Sensory Texture Evaluation Methodology

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Introduction

Texture is a recognized attribute of food quality, but it is only recently that it has taken the form of an organized subdiscipline of food science.

Meat texture has commanded much attention over the years due to its high economic importance, coupled with the high consumption of meat. Much of this work was done as part of breeding programs aimed at producing more tender meat, or as part of research on the biochemistry of muscle aimed at elucidating the causes of toughness. Frustrations with sensory evaluation, limitations of sample size and the desire for more calibrated and better defined measurements have given impetus to a large volume of work on instrumental methods of meat texture characterization, leading to the development and entrenched use of such instruments as the Warner-Bratzler Shear, the Kramer Shear Press and the Volodkevich Bite Tenderometer. At the same time, it was realized that none of the mechanical devices simulate well enough the complicated action to which meat is subjected in the mouth during the process of mastication. This involves not only the combined mechanical action of compression, puncture, shear, tensile stretching, etc. but also mixing with saliva and the temperature effect on the fat component in the sample. Thus, sensory evaluation continued to be used for much of the research on meat.

Sensory test methods can be divided into acceptance, differences and descriptive tests. This presentation will be confined to descriptive tests; they provide the most information and are the most useful for research purposes.

Historical Perspective

The literature abounds in studies on the effect on meat characteristics of animal traits, feeding regime, aging conditions, cooking methods, etc., involving the use of sensory panels.

A large majority of the early studies were conducted in a scientific culture which did not include an appreciation of the fact that sensory evaluation, just like physical and chemical testing, must be performed in a scientific manner. To be more precise, one must state that a large majority of these studies were conducted before the science of sensory evaluation was born. Untrained or poorly trained judges were used, hedonic scales were employed where trait intensities were sought and the characteristics evaluated were seldom defined. The characteristics evaluated were usually palatability, tenderness, and juiciness (or just tenderness), and it was taken for granted that the panel knew exactly what these terms meant. It was never considered that the precise definitions may be different for different judges. Publications included very detailed experimental accounts of meat cooking and handling procedures, but no details of the sensory procedure. A typical description read "steaks were evaluated by a panel of 5 staff members . . . Flavor, tenderness, juiciness, and general acceptability were scored on a 5-point scale, from 1-undesirable, to 5-very desirable," (Rodgers et al., 1963). Another paper reported "The taste panel, five members, scored the steaks for tenderness and overall acceptability on a 7-point hedonic scale" (Dikeman et al., 1971). A number of papers referred to the judges as "experienced" or "trained," but did not elaborate on the type and degree of possessed experience or training. This was a regrettable situation since much good biochemical work suffered by being paired with inadequately-designed and poorly-executed sensory work.

The realization that better sensory methodology was needed, coupled with the high degree of activity in meat research, resulted in some key developments. These had a profound influence on sensory texture evaluation in general and contributed greatly to a systematic approach and to the establishment of texture science as a subdiscipline of basic food science. The reverse ripple effect has not yet taken place.

Milestone Developments

The key developments dealt with definitions of texture and tenderness/toughness, with better quantification procedures, and with the argument that tenderness is a composite parameter and must be subdivided into several components for a proper description. Sensory meat testing methods were reviewed and discussed over the years by Deatherage (1951), Pearson (1963), Szczesniak and Torgeson (1965), and Larmond (1976).

For many years, the terms "texture," "consistency," and "tenderness" were used by researchers in the field of foods in general, and in meat science in specifics, without providing definitions and with a general assumption that everybody knew what they meant. This assumption was correct – everybody knew the meaning of these terms, but the specific meaning was often not the same for everybody.

Ball et al. (1957) constructed and used two tentative definitions of meat texture: 'sight' and 'feel.' The 'sight' definition read: "Texture of meat is the macroscopic appearance of muscle tissue from the standpoint of smoothness or fineness

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Table 1. Scoring sheet for six components of tenderness.

		Tenderness								
		Softness			*Muscle fibers*					
Juiciness		*To tongue and cheek*		*To tooth pressure*	*Ease of fragmentation across the grain*		*Mealiness*	*Apparent adhesion between fibers*		*Connective tissue*
V. juicy	9	V. soft	9	V. soft	V. easy	9	V. mealy	V. slight	9	Tiny amt. soft
	8		8			8			8	
Juicy	7	Soft	7	Soft	Easy	7	Mealy	Slight	7	Small amt. soft
	6		6			6			6	
Sl. juicy	5	Firm	5	Firm	Mod. easy	5	Sl. mealy	Moderate	5	Small amt. firm
	4		4			4			4	
Dry	3	Hard	3	Hard	Difficult	3	V. sl. mealy	Tight	3	Small amt. hard
	2		2			2			2	
V. dry	1	V. hard	1	V. hard	V. diff.	1	None	V. tight	1	Large amt. hard

(Cover et al., 1962)

of the grain. The 'grain' is defined as the ... appearance of cut surfaces of lean parts, which it is possible to describe as smooth, fine, rough or coarse. Fineness is assumed to be dependent upon the size of the fiber bundles; the smaller the bundles ..., the finer the texture." This definition was applicable to both raw and cooked samples. The 'feel' definition was applicable to cooked samples only and read: "Texture of ... meat is the feel of smoothness or fineness of the muscle tissue in the mouth." The sight definition of texture was used by Knopf and Graf (1959) with a 7-point scale for grading beef quality. These workers also rated for juiciness (5 points), tenderness (8 points), firmness of lean (7 points), and overall acceptance (9 points), but did not provide definitions.

