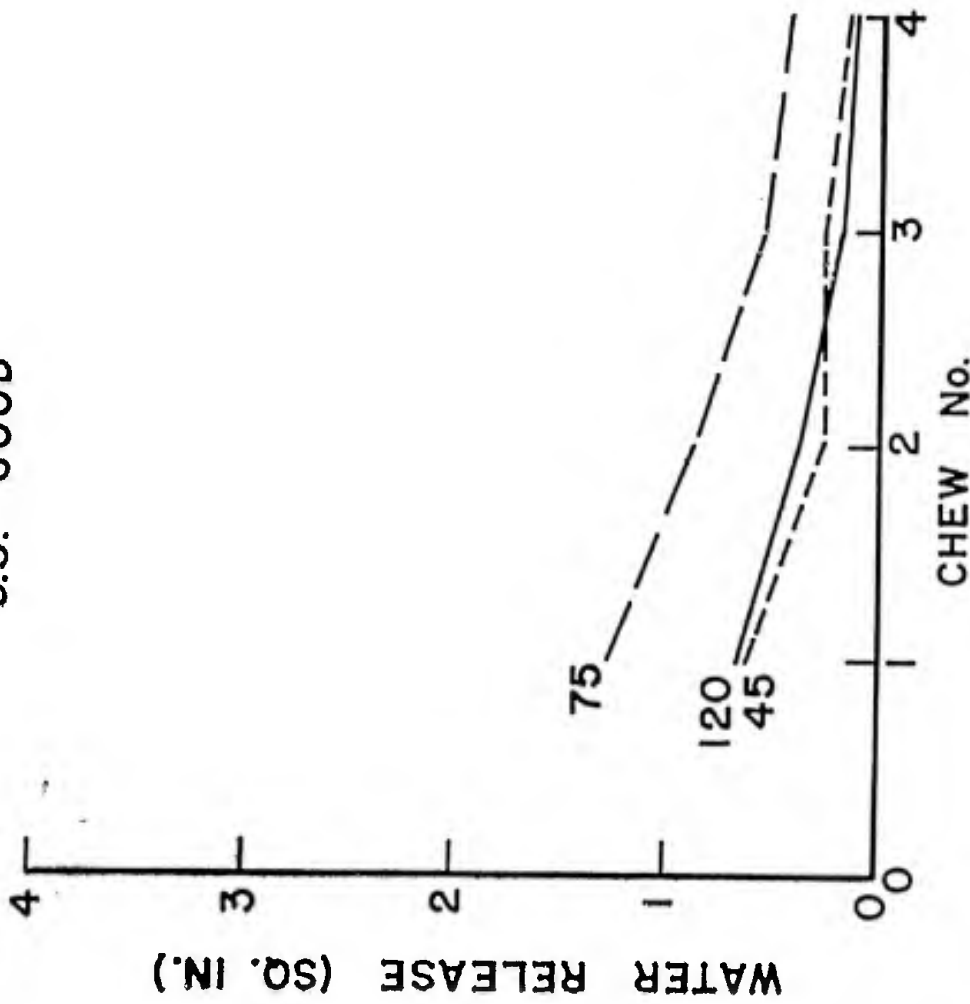


Figure 10
EFFECT OF REHYDRATION PROCEDURE ON WATER RELEASE

U.S. GOOD



CANNER/CUTTER

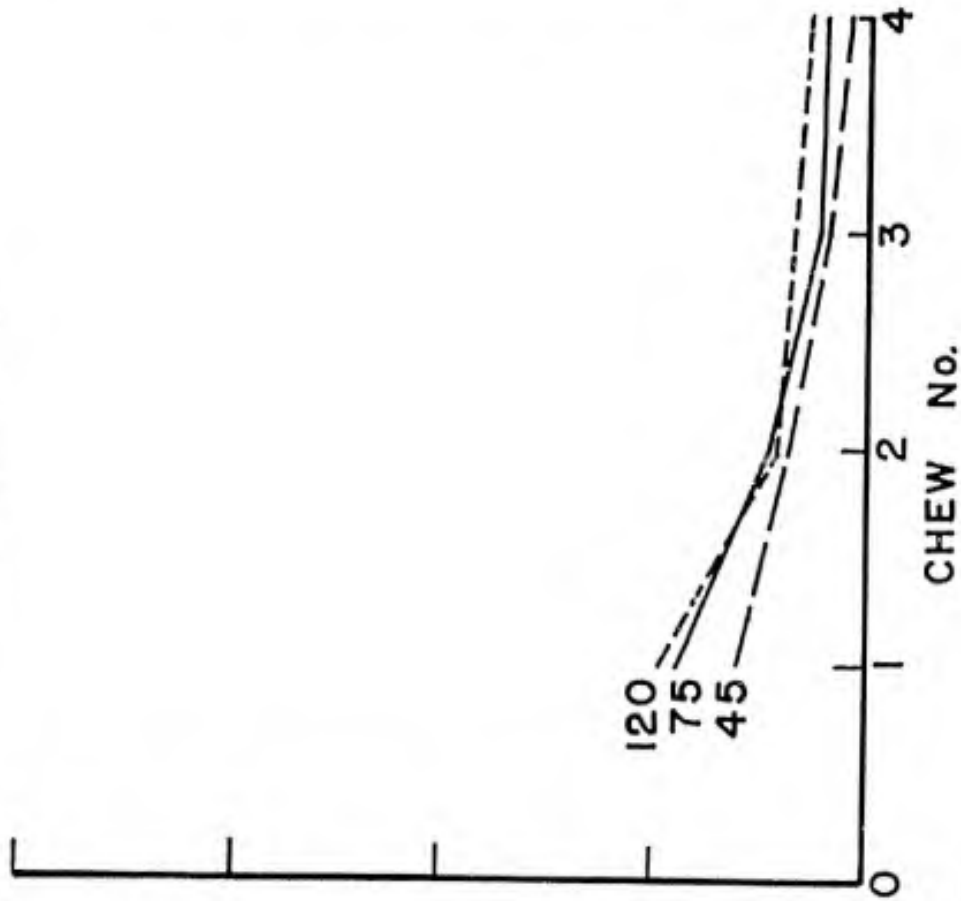
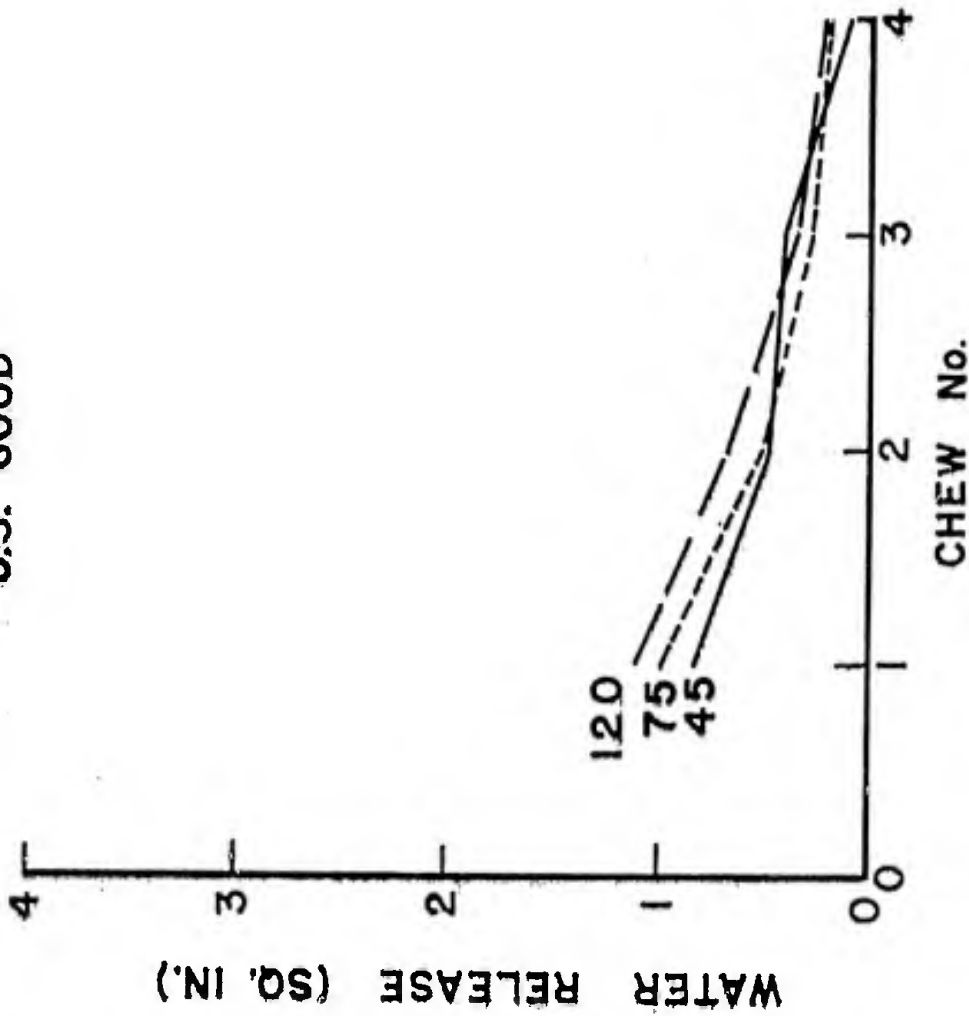


Figure 11A

WATER RELEASE vs GRADE, COOK TIME AND REHYDRATION PROCEDURE
(1 HR. IN 1% NaCl WITH OVERNIGHT EQUILIBRATION)

U.S. GOOD



CANNER/CUTTER

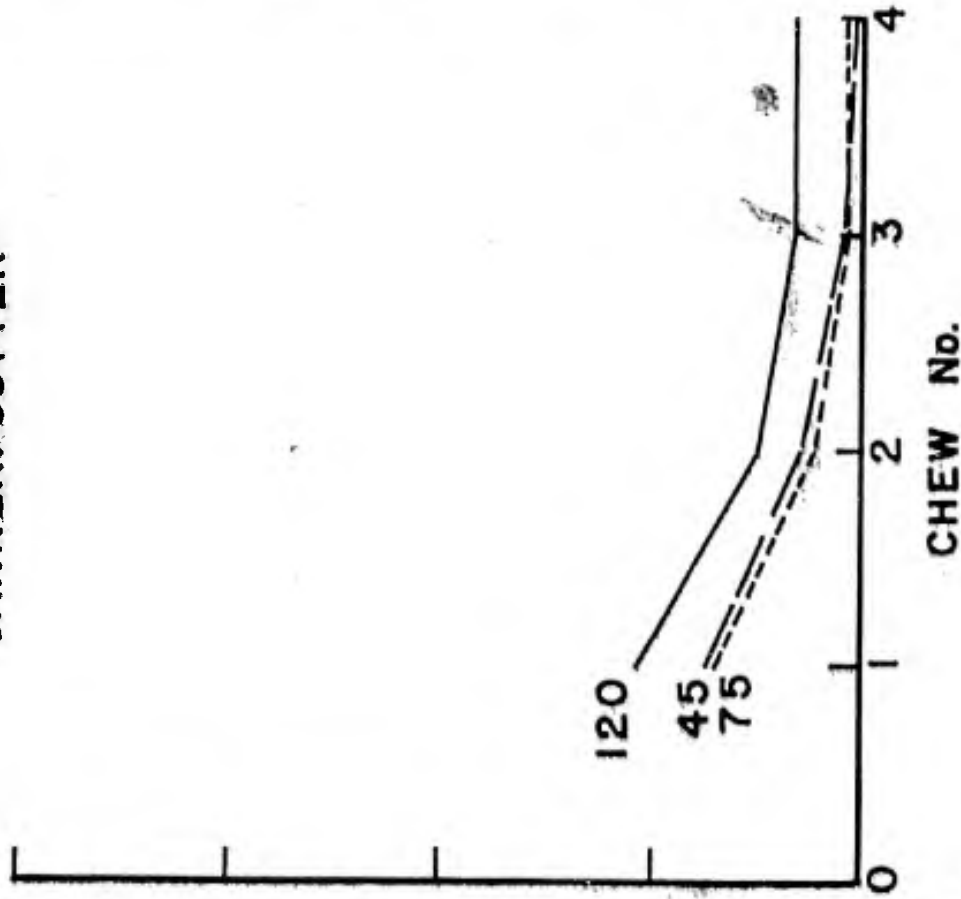
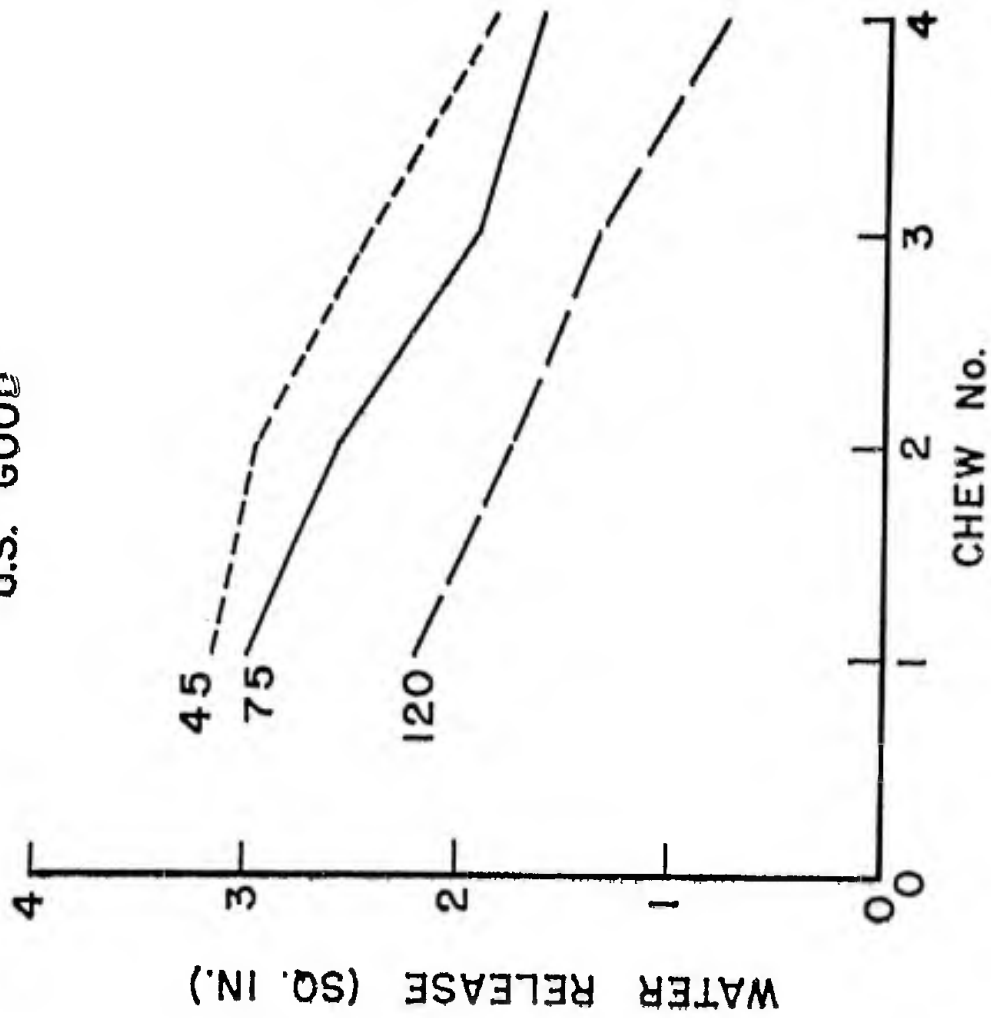


