FOOD TEXTURE AND PERCEPTION

By

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To the Faculty of Washington State University:

The members of the Committee appointed to examine the dissertation of MAITE ANDREA CHAUVIN find it satisfactory and recommend that it be accepted.

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FOOD TEXTURE AND PERCEPTION

Abstract

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The most complete system of sensory texture determination is the General Foods Sensory Texture Profiling Technique (Brandt et al. 1963; Szczesniak et al. 1963). The first objective of the current research was to validate, through a multidimensional (MDS) representation, the standard texture scales presented for select foods in the General Foods Sensory Texture Profiling Technique. MDS is highly instructive in quantitatively assessing the perceptions of naive panelists' qualitative textural differences of food, as well as a good statistical instrument to graphically validate existing food texture scales. The selected textures of standard foods were rated similarly using MDS and food standard texture scales.

The second objective was to study the sensory textural attributes of apples and pears, and the relationships between human sensory perception, instrumental firmness, and tensile material properties of apples and pears. Significant correlations were observed among the sensory texture attributes of crispness, firmness and fracturability for

apples and pears (r > 0.88). Differences in juiciness perception of apples and pears were attributed to differences in cell structure. When correlating sensory to instrumental determinations, the Sinclair iQ™ System texture assessment tool provided acceptable correlations of apple firmness (r = 0.79 to 0.82). Guss pressure sensor provided significant correlations of apple (r = 0.78 to 0.83) and pear (r = 0.83) firmness. Tensile determinations predicted crispness in apples (r = 0.88) and pears (r = 0.85) well.

The third objective was to establish a standard texture scale for dry and wet crisp, crunchy, and crackly foods. The relationship between acoustical and oral sensation of crispness, crunchiness and crackliness of selected standard foods was also evaluated. A consumer study of the newly developed texture scales was validated through MDS. The developed standard scales for crispness, crunchiness and crackliness for dry and wet foods provide individuals interested in auditory texture evaluation a starting point to assist in training panelists in descriptive analysis of food texture. MDS output demonstrated that crispness, crunchiness and crackliness are distinguishable sensory texture attributes that belong to selected discernible concepts and may be accurately recognized by the sole presence of auditory cues.

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DEDICATION

This work is dedicated to my husband Fariss for his patience, love, and care. I also dedicate my work to my parents for their encouragement and endless support.

My mother drew a distinction between achievement and success. She said that 'achievement is the knowledge that you have studied and worked hard and done the best that is in you. Success is being praised by others, and that's nice, too, but not as important or satisfying. Always aim for achievement and forget about success.'

By Helen Hayes (1900 - 1993)

Chapter One

INTRODUCTION

LITERATURE REVIEW

The following literature review is organized in association with each chapter:

1. Texture

Texture in food is difficult to define for many scientists since texture means different things to different people. Muller (1969) claimed that the term texture may be discarded because is confusing. Muller (1969) suggested that texture terminology usage may be divided into two terms in place of the word texture: "rheology" defining the physical properties of food, and "haptaesthesis" defining the perceptions of the mechanical behavior of materials.

Szczesniak (1990) wrote "texture can be defined as a sensory manifestation of the structure of the food and the manner in which this structure reacts to applied forces, the specific senses involved being vision, kinesthetics and hearing." The International Organization for Standardization (Standard 5492, 1992) wrote "Texture is a noun that comprises all the mechanical (geometrical and surface) attributes of a food product perceptible by means of mechanical, tactile, and, where appropriate, visual and auditory receptors." The British Standards Organization (No 5098) defines texture as "the attribute resulting from a combination of physical properties perceived by the senses of kinesthesis, touch (including mouth, feel, sight and hearing). The properties may include size, shape, number, nature, and conformation of constituent structural elements." Other authors such as Bourne (2002) stated "the textural properties of a food are that group of physical characteristics that arise from the structural elements of the food, are sensed primarily by the feeling of touch, are related to the deformation, disintegration, and flow of the food under a force, and are measured objectively by functions of mass, time and distance”.

2. Texture Profile Analysis and Standard Scales of Texture

The texture profile panel is a powerful instrument that can reliably determine the textural attributes of food products. The texture profile panel allows investigators to relate the way the food behaves in the mouth rather than only obtaining selected chemical and physical properties of food. The use of standard terminology, standard reference foods, and standard evaluation procedures in texture profile methods makes texture profile panels great objective assessing tools of sensory data (Civille and Szczesniak, 1973). The texture profile method is widely used for many applications in the food industry including food product development and quality assurance (Civille and Szczesniak, 1973).

The sensory texture profile method was developed from the A. D. Little Flavor Profile Method as a protocol based on the order of appearance of texture attributes (Brandt et al., 1963). The order of appearance relates to the chronological order in which the various attributes of foods are perceived (General Foods Corp., 1967). A texture profile is defined as “the sensory analysis of the texture 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 to complete mastication” (Brandt et al., 1963).

The texture profile analysis requires a panel of judges with prior knowledge of the texture classification system, use of standard rating scales, and appropriate panel procedures with regards to the mechanics of testing and food presentation (Brandt et al., 1963).

Szczesniak (1963) classified texture attributes in three categories. First are the mechanical characteristics related to the reaction of food to stress. Second are the geometrical characteristics related to the shape, size, and arrangement of particles within a food. Finally, are other characteristics related to the moisture and fat content.

The standard rating scales provide a method of correlating sensory and instrumental (texturometer) evaluations of texture (General Foods Corp., 1967). A trained sensory panel includes practice in the use of scales to reinforce the perception of the mechanical and geometrical characteristics of food. Standard scales are developed to identify each of the mechanical characteristics of texture: hardness, fracturability, chewiness, gumminess, viscosity and adhesiveness, and provide a defined, quantitative method of texture evaluation (Szczesniak, 1963). The standard scales represent the full range of a specific mechanical parameter as it is encountered in foods (Civille and Szczesniak, 1973). Geometrical characteristics are difficult to classify in a specific scale. There are, however, two general groups of geometrical characteristics: geometrical characteristics related to the size and shape of the particles such as gritty, grainy or coarse, and geometrical characteristics related to the particle shape and orientation such as fibrous, cellular or crystalline. Evaluation of the geometrical characteristics of foods is qualitative and semi-quantitative. Geometrical characteristics are evaluated as to type and amount present. Standard scales help panelists build confidence, and provide practice in perception and discrimination during the training process (General Foods Corp., 1967).

In texture profiling, it is necessary to standardize the technique of determination, handling and presentation of the foods. Each panelist must evaluate the foods in identical manner, and the replicate foods presented to panelists must be reproducible (Civille and Szczesniak, 1973). The first bite, or initial phase, encompasses the mechanical characteristics of hardness, fracturability, viscosity, and any geometrical characteristics observed initially. The second, or masticatory phase, encompasses the mechanical characteristics of gumminess, chewiness, adhesiveness, and any geometrical characteristics observed during chewing. The third, or residual phase, encompasses changes induced in the mechanical and geometrical characteristics through mastication (General Foods Corp., 1967). Procedures for evaluating texture are presented in Figure 1.

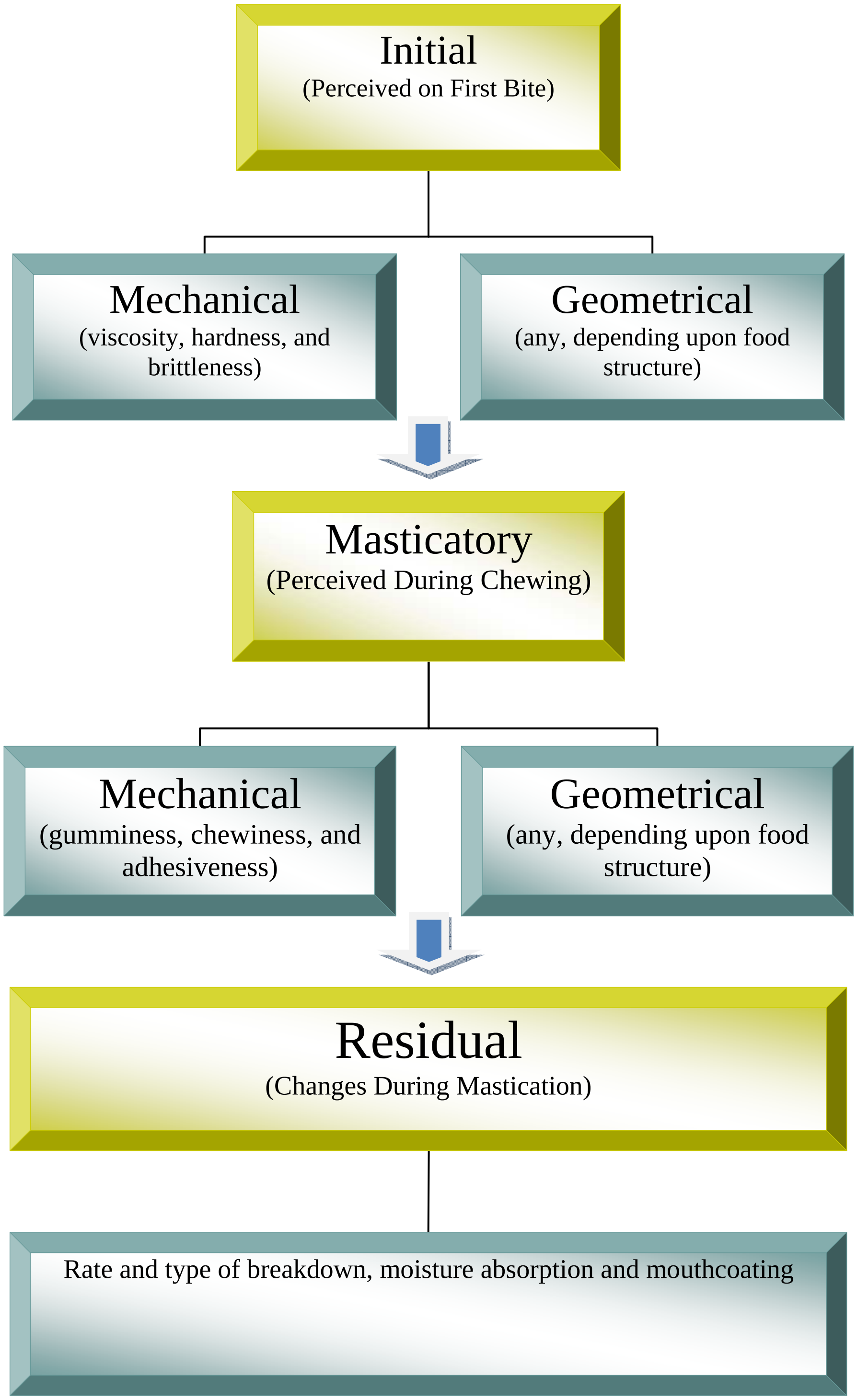

Figure 1: Procedures for evaluating Texture (Brandt et al., 1963)

The consistency of the panel performance will depend on three factors: the reliability of the trained panel as a whole to reproduce the whole panel findings from one evaluation to another; the ability of an individual panelist to replicate the panelists' findings from one evaluation to another, and the ability of the panelists to agree with one another. The panel performance can be determined through the use of blind controls and duplicate samples, regular review of panel results, and the presence of a good panel leader (Civille and Szczesniak, 1973).

The texture profile method is used to characterize sensory textural attributes of fruits. Paoletti et al., (1993) used a modified version of the texture profile method on selected apple cultivars to characterize textural attributes such as firmness, fracturability, cohesiveness, juiciness, and mealiness, and relate them to the mechanical properties of fruit. Abbott et al., (1994) investigated apple texture using sensory data evaluated as crisp, hard, tough, mealy, spongy, and juicy and developed a relationship with a modified version of the Instron texture profile analysis. Diehl and Hamann (1979) used texture profile analyses to characterize the sensory properties of raw potatoes, melons and apples, and related them with uniaxial compression and torsion methods.

3. Multidimensional Scaling

Multidimensional scaling (MDS) is a set of techniques designed for the statistical analysis of the degree of similarity or dissimilarity of experimental data on a set of objects (Borg and Groenen, 1997). MDS mathematical techniques enable a scientist to discover the "hidden structure" of data. MDS calculations use proximities among objects of any kind as input.

A proximity is a number that predicts perception of similarity or difference between two objects (Kruskal and Wish, 1978). MDS techniques represent objects judged as similar to one another as points close to each other in a resultant spatial map. Objects judged as dissimilar are represented as points distant from one another in a spatial map (Schiffman et al., 1981). The MDS graphical representation or spatial map allows the data analyst to interpret the data and explore panelists' perceptions visually (Borg and Groenen, 1997).

A common procedure for obtaining proximities data is to ask individuals to directly judge the "psychological distance" among stimulus objects. To discover rather than impose the dimensions, the attributes on which the stimuli are judged are usually not specified (Kruskal and Wish, 1978).

An advantage of MDS procedures is the small experimenter contamination. Panelists do not require prior knowledge of the attribute of the stimuli evaluated. MDS data provide a special context that reveals dimensions relevant to the subjects (Schiffman et al., 1981). Another advantage of MDS is its wide functionality. MDS represents similarity or dissimilarity data as distances in low-dimensional space to make data accessible to visual inspection and exploration. MDS is used as a technique allowing the experimenter to test if and how certain criteria by which the experimenter can distinguish among different objects of interest are mirrored in corresponding empirical similarities or differences of these objects. MDS is also a data-analytic approach that allows discovering dimensions that underlie judgments of similarity or dissimilarity.

The primary disadvantage of MDS is that such analytical techniques are often time consuming and expensive (Schiffman et al., 1981). A number of researchers have explored alternative data collection procedures for MDS modeling, some of which are less time consuming and fatiguing than pairwise similarity ratings. Alternative data collection procedures include sorting data and confusion measures (Lawless et al., 1995).

MDS calculations are complex and are difficult to perform without the aid of a computer. A variety of computational programs are used (Kruskal and Wish, 1978). Each program is capable of performing a wide variety of analyses, all of which are generically known as Multidimensional Scaling. Some example programs used for MDS applications are Minissa, Polycon, Kyst, Indscal, Sindscal, Alscal, Multiscale, etc. (Schiffman et al., 1981).

MDS is a robust technique that is used by researchers to assess visual, auditory, taste and olfactory stimuli (Drewnowski, 1984). In food sensory science, one approach to modeling the qualitative variation among sets of foods is to determine food similarity and submit the data to MDS analysis. Lawless et al. (1995) created perceptual maps of cheeses with the aid of MDS. MDS procedures were used to asses flavor perception and taste preferences of eight non-diet sodas judged by obese and normal weight sensory panelists (Drewnowski, 1984). Odor perception of six groups of panelists with varied experience and training in odor evaluation were examined using MDS (Lawless and Glatter, 1990). Auditory perception of crispness, crunchiness, and crackliness was examined in selected foods with the aid of MDS (Vickers and Wasserman, 1979). Zraick et al. (2000) demonstrated through MDS studies of voice perception that perception of normal voice quality is multidimensional.

MDS is a statistical procedure that provides a perceptual map of differences and similarities of stimuli based on the perceptions and interpretations of sensory panelists.

MDS is a powerful methodology that is valuable in assisting scientists to gain important unique understanding of human behavior.

4. Texture of Fresh Fruit

4.1 Fruit Texture

Szczesniak (1963) divides textural parameters into three categories: mechanical, geometrical, and other characteristics (moisture and fat). Studies of fruit texture focus primarily on the mechanical properties of the fruit tissue. The few studies on the geometric properties of fruit tissues, such as grittiness in pear, were conducted by fruit breeders (Bell and Janick, 1990) or as part of sensory studies (Diehl and Hamann, 1979; Stec et al., 1989). An increasing emphasis on the assessment of juiciness in fruits was also reported recently (Szczesniak and Ilker, 1988; Harker et al., 2006).

The complex nature of fruit is related to the variety of attributes required to fully describe textural properties of fruits and the textural changes that occur as fruit ripens. The lexicon for sensory texture attributes for fruits include: crispness, crunchiness, ease of breakdown, fibrousness, flouriness, graininess, grittiness, hardness, juiciness, mealiness, pastiness, pulpiness and starchiness (Harker et al., 1997). The physiological, genetic, biochemical nature of living tissues is important to an understanding of the complexity of the ripening process in fruit (Dilley et al., 1993).

4.2 Fruit Anatomy

The flesh in fruits is primarily composed of parenchyma cells that exhibit thin, non-lignified cell walls and large vacuoles that contain 90% of the water in the cell (Pitt, 1982). The walls of the adjacent cells are separated by the middle lamella, rich in pectin

(Huber, 1993). The texture of the fruit depends of the cell size, cell shape and packing, cell wall thickness, cell wall strength, cell turgor pressure, and cell-cell adhesion (Harker et al., 1997).

The skin in fruits varies in size and complexity depending on the mechanical properties of each fruit. In fruits such as apples and pears, the skin is consumed and imparts different textural characteristics than other fruits with inedible skins. Edible skins are considered simple and are composed of tightly fitting epidermal cells coated with wax layers. Beneath epidermal layers of cells are layers of hypodermis cells, which are smaller than the epidermal cells. In other fruits, such as melons or oranges, the skin is inedible due to the thickness and presence of collenchyma, sclerenchyma, and lignin impregnated cells (Harker et al., 1997).

Seeds in apples and pears are located in the interior of the flesh, called the core. The core is associated with the central tissue and contains seeds, seed cavities, and sclerified lining and vascular strands. Seeds associated with the core tissue are inedible and are avoided during eating (Harker et al., 1997).

Cell size and packing patters determine the volume of intercellular space, which influence cell adhesion by determining the extent of cell to cell contact. Very limited cell to cell contact occurs in ripen apples (Reeve, 1953). An increased cell wall thickness and decrease in cell size increase the strength of the fruit tissue. Cell size and cell wall thickness influence juiciness through their effect on packing of liquids. There is a good correlation between large cells and increased juiciness in fruits (Szczesniak and Ilker, 1988).

The strength and texture of fruit tissues are related to the mechanical properties of cell walls, the turgor of cells and the strength of bonds between adjacent cells. The mechanical properties of cell walls of fresh fruit are determined by a mixture of pectic, hemocellulosic, and fibrous cellulose polysaccharides. Also, cell wall properties differ depending on the calcium content, enzymatic hydrolysis and turgor of the cells. Cell wall properties confer plasticity, enabling a cell to expand as the cell enlarges during maturation, and rigidity confers strength and cell shape to the fruit. Cell wall breakdown results in a marked effect on texture changes such as fruit softening (Harker et al., 1997).

The excess of turgor or internal pressure of cells imparts a hydrostatic component to cell tissue strength and increases the brittleness of the cell wall. Turgor pressure is influenced by the membrane permeability, the osmotic gradient across the primary cell wall, and the cell wall expansion and contraction (Harker et al., 1997). Cell turgor is an integral part of fruit softening. As turgor decreases during the maturations process, the fruit softens. The turgor of cells in freshly harvested apples may contribute to the softening of fruit associated with the increasing separation of individual cells during storage (Harker and Hallett, 1992).

The way cells separate or break open and release cell contents is one of the most critical mechanical factors influencing fruit texture. Cell disruption and release is determined by the strength of the cell wall relative to the strength of the bonds between adjacent cells. Both are expected to decline as fruit ripens and softens. The strength of the bonds between cells is influenced by the strength of the middle lamella, the area of cell to cell contact, and the extent of plasmodesmatal connections (Harker et al., 1997).

4.3 Food-Mouth Interactions

An understanding of the physiology of the mouth and the occurrence of food breakdown during chewing is important to the perception food texture. The shape, size, texture, orientation and mechanical properties of food are perceived by the lips, tongue, teeth and jaw. When food is placed in the mouth, the teeth reduce the food to a size and shape that allows flow to the gut, which allows for bacterial hydrolysis (Harker et al., 1997). Additionally, saliva that is released and mixed with the food initiates digestion and alters overall texture of the food to facilitate swallowing (Jenkins, 1978).

The mouth is very sensitive to textural properties of food during biting and chewing. The speeds of the mouth determined during chewing are faster than speeds used during instrumental testing. Texture determinations alone performed by instruments may not simulate biting or chewing events occurring in the mouth well (Harker et al., 1997). During biting and chewing, the mandible moves in three directions: opening and lateral movement, protrusion and retrusion. The tongue is assisted by the muscles of the inner surface of the check and the lips manipulate the food and aid sensory perception of food. As food is chewed, saliva is induced to form a bolus for swallowing. (Beyron, 1964). Food is chewed and crushed by the molars. The forces necessary to chew decrease as moisture increases.