Tenderness was generally understood to mean resistance to mastication. An important step in its quantification was the development and popularization of the "chew count" method (e.g., Harrington and Pearson, 1962). In this method, the panel members count the number of chews (usually chewing at a rate of one chew per second) required to reduce a standard-size sample to the proper consistency for swallowing. Although important in the historical development of sensory evaluation methodology, this procedure is presently not recommended (Larmond, 1975) because of high variability among judges (Harrington and Pearson, 1962) and difficulty in standardizing the force of chewing which may tend to minimize differences between tender and tough samples (Szczesniak and Torgeson, 1965).

There are several scoring systems that can be used. In 1956, Raffensperger et al. reported the development of a structured bi-polar scale for grading tenderness based on a psychological scaling procedure. Its significance was twofold. Firstly, it proved that toughness and tenderness lie in the same continuum. Secondly, for the first time, a well-researched structured scale was made available for quantifying meat tenderness. It was an 8-point scale, "extremely tough" to "extremely tender," with no neutral point. These workers also showed that trained panelists could use an unstructured scale just as well as a structured scale. Today, "magnitude estimation" unstructured scales are often preferred by panel leaders.

The first published account of sensory measurements on meat by researchers specializing in sensory evaluation, rather than in meat science, is the 1965 paper by Pangborn et al. on tenderness of cooked turkey. These workers provided a detailed description of the sensory procedure and, very importantly, gave definitions of the quantified parameters. They defined tenderness as resistance to chewing and requested two judgments from the panel: force to bite (defined as the amount of force required to bite across the grain of the meat core with the front teeth only), and chew count (defined as the number of chews required to prepare the entire core for swallowing).

The greatest single milestone in sensory meat texture evaluation was the research by Sylvia Cover and her coworkers which acknowledged that tenderness is not a simple attribute and divided it into 6 components. This was preceded by individual contributions from several other researchers who were not satisfied with a single rating; e.g., Ginger and Weir (1958) who used a tenderness rating consisting of 2 parts: "tenderness, which was defined as the initial impression of softness, and residue, which referred to the amount of residual material remaining after chewing." Others added ratings for mealiness and "fiber fragility."

Cover et al. (1962) divided tenderness into softness, muscle fiber characteristics, and amount of connective tissue (Table 1). Two types of softness were recognized: softness to tooth pressure (a bulk property), and softness to tongue and cheek (primarily a surface property). The former is judged by the muscular force exerted and the latter by feel.

Muscle fiber characteristics encompassed ease of fragmentation across the grain, mealiness and apparent adhesion between fibers. Mealiness is a special kind of fragmentation where the meat breaks down into small, hard and dry particles that cling to the cheeks, gums and tongue. Adhesion between fibers refers to the strength of the forces holding the fibers together; at its highest, the muscle fibers are almost melted together. In addition to the six components of tenderness, Cover et al. also considered the degree of juiciness.

Unfortunately, the method never gained much popularity, probably because its complexity and the required high degree of panel training could not be justified at that period in meat science development where much research dealt with meat samples representing small and simple differences (Aldrich and Deans, 1962). An example of research utilizing Cover's method is the work by Ho and Ritchey (1967) aimed at defining the effect of animal age on the eating quality of beef meat. This work showed that the characteristics of muscle fibers play a major role in the overall tenderness.

Cross et al. (1978) published methodology for the selection, training, and evaluation of a descriptive panel for quantifying tenderness, juiciness and the connective tissue component of meat texture. Their objective was to consolidate the various techniques used by the meat industry and the university researchers. This methodology became part of an AMSA publication which also included directions on how meat should be cooked prior to evaluation. Guidelines to the description of sensory testing methodology in publications were prepared by Prell (1976).

Current Status of Texture Description

In the early 1960's, texture began to be studied as an important quality attribute of foods in a generic sense. It thus followed the pathway of color and flavor research. It became clear that it no longer made sense to talk separately about texture or tenderness of meat, texture of peas, texture of chocolate or texture of apples. Each group of commodity researchers had developed its own technical culture, its own nomenclature and testing methodology. Each group worked separately towards the solution of its sensory methodology problems, despite their commonality.

Taking a generic approach to texture characterization resulted in the development of a common definition, classification of textural parameters and principles of texture profiling applicable to both sensory and instrumental methods of testing. This work used as its building blocks key advances in commodity work, with research on meat providing a significant contribution. It also followed the principles and methodology of flavor profiling developed earlier.

The definition encompassed the earlier concepts of "texture," "tenderness," "body," and "consistency." Somewhat modified from the original wording published in 1963 (Szczesniak) and used in several slightly different versions, this definition states that "texture is the manifestation of the structural elements of the food in terms of appearance, feel and resistance to applied forces." With some foods, the sounds generated on fragmentation of the product may be an important part of the overall texture perception.