Figure 11B

WATER RELEASE VS GRADE, COOK TIME AND REHYDRATION PROCEDURE
(1 HR. IN 1% NaCl WITH NO OVERNIGHT EQUILIBRATION)

U.S. GOOD



CANNER/CUTTER

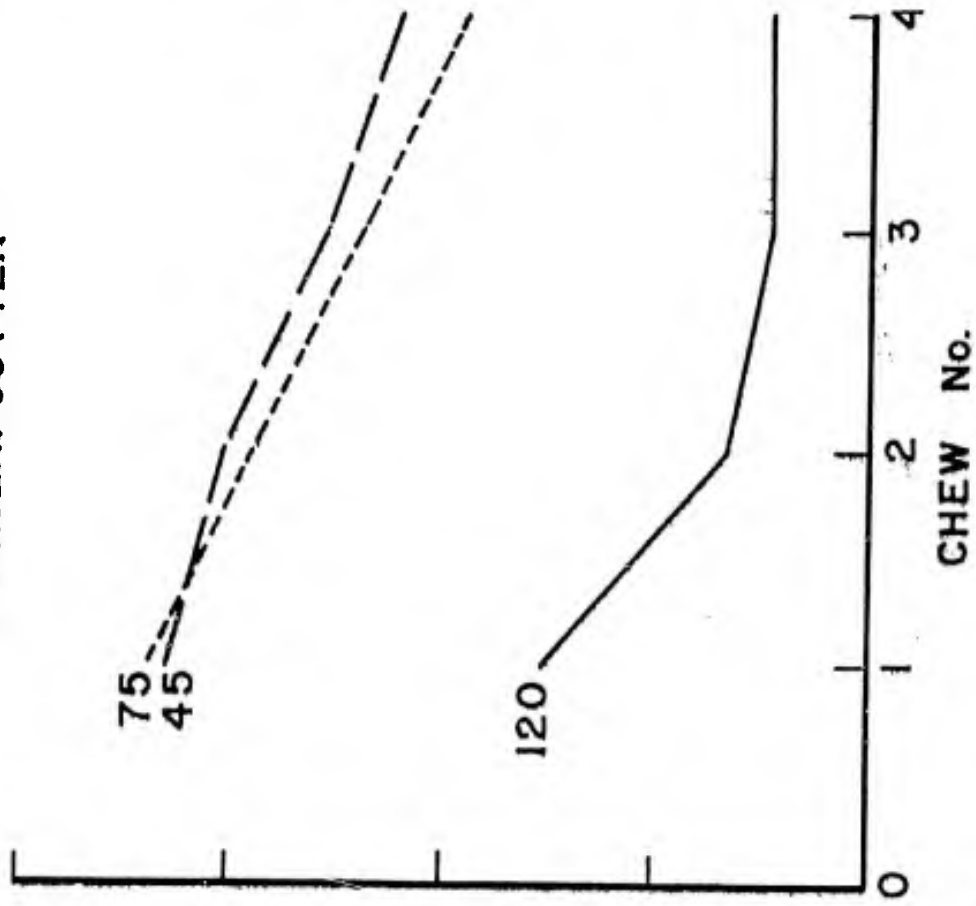
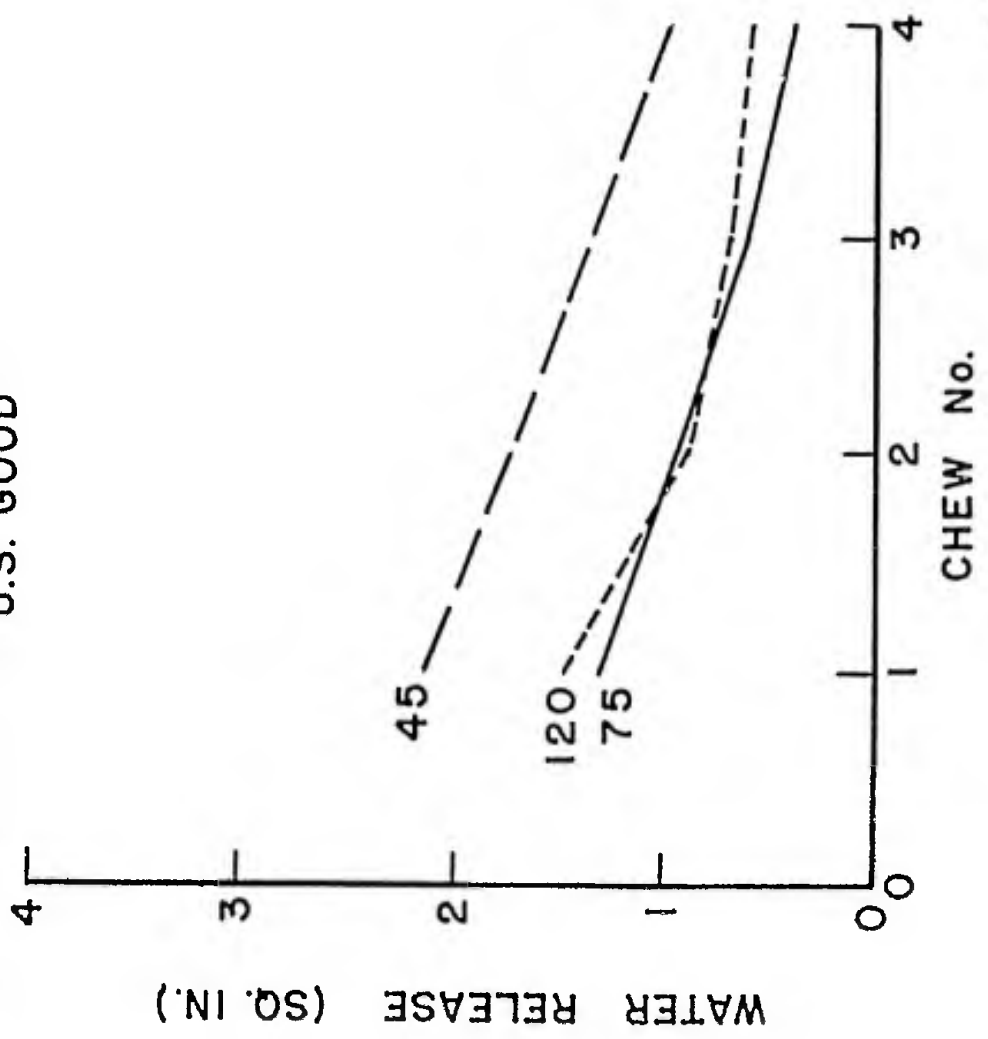


Figure 11 C

WATER RELEASE VS GRADE, COOK TIME AND REHYDRATION PROCEDURE
(20 MINS. IN DISTILLED WATER WITH NO OVERNIGHT EQUILIBRATION)

U.S. GOOD



CANNER / CUTTER

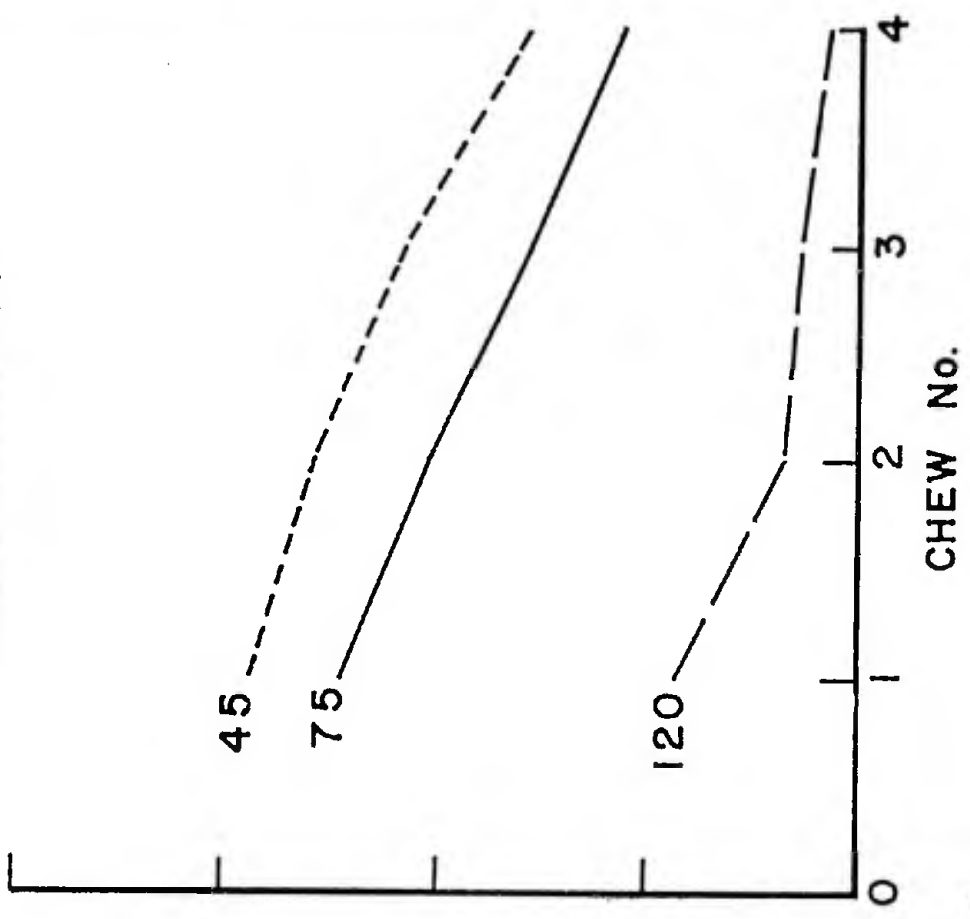


Figure 11D

WATER RELEASE vs GRADE, COOK TIME AND REHYDRATION PROCEDURE
(20 MINS. IN DISTILLED WATER WITH OVERNIGHT EQUILIBRATION)

Table XVIII

Effect of Rehydration Procedure on Objective Measurements of Texture
(average values)

<u>Instrument</u>	<u>Rehydration Procedure</u>				<u>Statistical Significance</u>
	<u>A</u>	<u>B</u>	<u>C</u>	<u>D</u>	
Warner-Bratzler Tenderometer	11.58	9.33	13.76	13.65	A, B vs. C, D
Kramer Shear Press lbs force	434.7	541.3	501.5	471.1	A, D vs B, C
lbs force/gm	11.59	18.05	13.04	12.11	A, D vs B, C (?)
Texturometer,					
hardness	110.1	109.0	97.4	98.0	A, B vs C, D
cohesiveness	.72	.76	.76	.73	A, D vs B, C
elasticity	5.08	5.32	5.31	5.26	n.s.
chewiness	430.5	459.6	403.9	384.1	n.s.
water release I	.84	.90	2.75	1.84	A, B vs C, D
II	.46	.45	2.30	1.42	A, B vs C, D
III	.28	.25	1.84	1.10	A, B vs C, D
IV	.21	.15	1.46	.79	A, B vs C, D

- d) Residual Error and Coefficient of Variation - Table XIX shows the effect of rehydration procedure on the residual error and the coefficient of variation. The residual error measures the variation from piece to piece for samples treated and handled in an identical manner. The final values were expressed as per cent of the average. The coefficient of variation was calculated as an average of the individual coefficients of variation determined for each of the twelve samples.