4.4 Consumer Awareness and Reasons to Determine Texture in Fruit

Consumer awareness and attitudes towards texture are affected by various factors. Szczesniak and Kahn (1971) reported that socioeconomic status, culture, gender, flavor intensity, and eating occasion influence consumers' perceptions of texture. Blindfolded panelists given pureed foods exhibited difficulty identifying pureed apples, strawberries and bananas. Difficulty in identifying pureed foods demonstrates that texture structures are essential for accurate food identification (Bourne, 2002). However, for most foods, texture is considered a minor component of sensory quality unless the texture does not meet expectations. Unexpected textures usually signal poor food quality (Szczesniak and Kahn, 1971).

Texture is very important to quality perception of food. The implication that fresh fruit is a flavor-predominant characteristic is no longer accepted. A consumer study conducted in the United Kingdom with 12 apple cultivars demonstrated that panelists preferred either a sweet, hard apple or an acidic, juicy apple (Daillant-Spinnler et al., 1996). In a study profiling aroma, flavor, and texture of Royal Gala apples, an increase in acceptability was observed when juiciness and crispness increased between 16 and 20 weeks of controlled atmosphere storage (Harker et al., 1997). Textural recognition with fruit is of critical importance to marketers of fruit, and there is a need for more research in this area.

4.5 Methods of Determining Texture in Fruits

A wide selection of fundamental, empirical, and imitative methods are available for determining fruit texture (Bourne, 2002):

- *Puncture tests*: Involve penetrating the fruit with a cylindrical probe with a convex tip. Examples are the Magness-Taylor, Effegi, Ballauf, Chatillon. Penetrometers are characterized by using a force determination instrument, rate of penetrometer movement into the food and a standard distance (Bourne, 2002).

- *Whole-Fruit Deformation:* Involves compressing an intact fruit between two parallel flat plates. This method involves deforming the fruit at a fixed distance and determining the force required to achieve the deformation (Bourne, 2002).
- *Tactile Assessment:* Squeezing fruit by hand is an important method for evaluation of texture quality. Human tactile sense is sensitive when fruits are relatively soft. However as fruit firmness increases beyond a threshold, individuals' discrimination among fruits becomes difficult. Tactile approach is not recommended with hard fruits such as apples and pears (Batten, 1990).
- *Shear and Extrusion:* A shear test for fruits can be conducted by obtaining a plug of tissue from a thin slice held between two rigid plates. The Kramer shear cell is the most frequently used method for determining the shear or extrusion properties of fruit tissue (Mohsenin, 1977).
- *Compression Tests:* Compression tests are usually applied to tissue excised from the whole fruit. A common test is the texture profile analysis where a bite size cube of tissue is compressed through two cycles between two plates or probes. The resulting force-distance curve is used to differentiate a number of food attributes: hardness, cohesiveness, adhesiveness, springiness, gumminess and chewiness (Bourne, 2002).
- *Beam Tests:* A cylindrical or rectangular fruit tissue is supported by pivots at both ends. A blunt blade, located between pivots, descends at constant speed so the fruit tissue bends and breaks. Beam tests are used to determine rupture force, shear, and elastic modulus of foods (Vincent et al., 1991).

- *Wedge Tests:* A sharp wedge is driven into a block of tissue and many elements can be determined from the force-distance curves (Vincent et al., 1991).
- *Tensile Tests:* Consist of securely fixing both ends of a fruit tissue into an instrument by either using clamps, cutting tissue into a shape which slots between sets of claws, or by gluing. Tensile tests allow scientists to examine fracture surfaces using a scanning electron microscope (Harker and Hallett, 1992).
- *Dynamic Tests:* Consists of deforming a tissue by applying a sinusoidal stress, usually between 0.1 and 500 Hz (Mohsenin, 1970).
- *Twist Test:* Consists of a rectangular blade fixed radially at its axis to a sharpened spindle. The fruit is impaled onto the spindle until the blade completely enters the flesh. The fruit is then twisted by hand or by an automated system. The twist tests allow scientists to determine tissue strength in different tissue zones by altering the length of the spindle (Studman and Yuwana, 1992).
- *Tissue Juiciness*: Generally, juiciness is characterized as percentage of juice released from a fixed weight of fruit tissue. A number of methods were developed utilizing homogenization, centrifugation or juice extractors (Szczesniak, 1987).
- *Auditory Recordings of Chewing Sounds:* Sound produced during biting and chewing can be recorded using a microphone pressed firmly against the ear and analyzed from amplitude-time plots (Edmister and Vickers, 1985).
- *Sensory Evaluations:* There are two types of sensory assessments: consumer and analytical panels. Consumer panels indicate preference or acceptability of a food. Analytical panels involve individuals trained to describe aroma, taste and texture

attributes of a product. Analytical sensory panels can be either difference tests or descriptive analysis techniques (Harker et al., 1997).

- *Electrical Impedance:* Electrical impedance spectroscopy is used to investigate the resistance of intracellular and extracellular compartments within plant tissue. At 50 Hz the resistance of the extracellular pathway is determined. Weakening of the cell wall is associated with changes in texture (Zhang and Willison, 1991).

4.6 Relationship between Instrumental and Sensory Determinations of Texture

Szczesniak (1987) recommended that instrumental determinations of texture may be established, depending on the accuracy and precision of the selected instrument to predict sensory texture attributes. Szczesniak (1987) determined correlations between instrumental and sensory measurements of food texture to satisfy the desire of the food industry for quality assurance instruments to predict consumer responses, to understand the textures being perceived in sensory assessment, and to develop instrumentation that will accurately replicate sensory evaluations. Szczesniak (1987) emphasized that the range, selection, and diversity of texture attributes in the assessment of food texture, as well as the scale and appropriateness of the comparison among foods, must be considered before correlating instrumental and sensory data.

Numerous studies examined the relationship between instrumental and sensory measurements on apples (Diehl and Hamann, 1979; Abbott et al., 1984; Richardson, 1986, Paoletti et al., 1993). Many studies report good correlations ($r > 0.8$) between firmness, crispness and instrumental determination with puncture (Abbott et al., 1984), sensory evaluation (Brenan et al., 1970), shear and extrusion (Hard et al., 1977), whole fruit compression (Abbott et al., 1984) and tensile tests (Holt and Schoorl, 1985). While significant correlations were reported between many mechanical and sensory assessments of texture, variation of fruit cultivars between seasons and during the storage period resulted in some problems due to the non-homogeneous distribution of the results.

5. Sensory Perception of Crisp, Crunchy and Crackly Textures

5.1 Structural Properties of Food with an Auditory Component

Food structure is fundamental to the production of sound during the biting and chewing of food. Food texture attributes such as crispness, crunchiness and crackliness are greatly influenced by the arrangement of the cells, chemical bonds, cracks, and impurities in the food (Al Chakra et al., 1996). Foods producing a perceivable auditory response may be divided into two groups: dry and wet crisp foods (Edmister and Vickers, 1985).

Fruits and vegetables are wet crisp foods because they contain fluid within cells. Fruits and vegetables are composed of turgid cells with elastic cell walls. An increase in turgidity is associated with an increase in crispy, crunchy, and crackly sounds. Turgidity occurs when the fluids inside the cell press outwards on the cell wall, while the cell wall presses inwards. Turgidity in wet food is characterized by strength and elasticity. During biting or chewing of the food the contents of the cell expand rapidly, and when released, a sound wave is produced. The resulting sound is responsible for the perception, not only of crispness, but also crunchiness and crackliness (Vickers and Bourne, 1976).

Dry crisp foods are cellular foods that contain air within the cells. Foods such as chips and biscuits contain air filled cavities with brittle walls. During biting or chewing the brittle walls bend and break. The remaining fragments of the cells produced during breakage snap back to their original shape and emit vibrations resulting in sound emission. The sound emission results in the perceptions of crisp, crunchy and crackly sounds (Vickers and Bourne, 1976).

Sound attributes in foods are at a maximum during the first bite. The decline or absence of sound is observed as chewing progresses (Lee et al., 1990). Sound perception is also influenced by length, width, and thickness of the food (Al Chakra et al., 1996). The perception of crispness, crunchiness and crackliness for both wet and dry foods declines as mastication and saliva hydration progresses.

5.2 Perception of Sound

Sounds produced during biting or chewing foods are detected by air conduction and by bone conduction. Air conduction sounds are perceived directly through the ear. Air molecules vibrate across molecules, producing sound waves that travel through the auditory canal. Vibrations reaching the eardrum activate the movements on the ossicles on the drum membrane, transferring the sound into the inner ear. The inner ear is responsible for the perception of loudness and pitch of the sound (Kinsler and Frey, 1962).

Bone conduction sounds are transmitted through the mandible bones, cheeks and tongue into the ears. Bone conducted sounds are perceived as a higher frequency when chewing with the mouth closed rather than opened, and exert a dampening effect on the sound. Because of the differences in sound contribution between air and bone, the two sounds must be combine and equalize in order to fully quantify the acoustic sensations produced by crisp, crunchy or crackly foods (Vickers and Borne, 1976).

5.3 Sensory Studies

Sensory evaluations of crispness, crunchiness and crackliness are reported by Jeon et al., 1975; Vickers, 1984a; 1984b; Seymour and Hamman, 1988; Szczesniak, 1988; Dacremont, 1995; Harker et al., 1997; Vincent et al., 2002; Duizer and Winger, 2005; and Dijksterhuis et al., 2005. Sensory evaluations were performed with trained and untrained panelists. Consumer evaluations with untrained panelists are reported using magnitude estimation (Vickers and Wassermann, 1979; Vickers, 1981; Christensen and Vickers, 1981; Mohamed et al., 1982; Edmister and Vickers, 1985). Trained panelists' evaluations are focused on descriptive analysis where panelists are asked to reach a consensus about the meaning of selected texture attributes. Thus, in some evaluations verbal definitions were developed to identify the attributes crispy (Table 1), crunchy (Table 2), and crackly (Table 3). Crispy, crunchy and crackly definitions exhibit only moderate agreement and large variation in the perception of each attribute. Important aspects cited when defining crispness, crunchiness and crackliness are the structure of the intact food, sounds emitted at chewing or biting, force needed to crush the food, and collapse and appearance of the food at fracture (Roudaut et al., 2002).

Differences in definitions among trained panelists demonstrate that the perception and sensory evaluation of crispness, crunchiness and crackliness is not an easy process. The difference between a sensory attribute concept and its definition should be acknowledged (Roudaut et al., 2002). Also, studies conducted in several countries add difficulty in comparing results among sensory studies. Drake (1989) indicated that crispness may be described as having more than one equivalent term in other languages. Also, even if a term exists in more than one language, the phrase may not express equivalent meaning in all languages. The lack of standardization in the procedures implementing sensory studies adds difficulty to the understanding of crispness, crunchiness and crackliness. Further research must standardize sensory evaluations to improve consistency in the outcomes of the studies.

Table 1: Definitions of Crispness

Definition	Technique	Reference
Relative force required to bite through the food.	Biting with front teeth	Jeon et al., 1975
Foods that produce a high pitched sound	Biting with front teeth	Vickers, 1984b
First Bite: place the food between the incisors, bite through and evaluate the level of high pitched noise.	Biting with front teeth	Seymour and Hamman, 1988
Firm and brittle, snaps easily, emitting a typical frequency sound upon deformation.	N/A	Szczesniak, 1988
The perceived relative force used by crunching the food in the mouth.	Molars	Onwulata and Heymann, 1994
The perceived force with which the food separates into two or more distinct pieces during a single bite with the incisors. An abrupt and complete failure of the food is required	Incisors first bite	Barrett, 1994
Foods that produce a high pitched sound. with a frequency higher than 5 kHz, especially for air conduction sounds	Only incisors, or bitten and chewed	Dacremont, 1995
The amount and pitch of sound generated when the sample is first bitten with the front teeth.	Front teeth bite	Harker et al., 1997
A combination of the noise produced and the breakdown of the food as bitten through entirely with the back molars.	Biting with the back molars	Duizer et al., 1998

Fractures in an abrupt manner after applying a relatively small force on the food.	Front teeth, first bite	Vincent et al., 2002
Fracture in an abrupt, brittle manner after applying a relatively small force on the food on the first chew with the molars.	Molars, second bite	Vincent et al., 2002
Cracks, you can force your teeth through slowly, more airy than crackling	At first bite	Dijksterhuis et al., 2005
Soft sound, more airy than crackling. Association with freshness. Disintegrates into pieces smaller than when crackling.	During chewing	Dijksterhuis et al., 2005
A combination of the type of sound i.e., short snapping and longer cracking sounds and the force to bite and chew as perceived on the first bite.	First bite	Duizer and Winger, 2005

Table 2: Definitions of Crunchiness

Definition	Technique	Reference
The perceived hardness of a food after it is crushed and chewed in the mouth 2-3 times. Also defined as the amount of force necessary to crush and grind the cube during the second and subsequent chews.	Chewing with molars	Moskowitz et al., 1974
Foods that produce low pitched sounds, are less loud and last longer than for crisp. Firm and brittle. Snaps easily with typical sound.	Chewing with molars	Vickers, 1984b
Degree of low pitched noise (with respect to crisp sounds) but above threshold pitch considered too low.	Place sample between molar teeth	Seymour and Hamman, 1988
Complex failure mechanism that involves repetitive deformation and fracturing of cell structure. Necessary are structural subunits, especially with cells, with brittle cell walls. Continuous fracture during chewing. Sensory description: the perceived intensity of repeated incremental failures of the food during a single complete bite with the molar teeth.	First bite with molars	Barrett, 1994
The perceived cumulative intensity of force required for repeated incremental failures of the food by chewing up to five times with the molars.	Chewing with molars	Guraya and Toledo, 1996
The amount of noise generated when the food is chewed at a fast rate with the back teeth.	Chewing with back teeth	Harker et al., 1997
Products that produce low pitched sounds with a characteristic peak on frequency range 1.25 to 2 kHz, for air conduction.	Only incisors, or bitten and chewed	Dacremont, 1995

Temporal aspects of the sensory feedback during mastication are important for the crunchy sensation. Crunchiness is independent from hardness.	Chewing with molars	Brown et al., 1998
Crunchy would be associated with a hard and dense texture that fractures without prior deformation producing a loud, low-pitch sound that is repeated during several chews. It was suggested that crunchy is more relevant to fruits and vegetables than crispness.	Mainly during chewing	Fillion and Kilcast, 2001
Fractures after applying a higher force on the food than for crispness.	Front teeth, first bite	Vincent et al., 2002
Fractures after applying a higher force on the food than for crispness on the first chew with the molars.	Molars, second bite	Vincent et al., 2002
High pitched sound, light sound, longer sounding.	During chewing	Dijksterhuis et al., 2005

Table 3: Definitions of Crackliness

Definition	Technique	Reference
To make small, sharp, sudden and repeated noises.	At first bite or during chewing	Vickers, 1984a
Foods that generate low pitched sounds with a high level of bone conduction. Discrimination between crackly and crunchy foods could be due to vibrations propagated by bone conduction that also generate vibrotactile sensations.	Only incisors	Dacremont, 1995
Combination of sound and bite force. Clip between the teeth and it breaks. Crackling is harder than crispy.	At first bite	Dijksterhuis et al., 2005
Audible for a long period during chewing, large pieces of food, mainly of the crust	During chewing	Dijksterhuis et al., 2005

5.4 Acoustic Studies

The association that acoustic sensations have with the perception of texture was reported for crisp, crunchy and crackly foods (Drake, 1963; Kapur, 1971; Vickers and Bourne, 1976; Vickers, and Wasserman, 1979; Vickers and Christensen, 1980; Vickers, 1981; 1983; 1984a; 1984b; 1987a; 1987b; Dacremont et al., 1991; 1995; Zampini and Spence, 2004). Two primary approaches were developed to study the relationships between texture of food and sound. The first approach involves recording the sounds produced during application of a force to a food to obtain quantitative information regarding the crisp and crunchy sounds (Drake 1963; Kapur 1971; Vickers and Bourne 1976; Edmister and Vickers, 1985; Vickers 1985; Seymour and Hamann 1988; Dacremont et al., 1991). The second approach consists of assessing the panelists' perceptions of air-conducted sounds to study the involvement of sounds produced when eating food to perceptions of crispness, crunchiness or crackliness (Christensen and Vickers 1981; Vickers and Wasserman, 1979; Vickers, 1980; 1981; 1984a, 1984b). Both acoustic approaches, combined with mechanical force-deformation techniques, more adequately describe the sounds resulting from biting or chewing foods than either approach alone (Vickers 1987a; Szczesniak 1988).

In the first approach, acoustic recordings are used to record sounds associated with crispness, crunchiness and crackliness of eating foods. Numerous studies using amplitude-time plots are reported and correlated to sensory determinations of crispness, crunchiness, and crackliness. Drake (1965) inferred that the higher the amplitude of the amplitude time plot, the crisper the food. Drake (1965) concluded the amplitude of the sound emitted during biting toasted bread increased as the degree of toasting increased.

Edmister and Vickers (1985) concluded that a combination of the mean height of the peaks x the number of peaks is a better predictor of crispness for dry and wet crisp foods than other parameters such as number of sound bursts, duration, mean height peaks x number of sound bursts, mean height peaks x number of sound bursts/thickness. Seymour and Hamann (1988) studied the effect of sound pressure in the perception of crispness and crunchiness in potato chips and reported that potato chips with a low water activity exhibited a higher mean sound pressure than potato chips with a high water activity. Seymour and Hamann (1988) concluded the sound produced during chewing of the potato chips was louder at low water activities than at higher water activities.

The Fast Fourier Transform (FFT) method is used to characterize the most evident frequencies during biting and chewing of foods. Comparison of the predominant frequencies resulting from biting and chewing crisp, crunchy and crackly is possible with FFT. The biting or chewing of crunchy and crackly foods is characterized by a sound in frequency range between 1.25 and 2 kHz. A large volume of bone conduction is evident when eating crackly foods and absent when eating crunchy foods. Consumption of crispy foods is characterized by sound with frequencies greater than 2 kHz (Dacremont, 1995). Tesch et al., (1995) determined the role of fractal analysis in mechanical and acoustical perception of crunchy foods and reported mechanical acoustical signatures of cheese balls and croutons, concluding that fractal analysis is potentially useful in calculations to assess auditory and mechanical perception of crunchy foods.

The second approach focuses on the contribution of air conducting sounds to crisp, crunchy and crackly textures resulting from biting and chewing selected foods. There are currently two techniques used: oral determination of air conducting sounds

(Vickers and Christensen, 1980; Christensen and Vickers, 1984) and auditory determination of air conducting sounds (Vickers and Wasserman, 1979; Vickers, 1985). The oral technique consists of asking panelists to bite or chew the food and evaluate the sound produced. The auditory technique involves playing prerecorded sounds of food and asking panelists to evaluate the food sound properties. Techniques are sometimes used together (Edmister and Vickers, 1985; Vickers, 1981). The information obtained from air conducting eating sounds is useful for development of standardized terms to describe crisp, crunchy and crackly foods (Szczesniak, 1988).

Even though air-conducting sounds impact the perceptions of crispness, crunchiness and crackliness, it is possible to evaluate them without the contribution of air conducting noise. Christensen and Vickers (1981) reported that panelists differentiated crisp foods when an auditory block was put in place during tasting foods. Christensen and Vickers (1981) concluded that accurate perceptions of crispness involved a vibro tactile acoustic sensation.

Snap, compression, and puncture tests are used as instruments to objectively determine the stimuli that produce textural sensations during food mastication (Al Chakra et al., 1996; Vickers and Christensen, 1980; Seymour and Hamann, 1988; Vickers, 1987; Mohamed et al., 1982). Although correlations exist between acoustic determinations and crispness, crunchiness and crackliness, better relationships were observed when objective mechanical testing was combined with acoustic determinations of sounds produced during biting or chewing (Mohamed et al., 1982; Vickers, 1987; Seymour and Hamann, 1988).

Acoustic determinations are important for the appreciation of crispness, crunchiness and crackliness in foods. Through the use of a combination of acoustic and instrumental techniques or either technique alone, sensory science may potentially improve the understanding of the perceptions evolving from biting or chewing crisp, crunchy and crackly foods. (Duizer, 2001).