This definition acknowledges that texture has its origins in the structure (molecular, microscopic or macroscopic), and that its evaluation includes the senses of vision, feel and kinesthetics. Thus, it is in agreement with Ball's definitions of meat texture and with other researchers' definitions of texture, body and consistency of different food products (Szczesniak, 1963; Kramer, 1972).

Following the construction of a generic definition, a generic classification of textural characteristics was developed. This classification divided textural parameters into three groups:

1. Mechanical characteristics – relating to the reaction of the food to stress;
2. Geometrical characteristics – relating to the size, shape, and orientation of the particles within the food;
3. Other characteristics – relating to the perception of the moisture and fat contents of the food.

The mechanical characteristics were further subdivided into:

a. Primary parameters of hardness, cohesiveness, viscosity, springiness and adhesiveness;
b. Secondary parameters of fracturability, chewiness and gumminess.

The definitions and relationship of these parameters to popular nomenclature are shown in Tables 2 and 3, respectively.

This classification formed the foundation for both sensory and instrumental texture profiling methodology. Profiling is a system of food texture description which acknowledges its multi-parameter nature and quantifies several parameters in one measurement. It has been used in conjunction with such universal testing instruments as the GF Texturometer (Friedman et al., 1963) and the Instron (Bourne, 1968). Examples of its application to meat products can be found in the publications by Szczesniak et al., 1963a (GF Texturometer) and by Brady et al., 1985 (Instron). An extensive review of instrumental texture profiling and its ramifications was published by Breene (1975).

Table 4 shows a schematic of the sensory texture profiling system, modified somewhat from its original version based

Table 2. Classification of textural characteristics.

Mechanical characteristics

Primary	*Secondary*	*Popular terms*
Hardness		Soft – Firm – Hard
Cohesiveness	Fracturability	Crumbly – Crunchy – Brittle
	Chewiness	Tender – Chewy – Tough
	Gumminess	Short – Mealy – Pasty – Gummy
Viscosity		Thin – Viscous
Springiness		Plastic – Elastic
Adhesiveness		Sticky – Tacky – Gooey

Geometrical characteristics

Class	*Examples*
Particle size and shape	Gritty, Grainy, Coarse
Particle shape and orientation	Fibrous, Cellular, Crystalline

Other characteristics

Primary	*Secondary*	*Popular terms*
Moisture content		Dry – Moist – Wet – Watery
Fat content	Oiliness	Oily
	Greasiness	Greasy

(Szczesniak, 1963, 1975)

Table 3. Definitions of mechanical parameters of texture.

Primary properties		Secondary properties	
Hardness	The force required to compress a substance between the molar teeth (for solids) or between the tongue and palate (for semi-solids) to a given deformation or to penetration.	Fracturability (brittleness)	The force with which a sample crumbles, cracks or shatters; the horizontal force with which the fragments move away from the point where the vertical force is applied. Fracturability is the result of a high degree of hardness and low degree of adhesiveness.
Cohesiveness	The extent to which a material can be deformed before it ruptures.		
Viscosity	The force required to draw (slurp) a liquid from a spoon over the tongue.	Chewiness	The length of time or the number of chews required to masticate a solid food to a state pending for swallowing. Chewiness is a product of hardness, cohesiveness and springiness.
Springiness (elasticity)	The amount of recovery from a deforming force; the rate at which a deformed material returns to its undeformed condition after the deforming force is removed.		
Adhesiveness	The force required to remove material that adheres to the mouth (generally the palate) during the normal eating process.	Gumminess	A denseness that persists throughout mastication, the energy required to disintegrate a semi-solid food to a state ready for swallowing. Gumminess is a product of a low degree of hardness, and a high degree of cohesiveness.

(Szczesniak, 1963 as modified by Brennan, 1980)

Table 4. Schematic of sensory texture profiling system.

Early (perceived on small compression)	
Mechanical	– Springiness
Surface	– Smoothness, Oiliness, Wetness, etc.

Initial (perceived on first bite)	
Mechanical	– Hardness, Fracturability, Viscosity
Geometrical	– Any, depending on product structure

Masticatory (perceived during chewing)	
Mechanical	– Gumminess, Chewiness, Adhesiveness
Geometrical	– Any, depending on product structure
Breakdown	– Type and rate
Moisture	– Degree of release or absorption
Oiliness/Fatness	– Amount and rate of release

Residual (perceived just before, during and after swallowing)	
Mouthcoating	– Type and amount
Swallow	– Ease of, throat coating
Geometrical	– Any, depending on product structure

(modified from Brandt et al., 1963)

Table 5. Original standard scale for hardness.

