DETERMINATION OF CRISPNESS IN BREADED FRIED CHICKEN NUGGETS USING ULTRASONIC TECHNIQUE

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Thesis submitted to the Faculty of the

Virginia Polytechnic Institute and State University

in partial fulfillment of the requirements for the degree of

Master of Science

in

Biological Systems Engineering

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December 18, 2001

Blacksburg, Virginia

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(ABSTRACT)

Crispness is one of the most important and desirable textural characteristics that signify freshness and high quality in breaded fried foods. Though many approaches to instrumental measurement of crispness have been made, the best measurements are still inconclusive. There is no reliable method available that can accurately measure and quantify crispness in breaded fried foods.

In this study, the mechanical and ultrasonic techniques were used to determine crispness in breaded fried chicken nuggets under different storage conditions. The mechanical measurements have been made, using an Instron universal testing machine. An ultrasonic non-destructive evaluation system was used to measure ultrasonic properties of breaded friend chicken nuggets. A pair of dry-coupling 250-kHz ultrasonic transducers was used to perform the ultrasonic transmission through the breaded fried chicken nugget. The equipment set up was in the through-transmission mode because breaded fried chicken nugget is highly attenuative material.

A sensory panel of eight members was trained to evaluate crispness in breaded fried foods. Panelists rated crispness on a nine-point category scale (1 = not crisp/soggy,

9 = very crisp). Sensory crispness values for breaded fried foods under different storage conditions were obtained.

Ultrasonic velocity, transmission loss, peak frequencies and its energies, peak force and total energy were determined for each tested product. Correlation between sensory crispness and instrumental parameters suggests that the ultrasonic method can be used to evaluate crispness. The ultrasonic velocity had high correlation with sensory crispness ($R^2 = 0.83$). This indicates that sensory crispness could be reasonably well predicted by the ultrasonic velocity.

ACNOWLEDGEMENTS

I would like to express my sincere appreciation and respect to my major advisor, Dr. Kumar Mallikarjunan, for his thoughtful guidance, friendship, encouragement, time and all of his assistance throughout my M. S. study and this research. I admire his research skills especially the ways to deal with the problems of different facets, and organize the thoughts efficiently.

I am grateful for Dr. Susan E. Duncan, Dr. C. Gene Haugh, and Dr. John C. Duke for serving on my advisory committee. I thank them for kindness, friendliness and all the help they have provided in this study. Their suggestions and support were very helpful and invaluable throughout this study.

Special thanks are extended to my fellow graduate students who have been very friendly and helpful in conducting many experimental tests in this study. My appreciation has also been given to my Russian friends who cherished and fancied my life here.

Lastly, I would like to express my deepest gratitude and love to my dear parents and my beloved son for their support. Without their love, understanding, support and encouragement, the completion of this study would have never become possible. I thank them for all their love and help they are giving me.

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SECTION I

INTRODUCTION

Crispness is one of the most distinctive characteristics of dry crisp and fried foods. It is conveyed to consumers by a snapping characteristic when the food is bitten through. This characteristic signifies freshness and high quality in food products.

Breaded fried foods are favored by consumers due to unique and desirable characteristic of crispness provided by a soft and moist interior with an outer crispy crust. However, the loss of crispness in fried foods is mainly due to the absorption of moisture by the crust, causing it to become soggy. Consequently, the breaded fried products become less desirable to consumers. The loss of crispness can be retarded temporarily by holding fried foods under a heat lamp. However, the holding time can be critical for fried foods.

Over the years, many investigators have worked on various techniques to measure crispness. However, most measurements were applied for low moisture foods. Studies related to crispness in high moisture foods have been very limited. There is no reliable method available that can accurately measure and quantify crispness in breaded fried foods with a dry outer crust layer and a moist core. The development of such an objective technique that can be correlated to sensory crispness will benefit the food service business and food processing industry to produce products with desirable attributes and high quality.

Hypothesis

The hypothesis for this research is that an ultrasonic technique can reliably quantify crispness on breaded fried food having a moist core.

Objectives

The goal of this research was to investigate and use an ultrasonic non-destructive testing method to evaluate crispness in breaded fried foods having a moist core. The specific objective were as follows:

1. Investigate the possibility of using ultrasound at various frequencies to perform the ultrasonic transmission on the breaded fried chicken nuggets.

2. Train a sensory panel for evaluating crispness in breaded fried foods.

3. Obtain sensory crispness values for breaded fried foods under different storage conditions.

4. Determine the ultrasonic parameters that can correlate well with sensory crispness of breaded fried chicken nuggets.

5. Measure the mechanical properties such as peak force and total energy for breaded fried chicken nuggets.

6. Investigate the relationships between the instrumental parameters and sensory crispness scores obtained using trained panel.

Rationale and Significance

Developing quality-enhanced products with desirable attributes give food companies an added advantage and increased competitiveness in the market. In order to achieve this, companies need a reliable method to evaluate the quality attributes of the product. This study was conducted to reveal the possibilities of using an ultrasonic non-destructive method as an objective method to quantify crispness in breaded fried chicken nuggets.

Outline

   This thesis consists of five sections. Section II, " Literature review", is presented first as a guide for the theoretical background and as a description of previous research work applying to crispness. Section III, "The development of an ultrasonic technique to evaluate crispness in breaded fried chicken nuggets", deals with the development of an ultrasonic non-destructive method for characterizing crispness. Section IV, "The sensory evaluation of crispness in a breaded fried foods held under a heat lamp", provides the information about training a sensory panel and obtaining sensory crispness scores. Section V, "Instrumental measures of crispness and their correlation with sensory crispness", provides discussion on some objective qualities and on the relationships between the instrumental parameters and sensory crispness. Section VI, " Summary and conclusions", is provided as the final section of this thesis.

SECTION II

LITERATURE REVIEW

Crispness is one of most important textural and desirable characteristic of dry crisp foods and fried foods, and has been studied by many investigators. Various definitions and meanings of crispness, studies of instrumental measurement of crispness, and its importance are described in this chapter. Ultrasonic technique is presented as a potential method for the objective evaluation of crispness. Ultrasonics have been used successfully in food industry for many years for various purposes. The basic principles of ultrasonics and its applications are reviewed in this chapter.

Batters/Breading for Fried Food and Its Significance to Crispness

Among battered and breaded food products, fried foods constitute a major portion. Fried chicken products exceeded $8.2 billion in sales in the U.S. in 1996. Coating seafood, poultry, red meat, and vegetable products with a batter and/or breading before cooking is a common practice of homemakers, food processors, and commercial fast-food outlets. Batter was defined as the liquid mixture comprised of water, flour, starch, and seasonings into which food products are dipped prior to cooking. Breading was defined as a dry mixture of flour, starch, and seasonings, coarse in nature, and applied to moistened or battered food products prior to cooking. Coating was referred as the batter and/or breading adhering to a food product after cooking (Suderman, 1983).

The batter systems are classified into two categories: interface/adhesion and puff/tempura (Loewe, 1992). The interface/adhesion batters are used with breading, serving primarily as an adhesive layer between the product's surface and the breading. Chemical leavening is not normally used. Puff/tempura batters use leavening agents and are used as an outside coating for the food. The batter uniformity and thickness, which is

related to the batter viscosity, determine acceptability of the finished product. A more viscous batter will pick up more breading than will a less viscous one.

Batters and breadings serve many functions as food coatings, such as enhancing a food product's appearance (Elston, 1975), giving a crispy texture (Elston, 1975 and Zwiercan, 1974) and contributing to the pleasure of substantial eating (Vickers and Bourne, 1976b). Coating material is a key for producing a desirable crispness in breaded fried chicken nuggets, chicken strips and seafood. Ideally, the coating should exhibit a structure that sufficiently resists the initial bite, and then should disappear with a quick meltaway in the mouth. A coating that does not readily break down during subsequent mastication will be rated chewy, heavy, undesirable, and perhaps even lacking in freshness (Loewe, 1992).

Hanson and Fletcher (1963) suggested that mixtures of thickening agents could be used for achieving desirable crispness. Cooking also affects coating crispness. Donahoo (1970) reported that crispness can be adjusted by time and temperature of cooking.

The optimum method for producing crisp coated foods is through deep-fat frying at temperatures ranging from 176^0 C to 204^0 C. Rapid heat transfer quickly sets the coating structure, allowing little time fore excess moisture infiltration. This cooking procedure is the method of choice in the food service industry for both interface/adhesion and puff/tempura coatings. Primarily used in the home, oven heating is the method for producing a moderate acceptable product in terms of crispness, color, and flavor. Although the heating rate is slower than that of deep-fat frying, the elevated chamber temperature of the oven causes some evaporative drying of the coating, resulting in the perception of crispness. It appears that microwave heating is not suitable method for

coated foods. Microwave oscillations cause molecular vibrations and resultant frictional heating within the food. The evaporative drying does not occur. The result is a soggy coating with minimal crispness. Use of microwave heating will require a unique technology for effective product development of coated foods (Kulp and Loewe, 1992).

One problem common to all battered and/or breaded products is adhesion. Poultry parts are known as the most difficult food substrate to batter or bread (Suderman, 1983). Batter and breading adhesion is affected by several factors such as poultry skin ultrastructure, freezing of parts, product surface temperature, predip composition, batter viscosity, breading and batter composition, and the cooking process. In typical deep-fat frying, the batter or breading coating quickly coagulates upon exposure to high frying-oil temperatures. As a result, the coating essentially takes the size and configuration of the product. However, as the food product continues to cook, the substrate shrinks to a size smaller than the coating matrix. Precooking of the product by steaming, simmering, or boiling has been recommended to improve its adhesive properties before the batter was applied (Kulp and Loewe, 1992).

Crispness in Foods

Crispness is a highly-valued and universally-liked textural characteristic that has many positive connotations. Its presence signifies freshness and high quality. It goes well with many other textural characteristics and is often used to create pleasing textural contrasts. Probing into consumer attitudes to texture and its specific characteristics Szczesniak and Kahn (1971) stated that crispness is particularly good as an appetizer and as a stimulant to active eating. It is very important to the pleasure of substantial eating. It appears to hold a particular place in the basic psychology of appetite and hunger

satiation. It is notable as a relaxing or satiable texture and appears to be universally liked characteristic. Crispness is very prominent in texture combinations that mark excellent cooking and is synonymous with freshness and wholesomeness. In their 1984 study of textural combinations Szczesniak and Kahn added that crispness appears to be the most versatile single texture parameter.

Over the years, many investigators have worked on the various definitions and meanings of crispness. However, the definition of crispness is not completely understood. Only the generalized concept has been established as close to the definition as possible. The importance and desirability of crispness have increased research efforts to define and measure this attribute (Vickers, 1988; Szczesniak, 1988; Lee *et al*., 1990; Dacremont, 1995).

Szczesniak (1988) tried to characterize crispness based on the consumer descriptions and found that crispness was associated with brittleness, crackling, snapping, crunchiness and sound emission during eating.

Crispness and Crunchiness

Several scientists have shown that crispness and crunchiness are very closely related sensations, but crunchiness is used more often in reference to moist foods (Szczesniak and Kahn, 1971; Moskowitz and Kapsalis, 1974; Vickers and Wasserman, 1980; Vickers, 1981). Moskowitz and Kapsalis (1974) derived regression equations relating descriptors to one another and found that crispness was most closely related to the quality of crunchiness and crunchiness was most closely related to crispness and hardness. Vickers and Wasserman (1980) used multidimensional scaling to arrange 15 food sound descriptors in two-dimensional space. The descriptors crisp and crunchy were

very close to each other in this space, indicating that they have similar meanings when used to describe sounds. Vickers (1981) had subjects judge 16 foods and the biting and chewing sounds of these foods for both crispness and crunchiness. She found large correlations between the two descriptors, whether the judgments were made on the basis of biting and chewing the foods or by only listening to the sounds.

It has been suggested that the sensations of crispness and crunchiness may differ in the pitch of their respective sounds (Vickers, 1979 and 1984). Foods that were more crisp than crunchy produced higher pitched sounds than foods that were more crunchy than crisp. However, pitch is a complex characteristic and is not dependent on a single physical quantity, the pitch of sound being determined by its frequency, intensity and waveform.

Seymour and Hamann (1988) studied the relationships between descriptive sensory crispness and crunchiness and acoustic and mechanical measurements for low moisture foods. A trained texture profile panel developed sensory definitions of crispness and crunchiness. Sensory crispness was evaluated by placing sample between incisors and detecting a level of higher pitched noise. Sensory crunchiness was evaluated by placing sample between molar teeth and detecting a degree of low-pitched noise. High correlations were found between sensory crispness and crunchiness in all products. Seymour and Hamann (1988) indicated that crispness and crunchiness are closely related sensory interpretations of food texture, and can be quantified by a combination of mechanical and acoustic measurements. Mechanical force and work done to failure had strong inverse correlations with sensory crispness and crunchiness. Acoustic parameters also had high correlations with the sensory parameters. Crisp products were mechanically

weaker than crunchy products. More force was required to fracture a crunchy product. However, the acoustic parameters that highly correlated with sensory crunchiness tended to be at lower frequencies than was the case for crisp products.

Characterization and Determination of Crispness

Though many approaches to the instrumental measurement of crispness in foods have been made, the best measurements are still inconclusive. However, the properties related to crispness were able to disclose the complexity of crispness and its association to other similar sensory attributes, such as brittleness, hardness, crackliness or crunchiness.

Structural and geometrical properties

Many researches agree that crispness should result from the structural properties of a food (Barrett *et al*., 1994; Gao and Tan, 1996a; Bouvier *et al*., 1997; Mohammed *et al.,* 1982; Stanley and Tung, 1976; and Vickers and Bourne, 1976b). Matz (1962) and Coppock and Carnford (1960) indicated that crisp, dry foods such as biscuits, break into many pieces when masticated and that their eating quality is affected by the size of air cells and thickness of the cell walls.

