JOURNAL OF AGRICULTURAL AND FOOD CHEMISTRY

SYMPOSIUM INTRODUCTION

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Food Texture Analysis in the 21st Century

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ABSTRACT: Food texture encompasses physical characteristics perceived by the senses. Research in this area must be multidisciplinary in nature, accounting for fracture of food, sounds it makes during biting and chewing, its microstructure, muscle movements during mastication, swallowing, and acceptability. Food texture thus encompasses chemistry, physics, physiology, and psychology. This brief review of the field covers the areas of recent research in food texture and specifies where further understanding is needed.

KEYWORDS: texture, fracture, acoustics, physiology, microstructure

INTRODUCTION

Food texture has been defined as "the sensory and functional manifestation of the structural, mechanical, and surface properties of foods detected through the senses of vision, hearing, touch, and kinesthetics".[1] The ability to feel body movements, kinesthesis, includes mechanical properties and the interior structure of food as perceived by the muscles. Detection of tactile properties, somesthesis, involves the surface structure of food as perceived by the mouth ("mouthfeel") and fingers.

Texture is an important attribute in consumer acceptance of food, more so than most people realize. One study showed that pureeing familiar foods (removing texture while retaining flavor) and then feeding them to blindfolded subjects resulted in less than half of the food being identified correctly.[2] Food scientists have tried to relate sensory testing with results of instrumental analyses, including empirical tests designed for a particular food type, imitative tests such as texture profile analysis, and fundamental tests such as oscillatory shear analysis.[3] The oral perception of a food is quite different from instrumental measurements, however, because humans evaluate many aspects simultaneously.[4] A 1988 discussion paper by Hutchings and Lillford[5] pointed out that texture perception is a dynamic phenomenon involving fracture mechanics of food breakdown in the mouth, lubrication with saliva, and time. The lack of information about oral processing has prevented researchers from building on this model, although work in this area is progressing.[6]

Fracture and rheological behavior, oral physiology, structure, friction forces, and expectations of food must all be addressed when one is trying to understand food texture.[7] The field involves chemistry (nature of bonds), physics (acoustics), physiology (oral processing), and psychology (perception of texture). Sensory studies, which deal with texture perception, are covered in another paper in this symposium. This brief introduction to food texture will address current understanding of other aspects of the topic and areas in which future research is needed.

CHEMISTRY OF FOOD TEXTURE

Fundamentally, the texture of food is rooted in chemistry, being derived from the arrangement of its molecules, the strength of the bonds holding the molecules together, and changes in state as the food changes temperature and is partially dissolved in the mouth. Many of the textural properties of fruits and vegetables arise from the bonding of the materials in cell walls and how they change during handling, processing, and storage. The textures of dry processed products such as cereals and crackers are closely related to water activity. Lipids, polysaccharides, proteins, and water all interact in dough formation, resulting in profound changes in the final product. Other interactions resulting in textural changes include freeze denaturation of fish protein and cross-linking of proteins and polysaccharides in sausage and surimi.[8]

Food texture could theoretically be explained by measuring the chemical interactions between molecules and describing the network they comprise.[9] Foegeding has suggested agar, agarose, whey protein, and mixed gels as model systems for this purpose.[9] Further research on the chemistry of food components will be needed to explain the resulting texture.

FRACTURE

Food is swallowed by breaking into fragments and lubricating with saliva to form a bolus. Forces, deformation, and particle properties of the food pieces must therefore be examined to obtain a more complete picture of food texture.[10] Compression, bending, and tensile tests have traditionally been used to investigate the mechanical and fracture properties of food,[11] but the data may be difficult to interpret because most material science theory has dealt with durable structural materials and not food that is supposed to be disintegrated.[12] Moreover, foods are composites of biopolymers in a heterogeneous matrix and encounter different forces in the mouth from those in an engineering environment.[12] Much of the food texture research performed in the 21st century has dealt with ways of mathematically treating the fracture processes that occur in the mouth.