Panel rating	*Product*	*Brand or type*	*Manufacturer*	*Sample size*	*Temperature*
1	Cream cheese	Philadelphia	Kraft foods	½ in.	45-55°F
2	Egg white	hard-cooked 5 min	—	½ in. tip	room
3	Frankfurters	large, uncooked, skinless	Mogen David Kosher Meat Products Corp.	½ in.	50-65°F
4	Cheese	yellow, American pasteurized process	Kraft Foods	½ in.	50-65°F
5	Olives	exquisite giant size, stuffed	Cresca Co.	1 olive	50-65°F
6	Peanuts	cocktail type in vacuum tin	Planters Peanuts	1 nut	room
7	Carrots	uncooked, fresh	—	½ in.	room
8	Peanut brittle	candy part	Kraft Foods	—	room
9	Rock candy	—	Dryden & Palmer	—	room

(Szczesniak et al., 1963b)

on later experiences. The key principles of sensory texture profiling are that:

a. Texture is a multi-dimensional quality.
b. The order of appearance of textural characteristics is predictable (in contrast to flavor, where the order of notes appearance may be totally different from product to product).
c. The food goes through several stages in the mouth, during which human senses perceive a number of textural characteristics.
d. The food undergoes mechanical disintegration in the mouth which is coupled with temperature and moisture (saliva) effects (it is acknowledged that for foods that undergo a phase change, e.g. ice cream and chocolate, thermal breakdown will predominate).
e. For a full description of texture, one must consider and quantify the different characteristics applicable to a particular product at different stages of mastication.
f. The applicable parameters must be selected by a knowledgeable panel, starting from a broad base.

In addition, and very importantly, standard scales were developed for the mechanical parameters which provided examples and reference points. A typical example, in the form of the hardness scale, is shown in Table 5. These scales cover the entire range of parameter intensities encountered

Table 6. Sensory texture profiling technique and definition of terms for frankfurters.

Stage I	place frankfurter into mouth; feel surface with the tongue and lips *Evaluate for:* – *Surface moisture:* degree to which the surface is wet or oily (moisture) – *Type of moisture:* wet or oily – *Surface smoothness:* degree to which the surface is smooth; i.e. not rough or uneven (geometrical)
Stage II	place frankfurter into mouth; compress partially between incisors; release *Evaluate for:* – *Elasticity:* degree to which sample returns to original shape after deformation (elasticity)
Stage III	place frankfurter into mouth; bite down with front teeth at ¼″ from end *Evaluate for:* – *Hardness:* force required to bite through the sample (hardness) – *Cohesiveness:* degree to which sample deforms before it ruptures (cohesiveness) – *Uniformity:* degree to which sample is same from outside to inside (geometrical, mechanical) – *Moisture release:* degree to which sample releases juices (moisture) – *Denseness:* compactness of cross section (geometrical) – *Coarseness:* degree to which mass feels rough (geometrical) – *Graininess:* degree to which sample or juice contain small particles (geometrical)
Stage IV	place ¼″ section crosswise between molar teeth *Evaluate for:* – *Hardness:* force required to bite through cross section (hardness)
Stage V	*Chewing:* – Chew a ¼″ piece with molar teeth *Evaluate for:* – *Chewiness:* number of chews necessary to prepare sample for swallowing (chewiness) – *Moisture release:* amount of juices released during chewing (moisture) – *Oiliness:* amount of oil or fat in juices (fat) – *Moisture absorption:* degree to which the sample mixes with saliva (moisture) – *Cohesiveness of the mass:* degree to which mass holds together after 5-7 chews (gumminess) – *Lumpy:* degree to which mass is made up of irregular pieces (geometrical) – *Grainy:* degree to which sample contains small distinct particles (geometrical) – *Skin:* degree to which skin is distinct from mass during the chew (geometrical) – *Description of breakdown:* describe changes occurring during breakdown (description of breakdown)
Stage VI	*Swallowing:* – Swallow sample *Evaluate for:* – *Ease of swallow:* degree to which the chewed mass can be readily swallowed (geometrical) – *Mouthcoating:* – *Oiliness:* amount of oil or fat coating mouth surface (fat) – *Particles:* amount and type of particles left in mouth (geometrical)

(Civille and Liska, 1975)

in food products. They can be expanded at any interval when evaluating specific food types.

The original texture profiling scheme provided a foundation on which additional knowledge was built. In the 20 years since it was first published, the texture profiling technique underwent considerable modification. It has been applied to a variety of different food products (Civille and Liska, 1975) and guidelines to training a panel were published (Civille and Szczesniak, 1973). The method is taught at several universities and by the Center for Professional Advancement in New Brunswick, NJ. Publications reporting its use are limited in number since most of the users appear to be in industrial establishments.

During the use of the method, it became evident that a number of parameters, not originally considered, needed to be evaluated. These are apparent to people trained in the basic method and are product-related. Quantitative scales for some of these parameters (e.g., denseness, adhesiveness to lips) were constructed (Munoz, 1986).

In its early stage of development, sensory texture profiling of meat considered only hardness, chewiness, juiciness and the amount of fat (Szczesniak et al., 1963b). Recent work by Brady et al. (1985) on ground beef considered hardness, cohesiveness, springiness, adhesiveness and fracturability. The texture profile for frankfurters developed in the Dept. of Food Science at North Carolina State University included 24 parameters. Table 6 gives the details of the evaluation procedure and the definition of the terms, while Table 7 summarizes the results on three types of frankfurters, using the 12-point flavor profiling scale. It will be noticed that the evaluated

Table 7. Sensory texture profiles for frankfurters.