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Chapter Two

MULTIDIMENSIONAL REPRESENTATION OF THE STANDARD SCALES OF FOOD TEXTURE

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(Multidimensional scaling of texture)

ABSTRACT

The use of standard terminology, standard reference foods, and standard evaluation procedures for utilizing standard scales in texture profile methods makes them effective objective tools for assessing panelists in descriptive analysis. However, their use is often limited due to lack of availability of foods and the drift of scales over time. The objective of this study was to evaluate the standard texture scales developed by Szczesniak et al. (1963) for the classification of the textural characteristics of foods through the use of multidimensional scaling (MDS). The texture perceptions of foods by eleven panelists were evaluated using the standard texture scales of Szczesniak et al. (1963). Each scale was anchored by a series of representative standard foods that illustrated the intensity gradation of the subjective magnitude of the texture dimension under study: hardness, chewiness, gumminess, viscosity, adhesiveness, and fracturability. MDS was highly instructive in quantitatively assessing the qualitative textural difference perceptions of naive panelists ($r > 0.89$). The selected foods were rated similarly using MDS and standard texture scales.

PRACTICAL APPLICATIONS

MDS is an efficient tool for the analysis of sensory perception data. Using MDS, it is possible to corroborate food texture standard scales published many years ago and assay food texture more accurately today. Caution is necessary when assuming that standard scales developed in the past are as useful today as when were developed. The item drift theory hypothesizes that questions become less reflective of a concept over time for natural reasons. The purpose of this study was to use Multidimensional Scaling

to reproduce the original dimensions and original order of stimuli to analyze existing food textural scales for hardness, chewiness, gumminess, viscosity, adhesiveness, and fracturability.

Key Words: Multidimensional scaling, MDS, texture, standard scales, sensory perception.

INTRODUCTION

Szczesniak et al. (1963) developed a series of standard food texture scales for the mechanical properties of texture using common foods to represent selected textures within the entire range of characteristic texture intensities encountered in foods (Table 1). Using the standard texture scales developed by Szczesniak et al. (1963), Brandt et al. (1963) developed the descriptive analysis technique for food texture designated as the General Foods Texture Profile. The General Foods Texture Profile technique uses terminology to describe basic categories or classifications of food texture characteristics developed by Szczesniak (1963) for training texture profile panelists. The primary characteristics of the food texture profile technique are standardization, reproducibility, and correlation of texture attributes with instrumental determinations of food texture (Civille and Liska, 1975). The General Foods Texture Profile represents experimental design of an organized and structured study of food texture, specifically to "study the sensory analysis of the texture 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" (General Foods, 1967).

Evaluation of the mechanical characteristics of food texture is both qualitative and quantitative and may be assessed by the standard texture scales. Texture standard scales use category scaling to designate differences in textural attributes. In texture analysis, the category scale is used to represent intensity of the attribute, with the number of categories varying with the texture attribute scaled. For each texture attribute scale, the full range of the textural attribute is demonstrated using foods that possess a given texture attribute as a major property. The standard texture scales developed by Szczesniak et al.

(1963) are practical tools to demonstrate the principal range of texture for each specific texture attribute. Szczesniak scales are evolving and were modified throughout the years by a number of researchers including General Foods (1967), Civille and Liska (1975), Szczesniak (1975), and Munoz (1986). However, the initial publication by Szczesniak (1963) is considered a highly standardized reference system for food texture.

Szczesniak (1963) concluded that texture is a discernible sensory attribute of foods and that in some foods, such as meat, potato chips, cornflakes and celery, texture may be more important than flavor. The effectiveness of sensory panelists to distinguish and articulate mechanical texture characteristics such as hardness, viscosity, adhesiveness, fracturability, gumminess and chewiness of foods varies among individuals. The complexity of the human masticatory apparatus, cultural diversity, health status, age, sex and food preferences influence texture perception of foods among individuals. The use of Multidimensional Scaling (MDS) may elucidate differences among panelists by developing configurations of attributes' cognitive grouping and describing multidimensional plots that illustrate similarity and differences in attribute observations.

MDS is a mathematical technique that describes proximities among objects on a spatial representation or map (Schiffman, 1981). The MDS method assumes that subjective estimates of similarity or dissimilarity represent individual estimates of spatial comparisons between the two stimuli in a selected geometrical space of relatively small dimensions (Moskowitz, 1977). Foods assessed as similar are closer together on the spatial representation (map) than foods assessed as dissimilar. The MDS spatial configuration may provide insights into important textural dimensions of foods that may exist. MDS may also minimize experimenter influence and provide fewer constraints to sensory panelists than panelists' data from attribute rating scales (Schiffman, 1981).

MDS was previously used in visual, auditory, taste and olfactory research of foods (Moskowitz, 1976a, and 1976b; Schiffman, 1976; Drewnowski, 1984; Hellemann et al., 1987; .Lawless and Glatter, 1990; Bertino and Lawless, 1993; Lawless et al., 1994; Zraick et al., 2000). However, little research is published using MDS to interpret assessment of food texture.

Magnitude estimation and category scaling are frequently compared for the determination of sensory intensity for a variety of stimuli. Controversy in the literature exists regarding the relationship between both scaling techniques. Some studies suggest that magnitude estimation may provide a more accurate depiction of the true underlying psychophysical function than category scaling (Mcdaniel and Sawyer, 1981; Moskowitz, 1982; Cardello et al., 1982a). However, Birnbaum (1982) and Vickers (1983) report no particular advantage for magnitude estimation or category scaling techniques. Category scaling was selected over magnitude estimation in the present study to avoid confusion among panelists resulting from the large number of foods presented.

The objective of this study was to evaluate, through MDS, the standard food texture scales for hardness, chewiness, gumminess, viscosity, adhesiveness, and fracturability developed by Szczesniak et al. (1963).

MATERIALS AND METHODS

Panelists were recruited from Washington State University staff, students and members of the community and screened for allergies, dental conditions, and interest in participating in the study. Minimal information about the study was provided to the panelists to reduce potential bias. Eleven panelists, five males and six females between the ages of 23-54 years, participated in the study. Panelists were awarded a small compensation for participation in the experiment. None of the panelists expressed previous experience with texture evaluation of foods and were considered naive panelists.

Experimental foods were selected to represent the complete standard texture scales for hardness, chewiness, gumminess, viscosity, adhesiveness, and fracturability (Szczesniak et al., 1963). Due to unavailability of some foods, substitutions were selected, as described in Cardello et al. (1982a, 1982b). Food items, source, size, and serving temperatures are presented in Table 1.

Two four-hour sessions were conducted. At the beginning of each session, panelists were required to sign a written consent form to participate in the study. Panelists were also given a demographic questionnaire and oral and written instructions. The written instructions included both an operational definition of the textural attribute judged (Table 2) as well as instructions on the use of similarity judgments scales. As explained in the sensory texture profiling manual (General Food Corp, 1967), the first 30 min of each session were devoted to familiarizing the panelists with the scales and the technique used for assessing texture of experimental foods.

There were N*(N-1)/2 possible pairs of foods to compare for a set of N foods in each scale. Representative food pairs were presented to panelists in a room fitted with individual tables. Three standard texture scales were analyzed in each session. The standard scales for hardness, viscosity and adhesiveness were evaluated in session one. The fracturability, gumminess and chewiness standard scales were evaluated in session two.

Two standard foods were presented as paired comparisons, together with a ballot asking each panelist to quantitatively judge the textural similarity between the two foods. A similarity scale consisting of a 9-point scale with the words "exactly the same" at the high end (9), and "completely different" at the low end (1) was presented to each panelist. A separate ballot was provided for each paired comparison. Panelists rinsed their mouths with distilled water and/or unsalted crackers between foods and were permitted to take as many breaks as necessary to avoid fatigue. Once each panelist was finished with the first comparison, she/he was instructed to advance to the next comparison. The panelists were instructed to wait one minute between each pair of texture evaluations. Panelists were advised not to go back to review or modify any previous responses. A mandatory 15-minute break was imposed between standard scales.

Food pairs were presented in a random order, identified with three digit codes. Each food was presented uniformly as established by Szczesniak et al. (1963) and placed inside a 3 oz soufflé cup (Solo Cup Company, Urbana, IL). Each food pair was evaluated once by each panelist. A total of 36 paired comparisons for hardness, 28 for viscosity and 10 for adhesiveness were assessed in the first session. A total of 21 paired comparisons for fracturability, 10 for gumminess and 15 for chewiness were assessed in the second session.

Data Analysis

For each of the eleven panelists, one individual matrix was constructed from the pairwise similarity scores for each of the standard texture scales: hardness, chewiness, gumminess, viscosity, adhesiveness, and fracturability. Each cell within each individual matrix yielded a similarity score ranging from 1 to 9, quantifying perceived similarities in texture on the 9-point scale.

The eleven panelists' matrices were combined to yield one matrix for each standard food texture scale reflective of the mean group pairwise similarity scores. Every cell within each group matrix yielded a mean score for all foods on each standard food texture scale, reflective of the 9-point scale.

Data were analyzed as similarity estimates using SPSS Version 12.0 statistical analysis software (SPSS Inc., Chicago, IL) and on XLSTAT 7.5.4 (Addinsoft, Paris-France). MDS algorithm ALSCAL module for nonmetric multidimensional scaling was employed, using the option for minimizing Kruskal's stress Formula 1 two-dimensional solutions. Output from the scaling software program included an assessment of stress, quantifying the fit among the data and the scaling model, and R^2 values, calculating the variance among underlying data that accounted for the scaling solution (Zraick 2000).

RESULTS AND DISCUSSION

Multidimensional scaling was performed on each paired comparison for the six standard texture scales. Stress and R^2 values were calculated on the two-dimensional configuration. Stress and R^2 results are presented in Table 3. Stress values for the three-dimensional configuration of the six standard texture scales slightly improved compared with the two-dimensional configuration. Thus, further analyses of the six standard texture scales were performed in the two-dimensional configuration only. The mean stress values were small (< 0.13) for hardness, viscosity, adhesiveness, fracturability, gumminess and chewiness. R^2 values were correspondingly large (> 0.89). Small stress values and large R^2values reflect the accuracy of the MDS algorithm to fit calculated distances to the texture results in two dimensions. Well organized two-dimensional structures and agreement among the panelists for food texture analyses were observed.

MDS two-dimensional graphical representation of mean hardness of standard foods on the hardness scale (Figure 1) illustrated agreement with the original standard hardness scale (Table 4). Cream cheese was located at the softest point (smallest scale value) and lemon drops were located at the hardest point (largest scale value). The remaining foods were distributed between the soft and hard extremes, with a cluster observed at the "softer" end of the scale. Specifically, the texture of cream cheese, egg whites, frankfurters, cheese and olives were perceived as very similar to each other, potentially resulting in perceptual confusion by the panelists during evaluation. Good separation of peanuts, carrots, almonds and lemon drops were observed, similar to the original standard scale. Confusion in assessing the similarity among softer foods may be attributed to changes in the standard foods' formulations over time. However, with further training, confusion among softer textures could be minimized.

Figure 2 presents two-dimensional perceived means of the viscosity standard scale. Agreement between perceived viscosity means and the original viscosity standard scale was observed (Table 5). However, distinctions among the viscosities of heavy cream, light cream and evaporated milk were difficult among panelists, as they were perceived to be very similar to each other. Unfamiliarity of the panelists with the foods may account for these results. For instance, today evaporated milk is mainly used as an ingredient for numerous recipes and very few people know what it tastes like on its own. On the other hand, in the early 1960's, when the original scales were developed, evaporated milk was marketed as a coffee creamer and evaporated milk taste was more familiar. Using standard scales generated a number of years ago may result in the assumption that foods consumed many years ago are still in use or of equivalent use today.

MDS two-dimensional graphical representation of means of adhesiveness standard scale (Figure 3) presented little variability from the original standard scale (Table 6). The only inconsistency from the original standard adhesiveness scale was between the perception of Crisco as less adhesive than Velveeta processed cheese. The discrepancy was attributed to taste preference and inability of the panelists to hold the Crisco inside their mouths for a required amount of time.

Figure 4 illustrates the means of fracturability standard scale, which agreed with almost all points of the original fracturability scale (Table 7). Only peanut brittle was an outlier in the MDS graphical representation. Differences in peanut brittle formulation may be a source of variation in fracturability assessment.

MDS two-dimensional graphical representations for gumminess (Figure 5) and chewiness (Figure 6) coincide with their standard original scale, equivalent at all points (Tables 8 and 9).

The gumminess standard scale, comprised of selected concentrations of white flour and water, were well discerned by the panelists. Controlled food systems may reduce problems related to continuous changes or unavailability of food standards. Nonetheless, the advantage of multi-food standard scales is that frequently a given characteristic is perceived differently in selected foods. Converting food texture scales to a one-dimensional series may be undesirable because a simple dimension may distort illustration of diversified sensory perceptions of the mechanical parameters (Civille and Liska, 1975).

For many years, research with food texture implied that texture was a single concept and did not actively recognize that the perceptions of texture are the result of a number of parameters. Szczesniak (1963) categorized the textural parameters of foods as mechanical, geometrical and other (fat, moisture). Furthermore, terms identified as primary food texture attributes include hardness, adhesiveness, cohesiveness and springiness. Secondary food texture attributes are described as perceived combinations of two or more primary food textures and include fracturability, chewiness and gumminess.

The first dimension of MDS analyses, or food texture attribute, calculated for all standard texture scales represents specific mechanical parameters as a main textural property. For example, hardness represents the first dimension on the hardness scale. This is demonstrated by the fact that food items that represented the strength of a specific stimulus are located in similar geometrical space as their location on the standard food texture scale. The second dimension can be credited to hedonics or liking because panelists were considered naïve consumers. Panelists generally respond to odor and taste of food pleasantness or unpleasantness first, prior to classifying the texture parameter or intensity (Moskowitz, 1976b). The second dimension is also defined by texture descriptive terms containing perceived fractions of several attributes. As a result, secondary terms describe texture as combinations of two or more primary texture attributes. Perhaps no descriptor term relates to a "pure" texture attribute, but rather each term is a mixture of primary textural attributes, to a greater or lesser degree (Moskowitz and Kapsalis, 1975). Food items selected for the standard scales of texture possessed sensory attributes other than texture that may affect the perception of texture.

The spatial MDS representation for each standard texture scale coincided with the arrangement of each point presented on the food texture standard scales (Szczesniak et al., 1963). Occasional deviant points were observed and are attributed to factors such as sensory panelist adaptation, fatigue, or carry-over effects (Lawless et al., 1995. Also, depending on the geographical location of the panel, distribution of selected foods is limited, making it difficult for people to recognize the standard foods. Familiarity with the standard foods may also change over time and cultural differences may also influence the results. Other factors to consider when employing standard food scales is that many foods initially designated as standards are no longer available or the textural character changed as a result of reformulation or processing alterations (Civille and Liska, 1974).

In addition, procedures for texture evaluation adhere to rigid experimental controls to minimize variation in texture perception. The preparation, serving and presentation of the experimental foods must be consistent. Techniques for biting, chewing and swallowing experimental foods must also be standardized (Civille and Szczesniak, 1973).

Panelists with limited training and with little sensory evaluation experience may also influence the results in the MDS output. Cardello et al. (1982) demonstrated that trained and consumer panel judgments of texture differ significantly, primarily due to expanded perceptual ranges of trained panelists.

CONCLUSIONS

The contribution of Szczesniak (1963) to food texture evaluation constituted the first step in creating a rational tool for scientific description of food texture. A modification of the standard food texture scales may be necessary as challenges are encountered in its practical use, including the change of food formulations over time and food distribution limitations. However, more than forty years later, the initial standard texture scales are still in use, and Szczesniak (1963) represents a highly standardized and well defined reference system for training texture profile panels.

Multidimensional scaling is a strong exploratory statistical and graphical technique, effectively producing a graphical representation of overall similarity in food texture perceptions from sensory panelists. MDS is highly instructive in assessing naive panelists' perceptions of qualitative textural similarities of food and provides a high-quality statistical instrument to graphically validate existing standard scales.

Table 1. Standard Scales of Texture

Standard Hardness Scale

Scale value	Product	Brand or Type	Manufacturer	Sample size	Temp
1	Cream Cheese	Philadelphia	Kraft Foods	1 cm cube	45-55 ºF
2	Egg white	hard cooked (5 min)		1 cm tip	room
3	Frankfurters	large, uncooked	Oscar Mayers Beef	1 cm slice	50-65 ºF
4	Cheese	mild Cheddar	Kraft Foods	1 cm cube	50-65 ºF
5	Olives	stuffed	Safeway	1 olive pimento removed	room
6	Peanuts	cocktail type in vacuum tin	Planters Peanuts	1 nut	room
7	Carrots	fresh, uncooked		1 cm slice	room
8	Almonds			1 nut	room
*9	Hard Candy	lemon drops	Safeway	1 piece	room

Standard Fracturability scale

1	Corn muffin	made from mix	Jiffy	1 cm cube	room
2	Shortbread	Shortcake	Keebler	1 cm cube	room
3	Graham crackers	Nabisco	National Biscuit Corp	1/2 square	room
4	Melba toast	plain	Old London	1/2 square	room
5	Wheat thins	Nabisco	National Biscuit Corp	1 cm square	room
6	Ginger snaps	Nabisco	National Biscuit Corp	1/2 square	room
7	Peanut brittle	candy part	Safeway	1/2 square	room

Standard Adhesiveness Scale

1	Hydrogenated vegetable oil	Crisco	Proctor & Gamble Co	1/2 tsp	45-55 ºF
2	Velveeta	unsliced	Kraft Foods	1 cm cube	45-55 ºF
3	Cream cheese	Philadelphia	Kraft Foods	1 cm cube	45-55 ºF
4	Marshmallow topping		Kraft Foods	1/2 tsp	45-55 ºF
5	Peanut Butter	Skippy, Smooth	Best Foods	1/2 tsp	45-55 ºF

Standard for Gumminess Scale

1	40 % flour paste	Gold Medal	General Mills	1 tbs	room
2	45% flour paste	Gold Medal	General Mills	1 tbs	room
3	50 % flour paste	Gold Medal	General Mills	1 tbs	room
4	55 % flour paste	Gold Medal	General Mills	1 tbs	room
5	60 % flour paste	Gold Medal	General Mills	1 tbs	room

Standard Viscosity Scale

1	Water	distilled		1/2 tsp	45-55 ºF
2	Light cream	half and half	Lucerne	1/2 tsp	45-55 ºF
3	Heavy cream	table cream	Lucerne	1/2 tsp	45-55 ºF
4	Evaporated Milk		Carnation Co	1/2 tsp	45-55 ºF
5	Maple Syrup	natural maple syrup	Wheelers Maple Products	1/2 tsp	45-55 ºF
6	Chocolate Syrup		Hershey Chocolate Corp	1/2 tsp	45-55 ºF
7*	Mixture 1 1/2 cup condensed milk &1 tbl heavy cream		Nestle	1/2 tsp	45-55 ºF
8	Condensed milk	sweetened	Nestle	1/2 tsp	45-55 ºF

Standard Chewiness Scale

1	White bread	fresh, center cut	Safeway	1 1/2 cm cube	room
2	Frankfurter	large, uncooked, skinless	Oscar Mayers Beef	1 1/2 cm cube	50-70 ºF
3	Gum drops	spice drops	Safeway	1 piece	room
4	Licorice candy	red vines	American Licorice Co.	1 piece	room
5	Caramel		Kraft	1/2 piece	room
6	Tootsie Rolls	midget size	Sweet Co of America	1 piece	room

Szczesniak et al. 1967

* Substitute item. Reference Cardello 1982, Munoz 1986

Table 2. Definitions of the textural attributes of hardness, chewiness, viscosity, gumminess, adhesiveness, and fracturability (General Foods Corp, 1967)

Hardness	Perceived force required to compress a substance between the molar teeth
Chewiness	Total perceived work required to masticate a sample to reduce it to a consistency suitable for swallowing
Viscosity	Perceived force required to draw a liquid from a spoon over the tongue
Gumminess	Energy required to disintegrate a semisolid food product to a state ready for swallowing
Adhesiveness	Force required to remove product completely from palate, using tongue, after complete compression of the sample between tongue and palate
Fracturability	Force with which sample ruptures when placing sample between molars and biting down completely at a fast rate

Table 3. MDS Stress and R^2 for paired comparisons of texture scales

	Stress	R^2
Hardness	0.06	0.99
Viscosity	0.09	0.97
Adhesiveness	0.13	0.89
Fracturability	0.10	0.96
Gumminess	0.04	0.99
Chewiness	0.13	0.91

Table 4. Standard hardness scale as described by Szczesniak et al. 1967

Scale value	Product
1	Cream Cheese
2	Egg white
3	Frankfurters
*4	Cheese (Medium Cheddar)
5	Olives
6	Peanuts
7	Carrots
*8	Almonds
*9	Hard Candy

* Substitute item. Reference Cardello 1982, Munoz 1986

Figure1. MDS representation of hardness textural perceptions of standard foods (n=11)