Crispness is related to the cellular structure of foods. Perhaps the most direct method of its objective measurement is likely to be the investigation of the product's structure and geometrical properties. Scanning electronic microscopy (SEM) is often used to reveal the internal structure of the product. Gao and Tan (1996a) used this technique to measure the cell size and density. Barrett *et al.* (1994) investigated the structural properties characterized in terms of cell size distribution and bulk density of corn-based extrudates. They found that mechanical strength, defined by a compressive

stress, and fracturability, quantified by fractal and Fourier analyses of stress-strain functions, increased with either decreasing mean cell size or increasing bulk density. The correlation of fracturability parameters or structural characteristics with sensory scores of crunchiness, crispness, and hardness indicated that cellular structure strongly influences the pattern of mechanical failure.

Recently Gao and Tan (1996b) proposed that some important sensory attributes could be analyzed by an image processing technique. Some important sensory attributes could be predicted by processing the surface and cross-section images of the product.

Mechanical properties

Perhaps the most prevalent objective measurement for crispness is a determination via mechanical properties. The mechanical properties are associated with the structural properties of materials derived by means of the resistance to a compression of blade/probe and to a tensile that pulls the structure of food material apart by a universal testing machine such as Instron or a texture analyzer.

In order to authenticate the sensory assumptions, various modifications of jigs and tools were created for objective investigations, such as shear compression blade, puncture probe, Kramer shear-compression test cell, and snap test cell. Nevertheless, there are no definite criteria for selection of an apparatus to measure the mechanical properties of foods. Also, the tests are dependent upon the nature of products. Therefore, a variety of mechanical tests have been reported for different low moisture foods.

Vickers and Bourne (1976a) used a snap test to measure such parameters as bend deformation to fracture, and stiffness (the slope of a force-deformation curve of Young's modulus). They found large correlations between these measurements and sensory

crispness. Voisey and Stanley (1979) suggested that the number of peaks or breaks using a Warner-Bratzler test cell would be a good indicator of crispness in fried bacon.

Mohamed *et al*. (1982) used a constant force rate texture testing instrument to study crispness of the biscuits. Good correlations were found between sensory crispness and the ratio of work to fracture to total work.   Seymour (1985) used a Kramer shear cell in an Instron to crush samples of several dry crisp foods altered in crispness by humidification. He found large negative correlations between crispness and the following mechanical parameters: maximum force at failure and work done to failure.

Although mechanical tests are relatively quick and easy to perform they have not produced high enough degree of correlation with sensory crispness. Also, many crisp foods cannot be tested by these tests because they are too small, have irregular sizes and shapes or are part of a food that also consists of noncrisp parts.

Acoustical properties

Drake (1963) was the first scientist to study food crushing sounds. He observed that sounds from crisp foods differ from those of noncrisp foods in their amplitude. In another study, Drake (1965) found high correlation between sound amplitude and perceived loudness. Since the pioneering work by Drake (1963, 1965), several studies have been made to relate textural characteristics (especially crispness) to a sound quality, which is a complex function of several acoustical parameters. Pitch is the main sound quality and is defined by the frequency of pure tones or by the frequency range with the highest energy level for complex tones. The sound produced when a food is crushed contains a large amount of information. It is composed of many different pitches and the loudness of the sound varies over these different pitches.

Studies have shown that the auditory sensations are an important for evaluating crispness (Vickers and Bourne, 1976b; Christensen and Vickers, 1981; Mohamed *et al.*, 1982; Edmister and Vickers, 1985; Lee *et al.*, 1988). Vickers and Bourne (1976) studied the acoustical properties of tape-recorded biting sounds of wet and dry crisp foods. They found that crisp foods consist of an uneven and irregular series of noises, and suggested that the repeated breaking or fracturing of food samples during biting and chewing produced these acoustical characteristics. Observing differences in amplitude-time plots between the samples, Vickers and Bourne concluded that less crisp samples produced less noise. Christensen and Vickers (1981) evaluated separately the loudness and crispness of 16 different products during chewing and biting. They found high positive correlations between crispness and loudness, indicating that biting and chewing sounds were important for evaluating crispness. Mohamed *et al.* (1982) studied the sound produced by five varieties of dry crisp foods stored at different relative humidities. The sounds were recorded as the foods were fractured by compressing in a constant loading rate texture testing instrument. The sound energy correlated significantly with sensory crispness. Edmister and Vickers (1985) investigated the relationships between several instrumental acoustical parameters and sensory crispness. They found that the best acoustical predictor of auditory crispness was the logarithm of the number of sound bursts and the mean amplitude of the bursts.

Dacremont (1995) asserted that sounds generated from a food fractured by a mechanical apparatus are different from eating sounds and do not contain the relevant information for texture judgment. Nevertheless, eating sounds are still varied in frequency components that are either airborne or conducted via the bone. Regarding this

matter, Lee *et al.* (1988) investigated acoustic behavior during 10 consecutive chews of potato chips and tortilla chips. They found that as chews increased, sound intensity tended to increase. Also, the higher frequency of chewing sound which is audible decreased as chews increased. This finding was supportive of the psychoacoustical theory proposed by Vickers and Bourne (1976a) that crispness should be characterized by high-pitched sound. Therefore, they hypothesized that the assessment of crispness may be more dependent on the information obtained from initial mastication as opposed to later chews.

Caution has been raised by Peleg (1997) concerning the recent development in acoustical properties that have been proposed and the measured acoustic variables used in the past in that the count for the number of peaks does not account for the peak magnitude and shape which can be sharp or broad. In addition, the count also can be affected by the selected resolution and sampling rate. Peleg (1997) recommended using the Fourier transform method to obtain more reliable information for determining crispness (or crunchiness) in foods.

Acoustical analysis is not sufficient enough to measure crispness. It has been suggested that combination of the acoustical and mechanical measurements might predict better the crispness of foods (Mohamed *et al*., 1982; Seymour, 1985; Vickers, 1987; and Vickers, 1988).

Combination Measurements

Sensory crispness has been predicted using both acoustical and force-deformation measurements by the multiple linear regression technique summarized in Table 2.1. Seymour (1985) studied crispness in four different low moisture foods. In all cases except

Crunch Twist, crispness was positively related to an acoustical parameter and inversely related to a force-deformation parameter. This inverse relationship of crispness to force-deformation parameters and positive relations to acoustical parameters was also shown by Vickers (1987, 1988). Vickers (1988) noted that the inverse relationship between crispness and the force-deformation parameters is more unusual and may mean that sensations of hardness and/or toughness are detracting from crispness.

Characterization of crispness has been more complicated since Tesch *et al*. (1996) found no relationships between the mechanical and acoustical parameters. They were concerned that complication may have been due to the effect of unequal frequency for the mechanical and acoustical measurements or that some parts of the crisp or crunchy information manifested in acoustical properties may not have been fully revealed in the mechanical properties, or vice versa.

However, all these tests were applied just for low moisture foods. Studies related to crispness in high moisture products have been very limited. In addition, the measurements may be very different from that developed for low moisture foods. Recent efforts by Tahnpoonsuk and Hung (1998) to characterize crispness in breaded shrimp did not give a conclusive correlation. They attempted to record sound signals during compression testing, using modified Warner-Bratzler shear blade.

Introduction to Ultrasonics

Ultrasound has been successfully used as an analytical tool in many areas, such as industrial processes, metal fabrication, medical scanning, and evaluation of biological and food materials. Ultrasonic technique is non-hazardous, provides means to determine mechanical properties, microstructure, imaging, and microscopy, and is cost-effective.

Propagation of ultrasound in a medium is not affected by its optical opacity. Table 2.2 provides an introduction to ultrasound measurements and to the information revealed either directly or through correlation (Ultran Laboratories, Inc., 1999).

Fundamental Physics of Ultrasonics

Sound waves are produced as a result of the mechanical vibration of the particles in gas, liquid, or a solid material about the equilibrium positions of these particles. Vibration of these particles in a material is an essential characteristic of acoustic propagation. If a particle is displaced from its equilibrium position by applied stress, such as by the pressure of a sound wave, internal forces in the particles tend to place a particle to its original equilibrium position. A displacement at one point induces a displacement at the neighboring points. The transmission of a wave through a medium is the result of the effects of elastic force between the particles and inertia of the particles.

Sound waves can provide useful information about the material through which they propagate. Ultrasonic is the name given to the study and application of sound waves having frequencies above those within the hearing range of the average person, i.e., at frequencies above 16 kHz.

Ultrasonic energy travels through a medium in the form of a wave. To study such waves, it is better to begin with the simplest type of a wave such as a plane wave. Plane wave is a sinusoidal vibration that has only a single frequency component occurring in an isotropic medium, which is perfectly elastic (Wells, 1969).

The displacement amplitude, u, from the mean position of particles in simple harmonic motion, at any time, t, and at a fixed point along the direction of propagation of the wave where $u = 0$ when $t = 0$, is given by

$$u = u_0 \sin \omega t \tag{1}$$

where u_0 = maximum displacement amplitude,

and $\omega = 2\pi f$, where f is the frequency of the wave.

Velocity (υ) is equal to rate of change of position, and so it may be found by differentiating the particle displacement with respect to time.

$$\boldsymbol{u} = \frac{\boldsymbol{du}}{\boldsymbol{dt}} = u_o \boldsymbol{w} \cos \boldsymbol{w}t \tag{2}$$

Velocity of propagation

The particle displacement amplitude, u, depends upon the distance x along the direction of propagation of the wave. In general terms,

$$u = u_0 \sin\left[\boldsymbol{w}\left(t - \frac{x}{c}\right)\right] \tag{3}$$

where c = velocity of propagation of the wave,

and $[\omega(t - x/c)]$ = phase angle of the wave.

The transmission of the disturbance is not infinitely fast, because a delay occurs between the movements of neighboring particles. The elastic properties and the density of the medium control the velocity of propagation. The relationship depends upon the kind of material and the wave mode.

For longitudinal wave propagation in fluids, the velocity of sound is given by the following expression (Wood, 1932):

$$c = \sqrt{\frac{K}{r}}$$

(4)

where K is the bulk modulus, and ρ is the mean density of the medium.

In the case of longitudinal bulk waves in isotropic solids, the situation is complicated by the fact that the shear rigidity of the medium couples some of the energy of the longitudinal wave into a transverse mode (Wood, 1932). The velocity of propagation will be a function of both the bulk modulus K and the shear modulus G, and it is given by

$$c = \sqrt{\frac{K + \frac{4}{3}G}{r}}$$

(5)

The bulk and shear moduli are related to Young's modulus Y and Poisson's ratio σ as follows:

$$K = \frac{Y}{3(1 - 2\boldsymbol{s})}$$

(6)

$$G = \frac{Y}{2(1 + \boldsymbol{s})}$$

(7)

Substitution of these values in Equation 5 gives

$$c = \sqrt{\frac{Y(1 - \boldsymbol{s})}{(1 - 2\boldsymbol{s})(1 + \boldsymbol{s})r}}$$

(8)

The elastic constants are temperature-dependent, and so the velocity of sound varies with temperature. The relationship can be quite complicated. In some media, the velocity is partly dependent upon the frequency of the wave. This phenomenon is known as velocity dispersion.

Acoustic Intensity

The energy e of a particle oscillating with simple harmonic motion is the sum of its potential energy and its kinetic energy. It is given by

$$e = \frac{1}{2}m\mathbf{u}_0^2$$

(9)

where m is the mass of the particle.

The total mass of particles per unit volume is equal to the mean density ρ of the medium. The corresponding total energy E of all the particles in unit volume is the energy density, and it is given by

$$E = \frac{1}{2}r\mathbf{u}_0^2$$

(10)

Ultrasonic energy travels through the medium with the wave velocity c. The energy which passes through unit area in unit time is determined as the intensity I of the wave. And it is equal to the total energy, E, contained in a column of unit area and length equal to [c/unit time].

Thus,

$$I = cE$$

(11)

$$I = \frac{1}{2} rc\boldsymbol{u}_0^2$$

(12)

In ultrasonics, variations of intensity and wave amplitude are expressed in a logarithmic manner. The logarithmic unit is the decibel (dB). It is defined as follows:

$$dB = 10\log(\frac{I}{I_0}) = 20\log(\frac{A}{A_0})$$

(13)

Acoustic Pressure

The oscillations of the particles in the medium lead to the formation of compression and rarefaction, relative to the mean pressure. The derivation of the relationship between pressure and the other parameters of the wave is rather complicated (Blitz, 1963). For plane waves in a non-absorbent medium the acoustic pressure (*p*) can be shown as:

$$p = rc\boldsymbol{u} = rc\boldsymbol{u}_0 \sin \boldsymbol{w}t$$

(14)

Characteristic Impedance

There is a similarity between the variations of sound wave characteristics and those of certain quantities used in electrical theory. Thus, the quantity ρc is known as the characteristic impedance Z of the medium. The value of the characteristic impedance for a given material depends upon its physical properties.

Reflection and Transmission

When an ultrasonic wave reaches a boundary between two different media, some of the sound energy will be reflected. If the boundary dimensions normal to the propagation direction are much greater than the wavelength and the thickness is much less that the wavelength, then the reflection coefficient, R, for normal incidence will be

$$R = \left(\frac{Z_2 - Z_1}{Z_2 + Z_1} \right)^2$$

(15)

And the transmission coefficient for normal incidence will be

$$T = 1 - R$$

(16)

$$T = \frac{4Z_2 Z_1}{(Z_2 + Z_1)^2}$$

(17)

where Z_1 and Z_2 are the characteristic impedances for the two materials, and R and T are the fractions of the incident ultrasonic power that are reflected and transmitted respectively.

Impedance matching to ensure that Z_1 and Z_2 are nearly equal is an important consideration when choosing a transducer for a given food, since if Z_1 and Z_2 are significantly different in value, then almost all the energy from the transducer will be reflected at the boundary and fail to enter the material (Povey and McClements, 1988).