Characteristic	*All-beef product*	*Kosher-type product*	*All vegetable protein product*
Stage I			
Surface wetness	1-2	1	0
Surface oiliness	1-2	2	0
Surface smoothness	2-3	1-2	1-2
Stage II			
Elasticity	2	2	χ-1
Stage III			
Hardness	1-2	2-3	χ-1
Cohesiveness	1	2	χ-1
Uniformity	1-2	χ	2-3
Moisture release	2	2	0
Denseness	1-2	2	2
Coarseness	1-2	2	χ-1
Graininess	χ	χ	1-2
Stage IV			
Hardness	1-2	2	χ-1
Stage V			
Chewiness	24 chews	35 chews	28 chews
Moisture release	1-2	2	0
Oiliness	1-2	2	0
Moisture absorption	1-2	1-2	2-3
Cohesiveness of the mass	1-2	2	2-3
Lumpy	1-2	2	χ-1
Grainy	χ-1	1	2
Skin	1	2-3	0
Description of breakdown	shears easily; mixes with saliva as large lumps which break down to smaller and smaller lumps until swallowed	hard to shear; skin is obvious in mass which is fibrous, juicy and meaty	absorbs moisture and swells to thick grainy mass
Stage VI			
Ease of swallow	2	1-2	χ-1
Mouthcoating:			
Oiliness	1-2	2	0
Particles	χ-1	1-2	2

(Civille and Liska, 1975)

vegetable protein frank was distinctly different from the meat products in that it released no moisture or fat; instead, it absorbed moisture for the mouth. It was also much softer and less elastic (springy).

The sensory texture profiling technique was applied to sliced beef by Szczesniak et al. (1963b) and to beef, pork, ham and chicken rolls by Segars et al. (1981). It was applied to ground beef by Dransfield et al. (1984) and Brady et al. (1985). However, in all cases the employed methodology involved only the originally-published parameters and no reports appear to exist on the application of the detailed sensory texture profiling technique to muscle meat.

At the present time, there are two general concepts of sensory meat texture measurement (Breene, 1978): the complex and the simple. The complexity concept advocates the consideration of a large number of characteristics. It is represented by the texture profile technique described above and by Cover's early work. The simplicity concept contends that meat texture can be described adequately by only two sensory parameters: tenderness and juiciness. The proponents of this approach (e.g., Bouton et al., 1975; Harris, 1976; Harries et al., 1972) rely on statistical evidence for high correlations among the detailed parameters and for reducing the number of meaningful characteristics to the above two. Harris (1976) added fine/coarse to juicy/dry and tender/tough.

The argument as to which group is right could be settled by stating that both may be right. The choice of the approach should be highly dependent on the purpose for which the sensory evaluation is being conducted, the amount of time, money and talent available for developing a profiling panel, and the textural complexity represented by the studied samples. There are plenty of literature references where the simple two-parameter approach yielded meaningful data. If circumstances prevent the establishment of a profiling panel and the nature of the study does not require a detailed textural description, the simplistic approach may be adequate. If, on the other hand, the study involves factors affecting the subtle nuances of texture (e.g., comparison of the action of tenderizing enzymes on beef muscles, or comparison of reconstructed vs. regular steaks), then the complex approach is necessary. This approach not only considers a larger number of parameters (mechanical, geometrical, surface properties, moisture and fat release), but also how they change during the course of mastication.

Lessons to be Learned and Applied

It has been recognized for some time that certain factors contribute to the scatter of sensory data and must be controlled. Some of this evidence was empirical, some based on proven facts. Rheological, biochemical and structural work done on meat in the recent past generated factual information that has a significant bearing on this issue. Much can be learned from this research and applied to the refinement of sensory testing methodology.

Variation Among Animals, Among Muscles and Within Muscles.

Recent work by Lepetit and Sale (1985) provided instrumental data which indicate that tenderness of raw beef meat varies among muscle and among animals for the same muscle. As illustrated in Table 8, *psoas major* was generally the most and *pectoralis profundus* the least tender. In addition, considerable variations were shown to exist within the muscle, with *biceps femoris* generally exhibiting the highest and *psoas major* the lowest coefficient of variation.

Table 8. Tenderness variations in different raw bovine muscles.

	Animal 2		Animal 3		Animal 4	
	force	*c.v.*	*force*	*c.v.*	*force*	*c.v.*
Pectoralis profundus	68	2.9	61	9.8	54	22.3
Biceps femoris	44	50.0	59	27.1	63	30.2
Semitendinosus	67	4.5	51	25.5	63	17.5
Triceps brachii	37	8.1	41	12.2	38	31.6
Semimembranosus	49	24.5	43	20.9	44	11.4
Psoas major	16	12.5	13	7.7	16	6.2
Longissimus dorsi	29	37.9	19	10.5	25	16.0

Animals; 2 and 3- 7 yr. old cows
4 - 4 yr. old steer

(after Lepetit and Sale, 1985)
(force, in newtons, to shear a 1 × 1 cm sample; average of 15 replicates).

Detailed data for cooked beef published by Segars et al. (1974) also demonstrated large differences within a muscle, as well as among muscles. These intra-muscle variations contribute to poor replications when samples are randomized. It appears that the more active the muscle, the greater the variation in tenderness. Evidence is available that textural differences among muscles may be related to structural and histological variations, i.e. the amount of collagen and the dimensions and tensile strength of myofibrils (Paul et al., 1970).

These differences point to the importance of careful and consistent sampling methods.