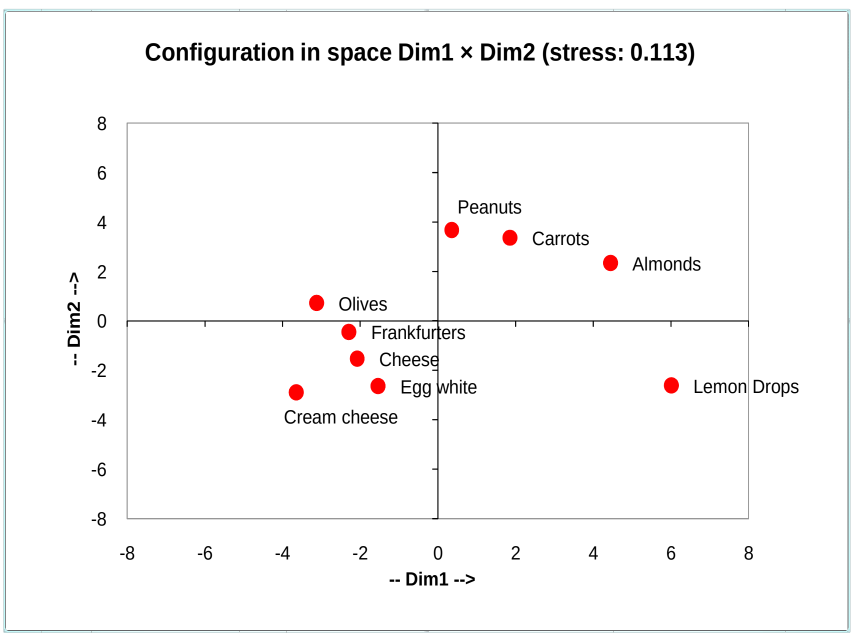


Table 5. Standard viscosity scale as described by Szczesniak et al. 1967

Scale value	Product
1	Water
2	Light cream
3	Heavy cream
4	Evaporated Milk
5	Maple Syrup
6	Chocolate Syrup
*7	Mixture 1 1/2 cup condensed milk &1 tbl heavy cream
8	Condensed milk

* Substitute item. Reference Cardello 1982, Munoz 1986

Figure 2. MDS representation of viscosity textural perceptions of standard foods (n=11)

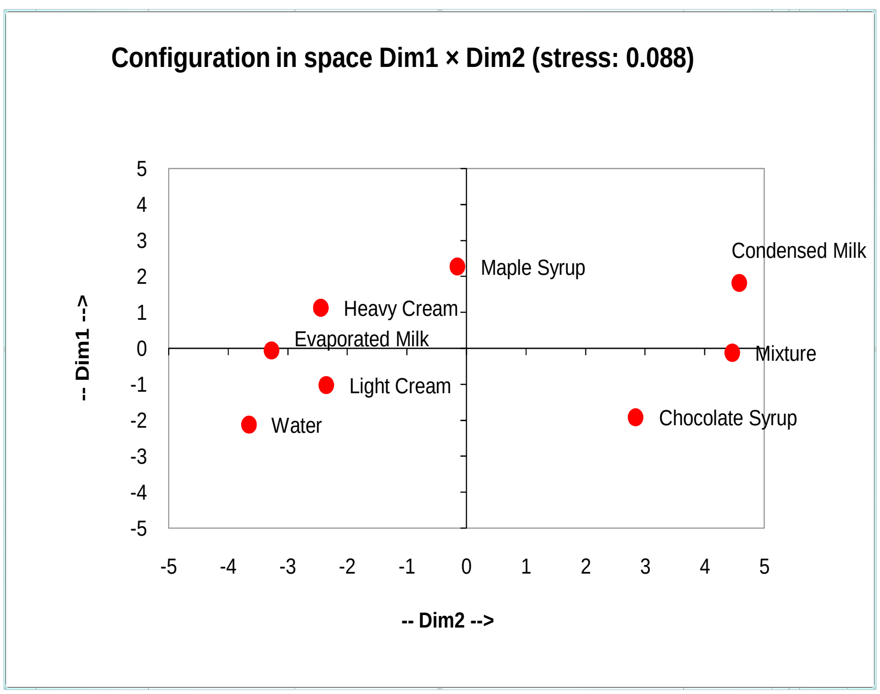


Table 6. Standard adhesiveness scale as described by Szczesniak et al. 1967

Scale value	Product
1	Crisco
*2	Velveeta
3	Cream cheese
4	Marshmallow topping
5	Peanut Butter

* Substitute item. Reference Cardello 1982, Munoz 1986

Figure 3. MDS representation of adhesiveness textural perceptions of standard foods (n=11)

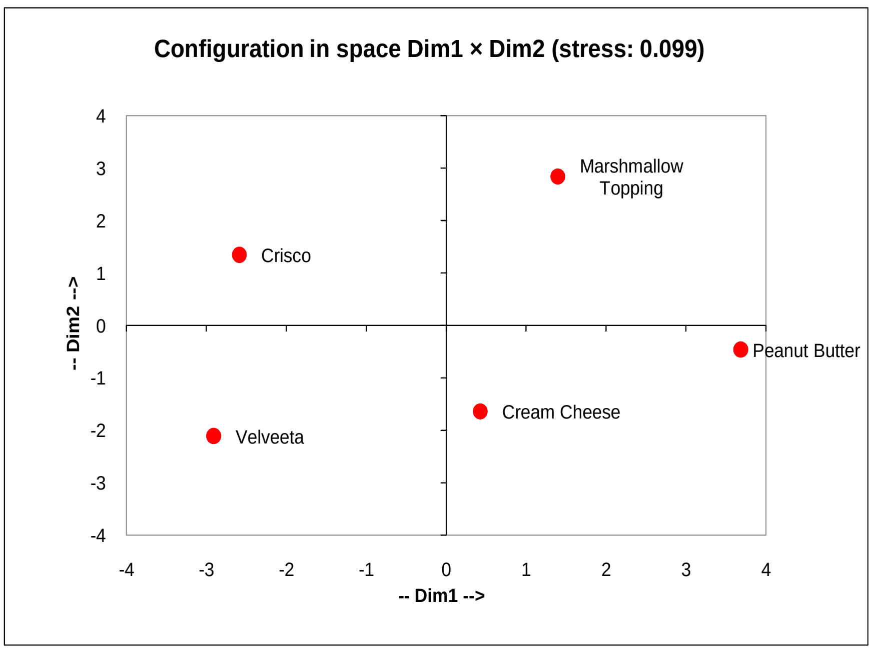


Table 7. Standard fracturability scale as described by Szczesniak et al. 1967

Scale value	Product
1	Corn muffin
*2	Shortbread
3	Graham crackers
4	Melba toast
*5	Wheat thins
6	Ginger snaps
7	Peanut brittle

* Substitute item. Reference Cardello 1982, Munoz 1986

Figure 4. MDS representation of fracturability textural perceptions of standard foods (n=11)

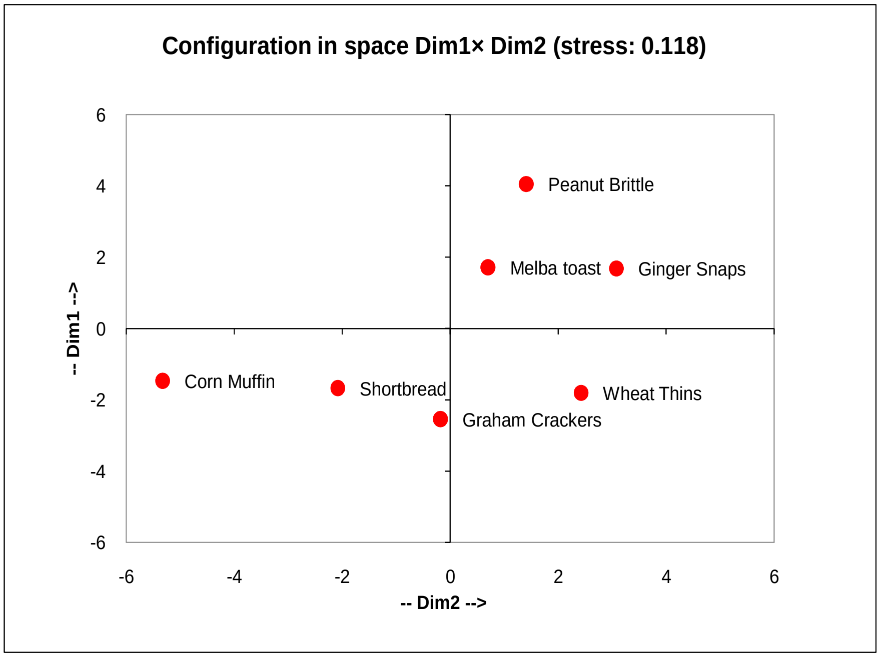


Table 8. Standard gumminess scale as described by Szczesniak et al. 1967

Scale value	Product
1	40 % flour paste
2	45% flour paste
3	50 % flour paste
4	55 % flour paste
5	60 % flour paste

Figure 5. MDS representation of gumminess textural perceptions of standard foods (n=11)

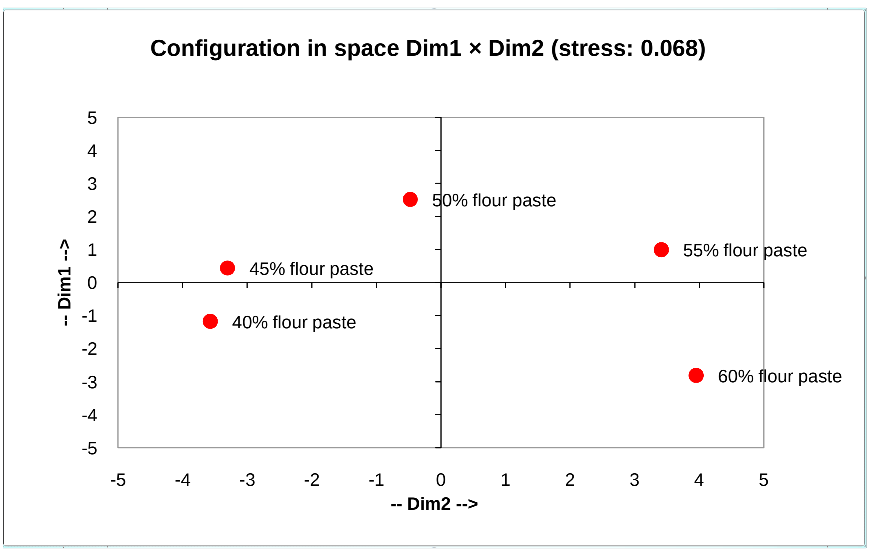
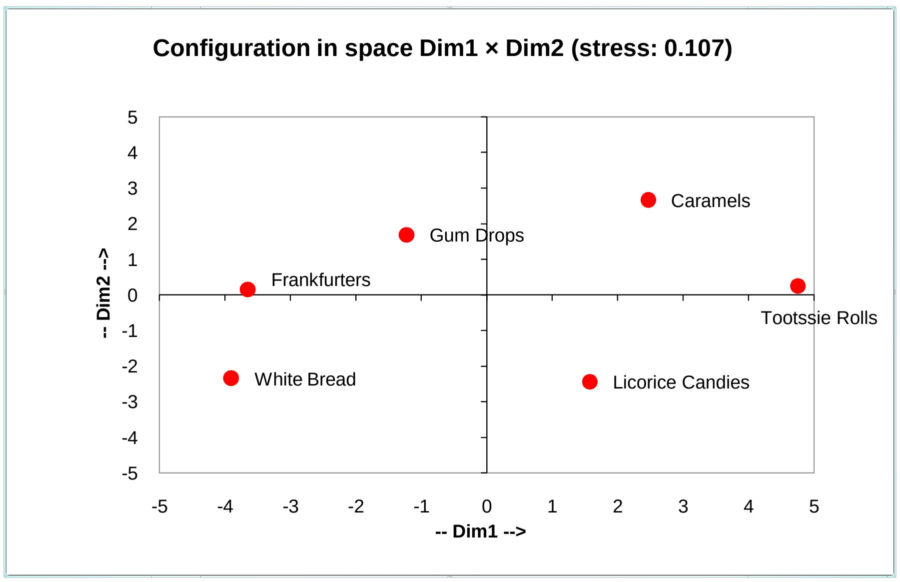


Table 9. Standard chewiness scale as described by Szczesniak et al. 1967

*1	White bread
2	Frankfurter
3	Gum drops
*4	Licorice candy
*5	Caramel
6	Tootsie Rolls

* Substitute item. Reference Cardello 1982, Munoz 1986

Figure 6. MDS representation of chewiness textural perceptions of standard foods (n=11)



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Chapter Three

Relationship between Instrumental and Sensory Determination of Apple and Pear Texture

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APPLE AND PEAR TEXTURE

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ABSTRACT

The relationship between compressive forces, tensile forces, and sensory analyses of apple and pear texture was evaluated. A total of twenty-seven sensory panelists were trained to assess a wide variety of texture attributes in apples and pears, including crispness, hardness, fracturability, juiciness, and chewiness. Apples from 2005 and 2006 harvest years and pears from the 2006 harvest year were evaluated by a trained sensory panel. The instrumental tests used to evaluate fruit texture were the Guss fruit texture analyzer (compression forces) and the Sinclair iQ™ system for both apples and pears. Tensile determinations were obtained using a unique method employing both tensile and compression elastic modulus of the fruit tissue. Significant correlations (r = 0.80 to 0.90) among the sensory texture attributes of crispness, hardness and fracturability for apples and pears was observed. The correlations between juiciness and hardness differed for apples (r = 0.65 to 0.80) and pears (r = -0.32). Hard apples and soft pears were perceived as the juiciest fruits among all firmness levels. When correlating sensory to instrumental determinations, the Sinclair iQ™ System texture assessment provided an acceptable determination of apple hardness (r = 0.79 to 0.82). Guss pressure sensor provided significant determination of apple (r = 0.78 to 0.83) and pear (r = 0.83) hardness. Tensile determinations predicted crispness in apples (r = 0.88) and pears (r = 0.85) well. A combination method of compressive and tensile determinations may offer the most accurate prediction of textural properties of apples and pears.

Key Words: Apples, pears, sensory evaluation, Sinclair iQ™ System, Guss Fruit Texture Analyzer, tensile tests.

INTRODUCTION

Consumers of fresh apples and pears consider fruit quality more important than price in making purchase decisions (Market Review 1996). Fruit quality incorporates sensory attributes such as appearance, flavor, aroma, and texture. Of these quality attributes, textural characteristics exert a strong influence on fruit acceptability. Daillant-Spinnler and others (1996) observed that in apples, the texture attributes of hardness and juiciness were the most important to consumers. Using preference mapping, Daillant-Spinnler and others (1996) confirmed that purchase intent of apple consumers in the United Kingdom tended to fall into two groups: consumers that preferred hard and sweet apples, or consumers that preferred juicy and acidic apples. Jaeger and others (1998) reported that soft and mealy apples were liked less than hard and non-mealy apples. Numerous other studies also confirmed the importance of texture to consumer acceptability of apples (Corrigan and others 1997, Thybo and others 2003). Turner and others (2005) observed that participants preferred a sweet pear with flavor. The most important quality factors recognized by consumers were texture, tartness and sourness, and juiciness. Consumer attitudes and attention to apple and pear texture cannot be ignored and are of critical importance to food marketers.

Comparative and quantitative assessment of apple and pear texture involves instrumental and subjective sensory determinations (Harker and others 1997). Sensory determination of texture is very important in food quality because no instrumental determinations are adequately developed to replace human evaluation. Sensory evaluation continues to be the gold standard by which the successes of instrumental determinations are evaluated (Bourne 2002). Instrumental quality control methods designed to evaluate texture are often difficult to implement because of the challenges associated with correlating instrumental rheological determinations to perceived sensory attributes or acceptability (Kapsalis and Moskowitz 1978).

The speeds measured during chewing are faster that those used during instrumental testing of food. Masticatory speeds and duration may result in shear thinning that may not be replicated using instruments of lower speeds. For this reason alone, textural determinations made using instruments may not represent the events occurring in the mouth (Harker and others 1997). According to Harker and others (2002), a reliable relationship between objective instrument-based and subjective sensory methods is not always feasible. However, because of practical concerns, such as the time, expertise and costs associated with sensory evaluation, instrumental analysis is often employed. Many empirical and imitative instrumental tests were developed to potentially correlate with sensory texture descriptors (Paoletti and others 1993; Peleg 1993; Harker and others 2002; Shmulevick and others 2003). However, the entire complex of actions that occur during mastication cannot be determined completely by instruments. There is no instrument available containing the complexity, sensitivity and extent of mechanical motions in the mouth or that can appropriately change the speed and mode of mastication in response to the sensations received during the previous chew (Bourne 2002).

Instrumental determinations of fruit texture such as Texture Profile Analysis (TPA) are the accepted foundation of fruit quality assessment In apples, many studies demonstrate satisfactory relationships between sensory texture attributes such as firmness and crispiness, and instrumental texture measurements including TPA, Kramer shear, disk compression, vibration and tension instruments (Harker and others 1997). Puncture tests using instruments such as the penetrometer are the most widely used instrumental texture methods in the apple industry (Harker and others 1997). Puncture tests determine the force required to push a cylindrical probe with a convex tip into the flesh of the fruit. Even with extensive replication of the penetrometer, ambiguity exists in the literature as to the relevance of penetrometer determinations as predictors of perceived apple firmness (Abbott and others 1976; Bongers 1992; Harker and others 1996).

In response to the need to develop an instrumental determination of texture with a strong correlation to sensory evaluation, a new methodology was developed whereby the tensile properties of apples and pears were measured. Analysis of apple tissue failure during biting or cutting with a knife suggests that dominant failure mode is a combination of tensile and shear failure resulting in the wedge action of the knife blade or teeth. One difficulty associated with tensile properties determination is food manipulation during measurement. Previous research in tensile determination was dependent on securely fixing both ends of a fruit tissue in the instrument designed to apply the test. Tensile determination was achieved using clamps (Schoorl and Holt 1983), cutting tissue into a shape with slots between sets of claws (Stow1983; Harker and Hallet 1992) or by gluing (Harker and Hallet 1994). However, the short amount of time available to mount and test the tissue before the tissue decay begins, and the amount of moisture loss proved to make tensile determinations very difficult.

A new method to determine tensile properties, based on recording the force, deflection values, and compressive elastic modulus to determine the tensile elastic modulus and failure stress in fruit is proposed. To assess the usefulness of this method, comparisons between results from the tensile determinations and sensory evaluation of texture were performed. Therefore, the objective of this study was to evaluate the new method and instrumentation of tensile properties and compare the results with human texture perception (trained texture panel), puncture test (Guss pressure sensor), and non-destructive test (Sinclair). Specifically, the relationships between tensile material properties and hardness, and human sensory perception of apples and pears were studied. To determine the most effective instrumental parameter for prediction of apple and pear texture, the relationships between the sensory textural attributes of apples and pears were also examined.

MATERIALS AND METHODS

Fruit Selection

'Red Delicious', 'Granny Smith', 'Pink Lady', 'Cameo' and 'Gala' apples (Wenatchee, WA) from selected sources were harvested in 2005 and 2006 at commercial maturity. Harvest times varied from mid-September to early November. 'Anjou', 'Bartlett' and 'Bosc' pears (Wenatchee, WA), were harvested in 2006. To effectively compare the performance of analytical methods to sensory measurement determinations, apples and pears with a diverse range of textures were presented to the sensory panel. The range of apple and pear textures was generated through use of a number of selected cultivars of each fruit and selected maturity levels.

Harvested apples were sorted into three predetermined groups; soft (< 11 lb), intermediate (14-16 lb) and hard (>18 lb), as identified by the Fruit Texture Analyzer. The range of apple firmness was identified as the apples were placed into storage at harvest from values seen historically in hard and soft cultivar lots. The range of hardness in the harvested pears was adjusted by holding the pears at room temperature (22°C) for a selected number of days (4, 6, 8 days or more) prior to evaluation. Pears were categorized in three selected groups for soft (<5 lb), intermediate (9-12 lb) and hard (> 15 lb).

Apple or pear firmness was evaluated using the nondestructive method, Sinclair iQ™ (Sinclair Systems International- Fresno, CA), and a destructive method, computerized Fruit Texture Analyzer (Guss, Strand, Western Cape, South Africa).

Sensory Panel

The sensory panel was composed of ten panelists in 2005 and seventeen panelists in 2006, all between the ages of 21 and 62. Panelists were recruited from the WSU/Pullman community. The panel was composed of two males and eight females in 2005 and three males and fourteen females in 2006. The panelists were regular apple and pear consumers (at least once a week). All panelists signed an Informed Consent Form and the sensory evaluation protocols were approved by the Washington State University Institutional Review Board for human subjects participation. Panelists were screened for dental problems and other conditions that may have affected their performance in this panel. A minimum amount of information on the nature of the study was provided to reduce potential bias; panelists were informed they were expected to assess the texture of apples and pears.