Attenuation of ultrasound

The intensity of a wave of ultrasound traveling through a medium may be attenuated by any of several different mechanisms. One of the mechanisms is the result of deviation from a parallel beam, so that the energy per unit area is reduced.

Another attenuation mechanism is due to scattering by elastic discontinuities within the medium. A discontinuity acts as a reflecting surface, the size of which in relation to the wavelength of the ultrasound determines its effect as a scatterer. Since the energy, which is scattered no longer, moves in the original direction of propagation the attenuation of the beam occurs.

These two effects are not really absorption mechanisms, for none of the ultrasonic energy is converted from its vibrational form. True absorption mechanisms involve energy conversion. The most important of these mechanisms are elastic hysteresis, viscosity and heat conduction in fluids, and molecular-level energies.

Attenuation is generally expressed in the following form (Bray and Stanley, 1997):

$$P = P_0 e^{-aL}$$

(18)

where

P_0 = original pressure level at a source

P = pressure level at second reference location

a = attenuation coefficient

L = distance from original source to second reference location

Ultrasonic Transducer

Ultrasonic energy is generated and detected by devices called transducers. By a definition a transducer is "a device that is actuated by power from one system to supply power to a second system" (Ensminger, 1973). A transducer converts energy of one from to that of another. Piezoelectric transducers are the most common mechanism, and are used at all ultrasonic frequencies for generating and detecting ultrasonic energy at all

levels of intensity. Most modern piezoelectric materials are ceramics such as barium titanate (BaTi), lead zirconate titanate (PZT), and lead metaniobate (PMN).

A transducer can be as simple as a piezoelectric disc with leads attached to both faces. Or, it can be a complex device intended to evaluate a number of materials and interfaces. A transducer device must be characterized by proper acoustics and mechanical construction.

The selection of the appropriate transducer is very important to any successful application of ultrasonics. It depends upon the composition, texture, microstructure, shape and the objectives of the materials testing. It also depends upon the mode of coupling the transducer to the test material.

A variety of devices other than piezoelectric ceramics, such as the piezoelectric film (PVDF), magnetostrictive, lasers, and electromagnetic-acoustic (EMAT) devices, offer current and future advantages in ultrasonic nondestructive evaluation.

Ultrasonic techniques in foods

Ultrasonic technology was first developed as a means of submarine detection in World War I, and developments in this area have continued to the present day (Kinsler *et al*., 1982). In the inter-war years the high-intensity ultrasonics has been applied for the ultrasonic cleaning, cell disruption and emulsification equipment. These high-intensity applications are characterized by relatively low frequencies, up to about 100 kHz, by continuous operation and by power levels from 10 kWm^{-2} upwards. Recently, high-power ultrasonics has used for promoting chemical reactions, acquiring the name "Sonochemistry" in the process (Mason, 1987).

Ultrasonic techniques for non-destructive testing (NDT) of metal were based on developments in radar electronics in World War II. Ultrasonics NDT is characterized by high frequencies (between 0·1 and 20 MHz), pulsed operation and lower power levels (< 100 mW) than high-power ultrasonics.

Ultrasonics have been used in the food industry for many years for various purposes, such as emulsification (Sajas, 1978a,b), cleaning (Lambert, 1982), animal backfat thickness estimation (Lister, 1984), and the bulk properties of food materials (Agricultural Research Council, 1982; Food and Drink Federation, 1985).

Ultrasonic measurements on food systems have special demands. Foods are generally more complex than other materials presented to ultrasonic systems. The electronic systems need to be environmentally protected, and their sensors must endure cleaning and maintenance. The sample temperature and properties and method of presentation to the sensor may be different from the laboratory ideal. However, ultrasonic techniques have such advantages as relatively low cost, a well-established theory of the interaction between acoustic fields and matter, and an indifference to hostile environments, for example hot materials and accessibility to materials opaque to light. Ultrasonic radiation also has fewer hazards associated with it most other forms of radiation (Apfel, 1981; Carstensen, 1982).

Food ultrasonics represents a new area of application and provides new sources of information about the properties of material being processed. The following properties can be determined from ultrasonic measurements (Povey and McClements, 1989).

1. Bulk modulus and rigidity modulus may be determined by measurements of the compressional and shear wave velocities and of the density.

2. The complex shear viscosity of viscoelastic media may be found by the shear reflectance technique.

3. Scattering experiments can provide information on shear viscosity and thermal diffusivity.

4. Reflection at boundaries can provide a means of gauging thickness and depth of acoustically dissimilar layers.

5. The temperature dependence of the quantities provides a means by which the velocity of sound measurements can be used to measure temperature.

6. Fluid flow velocity and velocity profile can be determined ultrasonically.

7. Measurement of ultrasound velocity in two-phase systems can provide information about the volume ratio of the phases and compressibility of the dispersed phase.

Applications of the ultrasonic technique in the food industry

Ultrasonic techniques have been used in food industry for various purposes. Povey (1984) and Miles *et al.* (1985) used ultrasonics for solids content determination. In liquids containing suspended solids, ultrasonic velocity and solids content are related. The solids content can be determined by measuring ultrasonic velocity. The technique has been applied to foods (Zacharis and Parnell, 1972), to polymer solutions (Kuster and Toksoz, 1974), and to coal slurries (Sayers, 1980). Povey and Harden (1981) measured solid foams and composites on biscuits, using soft-tipped ultrasonic probes adapted to the surface contours of the biscuit. Ultrasonics has been applied for gels (Pryor *et al*., 1958; Wyn-Jones *et al*., 1982; Morris, 1985). The measurements of rigidity and compressibility have been made by two methods that are transmitting a shear wave through the gel and measuring its velocity, and reflecting a shear wave from the gel surface. Shear waves

could not be transmitted through the gels. Povey and Wilkinson (1980) studied the components of the eggs such as yolk, thick white and thin white to design the ultrasonic quality control equipment for whole eggs. Bachaman *et al*. (1978) used ultrasonics to search the coagulation of milk protein. Ultrasonics has been used to study cheese maturation (Maiorov and Ostroumov,1977; Orlandini and Annibaldi, 1983; Benedito *et al*., 2001). Maiorov and Ostroumov (1977) evaluated the rigidity, which is an important factor in the development of the desired texture, from velocity measurements. Orlandini and Annibaldi (1983) suggested that ultrasonics could be used to indicate structural defects during the early stages of the maturation of Parmesan cheese. Gunasekaran and Ay (1996) applied ultrasonic technique to evaluate the curd firmness in order to determine the optimum cut-time for cheese making. Benedito *et al*. (2001) determined the degree of cheese maturity from ultrasonic velocity measurements performed in the through-transmission mode, and detected cracks within the cheese, using pulse-echo technique. The particle size, liquid shear viscosity and thermal diffusivity of emulsions were determined ultrasonically (McClements and Povey, 1987).

Povey and Harden (1981) measured crispness of biscuits using the ultrasonic pulse echo technique. They found good correlation between the crispness from sensory measurement and the velocity of longitudinal sound. The ultrasonic velocity correlated with crispness better than either the ultrasonically derived Young's modulus, or the Instron universal testing machine derived modulus. Povey and Harden concluded that the ultrasonic technique offers a promise as a method for the electromechanical measurement of the crispness.

Ultrasonics can be used to evaluate physical properties of fruits and vegetables. The parameters generally measured in low-intensity ultrasonics are the velocity, attenuation and acoustic impedance of the propagation medium. The measured parameter depends on the physical properties of the propagation medium, such as the elastic modulus, density and microstructure.

Ultrasonic nondestructive techniques have also been applied to detect anomalies, such as foreign bodies, voids, and hollow hearts. Hollow hearts in potatoes were detected analyzing ultrasound transmitted through the potato (Cheng and Haugh, 1994). Taubert and Stuempel (1997) used ultrasonic imaging technique to detect absences and foreign bodies in pork and pig carcasses.

Ultrasonic techniques can be successfully used in the food industry and can give significant advantages. Future successful applications depend upon understanding of the technology on which ultrasonics is based.

Conclusions

Crispness is one of the most important and desirable textural characteristics that indicate freshness and high quality in breaded fried foods. A general understanding of the crispness and its meaning exists but there is disagreement on a definition. There have been numerous approaches to the instrumental measurement of crispness in foods. However, there is no objective method available that can accurately measure and define this quality attribute for breaded fried foods having a moist core. Development of such a method will allow food product manufacturers to develop products with desirable attributes.

Ultrasonic techniques have not, so far been used for the measurement of crispness in breaded fried foods although successful applications of ultrasonics exist in characterization of foods. It has been pointed that there may be an encouraging relationship between the sensory crispness of biscuits and the velocity of longitudinal sound. In addition, ultrasonics is a technique that has wide application in industrially on-line, non-destructive measurement.

LIST OF SYMBOLS

A	Maximum amplitude
c	Propagation velocity
E	Energy
e	Particle energy
f	Frequency
G	Shear modulus
I	Intensity
K	Bulk modulus
L	Distance
m	Particle mass
T	Transmission coefficient
t	Time
p	Acoustic pressure
R	Reflection coefficient
ρ	Mean density
u	Particle displacement amplitude
υ	Particle velocity
Y	Young's modulus
σ	Poisson's ratio
Z	Impedance
ω	Angular frequency

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Table 2.1 The regression equation for crispness prediction in different foods

Products	Regression equation	R^2
Seymour (1985)		
Potato chips (Pringles)	Crispness = 13.6 – 0.19 Work^x + 0.03 MP4	0.96
Potato chips (O'Gradys)	Crispness = 6.1 – 0.08 Force + 0.21 SPL3	0.88
Potato chips (Rippled Pringles)	Crispness = 8.1 – 0.004 Work^y + 0.003 ILT	0.89
Crunch Twist	Crispness = 16.5 – 0.06 Force – 0.11 SPL1	0.95
Saltine crackers	Crispness = 9.5 – 0.12 Force + 0.017 MPL	0.91
Vickers (1987)		
Potato chips	Crispness = -15.6 + 5.35 NP + 133 MHP – 6.21 Peak	0.98
Vickers (1988)		
Breakfast cereals	Crispness = 538 + 539 (log MHP) – 222 Peak	0.74

Force = Maximum force at failure (N) by Kramer shear cell

Work^x = Work done to 1 cm deformation (mJ)

Work^y = Work done to failure (mJ)

MP4 = Mean sound pressure (N/m^2) in 2.6-3.3 kHz

SPL1 = Mean sound pressure level (dBA) in 0.5-1.2 kHz

SPL3 = Mean sound pressure level (dBA) in 1.9-2.6 kHz

ILT = Acoustic intensity (watts/m^2) in 0.5-3.3 kHz

MPL = Acoustic intensity (watts/m^2) in 0.5-1.9 kHz

MHP = Mean height peaks taken from oscilloscope display of bite sounds

NP = Number of sound occurrences during bite

Peak = Maximum force from a force-deformation curve

Table 2.2 Introduction to ultrasound measurements

Measurement Category	Measured Parameters	Applications
Time Domain	Times - of - Flight and Velocities of Longitudinal, Shear and Surface Waves	Density, Thickness, Defect Detection, Elastic and Mechanical Properties, Interface Analysis
Attenuation Domain	Fluctuations in Reflected and Transmitted Signals at a Given Frequency and Beam Size	Defect Characterization, Surface and Internal Microstructure, Interface analysis
Frequency Domain	Frequency-Dependence of Ultrasound Attenuation, or Ultrasonic Spectroscopy	Microstructure, Grain Size, Porosity, Surface Characterization, Phase Analysis
Image Domain	Time-of-Flight, Velocity and Attenuation as Functions of Discrete Point Analysis by Raster C-Scanning	Surface and Internal Imaging of Defects, Microstructure, Density, Mechanical Properties, True 2-D and 3-D Imaging

Source: Ultran Labs, Inc.

SECTION III

THE DEVELOPMENT OF AN ULTRASONIC TECHNIQUE TO EVALUATE

CRISPNESS IN BREADED FRIED CHICKEN NUGGETS*

ABSTRACT

This study explored the possibilities of using the ultrasonic non-destructive testing technique to evaluate crispness in breaded fried chicken nuggets. Pairs of dry-coupling ultrasonic transducers at frequencies of 250 kHz were used to perform the ultrasonic transmission on the breaded fried chicken nuggets. The evaluation of ultrasonic properties was based on analyzing the time domain of the transmitted ultrasound. This study found that ultrasonic parameters such as maximum peak-to-peak amplitude of the signal and ultrasonic velocity varied with the changes of samples properties. Maximum peak-to-peak amplitude ranged from 1.2 to 2.8 V. Ultrasonic velocity varied from 422 to 580 m/sec. Ultrasonic velocity seems to describe the changes in product crispness. The samples kept under ambient conditions had lower values for velocity than samples held under a heat lamp, which could be due to the lack of crispness in samples stored under ambient conditions.

INTRODUCTION

Crispness is one of the most important and desirable textural properties that indicate freshness and high quality in breaded fried foods. It goes well with many other textural characteristics and is often used to create pleasing textural contrasts (Szczesniak and Kahn, 1971). Crispness in low moisture foods has been studied by many investigators. Many definitions and meanings of crispness exist. However, this attribute was not adequately defined. In addition, the crispness in breaded fried foods with high moisture core has not been studied extensively (Tahnpoonsuk, 1999).

Many studies had shown that crispness is affected by the cellular structure of foods (Barrett *et al*., 1994; Gao and Tan, 1996a, b; Mohammed *et al*., 1982; Stanley and Tung, 1976; and Vickers and Bourne, 1976b). Crispness had been measured by the investigation of the microstructural properties such as cell wall thickness and cell size distribution.

Mechanical properties are associated with the structural properties derived from the stress-strain or force-deformation relationships of tested food material. The mechanical tests were performed for measuring crispness in different foods, such as bacon (Voisey and Stanley, 1979), potato chips (Katz and Labuza, 1981), biscuits (Mohamed *et al*., 1982), breakfast cereals (Sauvageot and Blond, 1991), and breaded shrimps (Tahnpoonsuk, 1999).