Examination of Table XIX indicates a low dependence of the coefficient of variation and of the residual error on the rehydration procedure. Overnight equilibration tended to lower coefficients of variation for practically all measurements except the Warner-Bratzler Tenderometer. Rehydration procedure D appeared to give the lowest coefficient of variation, with the Warner-Bratzler Tenderometer again being the exception.

- e) Meat Grade and Cooking Times - The results of the analysis of variance indicated that the ability of the three instruments to show grade and cooking level effects varied depending on rehydration procedure. In this series of samples, meat grade had a statistically significant effect on instrument values only when rehydration procedures A and D (overnight equilibration) were used. The effect was not consistent throughout all the measurements. For rehydration A, grade was significant only for the Warner-Bratzler Tenderometer, the Kramer Shear Press and the Texturometer elasticity. The Kramer Shear Press and the Texturometer cohesiveness were the only measurements which showed a significant grade effect for rehydration D. None of the measurements were significantly affected by grade for rehydration procedures B and C.

Cooking time had a general significant effect on Warner-Bratzler and Kramer Shear Press values, and on all four of the mechanical parameters measured on the Texturometer--hardness, cohesiveness, elasticity and chewiness. This effect was observed for all four rehydration procedures. It was dependent on the grade for the Warner-Bratzler Tenderometer and the Kramer Shear Press measurements, that is the effect of cooking time was different for the US Good than for the US Canner/Cutter grade. Because of large variations in replicates, the effect was not statistically significant for the Warner-Bratzler Tenderometer and the Kramer Shear Press for rehydration procedure B, and for the Kramer Shear Press

Table XIX

Effect of Rehydration Procedure on Residual Error
and Coefficient of Variation

	<u>Residual Error %</u>				<u>Coefficient of Variation %</u>			
	<u>A</u>	<u>B</u>	<u>C</u>	<u>D</u>	<u>A</u>	<u>B</u>	<u>C</u>	<u>D</u>
Warner-Bratzler Tenderometer	18.3	19.7	23.3	23.9	19.8	18.7	22.0	22.0
Kramer Shear Press								
lb. force	18.8	18.0	18.7	18.9	17.3	18.9	19.1	16.7
lb. force/gm	29.3	23.3	27.7	29.0	17.2	19.0	17.5	16.5
Texturometer,								
hardness	6.9	6.0	8.9	5.5	6.6	5.8	8.0	5.1
cohesiveness	7.0	7.4	9.5	7.4	6.7	7.5	8.6	6.2
elasticity	9.9	15.0	17.0	11.0	10.1	12.4	16.0	10.1
chewiness	16.4	20.8	27.0	16.4	16.8	21.1	27.5	16.6
water release I	35.7	25.6	17.8	16.8	33.9	24.1	18.0	16.9
II	45.8	48.8	24.3	24.8	48.2	48.6	26.7	28.5
III	60.8	76.2	24.5	23.7	76.5	77.4	34.0	31.1
IV	76.1	100.0	30.1	29.2	57.8	94.2	28.8	40.8

for rehydration procedure C. Cooking time also had a significant effect on water release measurements for rehydration procedures C and D (distilled water).

- f) Correlation Between Objective Measurements - The effect of the rehydration procedure was again observed with respect to correlations between the three instruments and among the Texturometer parameters.

The Warner-Bratzler Tenderometer correlated significantly with the Kramer Shear Press readings for all rehydration procedures, with Texturometer hardness, cohesiveness, elasticity and chewiness for procedure A and with Texturometer cohesiveness, elasticity and chewiness for procedure D. The Tenderometer also correlated significantly with all four Texturometer water release values for rehydration procedure D and with water release III and IV for procedure B. Correlation with the mechanical parameters of texture measurable on the Texturometer was similar to, but generally lower than that obtained in Phase II of the project. Statistical correlation with water release values is difficult to explain. Correlation with the mechanical parameters was positive i.e. high values on the Warner-Bratzler Tenderometer were associated with high values on the Texturometer. With respect to water release, the correlations went in a positive direction for rehydration procedure D and in a negative direction for rehydration procedure B. No explanation is available at the present time for this phenomenon.

Kramer Shear Press data expressed as pounds force generally correlated significantly with Texturometer hardness, cohesiveness, elasticity and chewiness for all rehydration conditions. They also correlated with water release values for procedure B. The correlation with the mechanical parameters was positive while that with water release was negative. Kramer Shear Press data expressed as pounds force per gram showed similar correlations with water release values, but not as many correlations with the mechanical parameters.

Correlations between Texturometer parameters showed the same trends as for previously evaluated sets of samples. The mechanical parameters correlated very significantly among themselves and only sporadically with water release values. The two mechanical parameters which correlated more consistently than others with water release were cohesiveness and elasticity. These correlations

depended on rehydration procedure and were present for rehydration B and C and completely absent for rehydration A. Water release values correlated highly among themselves for all four rehydration procedures.

- g) Correlation With Sensory Panel - No definite pattern due to the rehydration procedures could be detected. In general, the Warner-Bratzler Tenderometer and the Kramer Shear Press were highly correlated with sensory tenderness while the Texturometer was not. These correlations ranged in significance from the 95% to the 99.9% level. Their significance did not appear to depend on the rehydration procedure.

Thus, we can state that the manner in which freeze-dried meat is rehydrated has a significant effect on microscopic appearance, on the manner of liquid release, on numerical values for the mechanical parameters of texture and on correlations between objective measurements. Microscopic appearance most closely approximating that of fresh cooked meat was obtained when precooked freeze-dried beef was rehydrated in distilled water at room temperature for 20 mins. and equilibrated overnight in the refrigerator. Even this procedure, however, did not result in duplication of the appearance of fresh cooked meat. In agreement with the microscopic observation that rehydration in a salt solution allows more water to be absorbed intrafibrally, these samples also exuded less liquid when chewed mechanically by the Texturometer. Also in agreement with the microscopic appearance which indicated that meat rehydrated in a salt solution had tougher, larger and more irregular fibers, the Texturometer showed higher values for such samples. The Warner-Bratzler Tenderometer, however, indicated lower values for salt-rehydrated meat while the Kramer Shear Press did not show a statistical significance between salt and distilled water rehydration. Only a small effect of the rehydration procedure was noticed on the coefficient of variation and on the residual error of objective measurements, and no effect was found on the significance of correlations with sensory evaluation.

Based on this study, the rehydration procedure involving a 20 min. soak in 80°F. distilled water, drainage for 5 - 10 mins. followed by overnight equilibration in the refrigerator, was selected and used in all the subsequent work.

2. Effect of Trimming on Objective Measurements

Untrimmed semimembranosus muscle was used for this phase of the work. The processor was instructed to use matched sides for each sample and it can be assumed that one sample represented one animal. Two grades of meat (US Good and US Canner Cutter) and three precooking levels (45, 75 and 120 mins.) were incorporated into the experimental design. In addition, two raw samples were prepared for each grade. One was evaluated raw, while the other one was given a 20 min. cook in 180°F. water prior to being tested with the three instruments. Each sample was prepared in duplicate for a total of 20 samples. Prior to the objective evaluation, each sample was divided in half. One half was trimmed free of fat, gristle, tendons, etc. while the other half was left untrimmed.

As can be seen from Table XX, trimming of samples resulted in a general lowering of both the residual error and of the coefficient of variation, the effect being most pronounced for the Warner-Bratzler Tenderometer. The same observation was also made based on the analysis of the "within sample" error calculated from computed mean squares. It can, thus, be stated that the Warner-Bratzler Tenderometer is the most sensitive to errors introduced by the presence of fat, gristle, tendons, etc.

Certain differences in the magnitude of values were also noted between trimmed and untrimmed samples. On samples dehydrated raw, the Kramer Shear Press readings were significantly higher for the untrimmed samples. The Warner-Bratzler Tenderometer and the Texturometer values did not show significant differences, but the trend was the same as for the Kramer Shear Press. In the case of samples dehydrated after cooking, the results were somewhat different. The Warner-Bratzler Tenderometer and The Kramer Shear Press readings showed no significant differences, while the Texturometer parameters (except for elasticity) indicated that the untrimmed samples were significantly lower in value than the trimmed ones. No clear cut explanation of this phenomenon can be offered. It is possible that the uneven distribution of the non-muscle parts of the samples was responsible for these readings i.e. presence of much gristle, tendons, etc. would tend to raise the overall values, while presence of fat would tend to lower them. It is also possible that the inherent heterogeneity of meat was the causative factor.

Table XX

Effect of Trimming on Residual Errors and Coefficients of Variation
(freeze-dehydrated sliced beef)

<u>Instrument</u>	<u>Type of Reading</u>	<u>Residual Error %</u>		<u>Coefficient of Variation %</u>	
		<u>Trimmed</u>	<u>Untrimmed</u>	<u>Trimmed</u>	<u>Untrimmed</u>
Warner-Bratzler Tenderometer	max. shear force	18.9	26.4	16.7	24.8
Kramer Shear Press	pound force	17.4	18.5	16.1	16.5
	pound force/gm	13.2	16.8	13.0	15.1
Texturometer	hardness	8.4	8.7	9.2	9.0
	cohesiveness	8.5	10.1	7.6	8.4
	elasticity	8.6	11.4	8.0	10.6
	chewiness	16.2	17.4	18.6	20.1
	water release I	15.8	13.4	13.7	12.4
	water release II	17.7	16.9	17.1	18.7
	water release III	19.2	22.9	22.3	27.0
water release IV	23.6	30.4	30.0	35.3	

3. Effect of Freeze-Drying Meat Raw vs. Precooked

In addition to beef, pork and turkey dehydrated raw were also evaluated and compared to their cooked counterparts. In all cases, the Warner-Bratzler Tenderometer gave consistently higher readings for raw meat, while the opposite was true in the case of the Kramer Shear Press and the Texturometer. The explanation for this can be found in the mechanical section of the three instruments. The Warner-Bratzler Tenderometer is so designed that the meat must not only be completely sheared, but the cutting blade continues to travel a significant distance after it has left the lower end of the meat sample. As a result, the final reading is highly influenced by connective tissue or muscle fibers which have not been completely sheared and which are pulled downward by the moving blade. It was also noticed that the juice from the raw meat adhered to the blade causing friction and necessitating frequent cleaning. If this was not done, erroneously high readings were obtained. The shearing prongs in the Kramer Shear Press do not travel any great distances after leaving the sample and, thus, any forces caused by fiber pulling do not have as drastic an effect on the final reading. In the case of the Texturometer, the pulling of the tough meat fibers has very little, if any, effect because most of the action is of the compression rather than of the shearing type. Both the Kramer Shear Press and the Texturometer gave higher values for the cooked samples which agreed with visual observation of greater firmness and greater resistance to mechanical disintegration.

Conditions employed for cooking of beef samples dehydrated raw gave meat with mechanical characteristics similar to those exhibited by freeze-dried beef precooked between 75 and 120 mins. Elasticity was an exception in that it was somewhat higher for the meat processed raw and cooked during rehydration. The most significant effect of dehydration in the raw state was on the amount of liquid exuded during the mechanical chewing. As indicated by the Texturometer water release values, meat freeze-dried raw exuded considerably more liquid than that cooked before dehydration.

Cooking prior to dehydration also had an effect on coefficients of variation and residual errors. In the case of beef, cooking decreased significantly the spread of replicate values in mechanical Texturometer parameters, while it had an opposite effect on the Warner-Bratzler Tenderometer and on water release readings. No definite trend was noticed in Kramer Shear Press values.

Certain interrelations between grade and state of meat were noticed in the case of beef. The effect of raw vs. cooked meat as recorded by the Kramer Shear Press readings for untrimmed beef samples was inconsistent for the two grades in the study inasmuch as the average difference between raw and cooked samples for the US Canner Cutter grade was much larger than that observed for the US Good grade. In the case of turkey, a significant interaction between the sex and the condition of meat was noticed i.e. the effect of raw vs. cooked (both dehydrated raw) was not the same for hen as for tom turkeys.

4. Effect of Meat Type on Objective Measurements

In Table I on p. 23 are shown Texturometer values for fresh beef, pork and chicken. Since similar types of freeze-dehydrated meat were evaluated in this phase of the contract, it was thought of interest to tabulate the obtained average values in Table XXI. It will be seen that the numerical values for freeze-dehydrated meat are considerably higher than those for fresh meat. This is in line with the microscopic evaluation which indicated that freeze-dehydrated meat does not regain the appearance of fresh meat with any of the four rehydration procedures studied. It also is in line with the observations of the texture profile panel that dehydrated beef and pork had, on the whole, larger and tougher fibers (see p. 24) than fresh meat.

5. Correlation Between Objective and Sensory Evaluations

Table XXII summarizes coefficients of linear correlation between these two types of evaluation obtained for the four sets of dehydrated meat tested within this phase of the work. Two groups of dehydrated beef samples and one group each of dehydrated pork and turkey are included in this Table. The two groups of beef samples were used for the study of rehydration procedures and for the evaluation of the effect of trimming, respectively. Their nature has been described on p. 54 and p. 72.