Sensory Panel Training:

The panelists performed the Texture Profile Method following the procedures of texture profile analysis described in Civille and Szczesniak (1973). The texture attributes were selected based upon previous literature (Paoletti and others 1993). Panelists were trained to recognize apple texture attributes of hardness, juiciness, crispness and fracturability, as defined in Table 1. In 2005, the panelists were also trained to recognize chewiness; however, chewiness attribute was excluded from evaluations in 2006, as it did not yield significant results in the 2005 study. In 2005, the sensory properties of apples were evaluated by biting or chewing in an orientation parallel to the core of the fruit. In 2006, sensory properties of apples and pears were evaluated by biting or chewing the fruit in an orientation perpendicular to the core of the fruit. Published texture scales (Table 2) were used to train the selected texture attributes. Panelists were trained to recognize attributes using specific evaluative techniques (Table 3) and to assign intensity ratings on a 15 cm line scale indented 1 cm at both ends of the line. Fruits of selected texture maturities and selected cultivars were used for training. Panelists trained with selected apple cultivars may more clearly focus on texture attributes of the fruit. Panelists received 30 to 40 hours of training each year, learning the definition and technique for each texture descriptor with the goal of reducing panelist variability and increasing reliability. Validity of the panel was assessed by analyzing the number of correct responses over time. Reliability was assessed by using duplicate test fruits, and replicating the tests. Panelists were provided with feedback of individual and group evaluations following each training session and additional training was provided if necessary.

Firmness Evaluation of Fruit:

Apples and pears were equilibrated at room temperature for one day prior to testing. Firmness determinations were performed on the whole apple or pear with the

Sinclair iQ™ system (Sinclair Systems International- Fresno, CA). The results were a mean of three replications. Fruit firmness was also determined on two peeled sides of each fruit (sunny and shady) using a Fruit Texture Analyzer (Guss, Strand, Western Cape, South Africa). Results were expressed as lb of pressure and the mean value of the two replicates was recorded.

Sensory Panel Evaluations

Following apple or pear groupings for hardness by instrumental determinations, apples or pears from the soft, intermediate and hard groupings were halved. Half of the fruit was utilized for tensile property determination while the other half was utilized for sensory evaluation. The apples or pears were labeled such that the tensile data and the sensory data for each apple or pear were correlated. The fruit half that was utilized in the sensory testing was split in half. Two fruit quarters were obtained from each fruit half and presented to two panelists; thus each panelist was presented with ¼ of the apple for evaluation. During each formal evaluation session, panelists were presented with six quarters of apples or pears. Three replicated sessions were conducted over one week, with each session at a similar time each day. Within each session, each apple or pear grouping (soft, intermediate and hard) was evaluated twice in a randomized complete block design (3 x 2 x 3 = 18 fruit quarters).

Sensory evaluation took place in individual sensory booths equipped with laptop computers for entering and recording data. The apple quarters were randomly presented to the panelists at room temperature. Apple quarters were identified using three-digit codes and presented one at a time to panelists. The fruits were scored for intensity of each texture attribute using a 15 cm unstructured line scale, with an indent 1 cm at the left end of the scale corresponding to the lowest intensity (0 cm= extremely low) and an indent 1 cm at the right end corresponding to the highest intensity (15 cm=extremely high). Evaluations were conducted under normal light conditions. Panelists were presented with water and expectoration cups to cleanse the palate between fruit. A knife was provided to peel each fruit quarter.

Results were collected and analyzed using Compusense 6.0 software (Guelph, ON) and sensory data were quantified by determining the distance in cm of the mark along the line.

Instrumental Analysis

Tensile properties were determined using a new methodology developed by Pitts and others (http://www.bsyse.wsu.edu/Main/People/faculty/pitts.htm). Tensile properties were determined through a destructive test in which a slab of fruit tissue was removed from the apple or pear and placed in a bending apparatus. The bending created a combination of compressive and tensile loads on the fruit. A second tissue slab was removed from the apple or pear to determine the compressive elastic modulus required to determine the tensile material properties from the bending test. During the bending test, the force applied and the deflection of the block were recorded in triplicate. The force and deflection values were utilized together with the compressive elastic modulus to determine the tensile elastic modulus and failure stress of each fruit slab. In the first harvest year, the tensile properties were determined in an orientation parallel to the core of the fruit. In the second harvest year, tensile properties were evaluated in an orientation perpendicular to the core (for apples and pears).

Data Analysis:

The sensory data were subjected to two-way analysis of variance (ANOVA) using panelist and firmness grouping as the main effects. The interaction between panelists and firmness levels were also determined for evaluation of crispness, hardness, fracturability, juiciness and chewiness. The instrumental data was subjected to a one-way ANOVA to determine how well the instrument differentiated the apples and pears among the three firmness groupings. Tukey's HSD was calculated to interpret the significant differences among selected fruit firmness and sensory texture attributes (Version 7.5.3, XLSTAT Addinsoft, France). Significance was predetermined at $p < 0.05$. Correlation analysis was conducted to identify correlations between sensory texture and instrumental determinations. Principal component analysis was applied to sensory and instrumental terms as a function of procedure means to compare sensory and instrumental methods differentiation of apple and pear texture (Version 7.5.3, XLSTAT Addinsoft, France).

RESULTS AND DISCUSSION

Sensory attribute ANOVA results for apple firmness groupings characterization as determined by instrumentals determinations, panelists, and interaction between apples and panelists are presented in Table 4. Differences among panelists and interaction between apples and panelists were not significant ($p>0.05$). This reveals consistency among panelists and a small level of error. In 2005, there were no significant differences between intermediate and hard apples for selected texture sensory parameters. However, significant textural differences between the apples were observed for the selected sensory parameters of crispness, hardness, fracturability and juiciness in the 2006 cultivars.

Panelists were able to differentiate apples harvested in 2006 based on firmness level (Figure 1).

A logarithmic relationship between the physical properties of apples and associated sensory response is observed in our 2005 data. When apples are soft, the consumers might be expected to be more sensitive to texture differences than available instruments are capable of determining. When apples are hard, the ability of consumers to sense texture differences may decrease due to fatigue, and thus instrumental determination is more reliable than the consumer at discriminating between hard and very hard fruit (Harker and others 1998). Figure 2 presents a summary of panelists' ability to distinguish between soft and hard apples from the 2005 and 2006 combined harvest years. However, differentiating between intermediate to hard apple cultivars was more difficult than differentiating between soft and hard apples. PC1 describes 96.47% of variation and is primarily defined by soft, intermediate and hard firmness. PC2 describes only 3.53 % of the variation and is primarily defined by intermediate firmness. Similar patterns are observed for pears in 2006 (Figure 4). Increased panelists training resulted in a significant improvement in differentiating between intermediate and hard apples as observed in the 2006 results.

Table 5 presents the two-way ANOVA sensory attribute F values for pear texture parameters, panelists and interaction between pears and panelists. Significant differences were observed between pears for all attributes, with the exception of juiciness, indicating that the sensory training received was adequate and panelists were able to differentiate pears with selected firmness groupings (Figure 3). Significant differences were not observed among the panelists, demonstrating consistency within the panel. Also, no significant interactions were observed among pears and panelists for selected attributes.

Table 6 and Table 7 present the one-way ANOVA results of instrumental determinations and relationships with apple and pear groupings, respectively. Significant differences between apple and pear groupings were observed, indicating that selected instrumental determinations differentiated between soft, intermediate and hard apples and pears. Instrumental determinations were originally selected to characterize the apples and pears and the objective texture assessment of harvested apples and pears supported the initial groupings.

Correlation matrices for sensory texture attributes of apples are presented in Table 8. Strong correlations ($r > 0.80$) were observed among crispiness, hardness, fracturability and juiciness for apples harvested in 2005. Chewiness assessment resulted in weak correlations with the other sensory attributes, indicating that was not a strong predictor of apple firmness. Thus, chewiness was removed from the apple texture profiling in 2006. In the 2006 harvest year, correlations between sensory attributes were slightly smaller, especially the juiciness correlation to crispness, hardness, and fracturability as compared to apples harvested in 2005.

Correlation matrices for textural sensory attributes for pears are presented in Table 9. Strong correlations ($r > 0.86$) were observed among crispness, hardness, and fracturability of pears. However, juiciness of pears was weakly correlated to crispness, hardness, and fracturability sensory texture attributes. These observations demonstrated that the mechanism for releasing juice in the mouth is not the same among apples and pears, with the release of cell fluids depending upon the physiology of the fruit.

Harker and others (2006) observed that juice release in apples is dependent on the breakdown of individual cells and varies between firm and soft apples. In firm apples, tissue fracture is associated with breakage of individual cells and results in the release of cytoplasm fluids. In soft apples, fracture occurs as a result of cell-to-cell debonding. Individual cells do not always break open and release their contents, and this result in a mealy apple. Harker and others' (2006) observations are supported by the present study for both harvest years of apples, as an increase in juiciness was observed with an increase in apple firmness. Pears behaved differently from apples as evaluated by the sensory panel, in that increased fruit firmness resulted in a small amount of juice released from the fruit. The relationship between firmness and juice release for pears is attributed to cell-to-cell debonding and little juice is released from cells. Soft pear texture is associated with breakage of individual cells, resulting in the release of juice and often a juicy pear (Harker and others 1997). Differences between apples and pears in the way juice contents are released may be attributed to fruit physiology and starch hydrolysis during ripening.

Correlation analysis of the degree of association between instrumental and sensory determinations of apples is provided in Table 10. Large positive or negative values indicate a strong association. Strong to moderate correlations were observed among the Guss, Sinclair and compressive elastic modulus, and the sensory attributes of crispness, hardness, fracturability and juiciness. Weak correlations were observed between the tensile elastic modulus and selected sensory texture attributes in 2005. Strong correlations were observed between the Guss, Sinclair, compressive elastic modulus, tensile elastic modulus, and the sensory attributes of crispness, hardness and fracturability in 2006. Guss, Sinclair, and compressive elastic modulus provided determinations that did not significantly differ ($p > 0.05$) in their relationship to sensory attributes for both harvest years. However, tensile elastic modulus determinations differed significantly ($p < 0.05$) between apples from 2005 and 2006.

An increased predictability of apple crispness, hardness, and fracturability was observed in 2006. Also, small variability in correlations between instrumental and sensory determinations was observed in apples between both harvest years. In 2005, correlations between the Sinclair and the Guss determinations and sensory attributes were higher than the 2006 correlations. This variability may be attributed to structural differences in selected varieties of apples and the different location of fruit harvest when collecting the fruit. Harker and others (2002) suggested that possible reasons for the range of correlations obtained over different harvest years include the range of firmness of fruit presented to panelists, the variability between the texture of apples at the point of instrumental determination and region of the fruit eaten by each panelist, and the range of sensory acuities and cognitive abilities of individual panelists. Paoletti and others (1993) also suggested that the mechanical and texture characteristics of apples and pears are influenced by the structural features of the flesh and are affected by storage conditions that result in great structural variability.

Correlation analysis of the degree of association between instrumental and sensory determinations for pears is provided in Table 11. Strong correlations were observed between the Guss, tensile elastic modulus and the texture sensory attributes of crispness, hardness and fracturability of pears. Determinations made using the Sinclair and the average elastic modulus by compression demonstrated poor correlations for predicting sensory texture attributes in pears. Evaluation of juiciness was negatively and poorly correlated to instrumental determinations.

Tensile elastic modulus varied significantly between apples from the 2005 and 2006 harvest years. Differences of tensile determinations between harvest years may be attributed to the distinction in how the measurement was made between the two years. In 2005, the tensile elastic modulus and failure modulus were determined in a direction parallel to the core line. However in 2006, the determinations were perpendicular to the core line due to redesign of the experimental technique. Sensory evaluation techniques and training did not differ between harvest years. Tensile material properties are highly orthotropic, in that the properties change with orientation of the tissue with respect to the core line of the fruit. Paoletti and others (2003) observed that significant relationships between flesh density and stiffness measured in torsion of apples is limited to radial orientation (perpendicular to the core line) and not to the tangential orientation of the apples (parallel to the core).

The current study results affirmed Paoletti's (2003) observations. Strong correlations of tensile determinations and crispness for apples and pears were observed when samples were taken perpendicular to the core line as opposed to parallel to the core line. These observations are associated with the fact that tissue failure from biting with the front teeth is crack-related. Tensile material properties play a dominant role when a crack propagates and the length of the crack propagation. In the current study, fracturability and hardness were determined with the molars where compressive material properties dominated. The observations indicate that tensile material properties are correlated to compressive properties, and compressive properties are correlated to fracturability and hardness.

Fruit firmness, or strength, is a function of the mechanical properties of the cell wall, cell turgor, and bonding among cells. Another factor that impacts fruit firmness is the contents of the cell. Cell strength is a hydrostatic phenomenon that is diminished in the reduction or absence of cell contents (Harker and others 1997). Studies on fruits using pressure probes as a measure of compressive forces demonstrate that the cell wall elastic modulus increases with increasing turgor pressure in the cell (Harker and others 1997). The results indicate that tensile material properties in fruits are attributed to the strength of the pectin bonds between cells and the cell wall strength. The compressive material properties are attributed to the turgor pressure in the cell, and to a lesser extent on pectin bonds and cell wall strength. Under selected storage environments, the fruit may mature without noticeably changing cellular turgor pressure.

An advantage of tensile tests to assess fruit texture is the opportunity to determine the mechanism of tissue failure through the examination of the fracture surface in fruit (Harker and others 2002). There are three forms of tissue failure: cell fracture, cell rupture, and cell-to-cell debonding (Harker and others 1997). Harker and others (2002) studies demonstrated that cell fracture was dominant in high firmness apples (>66 N), cell rupture dominated in intermediate firm apples (45 to 66 N), and cell-to-cell debonding dominated in low firmness apples (< 39 N).

De Belie and others (2000) observed a curvilinear relationship between pear firmness and the tensile strength of cells demonstrating variation of mechanical properties of a population of cells versus individual cells. The compression and shear properties of the cell population is evaluated in puncture tests of whole fruits, while during tensile testing, the strength of thin layers of individual cells is determined. The strength of the weakest cell may define the strength of the entire fruit in tensile determinations. Generally, failure in uniaxial compression of fruit is associated with an increase in turgor pressure involving an increase of volume in the cells and rupturing of cell walls. Rupture during tension involves breakage of the cell walls and/or cell-to-cell debonding. Compressive properties may be relevant to understanding factors affecting the development of bruises in apples and pear while tensile determinations may be closely related to biting and chewing of fruit.

CONCLUSIONS

Determination of texture provides an indication of apple and pear maturity and acceptability and is an integral part of routine fruit quality evaluation. Sensory results of apple and pear texture indicated high correlations among the sensory texture attributes of crispness, hardness and fracturability for apples and pears. Disparity in juiciness perceptions in apples and pears was attributed to the dissimilarity in cell structure. When correlating sensory evaluation to instrumental determinations, both the Sinclair iQ™ System and the Guss pressure sensor provided a reasonable predictor of apple hardness. Most of tensile properties in apples and pears have potential in predicting crispness but are highly dependent on the orientation of the fruit. A combination approach, assaying with an instrument to determine compressive and tensile properties, provides the most accurate prediction of apples and pear textural properties compared to any existing method.

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Table 1. Apple and pear texture attributes and descriptors as evaluated by the trained texture panel.

Attributes	Description
Crispness	Crispiness is primarily an acoustical sensation that is detected by the ear during the fracturing of crisp foods.
Hardness/Firmness	Hardness is the force required to bite completely through sample placed between molars.
Fracturability	Fracturability is the force with which sample ruptures when placing sampl between molars and biting completely down at a fast rate
Juiciness	Juiciness is the amount of juice released on mastication.
Chewiness	Chewiness is defined as the energy required masticating a solid food product to a state ready for swallowing (only in spring)

Table 2. Texture standards used for the evaluation of texture sensory attributes.

Standard Crispness

Scale value	Product	Brand or Type	Manufacturer	Sample size	Temp
1	Chewy cookies	Chips Ahoy	Nabisco	1 cookie	room
5	Chizz Sticks	Cheez-it crackers	The Sunshine Biscuit Co	1 piece	room
10	Potato Chips	Miss Vicki's	Miss Vicki's	1 piece	room

Standard Hardness Scale

Scale value	Product	Brand or Type	Manufacturer	Sample size	Temp
1	Cream Cheese	Philadelphia	Kraft Foods	1 cm cube	45-55 ºF
2	Egg white	hard cooked (5 min)		1 cm tip	room
3	Frankfurters	large, uncooked	Oscar Mayers Beef	1 cm slice	50-65 ºF
4	Cheese	mild Cheddar	Kraft Foods	1 cm cube	50-65 ºF
5	Olives	stuffed	Safeway	1 olive pimento removed	room
6	Peanuts	cocktail type in vacuum tin	Planters Peanuts	1 nut	room
7	Carrots	fresh, uncooked		1 cm slice	room
8	Almonds			1 nut	room
*9	Hard Candy	lemon drops	Safeway	1 piece	room

Szczesniak et al. (1963)

* Substitute item. Reference Cardello et al. (1982), Munoz (1986)

Standard Fracturability scale

1	Corn muffin	made from mix	Jiffy	1 cm cube	room
2	Shortbread	Shortcake	Keebler	1 cm cube	room
3	Graham crackers	Nabisco	National Biscuit Corp	1/2 square	room
4	Melba toast	plain	Old London	1/2 square	room
5	Wheat thins	Nabisco	National Biscuit Corp	1 cm square	room
6	Ginger snaps	Nabisco	National Biscuit Corp	1/2 square	room
7	Peanut brittle	candy part	Safeway	1/2 square	room

Szczesniak et al. (1963)

Standard Chewiness Scale

1	White bread	fresh, center cut	Safeway	1 1/2 cm cube	room
2	Frankfurter	large, uncooked, skinless	Oscar Mayers Beef	1 1/2 cm cube	50-70 ºF
3	Gum drops	spice drops	Safeway	1 piece	room
4	Licorice candy	red vines	American Licorice Co.	1 piece	room
5	Caramel		Kraft	1/2 piece	room
6	Tootsie Rolls	midget size	Sweet Co of America	1 piece	room

Szczesniak et al. (1963)

Standard Juiciness Scale (10 = most juicy; all raw)

Scale value	Product
0	Banana
1	Carrots
2	Mushroom
3	Snap Bean
4	Tomatoe Wedge
5	Cucumber
6	Apple
7	Strawberry
8	Honeydew Melon
9	Orange
10	Watermenlon

Szczesniak and Ilker (1988)

Table 3. Sensory texture profiling technique for apples and pears.

Stage I	Place the fruit between front teeth. Bite through the fruit by applying steady force. Evaluate for: • Crispiness: amount of sound produced on the first chew
Stage II	Place the fruit between molars. Bite through the fruit by applying steady force. Evaluate for: • Hardness: force required to bite through the piece. • Fracturability: force with which the cookie shatters.
Stage III	Chew the whole fruit. Bite through the fruit by applying steady force. Evaluate for: • Juiciness: amount of fluid released on the first three chews. • Chewiness: number of chews required to hydrate the fruit and bring it to a state ready for swallowing.

Table 4. Two-way ANOVA for sensory analysis of apple texture by the trained panel in 2005 and 2006.

2005	Crispness	Hardness	Fracturability	Juiciness	Chewiness
Apple (S)	241.67*	2676.63*	285.91*	837.42*	172.99*
Panelist (P)	2.04	132.90	11.64	48.73	29.19
Interaction (S x P)	0.42	13.52	2.13	12.07	2.25
2006					
Apple (S)	130.00*	416.00	240.47*	271.49*	N/A
Panelist (P)	0.42	10.61	1.27	3.74	N/A
Interaction (S x P)	0.18	1.09	0.63	2.25	N/A

F value and significant levels from a two-way ANOVA
*** Significant at P < 0.05**

Table 5. Two-way ANOVA for sensory analysis of pear texture by the trained panel in 2006.

	Crispness	Hardness	Fracturability	Juiciness
Pear (S)	330.29*	258.55*	1771.90*	204.84*
Panelist (P)	11.97	8.05	50.65	63.17
Interaction (S x P)	3.61	2.26	19.87	21.54

F value and significant levels from a two-way ANOVA

*** Significant at P < 0.05**

Table 6. One-way ANOVA for instrumental analysis of apples in2005 and 2006.