Many investigators have performed acoustical analysis to evaluate crispness. The acoustical properties of biting and chewing sounds were studied to determine crispness in dry foods (Vickers and Bourne, 1976; Christensen and Vickers, 1981; Mohamed *et al*., 1982; Lee *et al*., 1988; Dacremont, 1995). Although acoustical tests produced high

enough correlations with sensory crispness and eating process may vary the quality of sound. It has been suggested that combination of the acoustical and mechanical measurements might predict better the crispness of foods (Mohamed *et al*., 1982; Seymour, 1985; Vickers, 1987 and 1988). Chakra *et al.* (1995) explained that mechanical measurement can ascertain the link existing between the acoustic emission and the elastic behavior by thermodynamic principles, and also found that the changes in mechanical parameters were compatible with the changes in acoustic parameters. Glass transition is believed to be associated with the loss of crispness as affected by the moisture content of the products (Tesch *et al*., 1996).

Ultrasonic technique was used to assess crispness in biscuits (Povey and Harden, 1981). Good correlation between sensory crispness and velocity of longitudinal sound was found. Ultrasonic technique offers a promise as a method for objective measurement of the crispness.

However, all these tests were applied just for low moisture foods. Studies on crispness in high moisture foods are very limited. Tahnpoonsuk (1999) studied crispness in breaded shrimps stored under a heat lamp. Sensory crispness had been predicted using both acoustical and force-deformation measurements. Crispness was positively related to amplitude of the sound emitted during eating process and a shear/compression force and inversely related to a sound energy. Although the model was significant it did not produce satisfactory correlations with sensory crispness. In addition, the method proposed was destructive.

There is no reliable method that can accurately measure and quantify crispness in breaded fried foods with a dry outer crust layer and a moist core. The objectives of this

study was to investigate the possibilities of using an ultrasonic non-destructive testing

method to evaluate crispness in breaded fried chicken nuggets, and also to study the

effect of holding samples under a heat lamp on the properties of breaded chicken nugget.

MATERIALS AND METHODS

The battered and breaded fried chicken nuggets obtained from local fast food

restaurants were sorted for similar size and weight (15 ± 2g), then reheated in a

microwave oven (model 1000W/R-21HT, Sharp Electronics Corporation, NJ) for 3 min

at full power. Samples were then placed uncovered under a heat lamp (model SW-2430,

Merco Inc., Lakewood, NJ) at 60 ^{0}C to maintain crispness. Samples were also held under

ambient conditions (45 –55% RH). Samples were removed at 5-min intervals and tested

for objective crispness. Breaded fried chicken nuggets that developed off color (dark

brown) during holding time were not used in the experiments.

The Ultrasonic Non-Destructive Testing System

The ultrasonic non-destructive evaluation system developed at Virginia Tech

(Cheng and Haugh, 1994) was used to conduct ultrasonic measurements. The basic setup

of the ultrasonic non-destructive evaluation system included an Ultran BP 9400A high-

power burst pulser, an Ultran BR 640A broadband receiver, a Tektronix 2232 digital

storage oscilloscope, pairs of dry-coupling ultrasonic transducers at frequencies of

50 kHz, 250 kHz, 500 kHz and 1 MHz, and a microcomputer system for data acquisition

and analysis (see Fig.3.1). For the ultrasonic transducers at frequencies of 250 kHz, 500

kHz, and 1 MHz, the driving voltage from the burst pulser to the transducers was 400

Volts with nominal impedance of 4 ohms. For the ultrasonic transducer at nominal

frequency of 50 kHz, a high-power step-up transformer was used to yield approximately

650 Volts into 50 ohms. The pulse width, pulse separation, and repetition period can be adjusted to match with transducers of different frequencies. The broadband receiver, performed as a signal amplifier and signal filter, had a maximum gain of 64 dB. The transmitted signal was measured and shown on the oscilloscope screen. A general purpose interface board (GPIB) installed in a microcomputer allowed the transfer of digital data of the signal from the oscilloscope to the microcomputer for further analysis.

Because breaded fried chicken nugget is highly attenuative material, the equipment setup was in the through-transmission mode, where the two broadband ultrasonic transducers were placed on the opposite sides of the surface of the chicken nugget, one acting as a transmitter, and the other one as a receiver. For ultrasonic transducers at frequencies of 250 kHz, 500 kHz, and 1 MHz, the transmitting transducer was connected to the burst pulser directly. For the 50-kHz transducer, the transmitting transducer was connected to the burst pulser through the step-up transformer. The receiving transducer was wired to the receiver directly. A breaded fried chicken nugget was placed directly between the two transducers along the center line of the sample and transducers to assure the optimal propagation of the sound wave. A transducer holding device was used to apply a uniform pressure and a precise alignment of the transducers during each ultrasonic measurement, permitting the most efficient ultrasonic energy transmission through the sample.

A single square pulse at defined duration and repetition period was generated from the burst pulser, and then converted to ultrasonic wave by the transmitting transducer. The ultrasonic signal traveled through the sample and reached the receiving transducer. The ultrasonic signal was converted back to an electrical signal in the

receiving transducer, and then was sent to the broadband receiver to filter out undesired frequencies in order to improve the recovery time and signal-to-noise ratio, and finally was amplified. The received signal was first displayed on the oscilloscope screen as real time radio-frequency traces, from which the properties of the ultrasonic wave could be determined. For further analysis, the digital data were then transferred to the microcomputer.

Determination of Ultrasonic Properties

From the transmitted ultrasonic signal, such ultrasonic properties as ultrasonic velocity and maximum peak-to-peak amplitude were determined in this study.

Ultrasonic velocity of breaded fried chicken nugget

An ultrasonic velocity was determined by placing breaded fried chicken nugget directly between the two transducers along the center line of the sample and transducers to assure the optimal propagation of the sound wave. This velocity represents the average speed of ultrasound through the sample from one side to the other. The holding device was used to assure a uniform pressure and a uniform alignment of the transducers during each ultrasonic measurement.

The time-of-flight (*TOF*), known as the traveling time of the ultrasonic signal from one side of sample to the other, was determined from the plot of time domain waveform as shown in Fig. 3.2. The predetermined sample thickness and the determined time-of-flight through the sample and time-of-flight of the transducer are used to calculate the propagation velocity of the ultrasonic wave through the sample.

The ultrasonic velocity for each breaded fried chicken nugget was defined according to the following equation:

$$u_{sample} = \frac{l}{TOF - TOF_0}$$

where

u_{sample}	=	Ultrasonic velocity of breaded fried chicken nugget (m/s)
l	=	Path length of transmission (mm)
TOF	=	Time-of-flight with the sample (ms)
TOF_0	=	Calibrated time-of-flight without the sample (ms)

Maximum Peak-to-Peak Amplitude of Transmitted Signal

The maximum peak-to-peak amplitude of transmitted signal was determined as a sum of two absolute maximum voltages from a positive peak and a negative peak from the time domain of the transmitted signal.

Sample thickness and moisture content

The thickness of the sample was measured in millimeters using a caliper (model CHC-60150-D, Aerospace Inc., China). The moisture content of the sample was determined using the freeze-drying method (AOAC method 960.39, 1985).

RESULTS AND DISCUSSION

Selection of Ultrasonic Frequency

The selection of frequency of transducer was based on the fact that the attenuation of the signal transmission at higher frequencies is greater than at lower frequencies. Cheng and Haugh (1994) used a frequency of 250 kHz rather than 1 MHz to detect the hollow heart in potato during their study. They did not successfully transmit ultrasound through a whole tuber of potato using the 1-MHz transducers.

Preliminary experiments were conducted to verify that the ultrasonic transmission is better at lower frequencies. Pairs of dry-coupling ultrasonic transducers at frequencies of 50 kHz, 250 kHz, 500 kHz, and 1 MHz were used to perform the ultrasonic transmission on the breaded fried chicken nuggets. No transmitted signal was observed using 500-kHz and 1-MHz transducers. Only the signals for 50-kHz and 250-kHz transducers were detectible. For the 50-kHz ultrasonic transducer, the transmitting transducer has to be connected to the burst pulser through a high-power step-up transformer. For the 250-kHz ultrasonic transducer, the transmitting transducer is connected to the burst pulser directly. Therefore, the experiments were conducted only using the 250-kHz dry-coupling broadband transducers to measure the ultrasonic properties of breaded fried chicken nuggets in this study.

Ultrasonic property measurements

The breaded fried chicken nuggets reheated in microwave oven were held under a heat lamp or ambient conditions and tested after every 5 min. The thickness of the samples was 15.5 ± 3 mm. Moisture content of the samples ranged from 35 to 48 %. Dehydration of the samples occurred when left under a heat lamp, and moisture content decreased significantly with holding time.

This study found that ultrasonic parameters such as ultrasonic velocity and maximum peak-to-peak amplitude of the signal varied with the changes of sample properties. The value of ultrasonic velocity varied from 422 to 580 m/sec.

The value of maximum peak-to-peak amplitude of the signal was found in range of 1.2 – 2.8 V. The samples held under a heat lamp had higher maximum peak-to-peak amplitude than the samples stored under ambient conditions (Fig. 3.3). The differences in

amplitude of the signal could be attributed to the sample temperature and moisture content. Samples held under the heat lamp stayed warm and dry compared to the samples kept under ambient conditions (cool and soggy).

The propagation velocity of the ultrasonic wave through the breaded fried chicken nugget seems to associate with the changes in product crispness. The samples kept under ambient conditions had lower values for the velocity than the samples stored under a heat lamp. This could be due to lack of crispness (or being soggy) in the samples kept under ambient conditions (Fig. 3.4). Ultrasonic velocity for the samples stored under ambient conditions decreased from 422 m/sec to 309 m/sec with holding time for up to 15 min, and then increased with further holding to 486 m/sec and remained unchanged. At the same time, ultrasonic velocity increased for the samples held under a heat lamp from 423 m/sec to 580 m/sec with holding time up to 15 min and then decreased with further holding and reached the value (486 m/sec) similar to the one for the samples kept under ambient conditions. Ultrasonic velocity had the highest value for the samples held under a heat lamp for 15 min. At this holding time, the samples were likely to be the crispiest and lose its crispness with further holding. The ultrasonic velocity has been investigated further in later experiments, as this parameter considered as a potential candidate to describe the changes in crispness in breaded fried foods.

CONCLUSION

The importance and desirability of crispness have increased the efforts to define and measure this sensation. There is no reliable method that can evaluate crispness in breaded fried foods with high moisture core. Ultrasonic techniques can be successfully used in the food industry and can give significant advantages in this industry. This study

explored the possibilities of applying an ultrasonic non-destructive method to evaluate crispness in breaded fried chicken nuggets. The experiments were conducted using the dry-coupling ultrasonic transducers at frequencies of 50 kHz, 250 kHz, 500 kHz, and 1 MHz in direct transmission mode. The ultrasonic transmission through the breaded fried chicken nugget using the 250 kHz transducers was successful. The basic signal analysis was performed in time domain of the transmitted ultrasound, and two ultrasonic parameters, such as ultrasonic velocity and maximum peak-to-peak amplitude, were determined. This study found that the ultrasonic properties changed with holding time. The ultrasonic velocity seems to describe the changes in product crispness. The samples kept under ambient conditions had lower values for velocity than the samples stored under a heat lamp, which could be due to the lack of crispness in those samples. Next study is to optimize measurement conditions that will correlate with sensory crispness parameters using trained panelists.

