Lebensm.-Wiss. u. -Technol., 9, 383–385 (1976)

Rheological Properties of Meats (Fresh, Intermediate Moisture and Dehydrated)

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(Received May 25, 1976; Accepted June 17, 1976; lwt 409)

The difference between what the human sensor perceives as texture and the measurement of mechanical properties of foods, in addition to sampling and other problems, account for the limited correlations obtained between the consumer and the instrument. We need to know more about primary and derived sensory properties and about the extend to which empirical and engineering parameters reflect these properties. Research in phychorheology may lead to the development of an instrument calibrated in terms of sensory tenderness.

Uniaxial compression testing on raw and cooked samples prepared from five muscles of a single beef hindquarter showed a greater variation of mechanical properties across rather than along the muscle. By following regions of similar characteristics from raw to cooked slices (matching) a correlation coefficient of 0.87 was obtained for mechanical measurements on both types of meat. Natural meat tenderizers may be used to advantage for selective tenderization of meat simulating the effects of aging.

In the intermediate and low moisture range the water has an important effect on mechanical properties.

Introduction

The purpose of this paper is to survey some recent work in our laboratories on the sensory and mechanical properties of fresh, intermediate moisture and dehydrated meats, as these properties affect the consumer response to texture. The work is interdisciplinary among the areas of rheology (engineering measurements), behavior sciences (sensory measurements), protein chemistry, and histology.

Texture from a Sensory and Mechanical Point of View

Researchers for many years have investigated the textural characteristics of meat with a view to developing practical tests for measuring tenderness and other properties. Prediction of consumer response to texture on the basis of mechanical measurements on the cooked or raw meat met with only partial success. The question is why?

To answer this, one has to consider that texture, from the standpoint of consumer, is made of "derived" sensory properties each of which is constituted of a number of elementary or "primary" properties. We know much more about derived properties than primary properties. Tenderness of cooked meat for example can be considered a derived property. It reflects composite sensory responses to what happens when the consumer chews the meat. We do not know what are the unit sensory elements of tenderness. One, for example, can speculate that the primary sensory responses to tenderness may include "hardness", perceived as resistance to chewing, "cuttability" or ease with which the fibers are severed by the teeth upon exertion of pressure, "fibrousness" indicating how readily discernible and persistent during chewing are the bundles of fibers, and "juiciness" which is the amount of liquid and the way (relating to the binding forces) with which it is held by the meat and released in the mouth.

From the instrumental point of view, we deal with similar situations of derived or "integrative" and primary or "analytical" mechanical properties (1).

Empirical instruments such as the Allo-Kramer Shear-Press, the Warner-Bratzler Shear and the Volodkevich Bite Tenderometer measure derived properties. For example, the "hardness" of the Allo-Kramer Shear-Press is an extremely complex property which is the result of mechanical operations taking place upon compression, cutting and extrusion of meat. No one has ever analyzed these operations on a fundamental basis. Simple as it may seem, the mathematics of it from a rheological point of view are prohibiting. Notwithstanding this complexity, empirical properties can at times give relatively high correlations with consumer responses and are of great usefulness to the industry. The shortcoming is that they usually apply to a specific commodity, and since they measure complex properties, they often do not provide information to the researcher as to what steps he should take to improve the product. The relationship between sensory attributes and the unit components of integrative mechanical properties such as "chewiness" and "hardness" is unknown and difficult to study experimentally.

Analytical instruments such as the Instron Universal Testing Instrument and the Mitex Bending Tester (2), provide physical measurements of rheological properties such as the *modulus of elasticity,* which is related to the force necessary to obtain a certain deformation (a measure of stiffness); *the ultimate strength,* which is the stress at the point of rupture; the *ultimate strain,* which corresponds to the percent deformation of the material at the point of rupture; and the *Poisson's Ratio,* which is the ratio of the transverse to the axial strain of a cylinder of meat upon compression. An advantage in measuring analytical engineering properties of meat is that from a physics point of view, "we know what we measure". We can treat the data mathematically and obtain new numbers which have physical significance. A truly fundamental property should be independent of the type of instrument used to measure it, and it should be applicable to any type of meat (or food commodity), although this ideal situation does not often exist, and one has to specify the mechanical probe used and the conditions of measurement.

In many cases it is advantageous to combine different mechanical properties in order to obtain high correlations with sensory responses. Ways to do this are by (a) multiple regression or (b) factor analysis. Since the first method is well known, we shall confine ourselves to a brief description of factor analysis which is not related to the factorial experiment (1).

Let us consider a multiple regression equation which has been developed to relate sensory hardness with five different sensory variables (dimensions) such as crispness, springiness and brittleness. We have information to suspect that all these five terms are a combination of a smaller number of unknown primary variables. In order to "extract" these primary variables, we can use computer programs to give us sets of new equations to account for different levels of variability (e.g. 60, 70, 80, 90% of variability). One equation, for example, on the basis of 80% of variability might express hardness using three terms in a polynomial equation. These three terms are the *imaginary* primary dimensions. They are mathematical entities derived from experimental data, and they could be named in a substantive way on the basis of our knowledge of the experimental material. The theory and process of factor analysis give us mathematical results which, in turn, lead us to the search of the experimental counterpart of the mathematical terms. (For a discussion of the method of factor analysis, see HARMAN [3].)