Effect of Fiber Orientation

It has been demonstrated that the orientation of the muscle fibers with respect to the direction of force application has a significant effect on instrumental values. Force to compress is the greatest with the fibers perpendicular to the direction of compression and the least with the fibers at 45° to this axis (Dransfield, 1975). Shear force is also much greater when applied at a 90° angle than when applied parallel to the fiber direction (Murray and Martin, 1980). Since compressive, tensile and shear forces operate in the mouth during mastication, and since fiber orientation is not constant throughout a muscle, this evidence is very relevant and could account for much of the variation reported to exist among different muscle locations.

Effect of Cooking Temperature

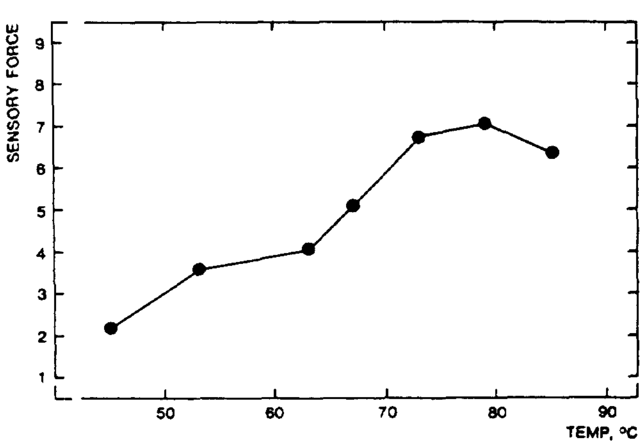
The effects of cooking on tenderness of beef are quite complicated but generally are attributed to two opposing factors. Partial hydrolysis of collagen leading to the softening of collagenous tissue tenderizes the muscle, whereas denaturation of myofibrillar proteins toughens it. The final effect depends not only on the proportion of these two structural components, but also on the type of muscle and its state prior to cooking.

Locker and Carse (1976) attempted to separate the contribution of these components and to study their effect with tensile measurements. They used strips of ox *sternomandibularis* muscle in which the myofibrillar component has been destroyed by alkali and others in which collagen has been destroyed by long cooking. They showed that in raw or lightly cooked meat the low tensile yield (1.4 kg cm^{-2}) is due to the myofibrils failure. With more extensive cooking, the connective tissue shrinks and contributes to toughening. Between 60°C and 80°C, the opposing effects mentioned above of connective tissue weakening and myofibrillar strengthening are essentially canceling each other, resulting in a constant tensile strength (5 kg cm^{-2}). At 100°C, much hydrolysis of connective tissue takes place, tensile strength decreases (3 kg cm^{-2} and is ascribed to the myofibrillar components.

Bouton et al. (1981) used the Warner-Bratzler shear force-deformation curves to study the effect of cooking temperature on beef. They also concluded that the connective tissue contribution decreases as the temperature is raised (above 50°C for young animals and above 60°C for very old animals).

Pennfield et al. (1976) studied the effect of cooking on both tensile and shear properties of beef *semitendinosus* and, in addition, investigated the effect of heating rate. They found a significant decrease in breaking strength and shear resistance in the range 50° to 60°C. Unlike shear values, the breaking strength increased on heating to 70°C. The rate of heating had no effect on the breaking strength but did influence the shear force values. Slower rate of heating (greater total heat supplied) gave significantly lower shear force values.

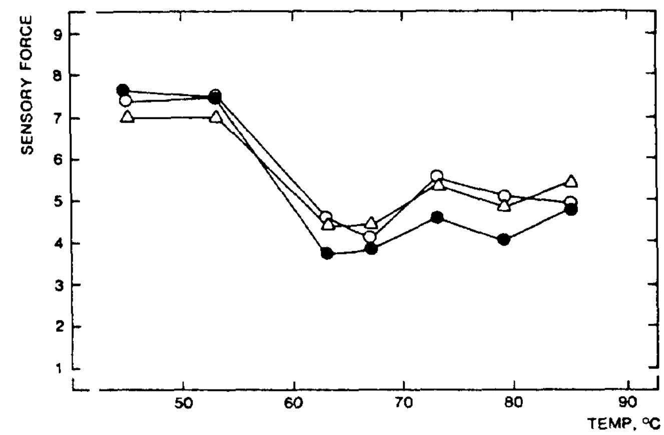
Figure 1



Firmness of bovine semimembranosus as a function of cooking temperature (mean of 2-3 replicates and 2 holding times; average error of the mean, $\bar{s} = 0.21$).

(Martens et al., 1982)

Figure 2



Cohesion between fibers, resistance to biting and residual bolus of bovine semimembranosus as functions of cooking temperature.