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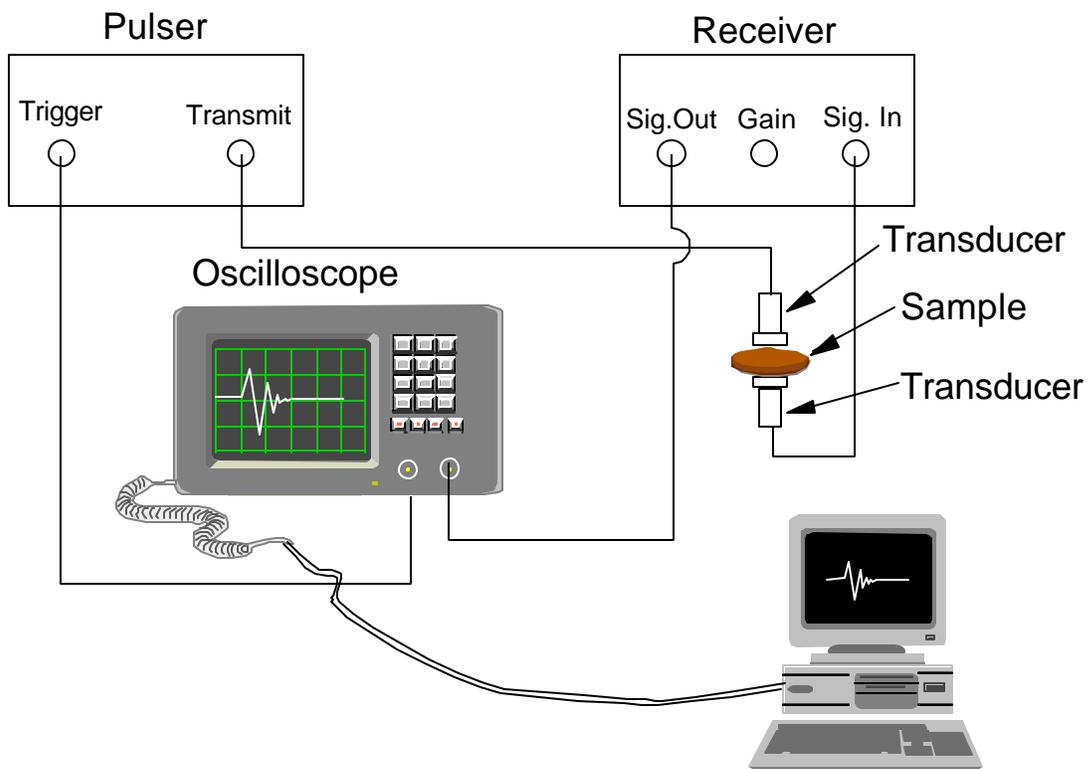
Fig.3.1   Instrumentation setup for 250-kHz, 500-kHz and 1-MHz ultrasonic transducers in through-transmission mode
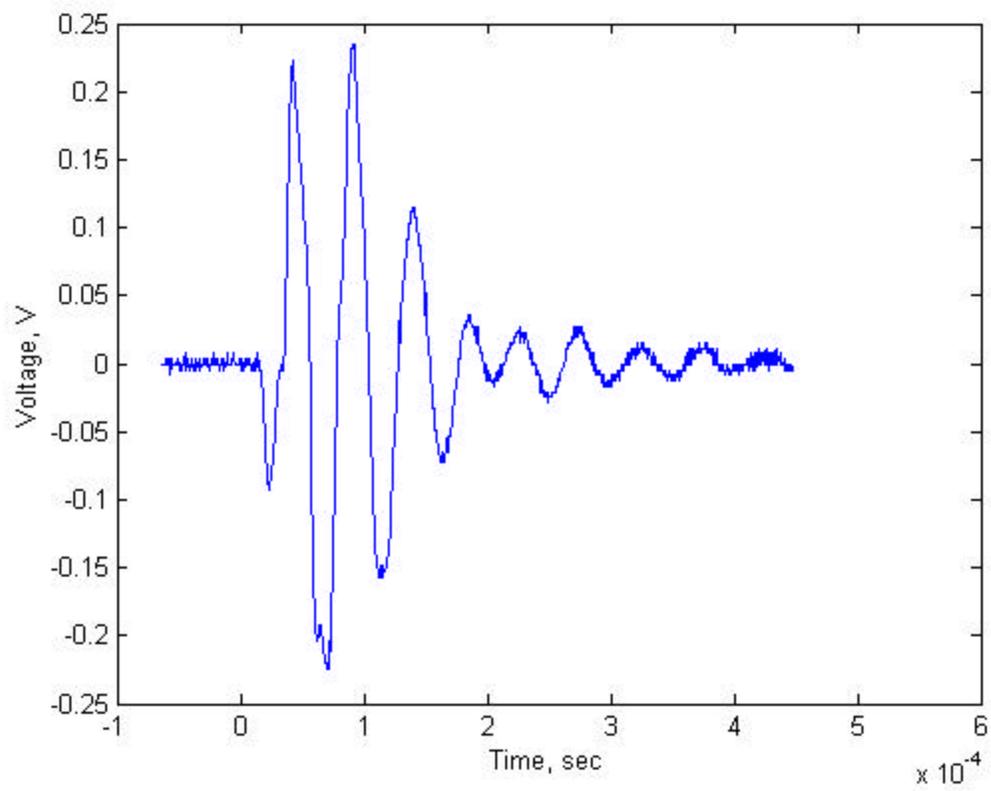
Fig.3.2 Time domain plot of the transmitted ultrasound
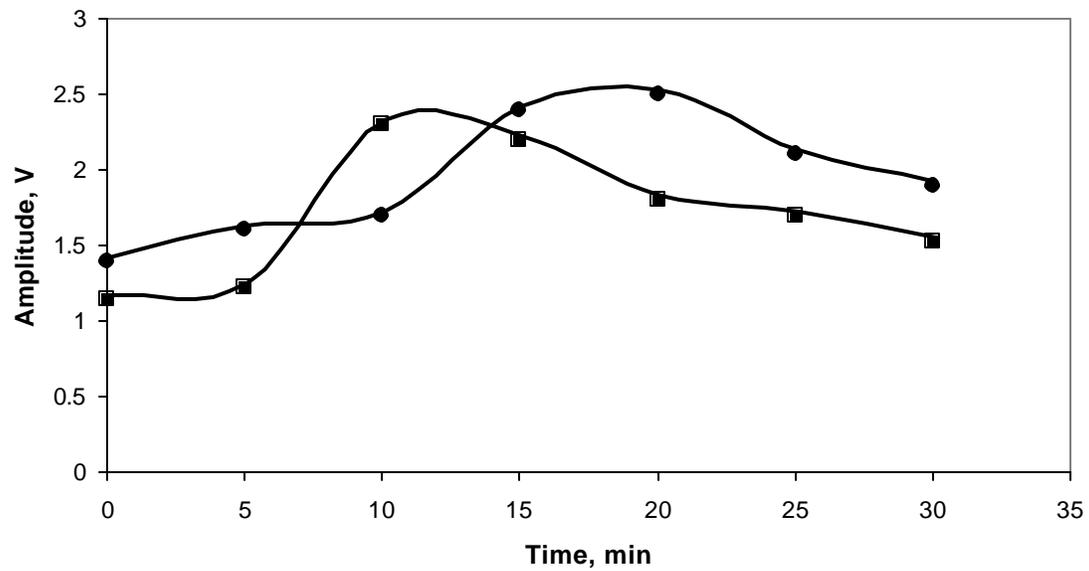
Fig.3.3   Effect of placement of breaded fried chicken nuggets either under a heat lamp or ambient conditions on maximum peak-to-peak amplitude of ultrasonic signal

(■- Samples stored under ambient conditions, ● - Samples stored under heat lamp)
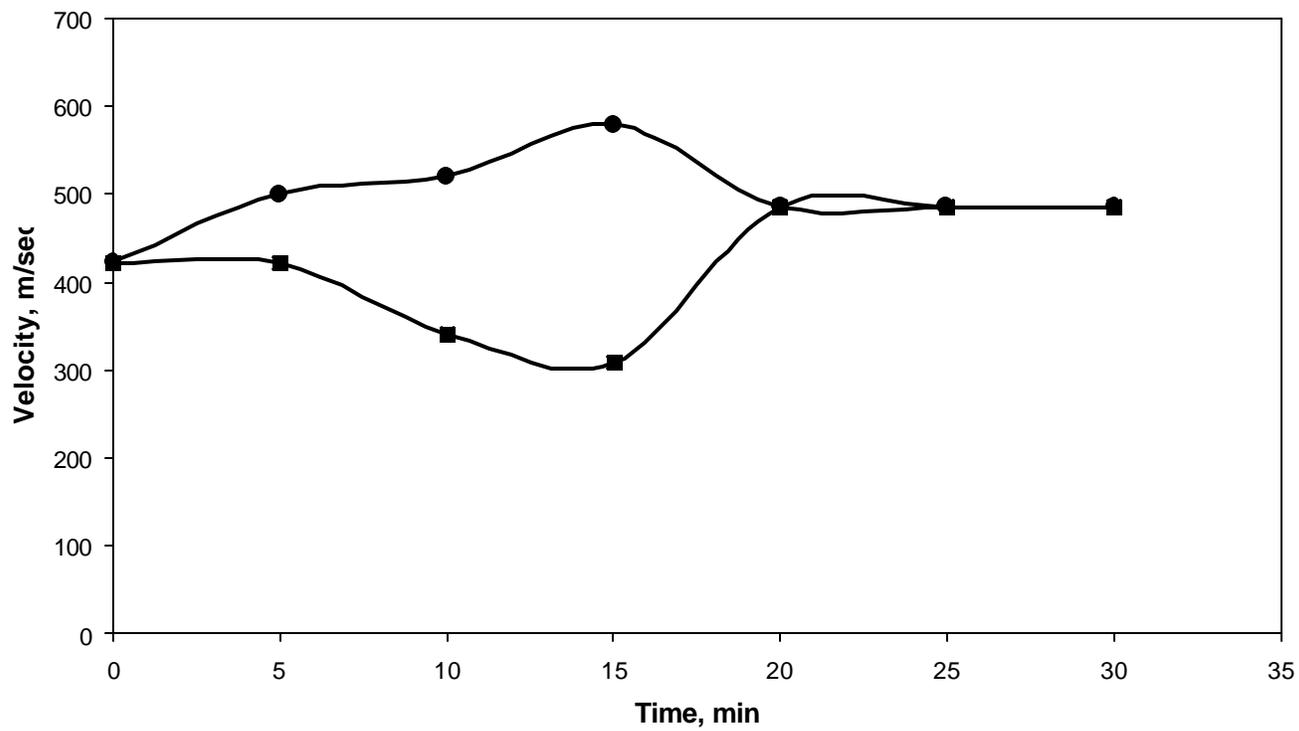
Fig. 3.4   Effect of placement of samples under either ambient conditions or a heat lamp on the velocity of ultrasonic propagation (■ - Samples stored under ambient conditions, ● - Samples stored under a heat lamp)

SECTION IV

SENSORY ASSESMENT OF CRISPNESS IN A BREADED FRIED FOOD HELD

UNDER A HEAT LAMP*

ABSTRACT

Crispness is an important textural characteristic that indicates freshness and high quality in breaded fried foods. There is no reliable method that can accurately measure crispness in breaded fried foods with high moisture core. Development of such an objective technique that can be correlated to sensory crispness will provide new opportunities to develop products with desirable attributes. This study was undertaken with following objectives: (1) to train a panel for evaluating crispness in breaded fried foods, (2) to assess whether panelists can perceive the intensity differences of crispness among the products, and (3) to obtain sensory crispness values for breaded fried foods held under different storage conditions.

A panel of eight members was selected and trained to describe the texture of breaded fried foods, focusing on crispness. A training period involved eleven sessions over a period of six weeks. Panelists rated crispness on a nine-point category scale (1 = not crisp/soggy, 9 = very crisp). Such breaded fried foods as chicken strips, chicken nuggets, onion rings, and French Fries were presented to a panel for crispness evaluation during training.

Panelists perceived a significant difference in crispness among the samples tested ($p \leq 0.05$). The mean scores for crispness (6.0 – 8.7) were significantly higher for samples held under a heat lamp to both samples stored under ambient conditions (3.4 – 5.2) and high humid conditions (2.8 – 3.4). The developed procedure for evaluating sensory crispness of breaded fried foods can be used to correlate the objective crispness measurements.

INTRODUCTION

The importance and desirability of crispness as a sensory quality in many food products is well documented (Szczesniak and Kahn, 1971; Vickers, 1988; Szczesniak, 1988; Lee et al., 1990; Dacremont, 1995). Crispness is a highly valued and universally liked textural characteristic that indicates freshness and high quality. Probing into consumer attitudes to texture and its specific attributes, Szczesniak and Kahn (1971) concluded that crispness appears to be the most versatile single texture parameter.

Szczesniak (1988) studied the sensory perception of crispness and developed sensory definitions of this attribute. Two hundred consumers were asked to give examples of crisp foods and to provide descriptions of crispness. Three types of crispness were perceived that are (1) in raw fruits/vegetables such as lettuce, celery, carrots, (2) porous, dry foods such as crackers, cold cereals, potato chips, and (3) in fried products such as bacon, chicken, French fries. Crispness was associated with crunchiness, crackling, freshness, brittleness, snapping and sound emission during eating.

The importance and desirability of crispness has increased efforts to define and measure that sensation. Many investigators have tried to measure crispness in foods, using different instrumental methods. However, the best measurements are still inconclusive. Studies related to crispness in high moisture products have been very limited. Tahnpoonsuk (1999) conducted sensory and instrumental measurements to evaluate crispness in breaded shrimps baked in an oven and held under a heat lamp. The panel consisting of 12 trained panelists rated the intensity of crispness on a 150 mm line scale with anchors at the ends. Crispness was defined as the ease of fracture in the mouth combined with loudness of the sound produced. Panelists perceived significant

differences in crispness among the tested samples. The change in sensory crispness was significantly dependent on the holding time under a heat lamp and baking location in the oven. Although the objective analysis was significant it did not produce satisfactory correlations with sensory crispness.

There is no reliable objective method that can accurately measure and quantify crispness in breaded fried foods with high moisture core. A successful instrumental measurement that correlates well to sensory crispness will allow control of crispness for process evaluation and to produce foods with desirable attributes.

This study has been conducted to develop a panel that produces valid and reliable results as an analytical instrument, and it was undertaken with the following objectives: (1) to develop and test a panelist training procedure for evaluating crispness of breaded fried foods, and (2) to assess the performance of the panel.

MATERIALS AND METHODS

Product Description

Different products were used to familiarize panelists with definitions of crispness. Eight samples of low-moisture foods were used as standard dry crisp samples with different levels of crispness (Table 4.1) during panel training. The purpose was to increase familiarity with the crispness attribute and practice describing it.

Four samples of breaded fried foods, including french fries, onion rings, chicken nuggets and chicken strips obtained from local fast food restaurants, were used to assist panelists in relating crispness intensity in a product with a dry outer crust layer and a moist core.

Panelists were presented with products stored under different conditions for crispness evaluation. The breaded fried chicken strips and chicken nuggets were stored uncovered under a heat lamp (model SW-2430, Merco, Inc., Lakewood, NJ) at 60^0C to maintain crispness. Samples also were held under ambient conditions (45-55% RH) and high humid conditions (75% RH) to accelerate loss in crispness. Samples were removed at 10-min intervals and tested for sensory crispness in order to validate a trained panel.

Panelist Training

Eight panelists, students, from the VPI&SU Biological Systems Engineering Department and Food Science and Technology Department, were selected on the basis of their willingness to participate in the project. Panelists participated in twelve 1-h training sessions over a period of six weeks during which training in identifying and rating the intensity of crispness was completed. Panelists were introduced to sensory definitions and techniques for different texture attributes, including crispness, hardness, cohesiveness, and fracturability (Table 4.1).