2005	Guss	Sinclair	AEMC	AEMT
Apple (S)	765.39*	420.93*	255.45*	27.01*
2006				
Apple (S)	1468.33*	1283.47*	195.76*	98.63*

F value and significant levels from a One-way ANOVA

*** Significant at P < 0.05**

Table7. One-way ANOVA for instrumental analysis of pears in 2006.

	Guss	Sinclair	AEMC	AEMT
Pear (S)	891.78*	138.25*	79.87*	110.12*

F value and significant levels from a One-way ANOVA

*** Significant at P < 0.05**

Table 8. Correlation matrix of sensory texture attributes of apples for 2005 and 2006.

Year 1	Crispness	Hardness	Fracturability	Juiciness	Chewiness
Crispness	1.00	**0.88**	**0.91**	**0.82**	**0.62**
Hardness	**0.88**	1.00	**0.92**	**0.80**	**0.64**
Fracturability	**0.91**	**0.92**	1.00	**0.85**	**0.61**
Juiciness	**0.82**	**0.80**	**0.85**	1.00	**0.58**
Chewiness	**0.62**	**0.64**	**0.61**	**0.58**	1.00
Year 2	**Crispness**	**Hardness**	**Fracturability**	**Juiciness**	**Chewiness**
Crispness	1.00	**0.82**	**0.79**	**0.73**	**N/A**
Hardness	**0.82**	1.00	**0.85**	**0.65**	**N/A**
Fracturability	**0.79**	**0.85**	1.00	**0.67**	**N/A**
Juiciness	**0.73**	**0.65**	**0.67**	1.00	**N/A**

Table 9. Correlation matrix of sensory texture attributes of pears for 2006.

Year 1	Crispness	Hardness	Fracturability	Juiciness
Crispness	1.00	0.86	0.87	-0.25
Hardness	0.86	1.00	0.90	-0.32
Fracturability	0.87	0.90	1.00	-0.28
Juiciness	-0.25	-0.32	-0.28	1.00

Table 10. Correlation matrix of sensory attributes and instrumental determinations of apples in 2005 and 2006.

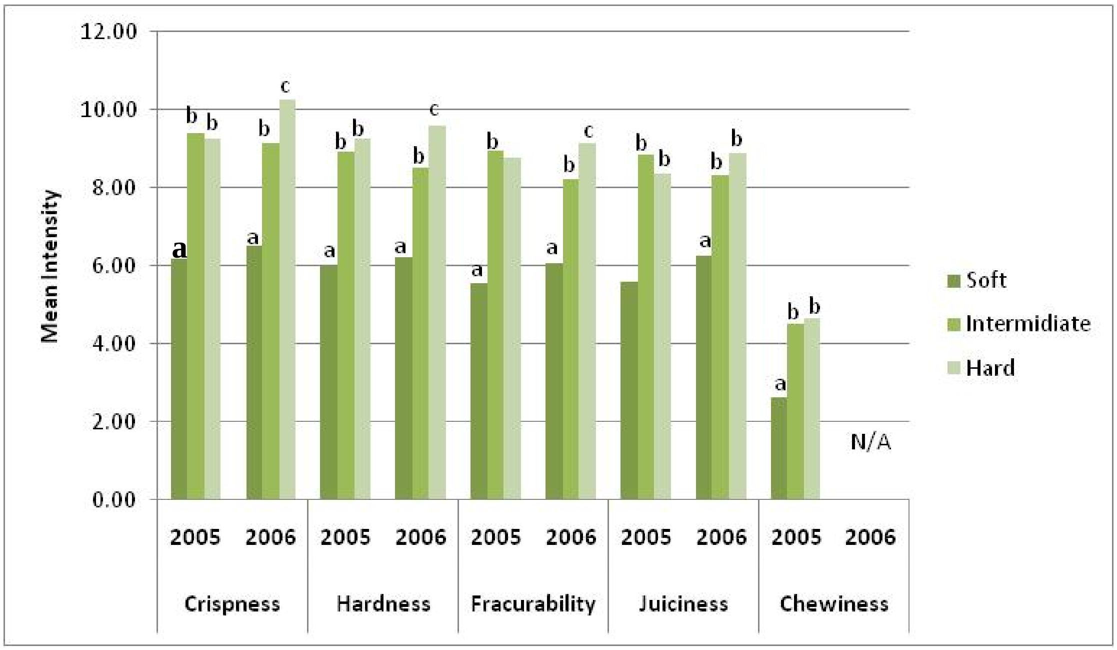
Year 1	Crispness	Hardness	Fracturability	Juiciness	Chewiness
Guss	0.72	0.78	0.74	0.66	0.64
Sinclair	0.81	0.82	0.83	0.76	0.65
Compressive EM*	0.76	0.78	0.78	0.70	0.64
Tensile EM*	0.57	0.62	0.63	0.53	1
Year 2	**Crispness**	**Hardness**	**Fracturability**	**Juiciness**	**Chewiness**
Guss	0.78	0.83	0.76	0.66	N/A
Sinclair	0.75	0.79	0.74	0.63	N/A
Compressive EM*	0.68	0.73	0.67	0.57	N/A
Tensile EM*	0.88	0.78	0.74	0.69	N/A

***EM: Elastic Modulus**

Table 11. Correlation matrix of sensory attributes and instrumental determinations of pears for 2006.

Year 1	Crispness	Hardness	Fracturability	Juiciness
Guss	0.79	0.83	0.81	-0.41
Sinclair	0.68	0.71	0.71	-0.25
Compressive EM*	0.59	0.61	0.59	-0.21
Tensile EM*	0.85	0.79	0.81	-0.31

Figure 1. Apple firmness effect on sensory texture attributes for 2005 and 2006 harvest years.



*** Different letters indicate significant differences (p<0.05) as determined by Tukey's HSD.**

Figure 2. Apple differentiation of soft, intermediate and hard apple firmness for 2005 and 2006 combined harvest years.

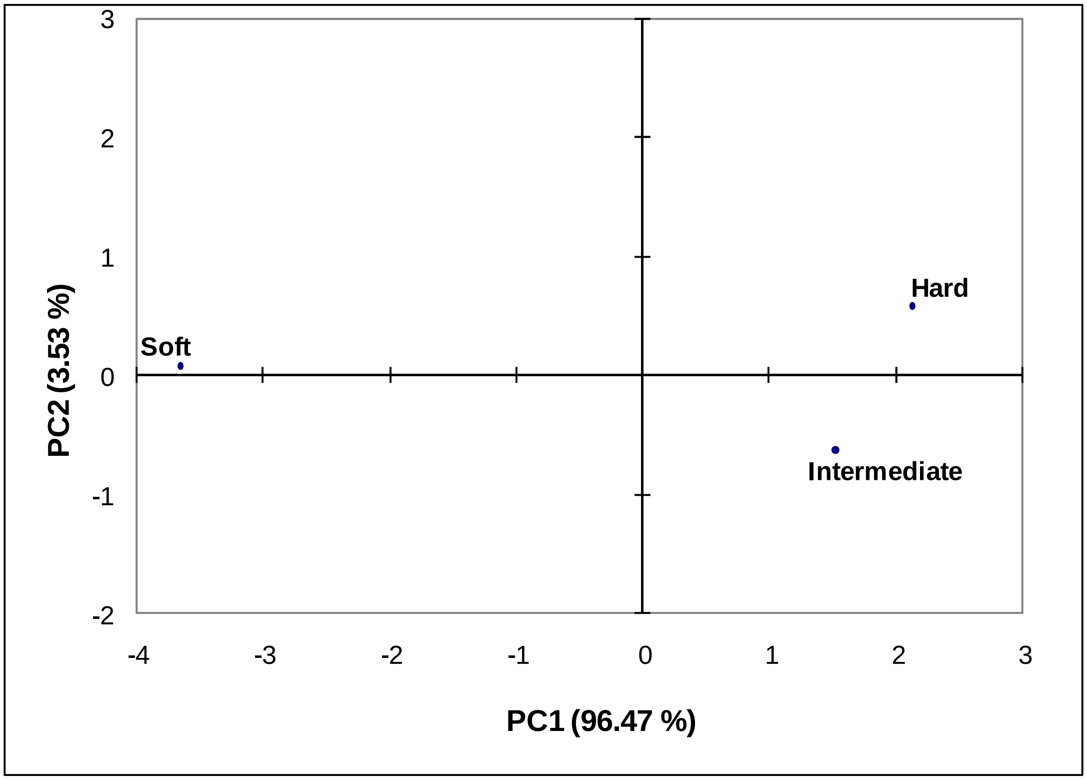
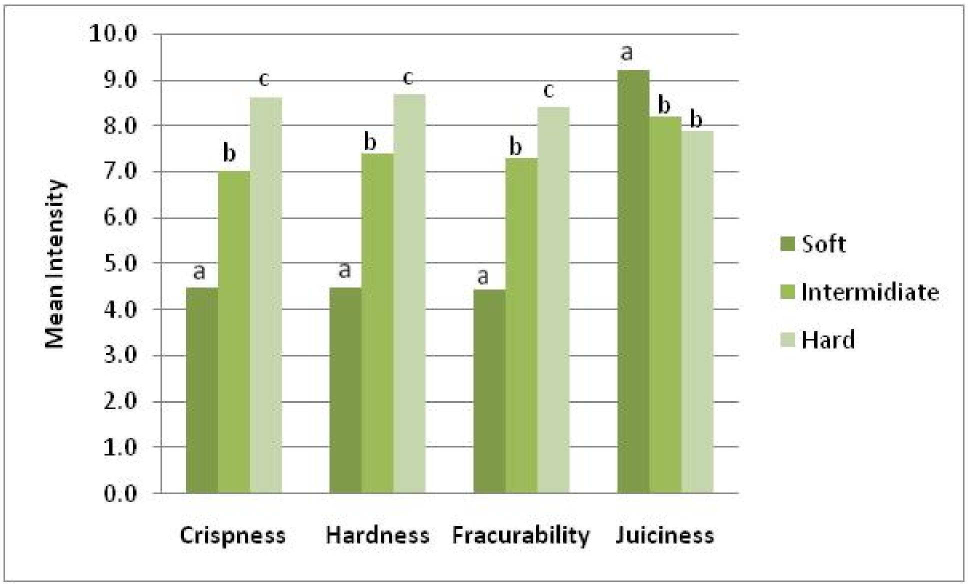


Figure 3: Pear firmness effect on sensory texture attributes for 2006 harvest year.



*** Different letters indicate significant differences ($p<0.05$) as determined by Tukey's HSD.**

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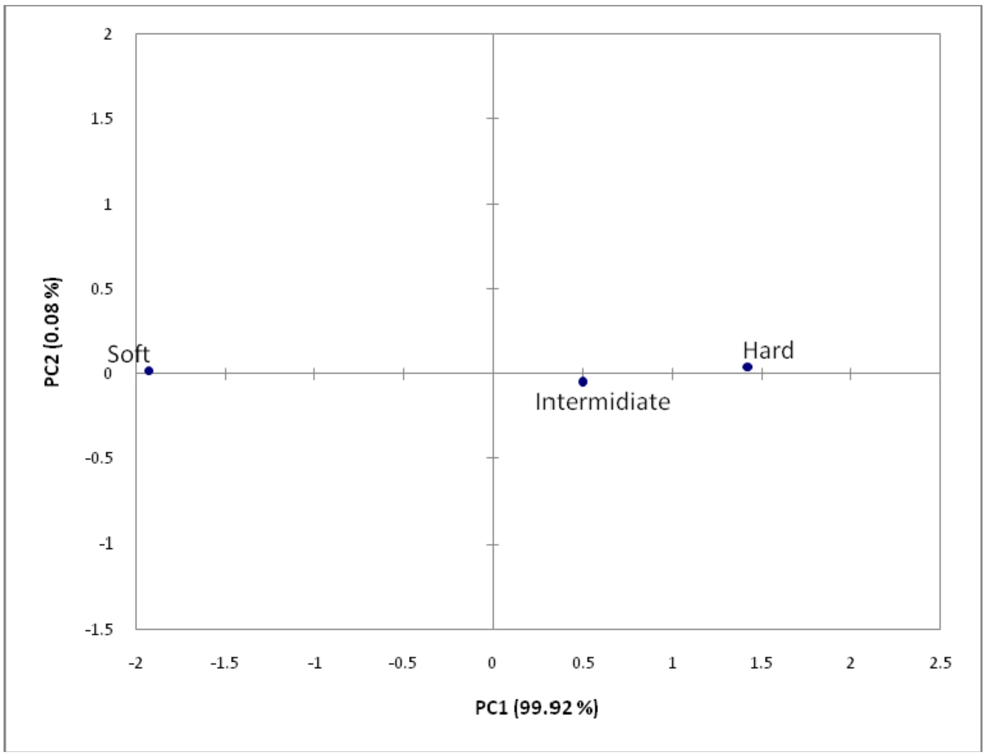
Figure 4. Pear differentiation of soft, intermediate and hard pear firmness for 2006 harvest year.



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Chapter Four

STANDARD SCALES FOR CRISPNESS, CRACKLINESS AND CRUNCHINESS IN DRY AND WET FOODS: RELATIONSHIP WITH ACOUSTICAL DETERMINATIONS

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STANDARD SCALES OF TEXTURE

ABSTRACT

To quantitatively evaluate food texture, a trained panel developed rating scales for crispness, crunchiness, and crackliness for dry and wet foods based on the auditory perception of selected foods. The newly developed scales were then evaluated by forty untrained panelists and the sound perception of standard foods was assessed through the analysis of the root mean square (RMS) of the 5 s audio waveforms and multidimensional scaling (MDS). The RMS was highly correlated to auditory sensory perception of crispness ($r = 0.83$ and 0.96), crunchiness ($r = 0.99$ and 0.99) and crackliness ($r = 0.88$ and 0.96) for dry and wet foods, respectively. MDS technique applied for the 40 untrained panelists was instructive in assessing auditory textural differences of naive panelists, and a good statistical instrument to graphically validate selected scales. Auditory perception of the selected foods were rated similarly using standard auditory texture scales for crispness, crunchiness and crackliness developed by the trained panel and MDS results from the consumer panel.

PRACTICAL APPLICATIONS

Crispness, crunchiness and crackliness are not only important and useful descriptors of food texture, but are desirable textural qualities in many foods. The lack of consistency in the procedures used for evaluation of crunchy, crispy and crackly in sensory studies often results in confusion when training expert panels. Research will benefit textural studies through an improvement of consistent textural definitions, development of standard scales and evaluation techniques.

The crispness, crunchiness and crackliness scales developed and applied in the current study represent a new potential standard frame of reference that may be used for training panelists in texture parameters related to food auditory perception. The scales may be considered illustrations demonstrating full and practical ranges for each texture attribute with regards to analyzing auditory parameters of foods. The root mean square (RMS) of the audio waveform is a reliable, fast, and convenient tool to analyze auditory texture parameters in food, while MDS is an effective means of analysis for comparing auditory data generated by untrained panelists.

KEY WORDS: crispness, crunchiness, crackliness, auditory perception, MDS, wet foods, dry foods, RMS.

INTRODUCTION

Textural properties are key drivers in food acceptability. Texture in food is perceived through a combination of visual, tactile, kinesthetic and auditory sensations. Crispy and crunchy properties are the main texture attributes affecting acceptability of food with regard to auditory sensations (Roudaut et al., 2002; Szczesniak, 2002). Although crispness and crunchiness are commonly used terms in sensory studies, there is little agreement among experts regarding their definitions and evaluation techniques.

The association of acoustic sensations with the perception of texture was previously studied for crisp, crunchy and crackly foods (Drake, 1963; Kapur, 1971; Vickers and Bourne, 1976; Vickers and Wasserman, 1979; Vickers and Christensen, 1980; Vickers, 1981; 1983; 1984a; 1984b; 1987a; 1987b; Dacremont et al., 1991; 1995; Lee et al., 1990; De Belie et al., 2002; Luyten and Van Vliet, 2006). The acoustic sensations of a food are affected by the arrangements of cells, chemical bonds, fruit or vegetable maturity, and moisture (Al Chakra et al., 1996). The noise production resulting from biting is attributed to the rupture of the cell wall. Few too many cells may rupture at any point during the mastication process, to produce an irregular series of sounds resulting from crushing the cellular structure of foods (Vickers and Bourne, 1976).

Cellular foods that contain only air within their cells, such as biscuits or chips, are designated dry crisp foods, while foods that contain fluids within their cells, such as fruits and vegetables, are called wet crisp foods. Edmister and Vickers (1985) believe that although dry crisp and wet crisp foods differ in cellular composition, both foods produce similar auditory cues for crispness perception. Vickers and Bourne (1976) suggested that the mechanism of sound production for dry and wet foods is different but the consumer perception while chewing either food is similar. However, Jowith (1974), Vickers and Christensen (1980), and Mohamed et al.(1982) suggest that the loudness of panelists' chewing sounds, perception of crispness, and/or instrumental crispness determinations may differ between dry and wet crisp foods.

The sensory evaluation of crispness, crunchiness and crackliness is a complex process. The use of the same descriptor in different studies with trained panelists is not a guarantee that an equivalent sensory perception is observed. For example, "crispy" is employed to illustrate the same parameters described by other panelists as "crunchy" (Brown et al., 1998; Guraya and Toledo, 1996). Whether crispy and crunchy refer to a similar sensory concept remains unresolved. Seymour and Hamann (1988) and Vickers (1981, 1985) reported a strong positive correlation between crispness and crunchiness, which favors the hypothesis of two descriptors for a unique sensory perception parameter. However, other research suggests that crispy and crunchy refer to different sensory parameters (Dacremont, 1991, 1995). Moreover, studies on crispness, crunchiness and crackliness conducted in several countries contribute additional complexities in comparing the results (Roudaut et al., 2002).

Descriptive analysis training of panelists for crispness, crunchiness and crackliness evaluation focuses on parameters such as the structure of the intact food, sounds emitted at fracture, the force needed to crush the food, the collapse of the food at fracture and the appearance of pieces observed and perceived following fracture (Roudaut et al., 2002). However, little agreement exists on definitions and techniques of oral manipulation during chewing in determining crispness, crunchiness and crackliness.

Depending on the definitions (Tables 1, 2 and 3), some parameters for crispy, crunchy and crackly foods are emphasized more than others (Roudaut et al., 2002).

For acoustic studies of crisp, crunchy and crackly food products, two approaches are generally followed. The first acoustic approach determines the contribution of the perception of air-conducted sounds to the sensation of crispness and crunchiness (Christensen and Vickers, 1981; Vickers, 1979; 1980; 1981; 1984a). The second acoustic approach involves recording sounds produced during the application of force to a food to obtain quantitative acoustic information regarding the crisp, crunchy or crackly sounds (Drake, 1963; Kapur, 1971; Vickers and Bourne, 1976; Edmister and Vickers, 1985; Vickers, 1985; Seymour and Hamann, 1988; Dacremont et al., 1991). Acoustic determinations are also combined with mechanical determinations (force-deformation) to predict crispness and crunchiness (Vickers, 1987; Szczesniak, 1988). A combination of acoustic and mechanical techniques more adequately describes food sound perception than either technique alone (Vickers, 1987).

The association that acoustic sensations exhibit with the perception of texture provides the opportunity to develop a standard scale composed of crispy, crunchy and crackly food sounds that can be recorded and be free of changes with time. The standard scales will also be useful for texture comparison of foods among laboratories (Vickers and Bourne, 1976), and for descriptive analysis by trained panelists. The objective of this study was to establish a standard reference scale for selected dry and wet crisp, crunchy, and crackly foods. The relationship between acoustical and oral perception of crispness, crunchiness and crackliness was also developed in order to distinguish between sensory evaluations of crispness, crunchiness and crackliness sensory parameters.

MATERIALS AND METHODS

DEVELOPMENT OF NEW TEXTURE REFERENCE SCALES

Panelists

Eight panelists from Washington State University participated in the development of texture references for dry and wet crispness, crunchiness and crackliness scales. Panelists included 8 females, 21 to 63 years of age, who were trained for 80 hours in a previous study using the Texture Profile method (Civille and Szczesniak, 1973). Panelists were screened for normal hearing ability, dental problems and other conditions that may have affected their performance on the panel. All panelists signed an Informed Consent Form and the sensory evaluation protocols were approved by the Washington State University Institutional Review Board for human subjects participation. Panelists received a small compensation for their participation in the study.