The freeze-dehydrated pork samples were comprised of longissimus dorsi muscle and involved three cooking levels (45, 75 and 120 mins.). The samples were prepared in duplicate for a total of six samples. One sample representing the longest cook time was mislabeled, thus, reducing the total number of samples to five. Four raw freeze-dried pork samples were also prepared within this series, but are

Table XXI

Textural Characteristics of Freeze-Dehydrated Precooked Meats

(averaged over three cook levels)

	<u>Beef</u>	<u>Pork</u>	<u>Turkey</u>
Warner-Bratzler Tenderometer (lbs.)	12.8	14.8	10.90
Kramer Shear Press (lbs.)	541.9	411.2	331.9
Texturometer, hardness (i.u.)	110.9	115.1	105.5
cohesiveness	.80	.772	.787
elasticity	5.34	5.68	5.76
chewiness	443.0	518.5	481.0
Panel			
tenderness	4.52	4.16	5.47
juiciness	3.03	2.97	3.83
overall texture	4.05	3.99	4.77

not included in correlations with panel evaluation. The processor was instructed to use, if necessary, matched animal sides for one sample. However, sides from the same animal were not to be used for two different samples. It was preferred that only one side be used per sample and the meat be obtained from large loins. The exact composition of the samples could not be determined.

In the freeze-dehydrated turkey series, each sample was composed of meat derived from a number of birds. This was necessitated by the large quantity of freeze-dried meat required for the three instrumental measurements plus the sensory evaluation by 24 judges. Two variables were included in the statistical design: sex (hen vs. tom), internal precooking temperature (150, 165 and 180°F.). The meat was raw boned, cooked and diced before freeze-drying to a size 1" x 1" x 1/2". A total of six precooked samples was involved with no replication. Similarly to the beef and the pork series, four samples dehydrated raw were also prepared, but are not included in the comparison with sensory evaluation.

All the samples used for calculation of the indicated correlations between sensory and objective methods of meat texture evaluation were trimmed and rehydrated according to the same procedure. Twenty minutes in 80°F. distilled water followed by overnight equilibration was used for samples subjected to instrumental analysis. Meat used for panel work was rehydrated in the same manner except that it was not equilibrated overnight, but served immediately to the judges. As has already been pointed out, the Natick panel evaluated samples in this phase of the work.

It is evident from Table XXII that correlations between objective and subjective evaluations differ drastically in significance among the four series of samples and among the three meat types. All three instruments correlated significantly with sensory tenderness for one series of freeze-dehydrated beef and only the Warner-Bratzler Tenderometer and the Kramer Shear Press correlated for the other series. With pork, only the Kramer Shear Press and the Texturometer hardness showed significant correlations, while with turkey none of the objective measurements were correlated with sensory tenderness. None of the instruments, except the Warner-Bratzler Tenderometer for one beef series, correlated with sensory juiciness. In two cases (beef and pork), panel overall texture correlated with the Kramer Shear Press and with the Texturometer. However, the Texturometer parameters which showed significant correlations with panel overall texture were not the same in the two cases: cohesiveness and chewiness for the beef series, and hardness for the pork series.

Table XXII

Correlation Between Objective and Sensory Evaluation on Different Types
of Precooked Freeze-Dehydrated Meat

(coefficients of linear correlation)

	Beef 1)			Beef 2)			Pork			Turkey		
	T	J	OT	T	J	OT	T	J	OT	T	J	OT
Warner-Bratzler Tenderometer	-.76**	.61*	-.42	-.77**	.35	-.57	-.10	-.74	-.26	.59	.41	.69
Kramer Shear Press	-.72**	.45	-.33	-.84***	.17	-.58*	-.81*	-.24	-.81*	-.53	.37	.18
Texturometer hardness	-.38	.04	-.16	-.67*	-.09	-.56	-.78*	-.50	-.86*	.38	-.15	.05
cohesiveness	-.62*	.53	-.10	-.72**	-.01	-.68*	-.63	-.12	-.67	.08	.03	-.04
elasticity	-.53	.57	-.10	-.66*	.19	-.43	-.66	.05	-.63	-.20	.78*	.51
chewiness	-.55	.41	-.12	-.74**	.00	-.62*	-.72	-.18	-.74	.09	.40	.28
water release												
I	-.44	.49	-.21	-.40	.02	-.43	-.14	-.21	-.21	.61	-.42	-.19
II	-.43	.50	-.18	-.41	.07	-.52	-.25	-.17	-.30	.52	-.39	-.23
III	-.48	.51	-.24	-.40	.12	-.38	-.38	-.22	-.44	.51	-.42	-.24
IV	-.43	.47	-.25	-.41	.16	-.39	-.48	-.28	-.53	.44	-.29	-.18

- 1) Series involving the study of the four rehydration procedures. The indicated values are for procedure D i.e., 20 min. in 80°F. distilled water with overnight equilibration.
- 2) Series involving the study of the effect of trimming. The indicated values are for trimmed samples.

Note: The statistical significance of the correlation coefficients is denoted by one asterisk for the 95% level, two asterisks for the 99% level and three asterisks for the 99.9% level.

T = panel tenderness
J = panel juiciness
OT = panel overall texture

The dependence on sample series of correlations between sensory and objective evaluations has been first demonstrated in Phase II of this work. Data obtained in Phase III of the contract have confirmed this observation. Postulated reasons for this phenomenon, based on known differences between the individual meat series, are discussed in the Evaluation of the Data section of this report.

6. Correlation Between the Three Instruments

Table XXIII summarizes coefficients of correlation between the three instruments for the different types of meat evaluated in Phase III of the contract. In the case of beef, only correlations for rehydration procedure D and for trimmed meat are shown. Correlation coefficients for the other rehydration procedures and for untrimmed beef were also calculated and may be found in quarterly reports 9 and 10, respectively.

Similarly to correlations between objective and sensory measurements and to observations made earlier, correlations between the three instruments vary from series to series. For beef, all three instruments were highly correlated with each other. The Warner-Bratzler Tenderometer even showed highly significant correlations with water release values. Similar correlations with water release values were exhibited by the Kramer Shear Press for untrimmed samples (not shown). For pork, only the Kramer Shear Press and the mechanical parameters measurable on the Texturometer showed significant correlations. In the case of turkey meat, none of the mechanical measurements correlated with each other. The only significant set of correlations for this series of samples was between water release values and the Kramer Shear Press.

7. Correlation Between Texturometer Parameters

Again, these correlations were found to vary from series to series. Except for the turkey series, the mechanical parameters of texture measurable on the Texturometer were highly correlated among themselves. The water release values were highly correlated among themselves for all types of meat evaluated in this phase of the work. Correlations between the two groups of parameters varied as follows: not significant for turkey and pork, significant at the 95% level for all mechanical parameters in trimmed beef, and significant at the 99% level for hardness and cohesiveness in untrimmed beef.

Table XXIII

Correlation Between Objective Measurement Performed on Different
Types of Precooked Freeze-Dehydrated Meat

(coefficients of linear correlation)

	<u>Beef</u> ¹⁾	<u>Beef</u> ²⁾	<u>Pork</u>	<u>Turkey</u>
WB vs. KSP	.77**	.77**	.04	.23
WB vs. Texturometer hardness	.20	.68*	.25	.16
cohesiveness	.70*	.74**	.06	.35
elasticity	.70*	.74**	-.28	-.16
chewiness	.61*	.76**	-.06	.13
water release I	.82***	.77**	.37	.00
II	.84***	.80**	.33	-.07
III	.87***	.81**	.28	-.11
IV	.83***	.83***	.25	-.06
KSP vs. Texturometer hardness	.64*	.88***	.82*	-.60
cohesiveness	.89***	.80**	.86*	-.69
elasticity	.77**	.85***	.91**	.51
chewiness	.81**	.90***	.91**	-.36
water release I	.51	.49	.14	-.91**
II	.55	.49	.24	-.90**
III	.58*	.48	.36	-.85**
IV	.51	.48	.42	-.86**

- 1) Series involving the study of the four rehydration procedures. The indicated values are for procedure D i.e., 20 min. in 80°F. distilled water with overnight equilibration.
- 2) Series involving the study of the effect of trimming. The indicated values are for trimmed samples.

Note: The statistical significance of the correlation coefficients is denoted by one asterisk for the 95% level, two asterisks for the 99% level and three asterisks for the 99.9% level.

8. Ability of the Measurements to Pick up Sample and Processing Variables

The ability of the three instruments to distinguish between trimmed and untrimmed beef and between raw and cooked beef, pork and turkey has been discussed earlier. We shall now concentrate on the discussion of the way in which the objective measurements could detect differences due to the length of precooking time, meat grade etc.

With both sets of beef evaluated, all three instruments were able to pick up differences due to the length of cooking time prior to freeze-drying. Some differences were noted between the measurements in their ability to detect effects due to meat grade. All three instruments showed the effect when trimmed meat was used and rehydrated in distilled water followed by overnight equilibration. Only the Warner-Bratzler Tenderometer and the Texturometer hardness showed a grade effect for the untrimmed samples. Of the sensory ratings, only tenderness reflected a significant difference between the grades. Although the difference was below the statistical significance, the panel rated the US Good grade higher on overall texture than the US Canner Cutter grade. The ratings for juiciness showed an interesting trend in that the US Good grade was rated juicier than the US Canner Cutter grade when meat was dehydrated raw, and less juicy when meat was dehydrated after cooking. This is not in disagreement with the trend exhibited by the Texturometer water release values.

With pork, the Kramer Shear Press and the Texturometer (both the mechanical parameters and the water release values), but not the Warner-Bratzler Tenderometer, showed a significant cooking time effect. Because of the high replicate error, none of the three panel ratings showed a significant cooking time effect although an upward trend with increasing cooking time was noticed in all cases.

With turkey, none of the measurements, instrumental or sensory, showed the effect of the cooking temperature. The Kramer Shear Press, Texturometer hardness and two water release values picked up sex differences. In addition, the Kramer Shear Press data calculated as pounds force per gram sample showed an interaction (significant at the 5% level) between cooking temperature and sex. These differences are somewhat inconsistent inasmuch as the Kramer Shear Press and the water release values show the hen turkeys

to be "tougher" and releasing less water, while the hardness values indicate the hen turkeys to be "softer". Although not statistically significant, the chewiness values also characterized the hen turkeys to be more tender. Panel evaluation appears to follow the Kramer Shear Press data in that hen turkeys were numerically rated less tender and poorer in overall texture. However, none of the differences indicated by panel ratings were statistically significant. Only the Texturometer detected significant differences due to bird sex alone. The involved Texturometer parameters were hardness, cohesiveness, chewiness and water release IV. For meat dehydrated raw, the panel rated tom turkeys significantly lower in tenderness than hen turkeys. Although the other two panel ratings did not show statistically significant differences, tom turkeys were rated numerically "less juicy" and "poorer" in overall texture.

9. Synopsis

The results of Phase III of this work indicated the important effect of the rehydration procedure on the microscopic appearance of meat, the rate of liquid release, the numerical values of the measured textural characteristics, the correlation between the objective determinations, and the ability of the three instruments to pick up processing and other sample variables. Based on the obtained results, rehydration for 20 minutes in distilled water at 80°F. followed by overnight equilibration was selected and used for the remainder of the study. Presence of non-muscle portions in meat samples was shown to increase the coefficient of variation and the residual error, with the Warner-Bratzler apparatus being the most sensitive. In addition, trimming was found to affect the numerical values of the tested characteristics and, to a certain degree, the correlations between the three instruments and their ability to distinguish sample and processing variables. Raw meat registered higher values on the Warner-Bratzler Tenderometer and lower values on the Kramer Shear Press and the Texturometer. This phenomenon can be explained on the basis of differences in the mechanical action of the three instruments.

Correlations between objective measurements as well as correlations between the panel and the three instruments varied significantly depending on sample series. The latter ranged from highly significant correlations between sensory tenderness and all three instruments for one series of beef, to no significant correlations for any of the objective measurements for turkey.

All three instruments were able to show differences in meat texture due to the length of cooking time prior to freeze-drying of beef, all but the Warner-Bratzler Tenderometer showed such differences in pork and none showed them in turkey. Differences were noted between the measurements in their ability to detect effects due to beef carcass grade and sex of turkeys.

SUMMARY AND EVALUATION OF DATA

In the almost four years of this work, seven series of dehydrated meat samples, representing a total of 106 samples ran in replicates, were evaluated with the three instruments and used to calculate correlations between objective measurements and the ability of the instruments to detect various variables built into the statistical designs and believed to affect meat texture. Of these, 81 samples were also evaluated by the sponsor's taste panel and the data used to correlate objective measurements with sensory ratings. In attempting to evaluate the collected information, the high dependence of the obtained results on the nature of tested samples becomes very evident. The questions which must be asked are - why did the results vary so much from series to series? - is there something in the design of the experiments or in the manner in which the measurements were performed that caused this situation? - is the nature of meat, the fundamentals of which are still so ill-understood, at the base of the problem? - what is the value and the shortcomings of the three instruments? - what is the value and the shortcomings of a taste panel? The information generated within this contract does not provide all the answers to all these questions. However, certain pertinent facts and some speculations will be discussed here in the hope that they may contribute to a better interpretation of the obtained results and to furthering research on the fundamentals of meat texture.