In order to become familiar with crispness, the panel of eight judges spent three sessions evaluating eight samples of dry crisp foods as reference standards with different intensities of crispness. Panelists were presented with standard crispness scale values of dry crisp foods (Table 4.2). During first session, panelists were involved in a group discussion of texture characteristics of presented samples, concentrating on crispness. For the following two sessions, panelists rated crispness of dry crisp products on a nine-point intensity scale (1=not crisp/soggy, 9=very crisp) by checking the appropriate space on the scale. Crispness scale values obtained by panelists were compared to standard crispness scale values. The worksheet (1) is included in Appendix.

Having established that panelists could rate crispness intensity in dry crisp products, the training then continued with discussion of crispness in breaded fried foods with a moist core. For the following four sessions, panelists were presented four samples of breaded fried foods such as onion rings, chicken nuggets, chicken strips, and breaded chicken breasts obtained from local fast food restaurants for crispness evaluation. Panelists practiced describing texture characteristics of presented products, focusing on crispness. For each session, panel was seated around a table to discuss product crispness, and then independently, in sensory testing booths, evaluated products for crispness. A nine-point category scale was used to indicate the intensity of crispness of tested breaded fried foods. The worksheet (2) is included in Appendix.

For the final training sessions, panelists evaluated five samples of commercially available fried products stored under different conditions for crispness intensity by using the same nine-point scale. Chicken strips and chicken nuggets were held under a heat lamp at 60^0C to maintain crispness. Chicken strips also were stored under ambient conditions. Samples were removed at 10-min intervals for sensory evaluation. The worksheet (3) is included in Appendix.

Each panelist performed independent evaluations, rating samples for crispness. Evaluations were completed in individual booths under white fluorescent light. Samples were served in plastic soufflé cups coded with 3-digit random numbers. Samples were presented such that each panelist received all samples, one at a time, in a random order. Panelists evaluated one sample, and then waited at least 30 seconds before the next sample was presented. The instructions to panelists were given in the appropriate scorecard (see Appendix).

To validate the performance of each panelist and the performance of the panel, two sessions of evaluating chicken strips for crispness intensity were conducted. Samples were stored under a heat lamp at 60^0C, ambient conditions (45 - 55% RH) and high humid conditions (75% RH). Panelists received three coded samples at a time at 10-min interval. Panelists were seated in individual testing booths with red lighting to mask appearance differences. The worksheet (4) and the appropriate scorecard are included in Appendix.

Evaluation of Breaded Chicken Nuggets Under Experimental Conditions

For actual experiments, a trained panel evaluated crispness intensity in breaded par-fried chicken nuggets under different conditions. Samples were finish cooked using following procedures: (1) finish-fried in a deep-fat fryer, (2) baked in a convection oven, and (3) heated in a microwave oven. Fried samples were placed uncovered under a heat lamp at 60^0 C for up to 40 min to maintain crispness. Samples also were held under ambient conditions (45 – 55% RH) to accelerate loss of crispness.

Panelists evaluated three samples at a time at 10-min intervals, using a nine-point category scale (1 = not crisp/soggy, 9 = very crisp). The instructions to panelists were given in the scorecard (Appendix). Evaluations were completed in individual testing booths with red lighting to mask appearance differences of the samples.

Statistical Analysis

A generalized randomized complete block design was used to analyze the data from each training test and to determine if panelists could perceive significant differences in crispness among the products. A randomized block design is effective when the panelists are consistent in rating the samples but might use different parts of the scale to

express their perceptions. Data in form of ratings from a randomized block design were analyzed by analysis of variance (ANOVA). Significant differences were determined at the confidence level of 0.05. Tukey's Test was used to determine which of the samples differ significantly. Experimental sensory data were analyzed, using split-plot design. Sensory data were analyzed by the Statistical Analysis Software (SAS, Cary, NC).

RESULTS AND DISCUSSION

Panel Training

A randomized complete block design used to analyze the panelists' responses allowed for the intensity differences of crispness among the products to be perceived. The analysis of data obtained from panelists' evaluations during training showed that the panel could determine a significant difference in crispness among the tested samples of breaded fried foods obtained from local fast food restaurants.

For first two training sessions, panelists were taught to describe crispness through the use of reference standards, which are needed to train an attribute-rating panel effectively. Panelists' scores were similar to standard crispness scale values (Table 4.3). These tests were conducted to indicate that panelists could use a nine-point category scale for crispness evaluation and recognize the differences in crispness intensity among the tested products.

However, the standard crispness scale for dry crisp products was not appropriate to use for rating crispness in high moisture products. Crispness intensity in breaded fried foods with a moist core would not be perceived at the same level of crispness intensity in dry crisp products. Therefore, panelists were practicing to rate crispness in breaded fried foods with various levels of crispness and moisture content. Panelists were asked to

determine the levels of crispness in high moisture products on a nine-point category scale as a complete range of crispness. The mean scores for crispness obtained from panelists' evaluations are summarized in Table 4.4. Chicken strips, breaded chicken, and chicken nuggets were defined to be significantly crispier (5.8 – 7.5) than french fries and onion rings (3.5 – 3.8). A panel did not perceive the intensity difference of crispness between french fries and onion rings.

To assess a performance of trained panel, two sessions to evaluate crispness of breaded fried chicken strips stored under a heat lamp, ambient conditions and high humid conditions were conducted. For the first replication, a panel perceived a significant difference in crispness among the tested samples. The panelists found that samples held under a heat lamp were crispier (6.0 – 8.0) than samples stored under ambient conditions (3.4 – 4.9) and high humid conditions (2.8 – 3.4) (Table 4.5). Most panelists could not indicate a significant difference in crispness between samples kept under a heat lamp for 10 min and samples kept under a heat lamp for 20 min. For the second replication of the same samples, panelists perceived a significant difference in crispness between samples held under a heat lamp (7.8 – 8.7) and samples stored under ambient conditions (4.5 – 5.2) and samples stored under high humid conditions (3.0 – 3.2), but most panelists could not identify an intensity difference of crispness between samples stored under ambient conditions for 10 min and samples kept in high humid conditions for 10 min. The sample means are arranged in Table 4.5.

Upon analysis of variance performed on the panelists' scores, the F-ratio for panelists was found to be not significant, indicating that a panel was adequately trained.

Sensory Crispness Evaluation of Breaded Fried Chicken Nuggets

Trained panelists perceived significant differences in crispness intensity among the samples cooked by different methods and stored under different conditions (Table 4.6). Breaded chicken nuggets cooked in a deep-fat fryer were significantly crispier than chicken nuggets cooked in either a convection oven or a microwave oven. Panelists indicated crispness changes with holding time under either a heat lamp or ambient conditions (Figure 4.1). Fried samples held under a heat lamp were significantly crispier than samples stored under ambient conditions.

CONCLUSION

The attribute-rating panel was trained to evaluate crispness in breaded fried foods with a high degree of reproducibility and precision. Samples were significantly different for the intensity of crispness ($p \leq 0.05$). Panel determined the increasing intensity of crispness among the samples stored under the heat lamp. No significant crispness changes with holding time under either ambient conditions or high humid conditions were perceived by judges.

A sensory panel, consisting of eight trained members, was used to evaluate sensory crispness in breaded fried chicken. Panelists determined significant differences in crispness intensity among the samples cooked by different methods and kept under different storage conditions. Panelists perceived crispness changes with holding samples under either a heat lamp or ambient conditions.

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TABLE 4.1

SENSORY DEFINITION AND TECHNIQUE FOR CRISPNESS

Term	Definition	Technique
Crispness	The force and noise with which a product breaks or fractures (rather than deforms) when chewed with the molar teeth (first and second chew).	Place sample between molar teeth and bite down evenly until the food breaks, crumbles, cracks or shatters.
Hardness	The force to attain a given deformation, such as the force to compress between molars, the force to compress between tongue and palate, and the force to bite through with incisors.	Place food between the molars and bite down evenly, evaluating the force required to compress the food.
Cohesiveness	The degree to which sample deforms rather than crumbles, cracks, or breaks.	Place sample between molars and compress fully (can be done with incisors).
Fracturability	The force with which the sample breaks.	Place food between molars and bite down evenly until the food crumbles, cracks, or shatters.

Source: Meilgaard *et al.* (1999)

TABLE 4.2

STANDARD INTENSITY CRISPNESS SCALE VALUES (0 TO 9)

FOR LOW-MOISTURE FOODS

Scale Value	Product	Brand/Type/Manufacturer	Sample Size
1.0	Granola Bar	Quaker Low Fat Chewy Chunk	1/3 bar
3.0	Club Cracker	Keeblers Partner Club Cracker	½ cracker
3.0	Graham Cracker	Honey Maid	1" sq.
4.0	Oat Cereal	Cheerios	1 oz.
5.0	Bran Flakes	Kellogg's Bran Flakes Cereal	1 oz.
6.0	Cheese Crackers Goldfish	Cheddar Cheese Crackers	1 oz.
7.0	Corn Flakes	Kellogg's Corn Flakes Cereal	1 oz.
9.0	Melba Toast	Devonsheer Melba Toast	½ cracker

Source: Meilgaard *et al.* (1999)

TABLE 4.3

COMPARISON OF PANELIST'S RATING* TO STANDARD RATING SCALE

FOR CRISPNESS DURING PANEL TRAINING

Product	Brand/Type/Manufacturer	Standard Value	R 1	R 2
Granola Bar	Quaker Low Fat Chewy Chunk	1.0	1.25	1.12
Club Cracker	Keeblers Partner Club Cracker	3.0	3.37	3.62
Graham Cracker	Honey Maid	3.0	2.12	2.7
Oat Cereal	Cheerios	4.0	4.25	4.6
Bran Flakes	Kellogg's Bran Flakes Cereal	5.0	5.78	5.78
Cheese Crackers Goldfish	Cheddar Cheese Crackers	6.0	5.25	5.25
Corn Flakes	Kellogg's Corn Flakes Cereal	7.0	8.0	7.6
Melba Toast	Devonsheer Melba Toast	9.0	9.0	9.0

* Rating: 1 = soggy/not crisp; 9 = very crisp
R = replication

TABLE 4.4

MEAN SCORES* FOR CRISPNESS INTENSITY FOR DIFFERENT BREADED

FRIED FOODS AS JUDGED BY AN 8-MEMBER SENSORY

PANEL DURING TRAINING

Samples of breaded fried foods	Average Intensity $\hat{y} \pm$ s.d.
French fries	3.52 ± 0.46
Onion rings	3.8 ± 0.32
Chicken nuggets	5.78 ± 0.72
Chicken breasts	5.9 ± 0.92
Chicken strips	7.5 ± 0.32

* Score Rating: 1 = soggy/not crisp; 9 = very crisp

TABLE 4.5

AVERAGE (N = 8) INTENSITIES* OF CRISPNESS FOR BREADED FRIED

CHICKEN STRIPS STORED UNDER A HEAT LAMP (HL), AMBIENT

CONDITIONS (AC) AND HIGH HUMID CONDITIONS (HH)

Samples	Average Intensity (R = 1) $\hat{y}$ ± s.d.	Average Intensity (R = 2) $\hat{y}$ ± s.d.
Chicken strips held under HL (10 min)	6.0 ± 1.12	7.86 ± 0.98
Chicken strips held under HL (20 min)	8.0 ± 1.17	8.7 ± 0.54
Chicken strips held under AC (10 min)	4.9 ± 0.57	5.2 ± 0.32
Chicken strips held under AC (20 min)	3.4 ± 0.23	4.5 ± 0.40
Chicken strips held under HH (10 min)	3.4 ± 0.21	3.1 ± 0.19
Chicken strips held under HH (20 min)	2.8 ± 0.19	3.0 ± 0.15

* Intensity Score Rating: 1 = soggy/not crisp; 9 = very crisp
R = replication

TABLE 4.6

THE EFFECTS OF COOKING METHOD, STORAGE CONDITIONS AND

HOLDING TIME ON SENSORY CRISPNESS OF

BREADED FRIED CHICKEN NUGGETS

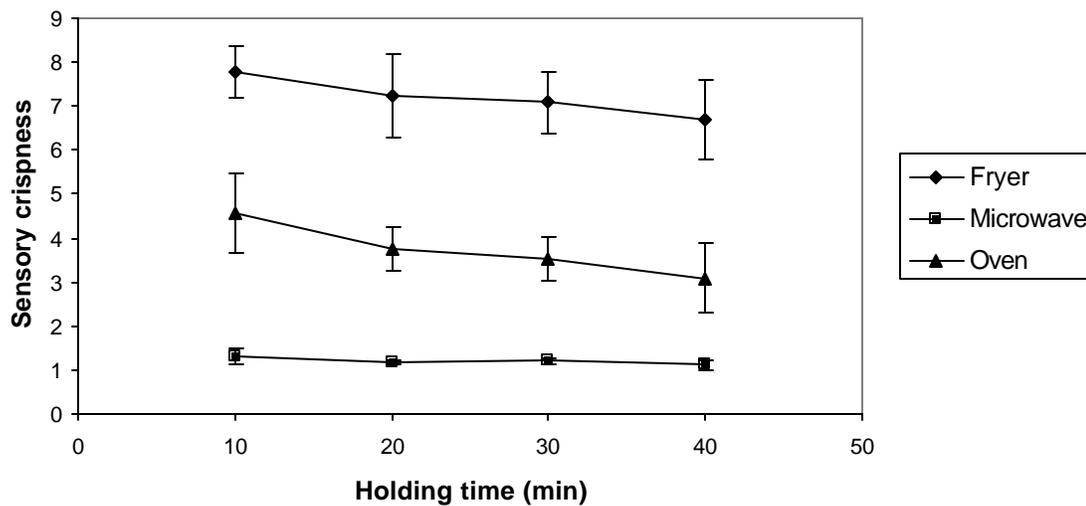| Main effects	DF	Mean Square
Storage condition	1	2.74[*]
Cooking method	2	371.89[*]
Storage condition*Time	3	2.79[*]
Storage condition*Time*Cooking method	6	0.36
Error	88	

a)
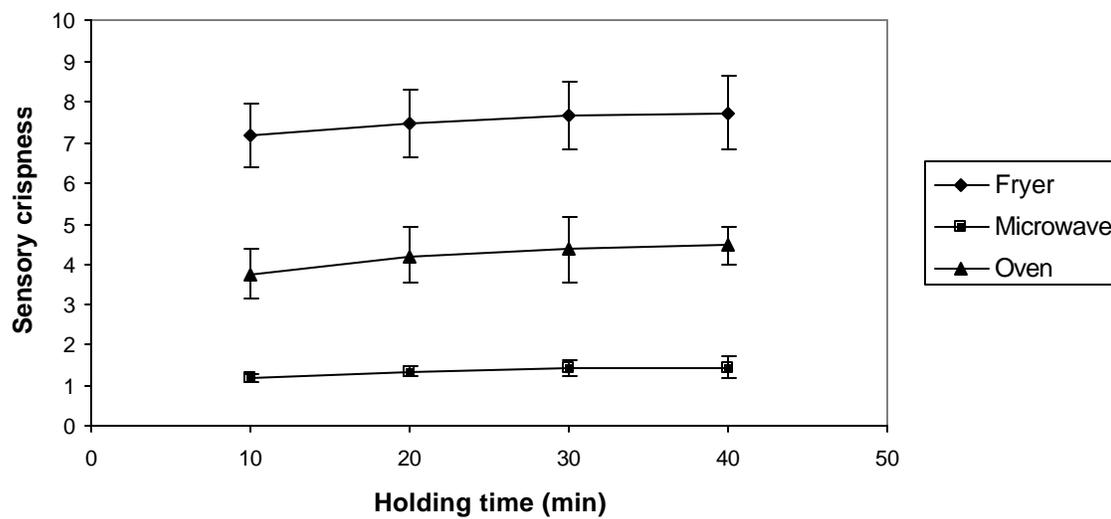
b)