Training Procedure

The first stage of training involved extensive instruction about methods and descriptors of interest. Literature regarding the techniques and definitions of crispness, crunchiness and crackliness was examined by the trained panel through a summary of existing literature presented by the facilitator (Tables 1, 2 and 3). A crispness scale, developed previously for descriptive training with dry foods (Meilgaard et al. 1999), was presented as a starting point of discussion and a modification of the scale was suggested by the panelists in a focus group setting. The facilitator took notes and the summary of the discussion was distributed to each panelist following each session. Due to the variability in procedures and texture definitions, the panelists agreed to establish a comprehensive evaluation technique and definition of crispness, crunchiness and crackliness for texture evaluation of foods. A variety of foods were selected for consideration by the panelists as preliminary evaluation. Foods were selected after review of previous studies of crispness, crunchiness and crackliness. The objective was to guide panelists in establishing the textural attribute of interest and standardization of corresponding evaluation procedures to characterize crispness, crunchiness and crackliness. The use of a 15 cm unstructured line scale indented 1 cm at both ends was introduced during this stage of training. Individual evaluations were marked on the unstructured line scales anchored at the ends with the terms "none" and "extreme". This rating method was used throughout the entire training period and during texture evaluation sessions.

Immediately following the initial orientation, the panel met for a total of twenty hours, four hours per week for five weeks, to practice the techniques developed during the orientation training session. Throughout this second stage of training, the crispness, crunchiness and crackliness standard scales for dry and wet foods were developed, and definitions and evaluation techniques were discussed. The development of each scale started with a group discussion to suggest food items representing the texture characteristic under study. For the subsequent evaluations, the potential reference materials were purchased by the facilitator and evaluated by each panelist. Group discussion followed individual evaluations for each standard scale development. Consensus approval of each item and size was required before a food was accepted as a standard. Within each standard scale, a range of commercial foods was selected to develop the final standard scale. Once the range of the standard scale was established, three replicate samples within a product type were evaluated. Texture data for each attribute were collected, analyzed and uniformity and appropriateness of each food were discussed by the panel.

In the third stage of training, two 2 hour sessions were held following scale development for each standard scale. The biting or chewing sounds generated by the facilitator from each food along the newly developed standard scales were recorded in triplicate. The objective was to compare the recorded sounds generated by biting or chewing every food on each standard scale by evaluation of the root mean square (RMS) of all recorded sounds. RMS was used as an instrumental method to compare the results from perceptual texture assessment of the trained panel. The RMS of the voltage output was determined from the microphone, which was proportional to the RMS of the sound pressure. Based on the RMS results of the recordings during subsequent sessions, several foods were eliminated by consensus of the panelists and new standard foods were considered in order to include the entire range of intensities for every attribute. When the panelists considered that a range of standard foods was representative of a specific intensity, the food was included in the standard scale. The final intensity of each reference food on the scale was established by individual judgments followed by group discussion to reach consensus. The final foods selected for each standard scale are presented in Tables 5 to 10.

Acoustic Analysis of the Standard Scales

Foods for the developed standard scales (Tables 5 to 10) were purchased in a local supermarket. Fruits and vegetables were inspected visually and manipulated by hand to determine freshness. Sound recordings of an individual biting or chewing of the foods in each standard scale were produced by employing the technique presented in Table 4. To avoid recording the clacking of teeth when biting during the crispiness test, a 1.58 mm thick piece of FDA compliant silicone rubber sheet (Durometer 50A firmness) was placed between the incisors in the mouth opposite of the food standard. During both the biting and chewing, an AKG condenser microphone (model C577, Nashville, Tennessee) was held inside a Koss headphone (model Ur/29, Milwaukee, Wisconsin) and against the outer ear immediately above the opening of the ear canal. Chewing or biting sounds were recorded on a personal computer using Syntrillium Cool Edit (Syntrillium Software Corporation, Phoenix, Arizona). A Radio Design Labs low noise microphone preamplifier (model STM 2, Prescott, Arizona) with a Power One 24 volt linear DC power supply (model HB24-1.2A), which was connected between the microphone and the personal computer. Six recordings of each food were recorded at 44,100 kHz mono in replicate and saved as 5 s ".wav" files. Recorded sounds were analyzed using root mean square (RMS) calculated from the voltage signal of the entire 5 s waveform by means of Cool Edit program (Syntrillium Software Corporation, Phoenix, Arizona).

Data Analysis

Correlation analysis was conducted to identify correlations between auditory determinations and the sensory panel evaluations. Principal component analysis (PCA) was applied to instrumental and sensory terms as a function of procedure means to compare how the instrumental and sensory methods differentiated the texture attributes (Version 7.5.3, XLSTAT Addinsoft, France). Significance was established at $p < 0.05$.

CONSUMER PANEL

Panelists

Panelists were recruited from Washington State University staff, students and members of the community. Panelists were screened for auditory conditions and interest in participating in the study. Minimal information about the study was given to the panelists to reduce bias. Panelists consisted of 27 women and 13 men between the ages of 21 to 60 years. All panelists signed an Informed Consent Form and the sensory evaluation protocols were approved by the Washington State University Institutional Review Board for human subjects participation. Panelists received compensation for participation in the study. Panelists were also given a demographic questionnaire, and oral and written instructions before their participation in the study. None of the panelists expressed previous experiences with auditory evaluation of foods and were considered naive panelists.

Preparation of Recordings:

The audio recordings from the acoustic analysis of the standard scales containing minimal background noise were selected for the consumer panel.

Multidimensional Scaling Test:

Test foods consisted of the audio recordings representing the standard scales for crispness, crunchiness and crackliness for dry and wet foods. Foods, source, and size of all standard scales are presented in Tables 5 to 10. Multidimensional scaling (MDS) was used to examine panelists' auditory perceived similarities among foods.

Panelists participated in a single one hour test session. Each panelist evaluated the sound files individually in the presence of the facilitator. Instructions to the panelists included both an operational definition of each attribute to be presented to the panelists (Table 4) as well as instructions on the utilization of similarity judgments scales.

There were N*(N-1)/2 possible pairs to compare for a set of N foods in each standard scale. Panelists listened to the audio recordings through a Koss Ur/29 headphones connected to a personal computer. Panelists were instructed that a person was biting or chewing a food and were asked to compare the loudness (the degree of volume of the sound) of each pair of audio recordings.

Audio recordings were presented as paired comparisons, together with a ballot asking panelists to quantitatively rate the similarity between the two audio recordings of food being bitten or chewed. A similarity 9-point scale with the words "exactly the same" at the high end (9) and "completely different" at the low end (1) was presented to the panelists. Similarity judgments were formulated by writing a number describing, quantitatively, the perceived similarity between each pair. Once each panelist was finished with the first comparison, she/he was instructed to advance to the second comparison. A separate ballot was provided for each standard scale and all panelists were instructed to wait one minute between each standard scale. Panelists were not permitted to go back review or change previous responses.

Pairs of foods audio recordings were presented in a random order labeled with a three digit code. Each audio recording pair was analyzed once by each panelist. A total of 10 paired comparisons for crispness of dry and wet foods, crunchiness of wet foods, and crackliness of dry and wet food sounds were analyzed. A total of 15 paired comparisons for crunchiness of dry food sounds were also evaluated.

Data Analysis

One matrix was constructed from the pairwise similarity scores for each standard scale for crispness, crunchiness or crackliness of dry and wet foods for each of the forty panelists. Every cell within each matrix yielded a similarity score ranging from 1 to 9, quantifying perceived differences in auditory perception on the 9-point scale.

The forty individual matrices were combined to yield one matrix for each standard scale illustrating the mean group pairwise similarity scores. Each cell within the group matrices yielded a mean score for each standard food on every scale, reflective of the 9-point scale.

Data were analyzed as similarity estimates with XLSTAT 7.5.4 (Addinsoft, Paris-France). MDS algorithm ALSCAL module for nonmetric multidimensional scaling, using the option for minimizing Kruskal's stress Formula 1 two-dimensional solutions, was applied. Outputs included an assessment of stress, quantifying the fit between the data and the scaling model, and R^2 values, calculating the variability among underlying data that accounted for the MDS solution (Zraick, 2000).

RESULTS and DISCUSSION

Tables 5 to 10 present the standard scales developed for crispness, crunchiness and crackliness of dry and wet foods. The standard scales include the range of intensity of a selected textural auditory characteristic observed with biting and chewing in food products as perceived by panelists. Each point on the scale is represented by a specific food product, allowing the designation of a numerical rating to an unknown food by comparing it to a known food. Within each scale, a range of specific auditory textural parameters is demonstrated using foods that have the attribute under study as a major property. The advantage of a multi-food standard scale is that frequently, a given attribute is perceived differently in selected foods. Converting food texture standard scales to a one-dimensional series may be undesirable because a single dimension may distort illustration of diversified sensory perceptions of the textural parameters (Civille and Liska, 1975). The standard scales are not intensity scales against which foods are compared to obtain a rating. Rather, the standard scales are illustrations that demonstrate the principal range of selected textural characteristics. The standard scales for crispness, crunchiness and crackliness of dry and wet products are offered as a means of helping the food researcher obtain descriptive and quantitative sensory data on textural characteristics related to sound emitted during chewing or biting of food. The use of a descriptive panel over a compression instrument is preferred when working with masticatory sounds because it includes changes during mastication, particularly its hydration with saliva (Dacremont et al.1991).

The procedures for texture sensory evaluation must adhere to rigid testing controls. Table 4 presents the methods used in this study to assess crispness, crunchiness and crackliness. Attention to preparation, serving, presentation, biting and chewing techniques must be standardized (Civille and Szczesniak, 1973). The entire panel must receive consistent training in the principles and evaluation methods of crispness, crunchiness and crackliness of foods. Many factors may be responsible for the large variation in crisp, crunchy or crackly sounds: the size, shape and orientation of the food in the mouth, the amount of contact surface between the teeth and the food, the degree to which the mouth is opened, variations within the food, the rate and force of biting, or the way the food breaks down. A properly trained panel will minimize variation (Vickers and Bourne, 1976). The appropriate use of auditory textural scales will yield data reproducible among panelists, panels and locations. The reproducibility of the trained panel is related to establishment of common frames of reference among panelists and panels.

The consumer study conducted was analyzed through Multidimensional Scaling (MDS). MDS was performed for the newly developed standard scales for crispness, crunchiness and crackliness of dry and wet foods. Analyses of the six standard auditory texture scales were performed in the two-dimensional configuration. The mean stress values were small (<0.1) and reflected the ability of the MDS algorithm to fit calculated distances to the texture results in two dimensions. MDS two-dimensional graphical representation of crispness, crunchiness and crackliness for dry and wet foods are presented in Figures 1 to 6. All figures illustrate agreement with the newly developed standard scales for all attributes. Every food in the consumer MDS graphical representation is located in a similar location as presented in all standard scales developed by the trained panel.

The first dimension in the MDS output for auditory crispness of dry foods is attributed to the texture characteristic of crispness (Figure 1). The food items that represented the intensity of a specific stimulus are located in similar geometrical space as their location on the standard food texture scale. The second dimension may be credited to other auditory cues because the panelists were not trained and were considered naïve consumers. Similar trends were observed for crispness in wet foods (Figure 2), and crunchiness in dry and wet foods (Figures 3 and 4, respectively). The second dimension in the MDS output for crackliness in dry and wet foods (Figures 5 and 6), is attributed to the texture characteristic of crackliness and the first dimension to other auditory cues. The consumer study confirms the perceptual differences identified by the panelists among crispness, crunchiness and crackliness. The consumer results indicate that the standard scales were appropriately developed and are useful for further training of panelists for texture evaluation.

Jowith (1974); Vickers and Christensen (1980); and Mohamed et al. (1982) suggested that sensory crispness and/or instrumental crispness determination may differ between wet and dry crisp foods. The results of the current study support this theory. Figure 7 from the MDS analysis illustrates the separation on wet and dry foods along the three attributes. Panelists were able to differentiate between auditory crispness, crunchiness and crackliness, and also between wet and dry foods. Three independent clusters between each texture attribute of crispness, crunchiness and crackliness are observed and within each cluster a clear distinction between dry and wet foods is seen.

The difference between dry and wet foods and its relationship with auditory perception presented in Figure 7 can be explained by the fact that most wet foods are comprised of living cells and contribute turgidity. A sound is generated whenever a turgid cell is ruptured. Strong cell walls can withstand more pressure and release more moisture on chewing or biting, producing a louder noise. Soft cell walls exhibit little or no accompanying sounds during chewing or biting; therefore a decrease in sound is observed (Vickers and Bourne 1976). The mechanism of sound production in dry foods is different. In dry foods, the cells are filled with air and the cell walls are brittle. The sounds are produced from the collective breaking of individual cells when biting or chewing is applied to a brittle cell wall. When the cell wall bends and breaks, the residual of the cell wall and any fragments snap back to the original shape, generating a sound. Loudness in dry foods is influenced by the velocity of which the broken cell wall vibrates. The decrease of cell wall stiffness resulting from an increase in moisture content is accompanied by a decrease in sound production (Vickers and Bourne 1976).

The assessment of wet foods standard scales could be problematic during training due to cultivar and regional differences of fruits and vegetables. Szczesniak and Ilker (1988) successfully developed a standard scale for juiciness analysis consisting of selected fruits. Using wet foods, Munoz (1986) also developed standard scales for adhesiveness to lip, cohesiveness of mass, adhesiveness to teeth and wetness analysis. Although work went into the selection of the foods representing the various points in each scale in the present study, some foods may not be readily available due to seasonality or location. It is feasible to substitute foods in each standard scale depending on specific needs, circumstances, and availability. When an appropriate food substitute is identified, it should be evaluated objectively to ensure that the food is similar to the original reference food. Evaluation is important to make certain that the food substitute exhibits the proper intensity of the desired auditory textural characteristic (Civille and Liska, 1974)

The newly developed standard scales for crispness, crunchiness and crackliness for dry and wet foods were validated instrumentally by calculating the average power estimated from the RMS of the voltage signal. Table 11 presents strong correlations (r = 0.83 to 0.99) between the average power and sensory evaluations of crispness, crunchiness and crackliness for wet and dry foods. The average RMS power is a strong measure of the overall loudness of the waveform selection. Vickers and Bourne (1976) observed less total sound produced in the less crisp foods and louder sound production in more crisp foods. The difference in perceived crispness was associated with a difference in the number of sounds produced in a given biting distance and the loudness of the sounds produced. Vickers and Christensen (1980) evaluated how crispness, loudness and firmness were perceived by panelists by both biting and chewing the food, concluding that the chewing or biting technique made no difference in the sensory judgments. The relationship between crispness and loudness suggested that crispness judgments were more highly correlated to the auditory sensation of loudness than to the tactile sensation of firmness. Snap, loud and crackly were other sensory attributes closely associated with crispness.

Moskowitz and Kapsalis (1974), Vickers (1979), Vickers and Wasserman (1980), Vickers (1984b), Szczesniak and Kahn (1971), and Vickers (1981) produced evidence to indicate that crispness, crunchiness and crackliness are closely related attributes and are not descriptors of one attribute alone. In the current research, perceptual sensory differences among crispness, crunchiness and crackliness were found (Figure 7). Untrained panelists separated auditory sensations when judgments were made on the basis of loudness only. Vickers (1981) observed high correlations between crispness, crunchiness and hardness and between oral and auditory perception of foods. Vickers (1984a) evaluated crackliness and hardness of food under three selected conditions: normal biting and chewing, with biting and chewing sounds blocked, and by listening to recorded biting and chewing sounds. Vickers (1984) concluded that either oral tactile cues or auditory cues can be used to make crackliness judgments. The current study research demonstrates that auditory cues are adequate to identify crispness, crunchiness and crackliness perception of foods.

CONCLUSIONS

The developed standard scales for crispness, crunchiness and crackliness for dry and wet foods provide individuals interested in auditory texture evaluation a starting point to assist in training descriptive analysis of food texture. Although future modifications in reference material, attribute definition or evaluation procedures are expected, this study represents a first step in the generation of reproducible auditory sensory data using standard scales. MDS output demonstrated that crispness, crunchiness and crackliness are distinguishable sensory texture parameters belonging to selected distinguishable concepts and can be analyzed by the sole presence of auditory cues. Also, it was demonstrated that there is a perceptual difference between texture attributes for dry and wet foods and that differentiating between both is essential for descriptive analysis training.

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TABLES AND FIGURES

Table 1. Literature citations of crispness

Definition	Technique	Reference
Relative force required to bite through the product.	Biting with front teeth	Jeon et al. 1975
Products that produce a higher pitched sound.	Biting with front teeth	Vickers, 1984b
First Bite: place the product between the incisors, bite through and evaluate the level of higher pitched noise.	Biting with front teeth	Seymour and Hamman, 1988
Firm and brittle, snaps easily, emitting a typical sound upon deformation.	N/A	Szczesniak, 1988
The perceived relative force used by crunching the product in the mouth.	Molars	Onwulata and Heymann, 1994
The perceived force with which the product separates into two or more distinct pieces during a single bite with the incisors. An abrupt and complete failure of the product is required	Incisors first bite	Barrett, 1994
Products that produce a high pitched sound. that show high level of frequency higher than 5 kHz, especially for air conduction sounds	Only incisors, or bitten and chewed	Dacremont, 1995
The amount and pitch of sound generated when the product is first bitten with the front teeth.	Front teeth bite	Harker et al. 1997
A combination of the noise produced and the breakdown of the product as it is bitten entirely through with the back molars.	Biting with the back molars	Duizer et al. 1998
Fractures in an abrupt manner after applying a relatively small force on the product.	Front teeth, first bite	Vincent et al. 2002
Fracture in an abrupt, brittle manner after applying a relatively small force on the product on the first chew with the molars.	Molars, second bite	Vincent et al. 2002
Cracks, you can force your teeth through slowly, more airy than crackling	At first bite	Dijksterhuis et al. 2005

Soft sound, more airy than crackling. Association with fresh disintegrates into pieces smaller than when crackling.	During chewing	Dijksterhuis et al. 2005
A combination of the type of sound i.e., short snapping and longer cracking sounds and the force to bite and chew as perceived on the first bite.	First bite	Duizer and Winger, 2006

Table 2. Literature citation of crunchiness

Definition	Technique	Reference
Is the perceived hardness of a food after it is crushed and chewed in the mouth 2-3 times. Also defined as the amount of force necessary to crush and grind the cube during the second and subsequent chews.	Chewing with molars	Moskowitz et al. 1974
Products that produce lower pitched sounds are less loud and last longer than for crisp. Firm and brittle. Snaps easily with typical sound.	Chewing with molars	Vickers, 1984b
Degree of low pitched noise (with respect to crisp sounds) but above threshold pitch considered too low.	Place product between molar teeth	Seymour and Hamman, 1988
Complex failure mechanism that involves repetitive deformation and fracturing of cell structure. Necessary are structural subunits, especially with cells, with brittle cell walls. Continuous fracture during chewing. Sensory description: the perceived intensity of repeated incremental failures of the product during a single complete bite with the molar teeth.	First bite with molars	Barrett, 1994
The perceived cumulative intensity of force required for repeated incremental failures of the product by chewing up to five times with the molars.	Chewing with molars	Guraya and Toledo, 1996
The amount of noise generated when the product is chewed at a fast rate with the back teeth.	Chewing with back teeth	Harker et al. 1997
Products that produce a low-pitched sound with a characteristic peak on frequency range 1.25 to 2 kHz, for air conduction.	Only incisors, or bitten and chewed	Dacremont, 1995
Temporal aspects of the sensory feedback during mastication are important for the crunchy sensation. Independent from hardness.	Chewing with molars	Brown et al. 1998

Crunchy would be associated with a hard and dense texture that fractures without prior deformation producing a loud, low-pitch sound that is repeated during several chews. Crunchy is more relevant to fruits and vegetables when compared to crispness.	Mainly during chewing	Fillion and Kilcast, 2001
Fractures after applying a higher force on the product than for crispness.	Front teeth, first bite	Vincent et al. 2002
Fractures after applying a higher force on the product than for crispness on the first chew with the molars.	Molars, second bite	Vincent et al. 2002
High-pitched sound, light sound, long sounding.	During chewing	Dijksterhuis et al. 2005

Table 3. Literature citations of crackliness

Definition	Technique	Reference
To make small, sharp, sudden and repeated noises.	At first bite or during chewing.	Vickers, 1984a
Products that generate low-pitched sounds with a high level of bone conduction. Discrimination between crackly and crunchy foods could be due to vibrations propagated by bone conduction that also generated vibrotactile sensations.	Only incisors	Dacremont, 1995
Combination of sound and bite force. Clip between the teeth and it breaks. Crackling is harder than crispy. It snaps.	At first bite	Dijksterhuis et al. 2005
Audible for a long period during chewing, bigger pieces, mainly of the crust.	During chewing	Dijksterhuis et al. 2005

Table 4. Technique for the evaluation of crispness crunchiness and crispness developed by seven trained panelists

Crispness	Place the product between the incisors (front teeth), bite through the product and evaluate the intensity of the sound after the first bite using as near as possible the same biting rate and force for all products in the scale.
Crunchiness	Place products between molars; bite down with low pressure (regular eating pattern). Chew product 2 to 3 times and listen to the sound produced and how the sound diminishes (intensity and duration of the sound).Place product between molars and bite once with a lot of force without grinding the products. Snap down.
Crackliness	Place product between molars and bite once with a lot of force without grinding the products. Snap down.