1. Correlation Between Objective and Sensory Evaluation

When all the data on freeze-dehydrated beef series in Phase II and Phase III, which were tested both by the panel and by the three instruments, were combined statistically, it was noticed that series 2 in Phase II behaved differently from the other sets of data. Both linear and quadratic regression models were hypothesized in seeking a correlation between sensory tenderness and objective measurements. Linear equations were found to express the relationship the best. When the series in question was included, the resulting fitted line had both intercept and slope different than when the series was excluded. Similar behavior was not evidenced by any other single set or any meaningful combination of sets, indicating that this series of samples was, for some reason, different in its statistical behavior from all the other sets of dehydrated beef samples.

Table XXIV summarizes the overall coefficients of correlation (r) between the three instruments and panel tenderness for all dehydrated beef samples, except the indicated set. Also included are equations which relate the sensory tenderness to the respective objective evaluations, and a measure of the effectiveness of the three instruments in predicting panel tenderness ratings (r^2). All the correlations coefficients are significant at the 99.9% level.

Table XXIV

Overall Correlations of the Three Instruments With Panel Tenderness (Y)

<u>Instrument</u>	<u>Equation</u>	<u>r</u>	<u>r²</u>
Warner-Bratzler Tenderometer	$Y = 6.54 - 0.13 \text{ (lbs)}$	-.76	.58
Kramer Shear Press	$Y = 6.89 - 0.004 \text{ (lbs.force)}$	-.77	.59
Texturometer	$Y = 9.05 - 0.04 \text{ (hardness)}$	-.67	.45

The calculated overall statistical relationship, thus, indicates that the Warner-Bratzler Tenderometer and the Kramer Shear Press measurements can account for 58% and 59%, respectively, of all the variations in panel tenderness ratings for beef, whereas, the Texturometer hardness can account for only 45% of such variations. This percentage could not be increased significantly by considering a combination of Texturometer parameters rather than just hardness. It must, thus, be concluded that the Texturometer is not as good a predictor of sensory beef tenderness ratings than the other two instruments and, in general, that none of the three instruments could account for a high enough per cent of variations in panel beef tenderness to make them good predictors.

Why did series 2 in Phase II behave statistically different from the other sets of data? It will be recalled that in that series (the first set of samples for which correlation between the three instruments and the "consumer" panel was sought) the Texturometer correlated with sensory evaluation better than the other two instruments, an observation which could not be confirmed on other

sets of samples. In examining the variables incorporated into that series, certain definite differences become obvious which distinguish it from subsequent sets evaluated. This was the only set of samples which involved replication over four animals (other sets involved replication over two animals or mixed animals within a sample), four cooking levels (180 minutes cook was omitted in subsequent series), one grade of meat only (US Canner Cutter), and rehydration in 1% NaCl instead of distilled water. As a result, this series showed the widest spread in sensory values (four tenderness units and two juiciness units as compared to a maximum of 2.6 and 1.1 respectively for the other sets involving the same muscle), and the widest spread in Texturometer values. Taking the parameter of hardness as the example, the spread was 74 units as compared to a maximum of 24 for the other series of samples. This wide spread of values was not shared by the other two instruments. It is quite likely that these differences were material in causing the wide variations in correlations with sensory evaluation. Of these, replication over a large number of animals and a much wider range of values covered appear to be the predominant factors. Differences due to the rehydration procedure were not found to be great enough to account for such variations (see p.71). In addition, certain differences in the sensory panel also existed and were described earlier in this report. These, however, do not appear to offer as clear a suggestion of reasons for the encountered variations as do differences in the spread of values and in number of replicates over animals.

Table XXV summarizes the significance of coefficients of correlation between sensory and objective measurements obtained for all the meat samples evaluated within this study. Work done in Phase I of the contract is not included since it involved only one instrument and the highly trained General Foods texture profile panel. It will be noticed from this summary that a relationship appears to exist between the spread of values covered within a series and the quality of correlations between sensory and objective measurements i.e. the greater the spread, the better the correlations. This point is clearly illustrated in the series involving turkey meat. The spread of objective values (except for the Warner-Bratzler Tenderometer) and of sensory ratings was extremely small and all the correlations were below the statistical level of significance. In addition, no differentiation between birds and between muscles was made in that set of samples. This was reflected in the higher coefficient of variation for the Texturometer and the Warner-Bratzler Tenderometer, but not for the Kramer Shear Press.

TABLE XXV

SUMMARY OF SIGNIFICANCE OF CORRELATIONS BETWEEN OBJECTIVE AND SENSORY EVALUATIONS

	Phase II	Phase II			Phase III	Phase III	Phase III	Phase III
	Beef, Series 2	s.m.	Beef, Series 3 b.f.	both	Beef, resh. C	Beef, trimmed	Pork	Turkey
Warner-Bratzler Tenderometer								
Vs. panel tenderness	*	*	**	***	*	**		
Vs. panel juiciness	*							
Vs. panel overall texture	—		**	***				
Kramer Shear Press								
Vs. panel tenderness	**	**	**	***	*	***	*	
Vs. panel juiciness								
Vs. panel overall texture	—	*		***		*	*	
Texturometer hardness								
Vs. panel tenderness	***	*	*	***		*	*	
Vs. panel juiciness								
Vs. panel overall texture	—	*		***		*	*	
Sample Description								
age (mos.)	3			2	5	7	8	8
meat grade	CC			G, CC	G, CC	G, CC	—	—
animals	16			12	mixed	?	?	mixed
muscles	1			2	1	1	1	mixed
sides	one only			mixed	mixed	mixed	?	mixed
cook levels	4			3	3	3	3	3
replication	4			2	2	2	2	1
no. samples	16			24	12	20	5	10
rehydration procedure	B			C	C	D	D	D
Panel Description								
location	Chicago		Chicago		Natick	Natick	Natick	Natick
judges/sample	10		27		24	24	24	24
samples/session	4		6		1	1	1	1
judgments/sample	40		108		24	24	24	24
tenderness, av.	5.40	5.23	4.64	4.94	5.01	4.52	4.16	5.37
range	3.39-7.38	3.4-6.3	2.4-6.7	2.4-6.7	3.04-7.00	3.29-5.54	3.00-5.63	5.27-5.85
juiciness, av.	4.74	5.03	4.18	4.60	2.83	3.02	2.97	3.83
range	3.64-5.64	3.7-6.5	2.8-6.1	2.8-6.5	2.0-3.96	2.62-3.77	2.77-3.21	3.37-4.11
overall texture, av.	—	4.97	4.31	4.63	4.14	4.05	3.99	4.77
range	—	3.8-5.6	2.9-5.3	2.9-5.6	3.38-4.92	3.38-4.71	2.96-5.29	4.42-5.08
Instruments Description								
W.B. av.	9.3	10.9	15.6	13.3	13.76	12.8	14.3	10.9
range	7.1-12.8			10.9-15.6	5.8-23.5	5.2-22.5	13.3-15.4	9.0-13.0
coeff. of var. %	19.1			14.4	22.0	17.3	12.0	28.4
K.S.P. av.	601.0	320.1	486.9	403.5	501.5	541.9	411.2	331.9
range	339.6-771.9			306.5-486.9	324.4-695.6	318.8-767.5	297.5-471.2	312.5-353.8
coeff. of var. %	20.1			18.5	19.1	16.8	10.9	16.3
Text. hardness, av.	112.3	82.4	104.2	93.3	97.4	110.9	115.1	105.5
range	71.1-146.9			80.9-101.7	82.5-105.6	96.6-120.3	106.4-122.4	104.4-107.2
coeff. of var. %	9.5			11.7	8.0	5.1	7.6	12.5

— = not evaluated

Note: The statistical significance of the correlation coefficient is denoted by one asterisk for the 95% level, two asterisks for the 99% level, and three asterisks for the 99.9% level.

It is also interesting to note that, of all the objective measurements, only the Warner-Bratzler Tenderometer showed significant correlations with panel juiciness. Contrary to expectations, Texturometer juiciness did not correlate with the sensory perception of juiciness.

All three instruments showed correlations with panel overall texture ratings, the quality of these correlations again being dependent on sample type. Since the Texturometer is the only instrument evaluated in this study which measures a number of textural parameters, multiple regression analysis was employed on data obtained in Phase III to determine if the predictability of panel overall ratings by the Texturometer could be increased by considering more than one parameter. This type of analysis was prompted by the observation that sensory tenderness and juiciness could be used to predict overall texture ratings (see p. 89). The obtained results are shown in Table XXVI. Single Texturometer parameters and those other measurements which showed high correlations with panel overall texture are also included for comparison. Three conclusions are evident from this Table:

- a. a considerably greater percentage of variation in panel overall texture can be explained by a combination of several Texturometer parameters than by the other two instruments or by a single Texturometer parameter
- b. a combination of several parameters makes the Texturometer a reasonably good predictor of panel overall texture ratings
- c. the nature of the equation correlating panel overall texture to several Texturometer parameters varies depending on sample series

No clear cut explanation for the variable nature of the multiple regression equations can be offered. The situation may be caused by the characteristics of the meat sample, the nature of the instrument and/or the reliability of sensory ratings.

2. Correlation Between Panel Ratings

A very large percentage of variation (up to 98%) in panel overall texture can be explained by sensory juiciness and tenderness values. Equations relating the three ratings are shown in Table XXVII.

Table XXVI

Correlation Between Panel Overall Texture and Texturometer Parameters

(based on data in Phase III)

<u>Meat Type</u>	<u>Equation</u>	<u>Variation Explained</u>
Beef, reh. C	POT = 4.690 - 3.335 Coh + .639 Elas - 1.729 WR I + 1.47 WR II	80%
	POT = a + b KSP	13.5%
Beef, untrimmed	POT = - 11.224 + .136 Hard + 2.641 Elas - .024 Chew - 2.348 WR I + 1.981 WR III	82%
	POT = a + b Chew.	37%
	POT = a + b WB	36%
trimmed	POT = -37.394 + .263 Hard + 14.187 Coh + 4.232 Elas - .051 Chew.	90%
	POT = a + b Coh.	46%
	POT = a + b KSP (lbs. force/gm)	35%
Pork	POT = 21.06 - .1479 Hard	74%
	POT = a + b KSP (lbs. force)	66%
Turkey	no significant relationship for any measurements	

Table XXVII

Correlations Between Panel Ratings

<u>Phase</u>	<u>Meat Type</u>	<u>Equation</u>	<u>Variation Explained</u>
II	Beef	$POT = .493 + .337 PJ + .525 PT$	
III	Beef	$POT = .903 + .484 PJ + .372 PT$	76%
III	Beef	$POT = .460 + .406 PJ + .518 PT$	85%
III	Pork	$POT = .127 + .250 PJ + .744 PT$	98%
III	Turkey	$POT = .719 + .555 PJ + .333 PT$	80%

POT = panel overall texture

PJ = panel juiciness

PT = panel tenderness

Similarly to the correlations between panel overall texture and Texturometer parameters, these equations also vary from sample to sample set. These variations are not only in the slope and the intercept of the straight line, but also in the relative importance of tenderness and juiciness in influencing the overall texture rating. For example, in the turkey series and in the first beef series in Phase III, sensory juiciness was more material in influencing the overall texture rating than sensory tenderness, while the reverse was true in the other sample sets.

Similarly to equations relating panel overall texture to Texturometer parameters, these equations are different enough from series to series so that they could not be combined statistically into an overall equation.

Sensory tenderness was not correlated with sensory juiciness in any of the evaluated sample sets.

3. Quality of Sensory Evaluations

There were two reasons for the use of a "consumer" panel in this work. First, the sensory evaluation was intended to be used as a measure of how well the three instruments could quantify the textural characteristics of meat. Secondly, it was of interest to the sponsor to assess the suitability of the tested objective measurements as quality control tools.

It will be remembered that with the Chicago panel (Phase II) each judge gave four separate evaluations for each sample, while with the Natick panel (Phase III) only one evaluation for each sample was required from each judge. According to the comments of the Natick panel supervisor, considerable differences were found to exist within a sample of meat presented to a taster. This was especially drastic with turkey meat. Differences in juiciness, tenderness and overall texture within a single sample were, thus, of considerable concern and had, undoubtedly, a strong effect on the validity of data.

It must also be asked what effect the flavor and appearance of samples had on texture ratings. Many judges expressed comments that the flavor and appearance of meat were unpleasant rather than neutral or acceptable. It should be noted (see Table XXV)

that samples in Phase III were 5 - 8 months old at the time of their evaluation. It is believed by the Psychology Laboratories of the US Army Natick Laboratories that the flavor and appearance of meat influence ratings for sensory texture characteristics.

The panel exhibited large variations from judge to judge indicating that the individual panel members either had different sensitivities, different frames of reference, or perceived the noted characteristics in different ways. It is of particular interest to compare the unexplained error in panel evaluations with that of the three instruments. This is illustrated in Table XXX. The panel exhibited a considerably larger unexplained error than the objective measurements. An indication was also obtained that the Chicago panel had a somewhat lower error than the Natick panel.

Members of the Natick panel also commented on the difference between the actual meat juiciness and the loosely bound water in rehydrated freeze-dehydrated meat, and the difficulty in distinguishing between the two.

Because of the above discussed factors, the sponsor requested that the quality of correlations with sensory evaluations should not be used as the main criterion in judging the suitability of the three instruments for objective description of meat texture.

4. Correlation Between Objective Measurements

A summary of the quality of correlations between objective measurements is presented in Table XXVIII. The sets of samples are listed in the order in which they were evaluated and the results described in this report. A total of eight sets of meat samples, representing 122 individual samples, were tested on the three instruments. The first set represents fresh beef (four muscles) and the subsequent sets represent freeze-dehydrated meat. The last six sets are the same as those shown in Table XXV.