Fig. 4.1   Effect of holding time on the mean sensory crispness intensity ratings of breaded fried chicken nuggets for each cooking method

      a)   under a heat lamp

      b)   under ambient conditions

SECTION V

CORRELATION BETWEEN INSTRUMENTAL AND SENSORY MEASUREMENTS

OF CRISPNESS IN BREADED FRIED CHICKEN NUGGETS

ABSTRACT

Crispness is one of the most distinctive textural characteristics of dry crisp and fried products. A reliable objective method to evaluate crispness of breaded fried foods is not currently available. This study was undertaken with following objectives: (1) to determine ultrasonic parameters that can correlate well with sensory crispness, (2) to measure mechanical properties for breaded fried chicken nuggets, and (3) to investigate the relationships between the instrumental parameters and sensory crispness scores obtained using trained panel.

Significant differences in ultrasonic velocity, transmission loss, peak force, and total energy were observed among the samples cooked by different methods. Ultrasonic velocity increased with increasing holding time, indicating that samples became crispier during holding under a heat lamp. This can be attributed to the changes in moisture content during holding. However, transmission loss, peak force, and total energy did not significantly change with holding time. The peak frequencies were found in a range of 216 – 252 kHz, 846 – 882 kHz, and 1368 – 1386 kHz, respectively. Samples stored under a heat lamp had higher signal amplitudes for each peak frequency than those stored under ambient conditions. This could be due to lack of crispness (or being soggy) of the samples kept under ambient conditions.

Ultrasonic velocity had high correlation with sensory crispness. This indicates that sensory crispness could be predicted reasonably by the ultrasonic velocity.

INTRODUCTION

Breaded fried foods are favored by consumers due to the increased palatability provided by a soft and moist interior along with a porous outer crispy crust. Studies sponsored by Proctor and Gamble and the National Restaurant Association confirmed an increase in breaded fried food consumption. They reported that more than 500,000 institutional and commercial restaurants in the U.S. were involved in deep-fat frying operations (Brooks, 1991). Traditional fried products, such as French fries, chicken nuggets and breaded chicken, are still prevailing in the food service business. Fried chicken products exceeded $8.2 billion in sales in the U.S. in 1996.

Crispness is one of the most important and desirable textural characteristics that signify freshness and high quality in breaded fried foods. Crispness appears to be the most versatile single textural characteristic in many foods. Over the years, many investigators have worked on various techniques to characterize and measure crispness. It has been suggested that crispness might be better predicted by combination of mechanical and acoustical properties (Mohamed and others, 1982; Seymour, 1985; Vickers, 1987 and Vickers, 1988). Characterization of crispness has been more complicated since Tesch and others (1996) found no relationships between the mechanical and acoustical parameters. This complication may have been due to the effect of unequal frequency for the mechanical and acoustical measurements or that some parts of crisp information manifested in acoustical properties have not been fully revealed in the mechanical properties, or vice versa.

However, all these measurements were applied to low moisture foods. Studies related to crispness in high moisture foods have been very limited. In addition, the

measurements may be very different from that developed for low moisture foods. Recent studies by Tahnpoonsuk (1999) to evaluate crispness in breaded shrimps stored under a heat lamp did not give a satisfactory correlation. Crispness had been predicted using both acoustical and force-deformation measurements. In addition, the method proposed was destructive.

There is no reliable method that can accurately measure and quantify crispness in breaded fried foods having a moist core. Development of such a method, which will correlate to sensory crispness, will allow food product manufacturers to develop products with desirable attributes. Ultrasonic techniques have not, so far, been used for the measurement of crispness in breaded fried foods although successful applications of ultrasonics exist in characterization of foods. This study was undertaken with following objectives: (1) to determine ultrasonic parameters that can correlate well with sensory crispness, (2) to measure mechanical properties for breaded fried chicken nuggets, and (3) to investigate the relationships between the instrumental parameters and sensory crispness scores obtained using trained panel.

MATERIALS AND METHODS

Sample Preparation

Breaded par-fried chicken nuggets were obtained from Perdue Farms, Inc., Monterey, TN and kept frozen at -20^0 C until used. Samples were sorted for similar size and weight, and most uniform samples were used for sensory and objective evaluation. Frozen breaded chicken nuggets were finish cooked using following procedures: (1) finish-fried in a deep-fat fryer at 375^0 F for 4-5 min, (2) baked in a convection oven at 400^0 F for 10 min, and (3) heated in a microwave oven at full power for 3 min. The finish

frying times were obtained by measuring the temperature in the product and frying the sample until the geometric center of the product reached 70^0 C.

Fried samples were then placed uncovered under a heat lamp (model SW-2430, Merco Inc., Lakewood, NJ) at 60^0 C for up to 40 min to maintain crispness. Samples also were held under ambient conditions (45 – 55% RH) to accelerate loss of crispness (by getting soggier). Samples were removed at 10-min intervals and tested for sensory and objective crispness. Five replications were conducted in the study.

Quality Characteristics of Breaded Fried Chicken Nugget

Temperature

A data logger (model 5100, Electronic Controls Design Inc., Milwaukie, Oregon) was used to monitor the temperature (at 5-min intervals) at the core of the samples during holding under a heat lamp and ambient conditions for up to 40 min.

Thickness

The thickness of the crust and the thickness of the sample were measured in millimeters using a caliper (model CHC-60150-D, Aerospace Inc., China) every 10 min for up to 40 min.

Mass

Mass of breaded fried chicken nugget during holding under a heat lamp and ambient conditions was measured using a digital balance every 10 min, for up to 40 min.

Moisture and Fat Contents

The moisture and fat contents of the crust and core of the sample were determined using the freeze-drying method (AOAC method 960.39, 1985) and a solvent extraction

method (SOXTEC System HT2, 1045 Extraction Unit), respectively. Two replications were conducted for the measurements.

Sensory Crispness Measurement

A sensory panel consisting of eight trained members was used to evaluate sensory crispness in breaded fried chicken nuggets. The panelists had previously participated in eleven 1-h training sessions over a period of six weeks during which training in identifying and rating the intensity of crispness was completed. Crispness was defined as the force and noise with which a product breaks or fractures (rather than deforms) when chewed with the molar teeth (first and second chew) (Meilgaard and others, 1999). Panelists were instructed to evaluate each tested sample for crispness by placing sample between molar teeth and biting down evenly until the food breaks, crumbles, cracks or shatters and rate the intensity of crispness on a nine-point category scale (1 = not crisp/soggy, 9 = very crisp) by checking the appropriate space on the scale. Panelists evaluated three samples at a time at 10-min intervals. The instructions to panelists were given in the appropriate scorecard (see Appendix). Evaluations were completed in individual testing booths with red lighting to mask appearance differences of the samples. Samples were served in plastic soufflé cups coded with 3-digit random numbers. Samples were presented such that each panelist received all samples, three at a time, in a random order.

Ultrasonic Property Measurements

The ultrasonic non-destructive evaluation system developed at Virginia Tech (Cheng and Haugh, 1994) was used to conduct ultrasonic measurements. The basic setup of the ultrasonic non-destructive evaluation system included an Ultran BP 9400A high-

power burst pulser, an Ultran BR 640A broadband receiver, a Tektronix 2232 digital storage oscilloscope, 250-kHz dry-coupling ultrasonic transducers, and a microcomputer system for data acquisition and analysis (Figure 5.1). The driving voltage from the burst pulser for the transducers was 400 Volts with nominal output impedance of 4 ohms (Ω). The pulse width and separation time between pulses were adjusted for 250-kHz transducers. The broadband receiver, performed as a signal amplifier and signal filter, had a maximum gain of 64 dB. The transmitted signal was measured and shown on the oscilloscope screen. A general purpose interface board (GPIB) installed in a microcomputer allowed the transfer of digital data of the signal from the oscilloscope to the microcomputer for further analysis.

The system setup was in the through-transmission mode because breaded fried chicken nugget is highly attenuative material. Two transducers were placed on the opposite sides of a chicken nugget surface, one acting as a transmitter, and the other one as a receiver. For ultrasonic transducers at frequency of 250 kHz, the transmitting transducer was connected to the burst pulser directly. The receiving transducer was wired to the receiver directly. A breaded fried chicken nugget to be tested was placed directly between the two transducers along the center line of the sample and transducers to assure the optimal propagation of the sound wave. A transducer holding device was used to apply a uniform pressure and a precise alignment of the transducers during each ultrasonic measurement, permitting the most efficient ultrasonic energy transmission through the sample.

The burst pulser sent electrical energy bursts into the transmitting transducer to convert the electrical energy to ultrasonic energy in form of ultrasonic pulses. The

transducer then launched an ultrasonic pulse into the sample material. The ultrasound traveled through the sample material until it reached a boundary or discontinuity in the material. In such case, some ultrasonic energy will be reflected. The transmitted ultrasound was received and converted to an electrical signal by the receiving transducer, amplified and displayed on the oscilloscope screen as real time radio-frequency traces, from which the properties of the ultrasonic wave could be determined. The data were then transferred to the microcomputer for further analysis.

From the transmitted ultrasonic signal, such ultrasonic properties as ultrasonic velocity (υ) and transmission loss (T_{loss}) were determined in this study.

Ultrasonic velocity

Ultrasonic velocity represents the average speed of ultrasound through the sample from one side to the other. The time-of-flight (*TOF*), known as the traveling time of the ultrasonic pulse from one side of sample to the other, was derived from the plot of time domain waveform as shown in Figure 5.2. The predetermined sample thickness and the determined time-of-flight through the sample and time-of-flight of the transducer were used to calculate the propagation velocity of the ultrasonic wave through the sample.

The ultrasonic velocity for each breaded fried chicken nugget was determined according to the following equation:

$$\boldsymbol{u}_{sample} = \frac{l}{TOF - TOF_0}$$

where

u_{sample} =   Ultrasonic velocity for breaded fried chicken nugget (m/sec)

l =   Path length of transmission (mm)

TOF =   Time-of-flight with the sample (ms)

TOF_0 =   Calibrated time-of-flight without the sample (ms)

Transmission loss

For ultrasound transmission through breaded fried chicken nuggets, the total loss of the ultrasonic energy, including attenuation, was determined. The transmission loss was calculated as follows:

$$T_{loss} = \frac{20 \log\left(\dfrac{A_{ref}}{A}\right)}{l}$$

where

T_{loss} =   Transmission loss (dB/mm)

A_{ref} =   Maximum amplitude of the signal without sample in between (V)

A =   Maximum amplitude of the signal after traveling the distance l (V)

l =   Path length of ultrasonic transmission (mm)

Mechanical Property Measurements

An Instron universal testing machine (Model 1011, Instron Inc., Canton, MA) interfaced with a microcomputer for data acquisition was used for mechanical property measurements. The test sample was placed in the Kramer shear-compression cell and the crosshead speed was set at 100 mm/min. The maximum peak force and total energy were obtained from the measurements.

Statistical Analysis

Experimental data were analyzed by the Statistical Analysis Software (SAS, Cary, NC). Statistical differences were determined among different levels of treatments using split-plot design and generalized linear model (GLM) at the 0.05 confidence level.

RESULTS AND DISCUSSION

Quality characteristics of breaded fried chicken nugget

Moisture content

The effects of cooking method, storage conditions and holding time on the moisture content of the crust and core are shown in Table 5.1. Significant differences in moisture content of the crust among the samples cooked by different methods and stored under either a heat lamp or ambient conditions were observed. The moisture content of the crust was higher for samples cooked in a microwave oven (33.66 – 47.20 % w.b.) than for samples cooked in an oven (28.50 – 43.44 % w.b.) and a deep-fat fryer (20.73 - 34.36 % w.b.). Effect of holding samples under a heat lamp and ambient conditions on moisture content of the crust is shown in Figure 5.3. The moisture content of the crust decreased with holding samples under a heat lamp and increased with holding samples under ambient conditions (45 – 55% RH).

The moisture content of the core did not significantly change among the samples cooked by different methods; however, the storage conditions had a significant effect on the moisture content of the core (Table 5.1). Samples held under ambient conditions had higher values of moisture content of the core (58.22 – 64.92 % w.b.) than samples stored

under a heat lamp (55.36 – 60.54 % w.b.). The mean scores of the moisture content of the core are arranged in Table 5.2.