Table 5. Crispness standard scale for dry foods developed by seven trained panelists

Scale value	Reference	Brand/Manufacturer	Sample Size
2	Rice Krispies Treats	Kellogg's	1/6 bar
5	Fiber Rye	Wasa	1/3 slice
8	Multigrain Mini Rice Cakes (Honey Graham)	Quaker	1 cake
10	Tortilla Chips (Bite size Tostitos)	Frito Lay	1 chip
15	Kettle Chips	Frito Lay	1 chip

Table 6. Crispness standard scale for wet foods developed by seven trained panelists

Scale value	Reference	Brand/Manufacturer	Sample Size
0	Banana	Supermarket	1/2" thick slice
4	Gala Apple	Supermarket	1/2" thick slice
7.5	Granny Smith Apple	Supermarket	1/2" thick slice
10	Jicama	Supermarket	1/2" thick slice
15	Carrots	Supermarket	1 mini peeled carrot

Table 7. Crunchiness standard scale for dry foods developed by seven trained panelists

Scale value	Reference	Brand/Manufacturer	Sample Size
1	Rice Krispies Treats	Kellogg's	1/6 bar
4	Goldfish Baked Crackers	Pepperidge Farm	1 cracker
7	Cheez-it Baked Snack Crackers	Sunshine	1 cracker
9	Tortilla Chips (Bite size Tostitos)	Frito Lay	1 chip
12	Honey Maid Graham Honey Sticks	Nabisco	1 stick
15	Melba Toast	Old London	1/2 toast

Table 8. Crunchiness standard scale for wet foods developed by seven trained panelists

Scale value	Reference	Brand/Manufacturer	Sample Size
0	Banana	Supermarket	1/2" thick slice
4	Gala Apple	Supermarket	1/2" thick slice
10	Jicama	Supermarket	1/2" thick slice
12.5	Banquet Baby Dill	Nalley	1/2" thick slice
15	Green Pepper	Supermarket	1/2" thick slice

Table 9. Crackliness standard scale for dry foods developed by seven trained panelists

Scale value	Reference	Brand/Manufacturer	Sample Size
2	Club Cracker	Keebler	1/2 cracker
7	Multigrain Mini Rice Cakes	Quaker	1/2 cake
9	Le Petit Beurre Tea Cookie	Lu	1/8 square
12	Triscuit	Nabisco	1/4 broken with the grain
15	Ginger Snap	Archway	1/2 cookie

Table 10. Crackliness standard scale for wet foods developed by seven trained panelists

Scale value	Reference	Brand/Manufacturer	Sample Size
1	Medium Black Olives	Canned	1 olive
5	Daikon Radish	Supermarket	1/4 ' thick slice
7.5	Turnip	Supermarket	1/4 ' thick slice
10	Jicama	Supermarket	1/4 ' thick slice
15	Carrots	Supermarket	1/2 mini peeled carrot

Table 11. Correlation between auditory recordings (average RMS) and sensory evaluation by untrained panel

	r
Crispness Dry Foods	0.83
Crispness Wet Foods	0.96
Crunchiness Dry Foods	0.99
Crunchiness Wet Foods	0.99
Crackliness Dry Foods	0.88
Crackliness Wet Foods	0.96

Figure 1. MDS representation of auditory crispness for dry foods

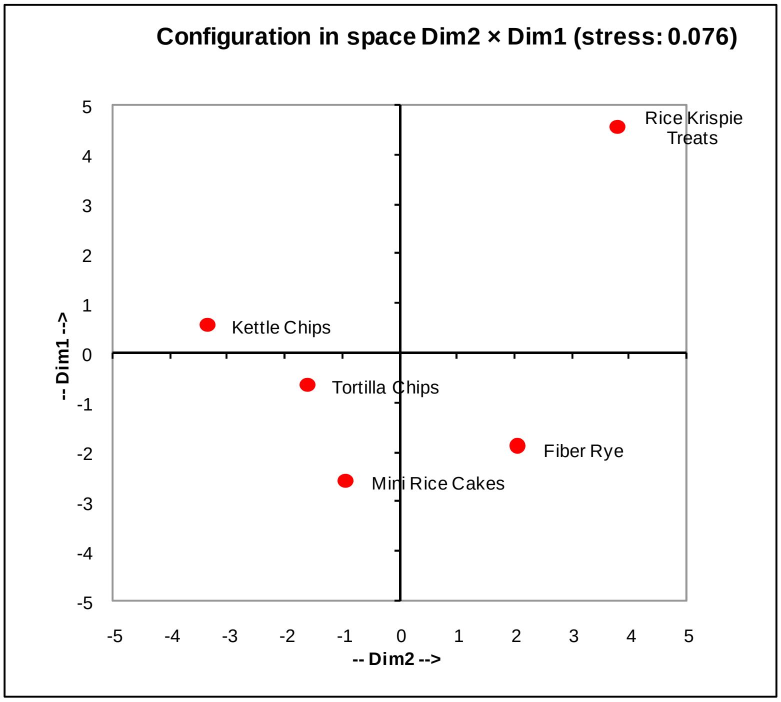


Figure 2. MDS representation of auditory crispness for wet foods

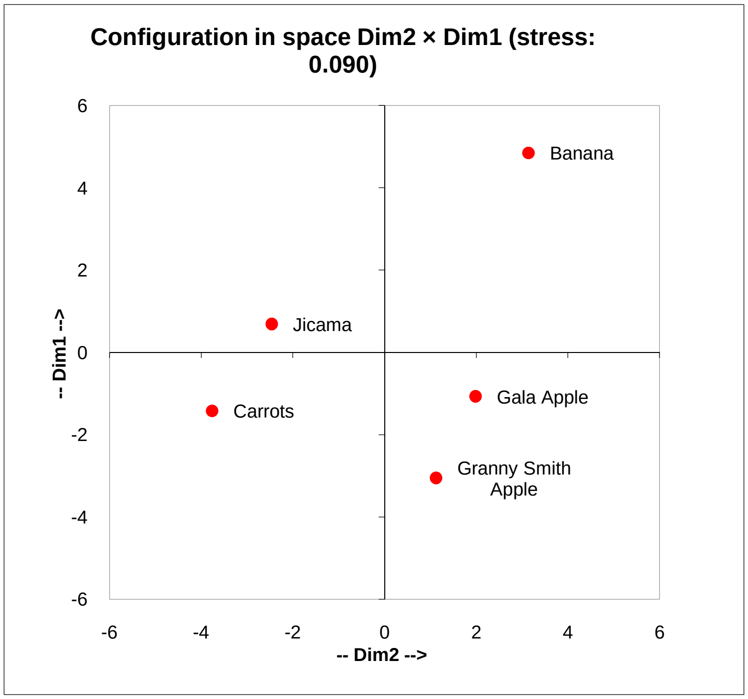


Figure 3. MDS representation for auditory crunchiness for dry foods

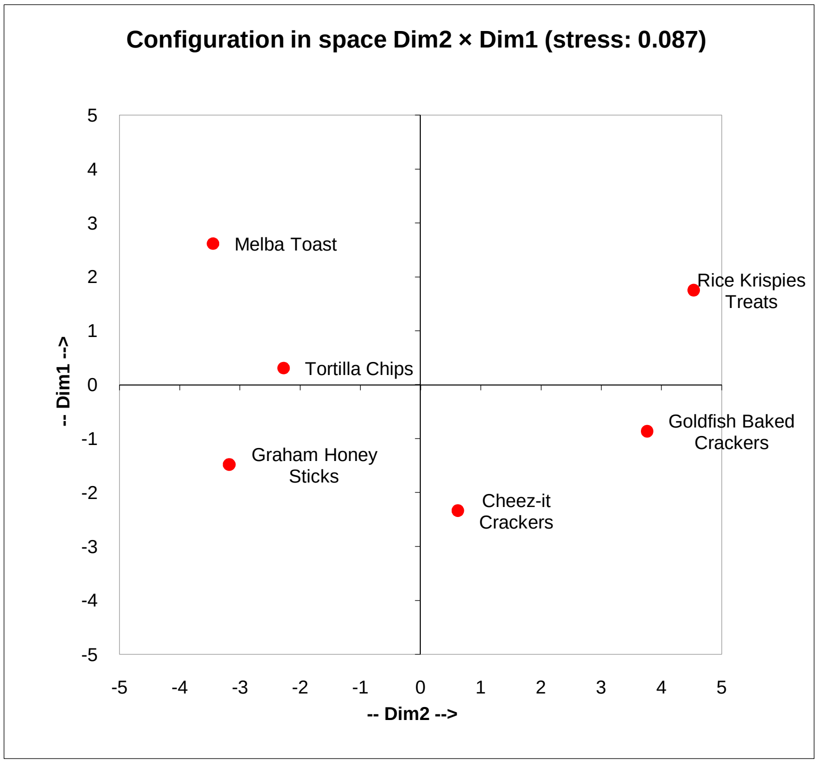


Figure 4. MDS representation of auditory crunchiness for wet foods

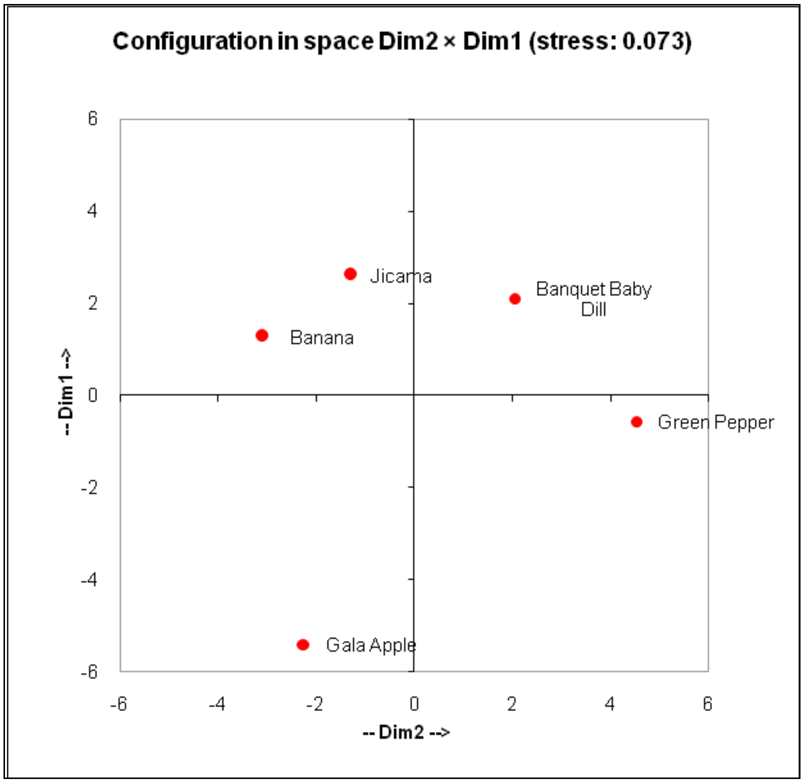


Figure 5. MDS representation of auditory crackliness for dry foods

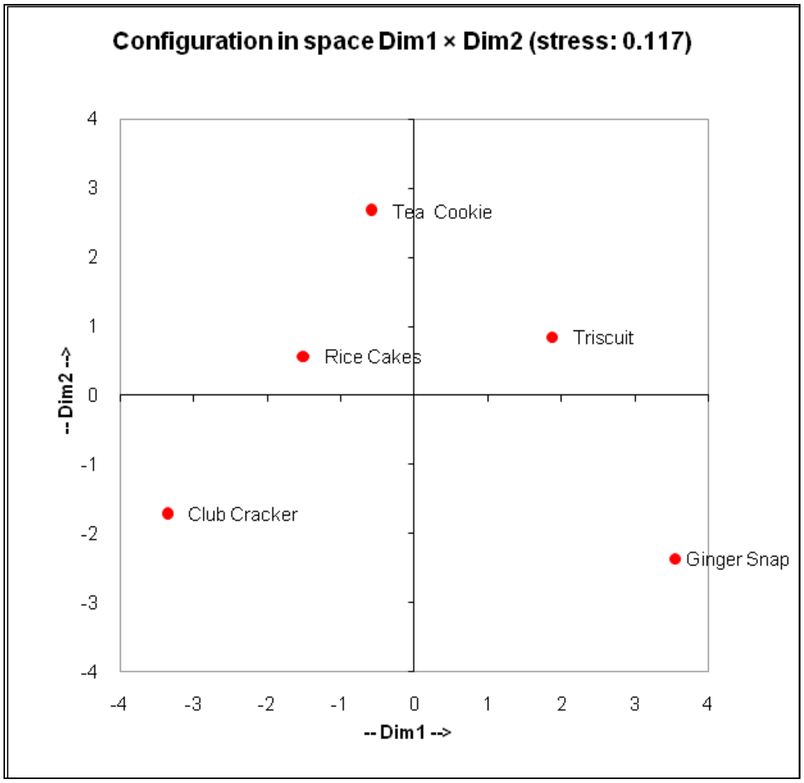


Figure 6. MDS representation of auditory crackliness for wet foods

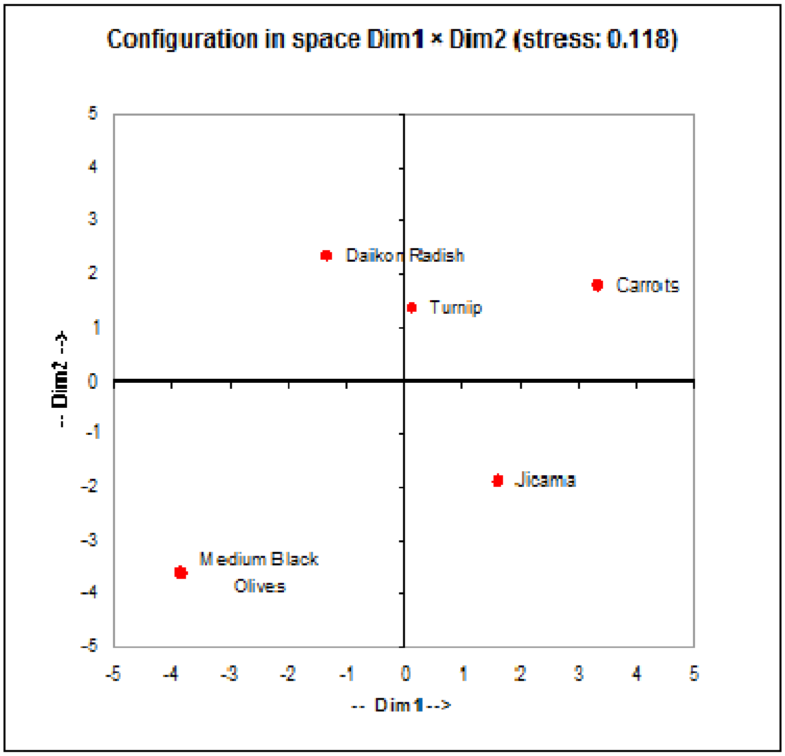
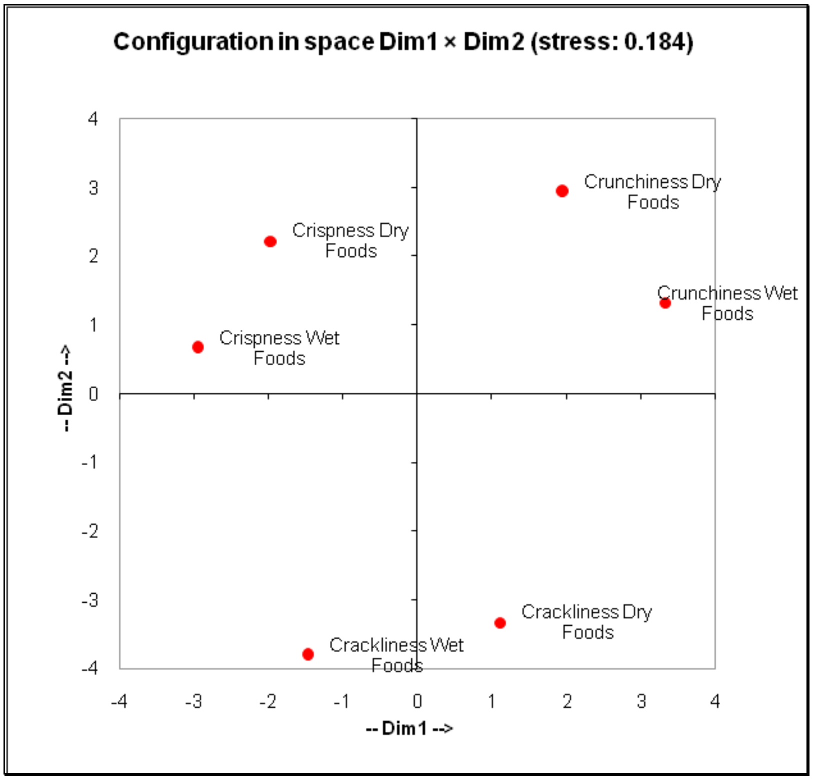


Figure 7. MDS representation for overall auditory crispness, crunchiness and crackliness for dry and wet foods



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Chapter Five

Conclusions and Future Work

1. Conclusions

- Multidimensional scaling is a robust exploratory statistical and graphical technique, effectively producing a graphical representation of overall similarity in food texture perceptions from selected sensory panelists. MDS significance in validating existing scales is to visually evaluate if scales created in the past retain their properties and functions as when they were originally developed.
- Sensory results of apples and pears texture indicate strong correlations among the sensory texture attributes of crispness, hardness and fracturability for apples and pears. Disparity in juiciness perceptions in apples and pears were attributed to the differences in cell structure.
- When correlating sensory evaluation to instrumental determinations, both the Sinclair iQ™ System and the Guss pressure sensor provided a reasonable predictor of apple hardness. The tensile properties of apples and pears may potentially predict crispness, but accurate predictions are highly dependent on the orientation of the fruit when analyzed by an instrument or in the mouth. A combination approach, assaying with an instrument to determine compressive and tensile properties, provides the most accurate prediction of apple and pear textural properties compared to any existing method.
- The developed standard texture scales for crispness, crunchiness and crackliness for dry and wet foods provides individuals interested in auditory texture evaluation a starting point to assist in training sensory panelists for descriptive

analysis of food texture. Although future modifications in reference foods' attribute definitions or evaluation procedures are expected, this study represents a first step in the generation of reproducible auditory sensory data using food standard texture scales.

- The average power calculated from the RMS voltage signal is a reliable, rapid, and straightforward tool to analyze auditory texture parameters in food.
- MDS output demonstrates that crispness, crunchiness and crackliness are distinguishable sensory texture parameters belonging to selected distinguishable concepts and may be analyzed solely by auditory cues. Also, a perceptual difference is observed between texture attributes for dry and wet foods. Differentiating between both is essential for more accurate descriptive analysis training.

2. Future Work

- There is a need for improved training of sensory texture panelists, selection for panelists sensitive to texture notes, and more attention devoted to understanding texture nomenclature. Developing official international standards for sensory texture testing procedures will allow for normalized results among panelists, laboratories and countries.
- More studies are needed to obtain improved correlations between sensory texture profile analysis and instrumental texture profile analysis.
- The knowledge base of the psychological factors influencing perception and individuals' choices should be integrated with physiological factors. This can be integrated with the use of multivariate statistical techniques widely used in sensory science. Interactions between texture and other sensory modalities must be taken into account in understanding texture influences.
- There is a fundamental lack of understanding of physiological factors influencing texture perception mechanisms and mastication processes. Dental research must be integrated into sensory research studies; for example, dental researchers are focused on mastication, while sensory scientists are focused on first bite. The integration of both sciences can complement each other and offer great opportunity of fully understanding the perception of textural properties in foods.

- A new generation of texture assessment instrumentation is needed that can operate at greater compression speeds, especially for foods that are strain rate sensitive.
- Understanding the influence of saliva on the texture of food may be valuable because knowledge may provide a better understanding of the full sequence of the mastication process. More studies are needed on the chemical composition and rheological properties of saliva, and how selected foods affect the amount or type of saliva induced in the mouth. Also, more studies regarding the interactions of saliva with foods and the effects on the structure of foods are needed to fully understand food texture.