Analytical engineering properties are easy to obtain and have a great potential value in providing the meat technologist with information necessary to improve a product according to consumer preference, or to develop new products with a high degree of acceptance. To some extent this is done right now in meat research laboratories where such instruments are used. But we need more work on what properties one should combine in what kind of functions in order to express specific sensory attributes.

If we know this, we can calibrate an instrument to read directly in terms of sensory magnitudes. The development and calibration of such instruments will be of great value in control and purchasing specifications.

Magnitude Estimation

In the much used method of interval scaling, the panelist rates a certain texture attribute; e.g., hardness, on the basis of a number of fixed points such as from 0–9. In such a scale, the zero point is not defined, and a panelist cannot state whether a certain perceived hardness is twice that of another, although he can say that one perceived hardness may be two scale units higher than another.

In cooperation with Dr. Moskowitz of the Behavior Sciences Division, we have recently used with success the method of *Magnitude Estimation* applied originally by Professor S. S. Stevens of Harvard University. According to this method the panelist is given a certain sample and asked to assign to it an arbitrary number, e.g., 50, for hardness. He is then presented with other samples and asked to say how many times these other samples are harder of softer than the first. This type of sensory testing uses ratios of numbers which can be treated mathematically, rather than fixed numbers on a scale. Magnitude estimation has been used for direct estimation of sensory magnitudes on the evaluation of response to stimuli ranging from the loudness of tone to the hardness of rubber samples. The method yielded simple power functions of the form $S = KI^n$ (S = sensory magnitude obtained from direct numerical estimation of intensity, I = instrumental magnitude measured by objective means). The exponent n is a constant characteristic of the material. In our laboratories the hardness and crunchiness of a number of compressed bite-size cubes, used in space feeding, gave exponents between 0.4–0.6 as a function of the modulus of elasticity (4).

Fresh Meats

The above considerations are more complicated when relationships between raw and cooked meat texture are sought. The biochemical changes brought about by cooking have been considerably discussed.

At the US Army Natick Development Center we have recently completed a study of the mechanical texture characteristics of raw and cooked meat samples from the following muscles of a single beef hindquarter: (1) *biceps femoris,* (2) *gluteus medius,* (3) *longissimus dorsi,* (4) *psoas major,* and (5) *rectus femoris.* We used the Instron Universal Testing Instrument in uniaxial parallel-plate compression testing to measure the following properties of the raw and cooked meat: apparent modulus of elasticity, E_a, determined from initial slopes; stress at 20% compression, σ_{20}; strain (compression) energy per unit volume, W_1; and hysteresis loss, $H = W_1 - W_{u1}/W_1$, where W_{u1} is the strain energy per unit volume recovered during unloading. These properties were finally selected out of 17 parameters which were computed and analyzed by a PDP-8 computer. In addition to the individual properties, the program determined mean values for a given slice, standard deviation, and confidence limits for each parameter of the slice. Results of the apparent modulus of elasticity, E_a, are presented in **Tab. 1.**

The greatest variation of mechanical properties was across the muscle (lateral to medial) rather than along the muscle (origin to insertion). Active muscles showed greater variation and were generally tougher than inactive muscles. On the basis of mappings of textural variability, we were able to distinguish zones of similar textural characteristics throughout the muscle. Linear regression curves for raw versus cooked beef, both tested instrumentally, on more than 500 experimental samples yielded the following correlation coefficients: 0.85 for the *gluteus medius* and *rectus femoris* muscles, 0.89 for the *biceps femoris,* 0.78 for the *longissimus dorsi,* 0.77 for the *psoas major* muscle. It should be emphasized that these correlations were based on *matching* samples of similar characteristics making up "a zone"—not on random samples (5).

In another study, the Food Engineering Laboratory developed a penetrometer probe to predict sensory meat tenderness from measurements on raw meat. This probe consists of five specially designed needles and it fits the Allo-Kramer Shear-Press. Simple linear correlations between raw penetrometer readings and technological taste panel ratings ranged from -0.78 to -0.84 for beef and -0.50 to -0.63 for pork (6, 7).

In addition to the Instrom and the Allo-Kramer Shear-Press, we used a new instrument, the Mitex Bending Tester, to measure the textural properties of a wide variety of foods including meat (2). This instrument was originally developed to measure the rheological properties of fabrics, and it measures the following basic properties: *bending moment, curvature, bending rigidity, modulus of elasticity, curvature set* and *bending moment loss.* Results on bologna, sausage and ham samples showed that the instrument can successfully determine the mechanical properties of relatively uniform foods.