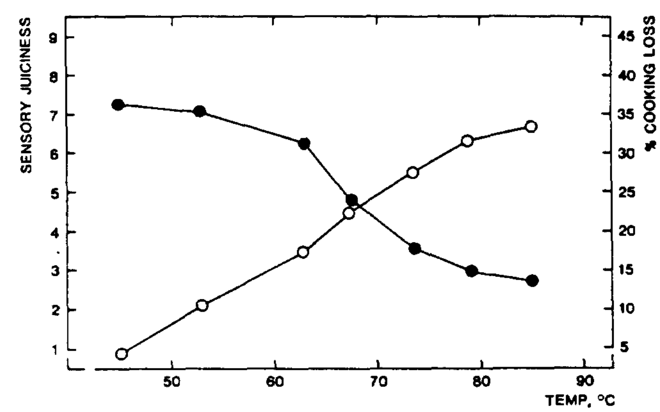
Fiber cohesion (o) s = 0.24 Bite-off force (o)$\bar{s}$ = 0.20. Residual bolus (△) $\bar{s}$ = 0.28

(Martens et al., 1982)

The most informative work on the effect of cooking temperature on sensory texture and biochemical/structural reasons for it is the paper by Martens et al. (1982). Differential scanning calorimetry (DSC) was used to study thermal changes in the three major structural proteins in bovine muscle: myosin, actin (components of myofibrils) and collagen. Sensory evaluation involved rating on 1-9 scales of firmness, juiciness, fiber cohesion, force to bite-off, total chewing work, heterogeneity and volume of residue. All the terms were defined for the panel.

Firmness (defined as the force needed to compress the meat strip about 30% with molar teeth) appeared to reflect the denaturation of myofibrillar proteins. It increased steadily with cooking temperature for *semimembranosus* muscle

Figure 3



Juiciness and cooking loss of bovine semimembranosus as functions of cooking temperature.

Juiciness (•, mean of juiciness in first bite and juiciness during chewing; left scale; $\bar{s}$ = 0.16). Cooking loss o, = ml liquid expressed from 100 g meat sample, right scale; $\bar{s}$ = 1.01).

(Martens et al., 1982)

Table 9. Thermal denaturation of proteins in bovine m. semimembranosus muscle after 5 min holding time at the indicated temperatures.

End Temperatures °C	*45*	*53*	*63*	*67*	*73*	*79*	*85*
STRUCTURAL PROTEINS:							
Myosin (LMM)	80	20	0	0	0	0	0
Myosin (HMM)	100	100	0	0	0	0	0
Collagen	100	100	0	0	0	0	0
Actin	100	100	100	80	10	0	0
SOLUBLE PROTEINS:							
Sarcoplasma proteins	100	90	30	10	1	0	0
Heme-proteins (myoglobin, hemoglobin)	100	100	100	100	70	10	0

[1]Partial denaturation fractions are approximate
LMM = Light meromyosin, HMM = Heavy Meromyosin

(% DSC peak area remaining after heat treatment); important changes are underlined.
(Martens et al., 1982)

(Fig. 1), but dipped between 55°C and 70°C for *psoas major*. Fiber cohesion (defined as the force required to separate the muscle fibers with fingers) appeared to be a sensory measure of collagen denaturation. It decreased drastically in the 53° to 63°C range and then showed a slight increase (Fig. 2). Fiber cohesion, bite-off force and the volume of the residual bolus changed in unison with increasing cook temperature. Juiciness decreased steadily with increasing temperature (Fig. 3). Table 9 summarizes the relationship between the heating temperature and the denaturation of specific meat proteins.

Effect of Serving Temperature

Opinions are divided on whether meat should be evaluated at the serving temperature or at room temperature, the latter being more convenient to maintain. It would appear that the serving temperature would have an effect on texture perception, especially on juiciness and other parameters that may be influenced significantly by the physical state of fat. This issue has not been studied adequately. The few published reports (Caporaso et al., 1978; Olson et al., 1980) suggest that fluctuations in the serving temperature may be a source of variation in sensory meat texture assessment. A double-broiler system for maintaining uniform sample temperature has been described in the literature and claimed to be superior to holding in gas or electric ovens (Caporaso, 1978).

Effect of Storage Time After Cooking

This effect has been studied even less than the serving temperature. It appears to be small, if any, and to depend on muscle type (Williams et al., 1983).

Structural Contributors to Texture Perception

As has been stated earlier, texture originates in the structure of food. It has been known for some time that tenderness is a reflection of the connective tissue and myofibrillar components of meat. More recent work, primarily by the Australian team of Bouton and Harris, which combined the biochemical approach with instrumental texture measurements, provided information on how these components respond to applied forces. Since texture is assessed sensorially by subjecting the test sample to forces of compression, pull, shear, etc., such information has great relevance to sensory texture evaluation. A good review of some of this work has been published by Harris (1976).

Compression appears to reflect the rheological properties of the connective tissue network, while shear forces appear to relate more closely to the muscle fiber characteristics. In neither case can the influence of the other component be ignored. Tensile force measurements made perpendicular to the fibers quantify how strongly the fibers are bound together. They appear to be an index of the connective tissue strength and its spatial arrangement. Tensile force measurements made parallel to the fibers describe the rheological properties of the fibers. These can have low or high extension before breaking. Thus, in sensory terms, they can be "mealy" and "fracturable" or "tough" and "elastic."

Carroll et al. (1978) studied changes in ultrastructure of meat subjected to tensile forces, using the scanning electron microscope, and confirmed the above conclusions. They found that tensile forces applied parallel to the fibers ruptured the muscle fiber endomysium sheath. Tensile forces applied perpendicular to the fibers ruptured the endomysium – perimysium junction (i.e. the connective tissue network) without disturbing muscle fibers.