In general, all three instruments correlated well with each other, correlations being generally significant at the 99 - 99.9% level. The most consistent correlations were obtained between the Kramer Shear Press and the Texturometer (especially hardness). It is interesting to note that poor correlations between the Texturometer and the other two instruments were obtained when several animals

Table XXVIII

Summary of Significance of Correlations Between Objective Measurements

	Phase II beef, fresh	Phase II beef, series 1	Phase II beef, series 2	Phase II beef, series 3 s.m. d.f. both	Phase III beef, reh. C	Phase III beef, trimmed	Phase III pork	Phase III turkey
WB x KSP	**	*	*	***	*	**		
WB x Text.								
hardness	**	**	**	***	*	*		
cohesiveness	**	**	**	***	*	**		
elasticity	**	*	**	***		**		
chewiness	**	**	*	***		**		
juiciness	**	*	*	*	-	-		
water release I	**	*	*	-	-	**		
II	*	*	*	-	-	**		
III	*	*	*	-	-	**		
IV	*	*	*	-	*	***		
KSP x Text.								
hardness	**	**	**	***	**	***	*	
cohesiveness	**	*	*	*	*	**	*	
elasticity	**	**	**	***	*	**	*	
chewiness	**	**	*	***	*	***	*	
juiciness	**	*	*	***	*	***	*	
water release I	*	*	*	-	-	-	-	**
II	*	*	*	-	-	-	-	**
III	*	*	*	-	-	-	-	**
IV	*	*	*	-	-	-	-	**

Note: See Table XXV and text for sample set description.

- = not measured

(or birds) are known to have been mixed for one sample. Even so this did not always reflect itself in the magnitude of the coefficient of variation, the apparent relationship is worth noting. In examining Table XXV, it is also of interest to point out the possible connection between the low range of Warner-Bratzler shear values in the pork series and the total lack of correlation of this instrument with the other objective measurements. The same lack of correlations for the turkey series (except for the water release values) could be attributed to the extremely low spread of values derived from the Kramer Shear Press and the mechanical parameters measurable on the Texturometer.

A summation of the overall correlations between the three instruments is shown in Table XXIX. All correlations, except Warner-Bratzler shear force vs. Texturometer elasticity are highly significant. However, neither one of the instruments is a good predictor of the values obtained from the other instruments. The best relationship in that respect was found between the Kramer Shear Press (lbs. force) and the Texturometer hardness where Kramer Shear Press readings could account for 69% of variation in hardness values.

5. Quality of Objective Measurements

Table XXX shows the unexplained errors for the three instruments and some of the panel evaluations. This error refers to fluctuations in values which could not be explained by the effect of any of the variables built into the experimental designs and comprises errors due to instrument, inherent sample variability, processing, rehydration, handling etc. It will be seen that, by far, the greatest unexplained error was exhibited by sensory evaluation. Among the instruments, the Texturometer had the lowest and the Warner-Bratzler Tenderometer the highest error. Of the Texturometer parameters, hardness showed the lowest and chewiness the highest error. This is understandable in view of the fact that chewiness is a composite parameter and its error encompasses the unexplainable fluctuations in hardness, cohesiveness and elasticity. Tabulation of coefficients of variation is shown in Table XXXI. A high dependence on sample type of the magnitude of the coefficients of variation is readily noticed from that Table.

Table XXIX

Overall Correlations Between the Three Instruments

<u>Objective Measurements</u>	<u>r</u>
WB vs KSP	.76
WB vs Texturometer	
hardness	.64
cohesiveness	.63
elasticity	.35
chewiness	.56
KSP vs Texturometer	
hardness	.83
cohesiveness	.59
elasticity	.65
chewiness	.79

Note: All correlations, except WB vs Texturometer elasticity, are significant at the 99.9% level.

Table XXX

Unexplained Errors (\$)

	Phase II beef, fresh	Phase II beef, series 1	Phase II beef, series 2	Phase II beef, series 3	Phase III beef, reh. D	Phase III beef	Phase III pork	Phase III turkey	OVERALL
Warner-Bratzler Tenderometer	9.0	7.1	18.7	16.9	23.9	18.9	11.9	32.2	17.3
Kramer Shear Press (lbs.)	11.5	10.6	21.5	22.9	18.9	17.4	12.3	18.0	16.6
Kramer Shear Press (lbs./gm.)	10.6	10.9	20.6	22.0	29.0	13.2	12.9	21.3	17.5
Texturometer hardness	3.3	3.6	9.5	13.9	5.5	8.4	7.1	10.1	7.7
cohesiveness	4.9	5.1	8.9	7.3	7.4	8.5	10.2	14.6	8.4
elasticity	10.2	9.6	27.2	25.5	11.0	8.6	11.8	12.7	14.6
chewiness	15.1	12.5	23.9	30.8	16.4	16.2	19.4	24.5	19.8
Juiciness	5.9	17.9	7.4	19.0	-	-	-	-	12.6
water release I	9.5	24.4	22.0	-	16.8	15.8	12.2	17.7	16.9
II	11.0	(67.7)	41.8	-	24.8	17.7	15.6	22.3	22.2
III	14.0	(105.3)	-	-	23.7	19.2	24.4	28.8	22.0
IV	17.1	-	-	-	29.2	23.6	26.6	25.7	24.4
Panel, tenderness				31.6		63.2	51.3	30.7	44.2
Juiciness				30.5		46.9	56.1	42.2	43.9
overall texture				30.5		49.1	48.2	32.9	40.2

Table XXXI

Coefficients of Variation (%)

	Phase II beef, fresh	Phase II beef, series 1	Phase II beef, series 2	Phase II beef, series 3	Phase III beef, reb. C	Phase III beef	Phase III pork	Phase III turkey	OVERALL
Warner-Bratzler Tenderometer	20.7	18.0	19.1	14.4	22.0	16.7	12.0	28.4	18.9
Kramer Shear Press (lbs.)	20.1	19.8	20.1	18.5	19.1	16.1	10.9	16.3	17.6
Kramer Shear Press (lbs./gm.)	19.7	19.6	17.8	16.7	17.5	13.0	10.4	16.9	16.4
Texturometer hardness	6.5	8.2	9.5	11.7	8.0	9.2	7.6	12.5	9.1
cohesiveness	9.7	11.1	9.3	6.9	8.6	7.6	9.8	14.3	9.6
elasticity	21.7	22.3	22.4	32.0	16.0	8.0	10.8	10.5	17.9
chewiness	26.7	31.2	26.6	33.1	27.5	18.6	20.2	24.9	26.1
juiciness	13.1	47.4	22.1	15.9	-	-	-	-	24.6
water release I	25.5	(58.0)	25.7	-	18.0	13.7	13.1	16.0	18.7
II	32.0	(126.2)	60.8	-	26.7	17.1	27.8	21.7	31.0
III	41.0	(128.2)	57.9	-	34.0	22.3	48.7	26.2	38.3
IV	60.1	-	110.7	-	28.8	30.0	28.7	24.7	47.2

6. Ability of Objective Measurements to Differentiate Sample and Processing Variables

In general, all three instruments showed significant effects on texture of variables incorporated into the experimental designs. The following were found to have a pronounced effect on the measured textural characteristics:

- length of precooking time
- type of muscle
- grade of meat
- condition of meat prior to processing (frozen vs. fresh)
- animal

Of these, the length of cooking time prior to freeze-drying had the most significant and the most consistent effect.

In addition, an interaction between animals and muscles was picked up by all three instruments in the series of samples involving fresh boiled beef and four muscles. Interactions between grade and cooking level, and meat grade and cooking level were picked up by some instruments in some of the dehydrated beef series. These observations are in agreement with the results obtained earlier in the sponsor's laboratory (11).

The order of sensitivity of the three instruments to sample and processing variables can be listed as follows: Texturometer > Kramer Shear Press > Warner-Bratzler Tenderometer. The differences, however, are not very large.

The sensory panel was the least sensitive to texture differences due to factors incorporated into the experimental designs. In most, but not all cases, the panel could differentiate between degrees of cook. In one experiment, the sensory ratings also reflected grade and muscle differences. The low sensitivity of the panel was due to the high replicate error connected with factors discussed on p. 90.

7. Comparison of the Three Instruments

Table XXXII summarizes information pertinent to the comparison of the three instruments evaluated. The cost of the Kramer Shear Press is given as quoted by the manufacturer at the time this report is being issued. It refers to the price of the mechanical unit with a maximum read-out dial and to the price of the electronic

Table XXXII

Comparison of the Three Instruments Evaluated

	<u>Kramer Shear Press</u>	<u>Warner-Bratzler Tenderometer</u>	<u>G.F. Texturometer</u>
Principle	shear (multiple prongs)	shear (single blade)	compression, some shear
Measured parameters	shear force	shear force	hardness, elasticity cohesiveness, chewiness, water release, fat release
Commercial availability	yes	yes	no
Cost (\$)	2170 - 4220	350	est. 3.000 - 3.500
Coefficients of variation (%)	17.6	18.9	9.1 (hardness) 26.1 (chewiness)
Unexplained errors (%)	16.6	17.3	7.7 (hardness) 19.8 (chewiness)
Correlation with panel tenderness	-.77***	-.76***	-.67***
Ability to pick up sample variations (order of sensitivity)	2	3	1
Correlation with each other	vs WB .76*** vs Text .83***	vs KSP .76*** vs Text .64***	vs WB .64*** vs KSP .83***

unit with a recorder. In both cases, the units would be equipped with a standard shear cell and the dynamometer ring covering the range suitable for meats. The price of the Texturometer has been estimated by General Foods Engineers. The indicated range refers to the cost of building a model redesigned for economy and sales appear (cost of redesign to be amortized by the manufacturer over the first ten units) and of duplicating the present instrument, respectively. In both cases, the price of the recorder was included. It was assumed in this estimate that the potential supplier is an original instrument manufacturer who is entitled to normal O.E.M. trade discounts in the purchase of the component parts.

Information dealing with correlations etc. refers to lbs. force for the Kramer Shear Press and to the parameter of hardness for the Texturometer, unless otherwise stated. Not included in this Table is information on correlations with panel overall texture which has been discussed on p. 87.

Based on this comparison, and the obtained data, it is very difficult to point out to any one of the three instruments as being superior. The Warner-Bratzler Tenderometer is the lowest in cost, but tends to be the least sensitive in distinguishing variables built into the experimental designs. It is, on the other hand, the most sensitive to errors introduced by the presence of gristle, tendons, fat, etc. Overall, it correlated somewhat better with the Kramer Shear Press than with the Texturometer. It should also be pointed out that the characterization of raw meat by the Warner-Bratzler Tenderometer gave results opposite to organoleptic observations i.e. raw meat registered higher values than cooked meat, while organoleptically it was judged to be softer and more tender.

The Texturometer offers the advantage of high sensitivity, ability to measure a number of different parameters, and (for the parameter of hardness) low unexplained errors and coefficients of variation. Although the overall correlation with panel tenderness indicates that it is not as good a predictor of sensory tenderness as the other two instruments, the combination of several parameters gives good predictability of panel overall texture (see p. 88). As has been discussed on p. 90, strong doubts exist regarding the reliability of the obtained panel data for comparison with objective measurements.

It would appear that, barring cost considerations, the combined use of the Kramer Shear Press and the Texturometer should be recommended for objective description of meat texture.

8. Suitability of the Instruments for Use in a Sampling Plan

One of the specific objectives of Phase III of this contract has been to determine a suitable sampling plan based on Military Standards 105 (Copy D). Since variations within a can, from can to can, and from case to case have not been determined within this study, a true sampling plan cannot be decided on. In the following discussion, we shall disregard these variations and concentrate on the relationship between objective and subjective measurements on precooked freeze-dehydrated sliced beef.

Before any attribute sampling plan can be chosen, it is first necessary to decide if the unit being sampled is defective or non-defective. In the case of freeze-dehydrated beef, this attribute is acceptability or lack of acceptability. The first difficulty encountered is - what is the measure of acceptability? The sponsor suggested that sensory tenderness be taken as a measure of acceptability and that ratings above 5.0 be considered to be acceptable, while those below 5.0 be considered unacceptable. The following instrument values correspond to this rating based on regression equations shown on p. 84.

<u>Instrument</u>	<u>Value</u>
Warner-Bratzler Tenderometer	12 (lbs.)
Kramer Shear Press	473 (lbs.)
Texturometer Hardness	101 (i. u.)

If the characteristics of the beef were being measured by the instrument without error, which is not the case, then we could make certain probability statements. For beef samples giving the instrument values given above, we can say that if our sample does in fact represent the totality of beef of interest, then the values of panel tenderness will fall between two given values.

These two values form a confidence interval, and unless a one in twenty chance has occurred in the sampling, these values will

be true. The intervals, based on the instrument values presented above, are:

<u>Instrument</u>	<u>Confidence Interval for Panel Tenderness</u>
Warner-Bratzler Tenderometer	$3.60 \leq \text{Panel Tenderness} \leq 6.40$
Kramer Shear Press	$3.61 \leq \text{Panel Tenderness} \leq 6.39$
Texturometer hardness	$3.37 \leq \text{Panel Tenderness} \leq 6.63$

For example, if the Texturometer reading for hardness were measured without error and were equal to 101.0, then the panel's value of tenderness would be between 3.37 and 6.63 with a 95% probability. Notice the possible consequence of using this instrument value. Beef samples could have a tenderness rating as low as 3.37 and still be accepted. The extreme width of these intervals indicates that the regression equations do not express panel tenderness as a function of the instrument readings as well as one would hope.