Recently in our laboratories we have studied a mechanical model consisting of spring (elastic component) and dashpot (viscous component) elements to simulate the mechanical behavior of meat upon testing. Solution to this model for the elastic component, as a first step, showed that uniaxial compression testing *is not sufficient to completely characterize the mechanical behavior of meat.* Two samples of widely different textural properties can give, when tested by uniaxial compression, similar values of the modulus of elasticity. To completely define the material, we need to measure the events taking place crosswise in the links which bind the fibers together during compression. In preliminary experiments, when we measured the Poisson's Ratio, which is the ratio of the transverse to the axial strain, high correlations between mechanical measurements on the cooked meat and sensory measurements were obtained. These results, however, need to be confirmed using more muscles of wider textural variability.

To gain an insight into the structural changes of meat when subjected to deformation upon testing, we have awarded a work order to the USDA Eastern Marketing & Nutrition Research Division for light microscopy (using a TV camera focusing on the specimen) and scanning electron microscopy

Tab. 1 Mean value of E_a in g cm^{-2} for each slice and standard deviation of the mean for the five muscles tested (ref. 5)

Slice No.	Psoas major	Longissimus dorsi	Gluteus medius	Rectus femoris	Biceps femoris
	Raw				
1	382.9± –	256.2± 57.8	125.5 ± 48.4	257.7±248.1	63.92± 6.71
3	388.7± –	394.6± 206.0	280.2 ±150.9	124.4± 40.5	73.52± 20.75
5	809.9± 92.9	207.5± 74.1	186.3 ±108.6	268.9±119.5	75.91± 25.41
7	764.0±445.3	194.0± 108.7	77.94± 24.33	258.0±169.2	69.38± 27.87
9	1289 ±593	295.4± 189.8			243.3±261.9[a]
11	1179 ±336	235.7± 368.6[a]			134.2± 73.8
13	653 ±131	618.1±1177.9[a]			129.5± 76.2
15	293 ± 8				338.1±371.4[a]
17					198.9±160.9
19					209.6± 88.9
21					226.0± 76.7
	Cooked				
2	2433± –	1443±396	2293±1018	1845± 871	322.5± 144.9
4	1900±111	1413±821	2124± 822	2152±1033	229.1± 84.5
6	2661±749	1434±295	1391± 559	1950± 889	195.0± 38.9
8	2395±948	1096±432		1561± 586	1217.6± 776.8
10	2344±270	1045±667			814.4± 582.8
12	2267±453	1158±609			585.2± 260.3
14	1950±149				580.1± 110.5
16					1301.4±1336.2
18					724.5±1124.1
20					890.3± 974.1

[a] Contain one extreme sample

work. Application of these methods showed the slipping and rupture of bonds on the microscopic and molecular level, which, hopefully, will enable us to develop a texture test for objective measurements.

Besides the methodology work on texture, we have been able recently to make inroads into a new method of meat tenderization using the natural enzymes of meat. Mechanical measurements using controls, extracts of cathepsin D and B and tenderizers of plant origin showed specific effects on the Z line by cathepsin D simulating the effects of aging, and on the connective tissue by cathepsin B similar to the action of a colagenase; the tenderized meat was free of the mushiness produced by tenderizers of plant origin (8).

Intermediate and Low Moisture Meats

The water activity (or water content) of intermediate and low moisture foods has an important effect on textural properties. This effect can be sensed using specific testing methods, or instrumental probes. As mentioned earlier in this paper, when the plate-cell combination of the Allo-Kramer Shear-Press is used, the meat is subjected to compression, shear and extrusion, with a severing of mechanical bonds which hold the fibers together. Under these conditions, we observed a maximum in the force value ("hardness") at about $A\omega$ 0.75–0.85, which is within the intermediate moisture range. When low strain parallel-plate compression was used, the bonds were not severed; in this case a maximum of the modulus of elasticity and other mechanical properties was detected at about 0.16–0.30 water activity, which is within the low moisture range (9).

Besides the mechanical texture properties, the heat released in the mouth during chewing is an important characteristic which affects the acceptability of foods consumed without rehydration. We have examined this sensory heat released in the mouth in relation to the water activity and found an increase in the heat with decreasing water activity from $A\omega$ 0.66 to the completely dry food. This increase paralleled the thermodynamic enthalpy change as determined from sets of isotherms (10).

Conclusions

1. The difference between what the human sensor perceives as texture and the measurement of mechanical properties of foods, in addition to sampling and other problems, account for the limited correlations obtained between the consumer and the instrument. We need to know more about primary and derived sensory properties and about the extend to which empirical and engineering parameters reflect these properties. Research in phychorheology may lead to the development of an instrument calibrated in terms of sensory tenderness.
2. Uniaxial compression testing on raw and cooked samples prepared from five muscles of a single beef hindquarter showed a greater variation of mechanical properties across rather than along the muscle. By following regions of similar characteristics from raw to cooked slices (matching) a correlation coefficient of 0.87 was obtained for mechanical measurements on both types of meat.
3. Natural meat tenderizers may be used to advantage for selective tenderization of meat simulating the effects of aging.

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