Special Issue: Food Texture Analysis in the 21st Century

Received: December 14, 2009
Published: July 01, 2010

Energy has to be applied to a food, or any material, to deform it. The amount of energy during deformation and fracture as defined by van Vliet includes the part of the strain energy that is elastically stored, the energy dissipated due to viscoelasticity, the energy due to friction, and the fracture energy.[13] Lucas et al. defined the energy required to fracture a food particle as its toughness (R), and if a food has a stress−strain relationship that is approximately linear, the stress−strain ratio is Young's modulus (E).[14] The cracking response of most food would be $(R/E)^{0.5}$, but would be $(ER)^{0.5}$ if the forces are high, and would be dominated by R if the particles are thin.[15] Strong linear relationships ($R^2 > 0.99$) have been found between $(ER)^{0.5}$, defined as the stress intensity factor, and sensory hardness and sensory crunchiness for fruits and vegetables.[16] The hardness and crunchiness of these foods are therefore related to the stress needed to start a crack running in them. Sensory crispness was not correlated with any of the parameters in the experiments, however. Vincent theorized that crispness is related to total drop in force during fracture, the total length of the fracture path, and the velocity with which the crack spreads.[16] Texture research is continuing to incorporate processing in the mouth with fracture mechanics and their relation to sensory and instrumental results.

ACOUSTICS

Closely related to the fracture properties of a food are the sounds made while it is bitten and chewed, which add to the eating experience. When a food is bitten, the work performed by the external forces is stored as elastic potential energy, which is liberated as acoustical energy when the interatomic bonds are finally ruptured.[17] The noise produced is due to the rupture of the cell walls it contains, and variations in the number of cells being crushed with time give rise to irregular sounds. Fruits and vegetables, which contain fluid in their cells, are considered wet crisp foods; foods containing only air in their cells, such as crackers, are dry crisp. Chauvin et al. used audio waveforms and multidimensional scaling to relate sensory perception to crispness, crunchiness, and crackliness in wet crisp and dry crisp foods.[18] Acoustic parameters used to characterize "noisy" foods include amplitude, height of peaks, number of sound bursts, and sound pressure.[19] Fast Fourier transform and fractal analyses are newer methods for evaluating chewing sounds.[20] Salvador et al. examined crispness of potato chips by simultaneously measuring sound peaks, sound pressure levels, area below force-displacement curve, slope of the curve, and number of force peaks.[21] This multiple determination was an effective way of predicting sensory results.

Crispy foods have multiple fracture events, each with a crack velocity of roughly 300−500 m/s, initiating at different places at slightly different times and with accompanying sound emission.[22] These cracks must also stop within a few hundred micrometers to prevent the entire product from breaking in <1 ms. Using acoustic and mechanical measurements, Luyten and van Vliet pictured the microstructure of a crispy food as a network of beams, struts, and pores; the beams were 50−400 μm in length to allow for fracture without the texture being too hard, and the pores were 120−350 μm in diameter and acted as crack stoppers.[22] Future work in this area should combine acoustics and microstructure.

MICROSTRUCTURE

The physical structure of a food is a key to the perception of its texture. Because somesthesis and kinesthesis deal with surface and internal food structure, respectively, their relationships with microstructural data should reveal information on texture perception. Friction forces among the tongue, palate, and food are important elements in texture perception, with the structure of the outer surface of the food being a determining factor.[13] Various microscopic techniques are available for characterizing surfaces and internal structures. Common methods for investigating the surface and interior structures of food are scanning electron microscopy (SEM), in which electrons are reflected off the specimen, and transmission electron microscopy (TEM), in which electrons pass through the sample. SEM and TEM yield two-dimensional nanoscale results and require pretreatment to dry the sample.