We may also find a confidence interval for the instrument reading in a similar manner. Assuming the panel's evaluation of a representative sampled unit of beef is 5.0 on their tenderness scale, then the resulting interval for the instrument value is given below.

<u>Instrument</u>	<u>Confidence Interval for Instrument Value (X_0)</u>
Warner-Bratzler Tenderometer	$10.27 \leq X_0 \leq 13.42$
Kramer Shear Press	$419.2 \leq X_0 \leq 524.2$
Texturometer hardness	$95.29 \leq X_0 \leq 107.29$

According to the regression equation, when the panel tenderness is equal to 5.0, we find that the instrument reading is 101 on the Texturometer. But, the interval above indicates the true value may vary between 95.29 and 107.29.

The correct instrument value to use in judging acceptance must be decided by the US Army Natick Laboratories. We suggest that the sponsor begins with one of the values in the confidence interval. If the lower limit is chosen, the result may be that too many of the units being samples are rejected when, in fact, they are acceptable. In this case, the instrument value to use could be adjusted upward.

Not having either an A.Q.L. (Acceptance Quality Level) or the lot size, it is impossible to state a definite sampling plan. However, once the lot size and the A.Q.L. are specified, Military Standards 105 may be used to determine the sample size. It seems worthwhile to consider an example. Let us assume we use the Kramer Shear Press and decide that an instrument reading of 524.2 will be the critical point. Also assuming the lot size is 5,000 and the inspection level is S-2, the sample size code letter given in Table I (MIL-STD-105D) is D. Using a single sampling plan for normal inspection (Table II-A), and specifying an A.Q.L. of 10, the result will be a sample of size eight. If the number of unacceptable units of beef, determined using the critical instrument value of 524.2, is equal to or less than two, the lot will be acceptable. The lot shall be rejected if three or more unacceptable units are found.

DISCUSSION

A review of the usefulness of the various objective methods in meat characterization has been presented elsewhere (2). A discussion of the most recent publications dealing with subjects directly related to the nature of this investigation is of special interest and will be presented here.

Two studies published on the correlations between the Warner-Bratzler Tenderometer, the Kramer Shear Press and a sensory panel, and on the dependence of these correlations on sample type and sensitivity of the judges, confirm the results obtained within this research contract. Burrill et al. (12) found correlations significant at the 99% level between a trained taste panel, the Warner-Bratzler Tenderometer ($r = -.83$)

and the Kramer Shear Press ($r = .72$) when data on four fresh beef muscles from 46 animals (a total of 82 samples) were combined. However, when data for the individual muscles are examined, one finds that correlations were significant (95% level) only for longissimus dorsi and semimembranosus, and not significant for semitendinosus and biceps femoris. Correlations between the two instruments were significant for all four muscles, but the degree of significance varied. When all the muscles were combined, a correlation coefficient of .84 was obtained. The data presented by these researchers also indicated that the "estimate of work performed in shearing the sample with the Kramer Shear does not appear to provide any better measure of tenderness than measurement of the maximum force."

Sharrah et al. (13, 14) compared the Warner-Bratzler Tenderometer, the conventional Kramer Shear Press, a modified Kramer Shear Press equipped with a Warner-Bratzler shear plate attachment, and a trained taste panel using semimembranosus and longissimus dorsi muscles from 176 animals. Correlations coefficients indicated that the Warner-Bratzler Tenderometer correlated slightly higher with sensory tenderness scores than the Kramer Shear Press. Again, the correlations differed from muscle to muscle and, also, from judge to judge. For example, correlations between the Warner-Bratzler Tenderometer and sensory tenderness could vary for one judge from -.07 for longissimus dorsi to -.45** for semimembranosus, and for another judge from -.62*** to -.25, respectively. The latter observation is extremely interesting in view of the high degree of expertness on the part of the judges. As the authors stated, "A panel of eight judges was selected from a group of 20 people on the basis of their ability to distinguish differences in beef tenderness, juiciness and flavor. All judges had one to two year's previous experience evaluating lamb quality." In addition, in parts of the reported study samples previously sheared by the modified Kramer Shear Press were given to the panel for evaluation, thus, reducing sample heterogeneity between objective and subjective measurements. The authors felt that this method provided the best data for correlating mechanical and sensory values. In spite of this, judges were found to vary considerably in sensitivity and reproducibility and to give relative judgements within a set of variables. Sharrah et al. concluded that the correlation coefficient may not be sufficient in relating subjective and objective measurements and that additional work is required to establish variations in shear force which are meaningful in terms of sensory evaluation of tenderness. As the research work described in this report has shown, the significance of the correlation coefficient is very highly dependent on the range of values covered by the measurements being correlated.

The fact that correlations between sensory tenderness and objective methods vary in significance depending on a variety of meat and processing factors have led the researchers in the field to voice the opinion that tenderness is not one "thing" but, rather, that it is a composite of several characteristics. Thus, to quote Sylvia Cover "agreement between the results from a mechanical device and (sensory) score may be close when certain components are involved but less close or even poor when other components are involved."

Culminating the research of many years, Dr. Cover and her group at Texas Agricultural Experiment Station (3) divided sensory tenderness into six components:

- softness to tongue and cheek
- softness to tooth pressure
- ease of fragmentation
- mealiness
- adhesion of muscle fiber
- tenderness of connective tissue

When textural parameters measurable on the Texturometer are compared with these components of sensory tenderness, certain striking similarities can be suggested. For example, the parameter of hardness appears to correspond to Cover's "softness to tooth pressure"; the parameter of cohesiveness to the "apparent adhesion between fibers" and also possibly to the "ease of fragmentation" of muscle fibers. Cover et al. report that, in subjective tests of fresh beef, ease of fragmentation was related most closely to lack of adhesion. The next closest association was with softness to tooth pressure. There was no significant correlation with scores for juiciness or tenderness of connective tissue. Calculation of simple correlations among primary Texturometer parameters indicated that, in fresh beef, cohesiveness is highly correlated with hardness and elasticity, but not with juiciness or rate of water release. In the case of freeze dehydrated meats, of all the tested mechanical parameters of texture, only elasticity showed a correlation (significant at the 5% level) with juiciness and rate of water release. Elasticity thus might be a property associated with physicochemical characteristics of muscle fiber proteins also responsible for the water-holding capacity of dehydrated meat.

The existence of these two methods for evaluation of individual components of tenderness opens the door to more refined studies on this very important quality of meat. It appears very logical, from the standpoint of both fundamental and applied research, that attempts be made to study

these two methods together and to define the possible correlations. This will lead not only to a better understanding of the potential of the Texturometer for meat work, but may also indicate the way to even better objective methods of meat texture evaluation.

Although statistically, the parameter of hardness measured on the Texturometer was found to be adequate in describing differences in "tenderness", it cannot be recommended at this time that only this measurement be taken on the instrument. Differences in hardness may describe sample differences adequately when variations in other parameters are small and parallel variations in hardness - this is often the case when similar samples are compared (e.g. freeze-dehydrated sliced beef). However, when widely different samples are tested (e.g. different types of meat, see Table 1) or when it is advisable to pay attention to small differences, all the parameters measurable on the Texturometer should be considered. Thus, the parameter of hardness may be all that is needed for quality control purposes, but all the other measurements should be done when research is the primary goal.

Finally, a word should be said about the fundamental problem of what is involved in the mechanics of chewing meat as compared to the action of the instruments used for objective characterization of meat tenderness. Even assuming that a highly trained group of judges is used for sensory evaluation, the effects of appearance, flavor, juiciness and range of tenderness exhibited by the test sample may influence the judges' scores. For example, it is possible that the panel may tend to chew tough meat with greater force than more tender meat. It is also possible that, due to fatigue, the panel may tend to stop chewing tough meat before it is masticated to the same degree as a more tender sample. Both of these factors would tend to decrease differences in scores between tough and tender meat. Since chewing involves not only a mechanical disintegration of meat, but also getting it ready for swallowing, it is quite possible that dry meat would tend to be "worked around" in the mouth longer than juicy meat in order to mix it properly with saliva and lubricate it for the process of swallowing. Techniques for studying such phenomena (e.g. by measuring objectively muscular forces involved in chewing and swallowing, and the number of chews before swallowing) have been developed by dental researchers and could prove very valuable when applied to the problem of meat tenderness.

A histological study of the manner in which the meat disintegrates in the mouth compared to the damage done by the instruments, should be of considerable value in furthering our knowledge of the fundamental aspects of meat texture. Considering the economic importance of meat tenderness and the tremendous amount of researching that has been done in this area, it is surprising that practically no fundamental rheological work has been done on meat.

CONCLUSIONS

The following general conclusions can be drawn based on the performed work:

1. The General Foods Texturometer is applicable to objective characterization of meat texture. This promising new tool describes meat texture in terms of several numbers, each indicative of a defined textural parameter. These encompass mechanical parameters (hardness, cohesiveness, elasticity and chewiness) and those related to moisture release (juiciness and rate of water release). The release of fat on mechanical chewing may also be measured on this instrument. For quality control purposes when similar samples are compared, the measurement of the parameter of hardness may be adequate.
2. The Texturometer showed high correlations with the trained texture profile panel on a variety of freeze-dehydrated meats and with a number of physical, chemical and sensory tests performed by the sponsor on freeze-dehydrated beef.
3. Based on measurements performed on fresh and freeze-dehydrated meats, high correlations were found between the Texturometer, the Warner-Bratzler Tenderometer and the Kramer Shear Press. The quality of these correlations varied significantly between the individual sets of samples evaluated and, in general, appeared to be related to the range of values covered. Overall, the most consistent correlations were obtained between the Kramer Shear Press and the Texturometer, and the least consistent between the Warner-Bratzler Tenderometer and the Texturometer.
4. All three instruments were able to differentiate between the important sample and processing variables incorporated into the experimental designs. Differences due to precooking time levels, meat grade, muscles, animals, etc. were found and described for each set of samples evaluated. The ability of the instruments to distinguish the different variables was, again, highly dependent upon the sample type. In general, the Texturometer appeared to be the most, and the Warner-Bratzler Tenderometer the least, sensitive in defining differences due to the built-in variables.

5. The Warner-Bratzler Tenderometer was found to be the most susceptible to errors caused by the presence of fat, tendons, gristle, etc. in untrimmed beef samples.
6. In general, all three instruments were highly correlated with sensory tenderness ratings obtained by the sponsor, but no one instrument could be considered a good predictor of sensory tenderness. The quality of these correlations, again, was dependent on sample set and could be related to the range of values and the reliability of sensory scores.
7. None of the objective measurements, including Texturometer juiciness, correlated consistently with sensory juiciness. Shear force measured on the Warner-Bratzler Tenderometer showed occasional correlations.
8. When several measured parameters were combined in a regression equation, the Texturometers could account for up to 90% variation in panel overall texture ratings. However, the nature of these equations and the contributions of the individual parameters varied depending on sample set.
9. Sensory ratings for overall texture were found to be highly dependent on tenderness and juiciness ratings and could be expressed in terms of these two sensory parameters. However, the nature of these equations and the relative contributions of tenderness and juiciness were, again, dependent on sample type. There was no correlation between sensory tenderness and sensory juiciness.
10. The manner in which the freeze-dried beef samples are rehydrated was found to have a significant effect on meat characteristics. Rehydration in 1% NaCl gives tougher fibers, allows more water to be absorbed intrafibrally and less liquid to be released on mechanical chewing. Microscopically, samples rehydrated in distilled water for 20 mins. and held overnight were the closest to freshly cooked meat. The rehydration procedure also affected the numerical values of the measured parameters and correlations between the three instruments.
11. Based on correlations obtained between sensory and objective measurements, a sampling plan for beef under Military Standards 105 (Copy D) was suggested following equating instrument values with acceptability ratings. Because of the imperfect relationship, this plan must have very wide limits of confidence.

12. A total of 122 samples were evaluated within this contract using the three instruments. An additional 115 samples were evaluated using the Texturometer only. Most of the work dealt with precooked dehydrated sliced beef. Samples of dehydrated pork, turkey, fish and comminuted meat, as well as fresh boiled meat, were also tested. Both raw and precooked freeze-dehydrated meats were evaluated.
13. Due to the heterogeneity of the tested meat samples, it is not possible, on the basis of the obtained data, to single out one of the three tested instruments as being definitely superior. The Warner-Bratzler Tenderometer has the advantage of a low cost, but is the least consistent and the most susceptible to errors caused by non-muscle portions of the meat. The Texturometer has the advantage of the greatest sensitivity and of being able to measure a number of different parameters. It appears that the combined use of the Kramer Shear Press and of the Texturometer should be considered for research on meat texture.
14. A well trained panel and meat samples exhibiting reasonably wide variations in textural characteristics must be used in order to obtain meaningful and statistically significant correlations between sensory and objective measurements.