A number of workers (e.g. Culler et al., 1978) have advocated the importance of myofibril fragmentation to meat tenderness and have even suggested the "myofibril fragmentation index" (MFI) as an objective test for tenderness.

Strain and Strain Rate

Since rheologically meat is not an ideal, but a viscoelastic system, and since it has several structural components of different strengths, its response to applied forces must depend on the degree and rate of strain applications. This issue has been studied by Lepetit and Sale (1985) for raw meat, but no corresponding detailed study appears to exist for cooked meat.

Lepetit and Sale found that the breaking strain decreases with increasing strain rate; i.e., the faster the meat is deformed, the less it will stretch before breaking. That means that, at least for raw meat, the rate of chewing is an important variable. These workers also found through factor analysis that the seven muscles studied could be differentiated, based on two groups of rheological parameters: those evident at low deformation and those evident at high deformations. They postulated that, for raw meat, small deformations picked up the characteristics of the myobrillar structure, and large deformations reflected the characteristics of the connective tissue network. Their data also demonstrated that correlations between shear and compressive measurements exist at high degrees of compression (where some failure due to shear may be expected), but not at low degrees of compression.

This work provides an additional argument for the profile method of meat texture characterization with its several stages of evaluation involving different degrees of deformation (Table 6).

Concluding Remarks

Sensory evaluation of meat texture should be based on:

- sound sensory practices
- accounting for natural uncontrollable variations
- controlling of controllable variations
- knowledge of meat microstructure
- appreciation of rheology
- appreciation of the multi-parameter nature of texture

For some applications, quantification of a limited number of parameters, such as overall tenderness and juiciness, may be sufficient. For other applications, especially those involving structural and biochemical research, texture profiling techniques should be employed.

It is hoped that the future will see a closer cooperation between meat researchers and sensory scientists, so that the most updated sensory techniques could be applied to meat characterization. The field of sensory evaluation, which developed some of its vital roots in meat work, owes meat researchers the benefit of its latest techniques and knowledge. Because of the complexity of meat texture, these techniques should envelop the current knowledge of meat structure and rheology.

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Discussion

D. Beermann: How important do you feel it is that an instrumental method exactly mimic an action of the mouth? Do you feel that's important or necessary?

A. Szczesniak: This is what everybody likes to have in the field because instruments don't get sick, they don't have fights with their husbands or wives, which may make them a better or worse panelist. They can be fed non-FDA approved materials, they are repeatable, fast, much less expensive. They need to be calibrated, but they don't need to be trained. An ideal instrument that simulates the human mouth does not exist yet. It may be invented, I would guess, within ten years, but not tomorrow.

How important is it? I think it is very important for those reasons I have outlined. There are a number of people who work in this area. I'm pleased to say that several years ago we made a plea for basic engineers to get into the area of texture evaluation. It has happened and now we have very able people, like Michelle Pellek at the University of Massachusetts who is working in this direction. The dental researchers are very much interested in duplicating, not simulating; we can simulate, but we still cannot duplicate the mastication process in the human mouth, and they too are making progress.

Trout: The first point I have is more of a comment than anything else. You talked about strain rate and the affect on texture measurement, and you said that you thought that work only had been done on uncooked meat. I think I recall seeing a paper by Peter Purslow who published in *Meat Science* last year. He looked at strain rate and texture of meat, can you recall that paper?

Szczesniak: No, I don't. I would like to get reference to it.

Trout: He is one of the engineers who is working in the food area and trying to apply engineering concepts to a cooked-meat texture evaluation. He was looking at some of the collagen aspects, particularly.

I have another question, when doing sensory evaluation work. You talked about using "anchors." The question is: How do you get your anchors? You like to have something either extreme and probably something in the middle. You need to get them from somewhere, something that's consistent. How do you define them?

Szczesniak: That's a very good question, a very important point. You might have noticed, on the slide showing the hardness scale, that we avoided natural products, like apples or meat or bananas, because they are very variable and are not very good anchor points or standards. Even the processed products that we have on our scales did change with time, and people have recently updated the original scales. In the first issue of the new journal called the *Journal of Sensory Studies*, there's a paper by Alexandra Munoz (who was with Best Foods) which deals with the updating of these scales using current standards and also with the addition of some other scales like adhesiveness to lips and adhesiveness to teeth, etc.

The best thing to do is start first with a very broad base. You say: "I'm dealing with this branch of tenderness, let me go out and get all kinds of food samples, fairly standard processed food samples, be it sandwich loaves or bologna or frankfurters of different manufacturers." We know that these different brands are different in texture and cover the entire world.

Once you have the samples, zero in on those particular products which will be almost equidistant from one another so that you can have those anchor points at 1, 2, 3, 4, 5 on your expanded scale.

Trout: That applies very well to profile work, but is not so easily applied to just straight tenderness.

Szczesniak: First you have to define tenderness. Do you define it as softness to compression, or do you define it as ease of chewing? Tenderness is a very complex term.

Trout: That's true and that's probably why profiling has been pushed so much. Because profiling is very complex, and the interpretation of it is complex, in a lot of ways it's not as useful to some people as just a straight tenderness measurement.