Confocal laser scanning microscopy (CLSM), environmental scanning electron microscopy (ESEM), and atomic force microscopy (AFM) are newer techniques for examining food microstructure. CLSM provides three-dimensional images of the fluorescence of hydrophobic components bound to fluorescent dyes and is especially useful for high-fat foods, although resolution is low.[23] Samples may be viewed in their natural state without prior preparation in ESEM, making it applicable to soft and moist foods.[24] AFM, which measures changes in the van der Waal's forces between the probe and the sample surface, also requires minimal sample preparation and produces nanoscale results.[25]

A growing area is the conversion of microscopic images into numerical data to remove subjective judgments.[26] Digital imaging provides information on dimensions, shapes, area fractions, and gradients; cheese, for example, may be analyzed in this manner to determine the area percentage of protein, the shape of fat globules, and the number of remaining starter culture bacteria.[26] Development of microstructural studies of dynamic processes will aid in determining the relationships between food structure and texture perception.

MUSCLE MOVEMENTS AND SWALLOWING

Jaw muscle movement allows food to be cut, ground, and torn by the teeth; people with masticatory impairment must make adjustments before they can swallow.[27] Muscle activity during mastication may be measured by electromyography (EMG), in which electrical activity is detected by electrodes placed on the four main masticatory muscles. The total work required to chew a food sample is then calculated.[28] Foster et al. used EMG to show how jaw movements and muscle force are affected by hardness, elasticity, and plasticity.[29] This research demonstrated that mastication parameters varied depending on stress−deformation pattern and hardness level and should lead to further work on how chewing is related to the rheology of the food.

Magnetic resonance imaging and the X-ray technique of videofluoroscopy provide visual data on mastication. In research on retronasal aromas, Buettner et al. used both techniques to visualize food as it was chewed and swallowed.[30] The ability to analyze the act of chewing and swallowing in real time should help to identify and quantitate more of the factors involved in texture perception.

The swallowing of a bolus is influenced by mechanical properties of the food and saliva flow rate. Lucas et al. defined the force tending to stick food particles together as F_V and the force attracting them to the oral cavity as F_A. Their computer simulations showed that $F_V < F_A$ when chewing begins, bolus formation starts when $F_V > F_A$, and swallowing occurs when $F_V - F_A$ is at a maximum, at some point between 15 and 30 chews.[15] Peyron et al. showed that particle size was a key factor (small for hard foods, larger for softer foods) and that a bolus had to have a precise and predetermined texture before it could be swallowed.[31] Investigations on the rheology of oral processing and swallowing of food have provided some data on shear rates and swallowing speed, but studies have been hampered by a lack of instrumentation.[6] More research will be attempted as this issue is addressed.

■ ACCEPTABILITY

Every food product developer, processor, or preparer aims to meet consumer expectations. The acceptability of various textures depends on various factors including the following:

- Age. Young children have problems with textures that are difficult to manipulate,[32] and the elderly may be unable to chew food properly.[33]
- Contrast. Most people prefer a variety of textures within a large meal.[34]
- Culture. The most preferred textural characteristics of Americans are crispy, crunchy, firm, juicy, and tender.[34] Among Japanese the list includes crispy, crunchy, hard, soft, and sticky.[35]
- Disgust. Slimy, gooey, and mushy foods have been correlated with adverse textural properties.[36]
- Expectation. Consumers will not tolerate food that does not exhibit the texture they expect, even if the flavor is satisfactory.[34]
- Physical activity. Energy snacks are usually firm or chewy, but soothing snacks such as ice cream should be creamy.[1]
- Physiology. Stringy, slick, and sticky foods may be hard to control in the mouth.[34]
- Time of day. Familiar, easily consumed textures are preferable at breakfast, whereas dinner invites experimentation.[34]

Research on acceptability continues as the above factors are addressed. For instance, food products are being tailored to older people with decreased sensory capabilities by enhancing flavor and having an appropriate texture.[27]

Although sometimes taken for granted, texture is as much a part of the enjoyment of eating as flavor. A multidisciplinary approach is essential for understanding food texture. The relationships between objective measurements, sensory perception, and consumer preferences need to be addressed as research continues in the 21st century.

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