RECOMMENDATIONS

The following recommendations are offered:

1. that the combined use of the Kramer Shear Press and of the Texturometer be considered in work on fundamentals of meat texture
2. that a correlation be established between the parameters measured on the Texturometer and Cover's six components of sensory tenderness
3. that fundamental information be obtained on the influence of flavor, juiciness, personal preference, tenderness range, etc. on the sensory perception of meat texture using techniques available in the field of dental research
4. that the manner in which meat is disintegrated on chewing be compared histologically to the mechanical damage done by the three instruments

It is also recommended that future research on meat texture combines several disciplines of science (biochemistry, histology, instrumentation, rheology, refined sensory testing, animal science, etc.), since the answer to meat tenderness must be sought through an organized multi-pronged attack rather than through any one line of approach.

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APPENDIX

DESIGN AND CONSTRUCTION OF THE TEXTUROMETER

The Texturometer consists of two parts, a motor driven mechanical masticator, and an electrical circuit designed to measure the chewing parameters. A schematic diagram of the instrument and its component parts is shown in Figure 12. The masticator is a modified dental articulator driven by a motor and controlled by the motor control box. Two sets of gears provide different chewing rates. The toggle switch on the box provides continuous operation of the masticator, the push button is used for one cycle operation.

The effect of chewing is measured by two strain gages mounted on the lower arm of the masticator. The gages are cemented one on each side of this arm and form two legs of the Wheatstone bridge as shown in the circuit diagram, Figure 13. The other two legs of the bridge are two wire wound, 500-ohm resistors. The bridge is balanced by a potentiometer contained in the bridge balance box. The rest of the electrical circuit consists of a voltmeter (RCA Volt Ohmyst), a voltage divider, two twelve volt wet cell batteries and the recorder.

The masticator arm and the chewing head of the instrument are made so that various platforms and plungers can be screwed into these positions. Different types of platforms may be used for specific purposes, i.e. high sided platforms for puddings, gels, etc., and low sided larger platforms for solid foods. In addition, sample cups may be placed on the platform if required. Various types of plungers, having large, small, ridged, notched or knife edged chewing areas may also be used. All are interchangeable, but one prescribed set of plunger and platform is usually used for each type of sample investigated, and for comparative work the same plunger and platform are used throughout.

Before each set of samples is tested, the clearance must be carefully checked according to the following procedure:

Set voltage at 10 using voltage divider controls. Screw platforms into arm which has strain gages, putting washers and spacers (thin metal discs) on screw thread of platform to obtain approximate height desired. Screw plunger into Texturometer head using washers and spacers to obtain approximate depth of stroke required. Place sufficient spring steel gages of known thickness to give desired clearance on platform at place where plunger will hit them at bottom of down stroke. Depress plunger by pushing push button on motor control box and run recorder. Precise clearance is obtained when recorder just barely moves from base line. Adjust clearance with addition or removal of washers and spacers from either plunger or platform.

Next, the standard must be checked.

Set voltage using coarse and fine adjustments of voltage divider box to 1.0 volt. Set recorder zero with bridge balance knob. Place standard (weather stripping may be used) on platform and push button for one cycle operation. Recorder Chart switch should be turned on just before depressing button. Note the height of the curve obtained. The standard may be changed to check conditions for different types of samples. For example, soft sponge rubber may be used when soft samples requiring high voltage are examined. If value obtained for standard falls outside of the range set for the particular standard used, recheck clearance and run standard again. If standard value cannot be brought to proper range, the electrical system should be checked starting with the Recorder battery.

With the clearance adjusted and the reading on the standard checked, the Texturometer is ready for operation.

SCHEMATIC DIAGRAM OF TEXTUROMETER

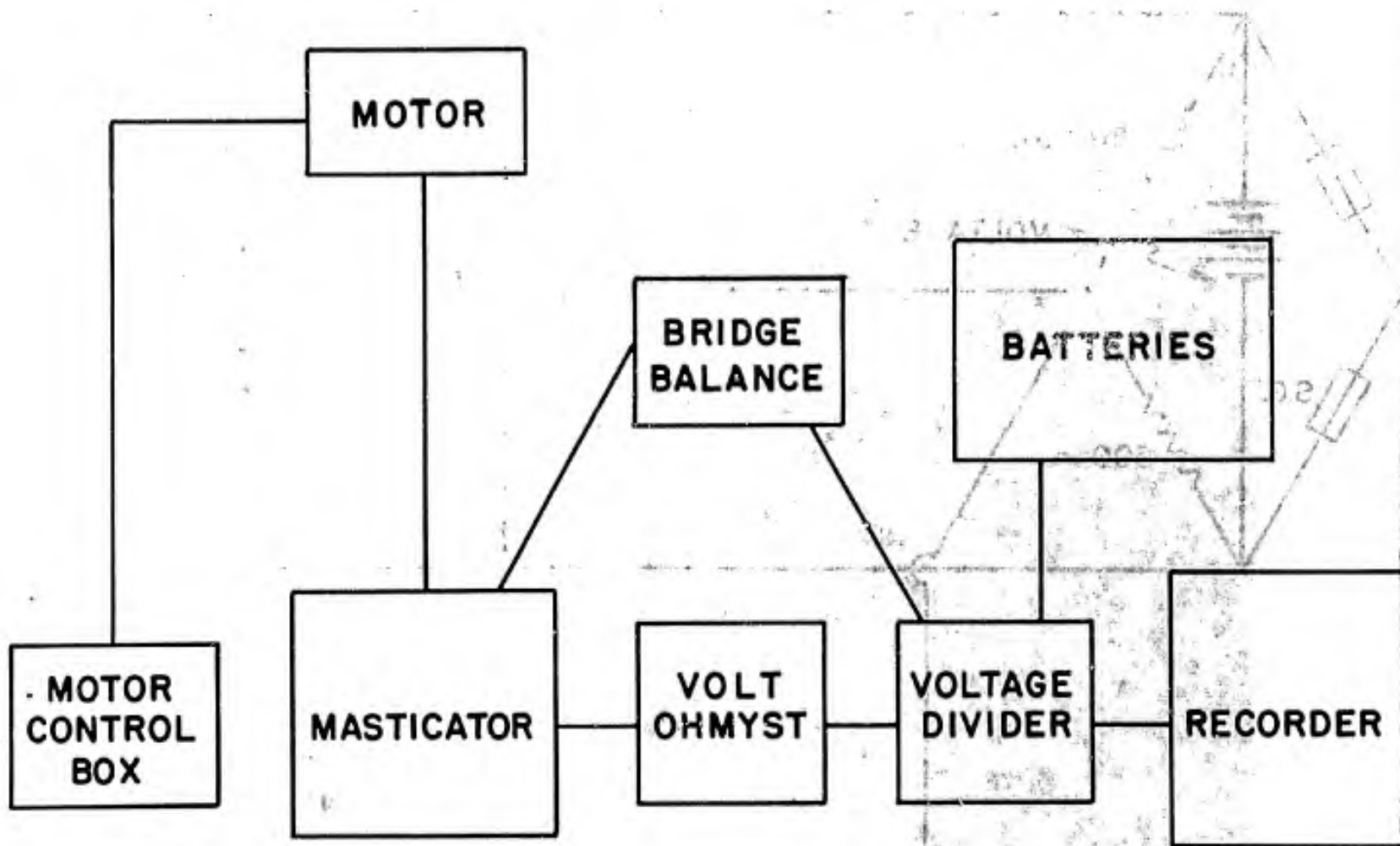


Figure 12

ELECTRICAL CIRCUIT OF TEXTUROMETER

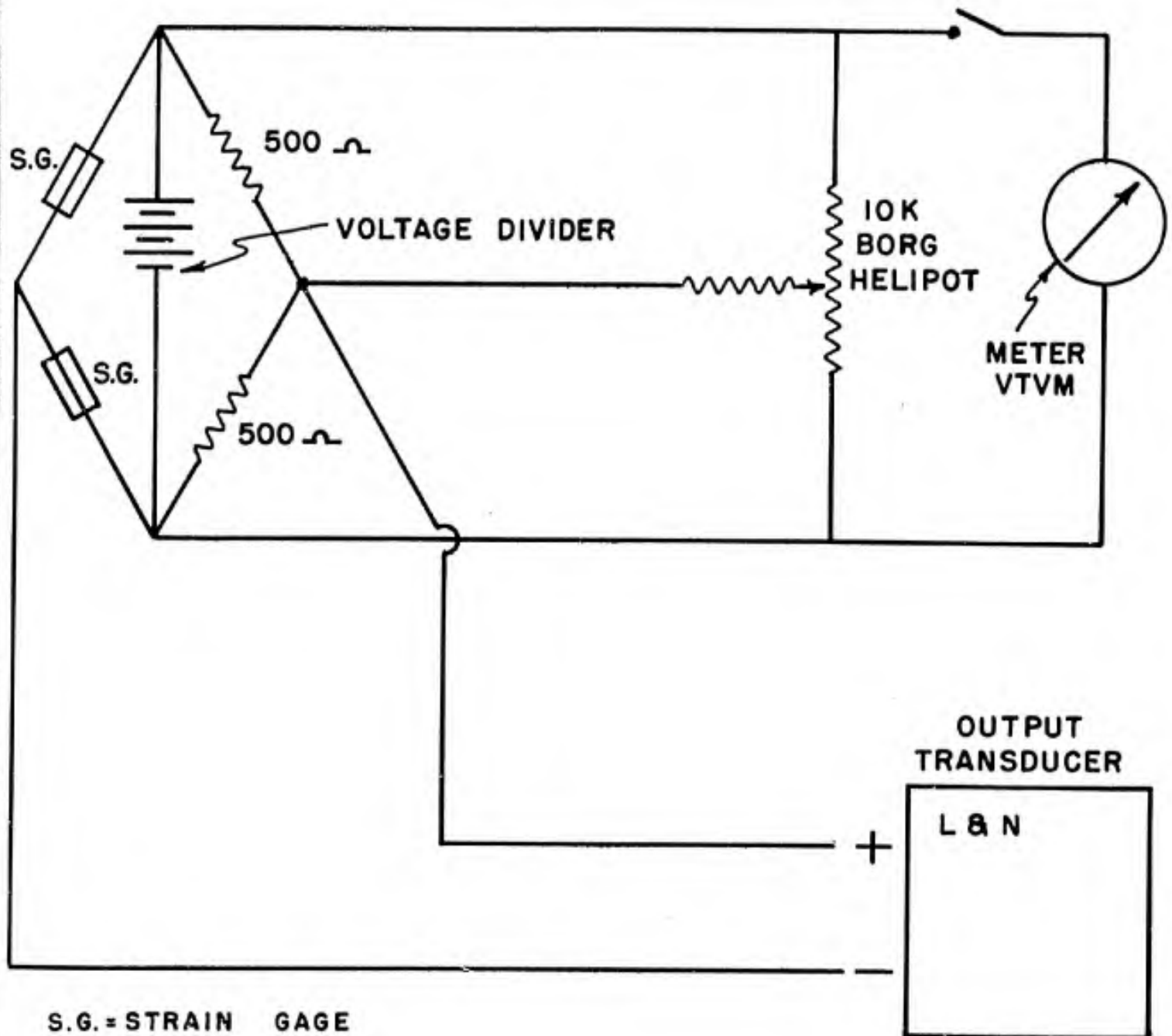


Figure 13

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13. ABSTRACT

This report summarizes work done over a four year period on the suitability of the General Foods Texturometer (I) for meat texture description and its comparison with the Warner-Bratzler Tenderometer (II) and the Kramer Shear Press (III). Parameters of hardness, cohesiveness, elasticity, chewiness and water release measurable on I were found applicable to fresh and freeze-dehydrated meats (beef, pork, turkey, fish, comminuted meat). Correlations of I with panel and with II and III varied in significance depending on variables incorporated into the sample design and were related to the range of values covered. Implications of this observation are discussed. In general, all three instruments correlated highly significantly with sensory tenderness and with each other. However, they could not be considered good predictors of tenderness. None correlated consistently with sensory juiciness. Sensory overall texture ratings could be described in terms of tenderness and juiciness. When several parameters were combined, I was superior to the other instruments in that it could account for up to 90% variation in sensory overall texture. However, the nature of equations and contributions of individual parameters varied depending on sample set. All three instruments were able to differentiate between important sample processing variables incorporated into the experimental design. In general, I appeared to be the most, and II the least sensitive to defining these differences.

CONTINUED

13. ABSTRACT (Continued)

Rehydration in salt solution gave tougher fibers, allowed more water to be absorbed intrafibrally and less liquid to be released on mechanical chewing. Microscopically, samples rehydrated in distilled water and held overnight were the closest to freshly cooked meat. II is most susceptible to errors caused by non-muscle portions of the meat. I showed the lowest coefficient of variation and unexplained error. Due to the heterogeneity of the tested samples, it was not possible to single out one of the evaluated instruments as being definitely superior. It is recommended that the combined use of I and III be considered for research on meat texture. This, and other recommendations stemming from the completed work, are discussed in detail. (U)

14.

KEY WORDS

KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Adhesiveness					1	
Brittleness					1	
Chewiness					1	
Gumminess					1	

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
General Foods Texturometer			10			
Warner-Bratzler Tenderometer			10			
Kramer Shear Press			10			
Evaluation	8					
Tenderness	9				8,2	
Texture	9		9			
Measurement	9		8			
Procedures	9					
Meat	9		9		8,2	
Dehydrated	0		0		0	
Parameters					8,2	
Hardness					1	
Cohesiveness					1	
Elasticity					1	
Viscosity					1	

Continued

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