Fat content

Significant differences ($p \leq 0.05$) in fat content of the crust among the samples cooked by different methods were observed (Table 5.1). The fat content of the crust had higher values for samples cooked in a deep-fat fryer (30.73 – 39.25 % w.b.) than for samples cooked in an oven (25.36 – 33.93 % w.b.) and microwave oven (21.92 – 28.82 % w.b.). The holding time under either a heat lamp or ambient conditions did not significantly affect the fat content of the crust (Table 5.1). Effect of holding samples under a heat lamp and ambient conditions on fat content of the crust is shown in Figure 5.4.

The fat content of the core did not significantly change among the samples cooked by different methods and held under either a heat lamp or ambient conditions (Table 5.1). The mean scores of the fat content of the core are shown in Table 5.3.

Sensory crispness evaluation of breaded fried chicken nuggets

The cooking method of breaded chicken nuggets, storage conditions either under a heat lamp or ambient conditions, and holding time had a significant effect on sensory crispness (Table 5.4). Breaded chicken nuggets fried in a deep-fat fryer were crispier (6 – 8) than nuggets baked in an oven (3 – 5) and nuggets cooked in a microwave oven (1 – 2). The panelists found that cooked samples held under a heat lamp were significantly crispier than samples stored under ambient conditions. Crispness changes with holding time under either a heat lamp or ambient conditions were perceived by judges. Panel determined the increasing intensity of crispness among samples kept under a heat lamp.

Effect of holding time under a heat lamp and ambient conditions on the crispness intensity ratings of breaded fried chicken nuggets for each cooking method is shown in Figure 5.5. Panel indicated the decreasing intensity of crispness with holding time under ambient conditions. Sensory crispness was inversely related to moisture content, indicating that crispness intensity was increasing, while moisture content was decreasing when the samples were held under a heat lamp (Fig. 5.6).

Time domain signal analysis

The ultrasonic parameters, which are ultrasonic velocity and transmission loss, were obtained from the time domain of the transmitted signal.

Ultrasonic velocity

The significant differences in the ultrasonic velocity for the breaded chicken nuggets cooked by three different methods and stored under either a heat lamp or ambient conditions were observed (Table 5.5). The samples cooked in a deep-fat fryer had higher ultrasonic velocities (431.56 – 715.38 m/sec) than the samples cooked in an oven (221.41 – 533.83 m/sec), while the samples cooked in a microwave oven had much lower velocities (90.22 – 306.92 m/sec). This can be attributed to the changes in moisture and fat contents among the samples. The samples cooked in a deep-fat fryer had the lowest moisture content, while the samples cooked in a microwave oven had the highest moisture content. The mean values of ultrasonic velocity for each cooking method are arranged in Table 5.6. The ultrasonic velocity increased with increasing holding time under a heat lamp as the moisture content decreased during holding. This implied that samples became crispier during holding under a heat lamp. On the other hand, ultrasonic velocity decreased with holding samples under ambient conditions as samples became

soggier and softer. The changes of mean ultrasonic velocities of the breaded fried chicken nuggets are plotted in Figure 5.7. The relationships between ultrasonic velocity and moisture content are shown in Figure 5.8. The decrease in the velocity with respect to an increase in moisture content can be attributed to the transmission loss in liquid than the transmission loss in a solid. Ultrasound can propagate better in solids than liquids.

Transmission loss

The differences in the values of transmission loss measured for the breaded chicken nuggets cooked by different methods were found statistically significant (Table 5.5). The values of transmission loss measured for the samples cooked in a deep-fat fryer (0.36 – 0.64 dB/mm) were lower than those measured for the samples cooked in an oven (0.69 – 1.09 dB/mm) and a microwave oven (0.76 – 1.12 dB/mm), which can be due to the moisture and fat contents of samples. However, the storage conditions and holding time did not have a significant effect on the transmission loss (Table 5.5). The mean scores for transmission loss are shown in Table 5.7.

Frequency domain signal analysis

Frequency analysis was performed to obtain the energy content distributed over the frequency bandwidth determined as a power spectrum of the signal. A Fast Fourier Transformation (FFT) algorithm was used to convert data at the time domain into frequency domain, using Matlab. The frequency domain plots shown in Figure 5.9 reveal the distribution of frequency components of the time-domain signals. The peak frequencies of tested samples were found in a range of 216 – 252 kHz, 846 – 882 kHz, and 1368 – 1386 kHz, respectively. The signal amplitudes for each peak frequency did not significantly change among the samples cooked by different methods; however, the

storage conditions had a significant effect on the signal amplitude (Table 5.5). The breaded fried chicken nuggets kept under a heat lamp had higher peak amplitudes than those stored under ambient conditions. This could be due to lack of crispness (or being soggy) in the samples kept under ambient conditions. The mean values of the signal amplitude for each peak frequency are shown in Table 5.8.

Mechanical property measurements

Normalization of the peak force and total energy was done by dividing the values by mass of the sample. The normalized peak force and normalized total energy significantly varied among the samples cooked by different methods and stored under different conditions (Table 5.9). The mean values of peak force and total energy for each cooking method are shown in Table 5.10. Samples cooked in a deep-fat fryer had higher values for the peak force and total energy than samples cooked in an oven and microwave oven. However, holding time either under a heat lamp or ambient conditions did not have a significant effect on either the peak force or total energy (Table 5.9). The effect of holding time under a heat lamp and ambient conditions for each cooking method on the peak force is shown in Figure 5.10. The peak force slightly increased with holding time under either a heat lamp or ambient conditions. Samples stored under a heat lamp had higher values of the total energy than those kept under ambient conditions (Fig. 5.11).

Relating instrumental parameters to sensory crispness

To investigate the relationship between sensory crispness and objective quality parameters, the linear regression procedure was performed. Correlation coefficients between sensory crispness and instrumental measurements are summarized in Table 5.11. Except for the relationship between ultrasonic velocity and sensory crispness, all the

objective parameters did not have an improvement in the correlation coefficient when analyzed separately against each cooking method.

The relationship between sensory crispness and peak force is shown in Figure 5.12 and described by equation 1. The positive sign preceding the slope implied that sensory crispness increased when a high peak force was required.

$$\text{Sensory crispness} = 3.3518(\text{Peak Force}) - 5.1989 \qquad (1)$$

$$[R^2 = 0.6379]$$

The positive relationship between sensory crispness and ultrasonic velocity is described by equation 2 showing that sensory crispness and ultrasonic velocity are closely related. Increasing sensory crispness of the breaded fried chicken nuggets is illustrated by increasing mean ultrasonic velocities, as presented in Figure 5.13.

$$\text{Sensory Crispness} = 0.0127(\text{Velocity}) - 0.6692 \qquad (2)$$

$$[R^2 = 0.8257]$$

On the other hand, the transmission loss decreased as the samples became crispier, as is shown in Figure 5.14. The inverse relationship of sensory crispness to transmission loss is described by equation 3. The negative sign preceding the slope implied that sensory crispness increased when the transmission loss was low.

$$\text{Sensory Crispness} = -7.6352(\text{Transmission loss}) + 8.8325 \qquad (3)$$

$$[R^2 = 0.5532]$$

The model was significant at the 0.05 confidence level. This indicates that sensory crispness could be explained based on the ultrasonic and mechanical parameters. The ultrasonic velocity had high correlation to the sensory crispness ($R^2 = 0.8257$). This

implies that sensory crispness could be reasonably well predicted by the ultrasonic velocity.

CONCLUSION

Significant differences in ultrasonic velocity, transmission loss, peak force and total energy were observed among the breaded chicken nuggets cooked by different methods. During holding of samples either under a heat lamp or ambient conditions, transmission loss, peak force and total energy did not significantly change. However, ultrasonic velocity varied with holding time, indicating the changes in intensity of crispness. This can be attributed to the changes in moisture content during holding.

Breaded fried chicken nuggets held under a heat lamp had higher signal amplitudes for each peak frequency than those stored under ambient conditions. This could be due to lack of crispness (or being soggy) in the samples kept under ambient conditions.

Sensory crispness of breaded fried chicken nuggets was found to be affected by cooking method, storage conditions and holding time. The relationship between sensory crispness and instrumental parameters suggests that the ultrasonic method can be used to measure and explain sensory crispness in breaded fried chicken nuggets. Ultrasonic velocity had high correlation with sensory crispness ($R^2 = 0.83$). This indicates that sensory crispness could be reasonably well predicted by the ultrasonic velocity.

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Table 5.1 Effects of cooking method, storage conditions and holding time on moisture and fat contents of crust and core of breaded fried chicken nuggets

Main effects	DF	Mean Sum of Squares			
		Moisture content		Fat content	
		Crust	Core	Crust	Core
M	2	684.35[*]	6.48	371.58[*]	0.96
C	1	132.58[*]	156.45[*]	1.15	3.34
C * T	3	359.61[*]	14.71	12.47	9.38
C * T * M	8	44.50	11.14	17.64	4.98
Error	22				

* indicates a significant difference for the main effect at 0.05 level

DF = Degrees of Freedom

M = Cooking method

C = Storage condition

T = Holding time

Table 5.2 Mean[*] core moisture content (% w. b.) of breaded fried chicken nuggets

Holding Time, Min	Deep-fat Fryer		Microwave Oven		Oven	
	HL	**AC**	**HL**	**AC**	**HL**	**AC**
10	55.94±3.98	65.50±0.45	55.67±0.12	61.53±0.17	59.72±1.24	63.52±4.59
20	55.86±5.48	62.29±1.38	58.46±0.95	62.24±4.15	59.52±0.12	62.27±1.38
30	56.67±2.18	61.46±1.85	56.42±0.89	59.85±0.78	61.26±3.08	59.59±2.5
40	59.39±0.03	61.49±2.77	56.44±0.46	62.20±1.06	60.19±1.87	56.89±9.87

* Values are ŷ ± s. d.

HL = Heat lamp

AC = Ambient conditions

Table 5.3 Mean[*] core fat content (% w. b.) of breaded fried chicken nuggets

Holding Time, Min	Deep-fat Fryer		Microwave Oven		Oven	
	HL	AC	HL	AC	HL	AC
10	24.85±3.15	25.14±1.86	24.23±1.50	23.79±0.32	24.38±0.89	21.62±1.18
20	22.08±3.53	23.09±3.08	23.18±1.35	22.73±2.04	26.46±3.05	21.59±1.07
30	23.42±1.24	23.16±2.93	23.62±0.14	21.78±0.83	22.91±0.96	20.96±6.45
40	20.18±0.72	23.43±0.29	21.00±0.28	22.45±0.11	22.12±0.35	21.40±0.82

* Values are $\hat{y} \pm$ s. d.

HL = Heat lamp

AC = Ambient conditions

Table 5.4 The effects of cooking method, storage conditions and holding time on sensory crispness of breaded fried chicken nuggets

Main effects	DF	Mean Square
Storage condition	1	2.74[*]
Cooking method	2	371.89[*]
Storage condition*Time	3	2.79[*]
Storage condition*Time*Cooking method	6	0.36
Error	88	

* indicates a significant level at $p < 0.05$

Table 5.5   Effects of cooking method, storage conditions and holding time on ultrasonic properties of breaded fried chicken nuggets

Main effects	DF	Mean Sum of Squares				
		u	T_{loss}	**A₁**	**A₂**	**A₃**
M	2	1406427.86*	1.83*	830.15	33.65	1.85
C	1	280495.76*	0.12	5400.42*	163.11*	13.48*
C * T	3	223260.95*	0.31	698.74	6.43	0.92
C * T * M	6	7140.46	0.25	282.89	1.52	0.14
Error	88					

* indicates a significant difference for the main effect at 0.05 level

DF   = Degrees of freedom

u = Ultrasonic velocity for breaded fried chicken nugget (m/sec)

T_{loss} = Transmission loss (dB/mm)

A_1, A_2, and A_3 = Signal amplitudes for each peak frequency, respectively

M   = Cooking method

C   = Storage condition

T   = Holding time

Table 5.6 Mean[*] ultrasonic velocity (m/sec) for each cooking method

Cooking method	Mean value
Deep-fat fryer	573.47 ± 141.91
Microwave oven	198.57 ± 108.35
Oven	377.62 ± 156.21

* Values are $\hat{y} \pm$ s. d.

Table 5.7 Mean[*] transmission loss (dB/mm) for breaded fried chicken nuggets

Holding Time, Min	Deep-fat Fryer		Microwave Oven		Oven	
	HL	**AC**	**HL**	**AC**	**HL**	**AC**
10	0.41±0.28	0.27±0.30	0.60±0.55	0.84±0.30	0.94±0.39	0.36±0.20
20	0.36±0.24	0.34±0.38	0.93±0.36	0.71±0.45	0.59±0.53	0.65±0.56
30	0.19±0.16	0.30±0.20	0.61±0.32	0.87±0.52	0.46±0.21	0.78±0.37
40	0.53±0.43	0.49±0.24	0.70±0.55	0.84±0.48	0.57±0.45	1.19±0.37

* Values are $\hat{y} \pm$ s. d.

HL = Heat lamp

AC = Ambient conditions

Table 5.8 Mean[*] signal amplitude for each peak frequency of breaded fried chicken nuggets

a) held under a heat lamp

Time	Peak Frequency 1			Peak Frequency 2			Peak Frequency 3		
	FR	MO	OV	FR	MO	OV	FR	MO	OV
10	38.7±12	55.9±17	62.5±21	5.1±3.6	6.2±1.4	9.4±3.3	2.08±1.44	1.97±0.8	3.14±1.07
20	56.9±17	51.8±32	50.8±10	6.4±1.6	6.8±4.7	6.8±3.2	1.94±0.87	2.6±2.36	2.27±0.97
30	64.5±32	56.4±30	46.5±20	9.7±5.6	7.7±4.02	6.7±2.3	2.75±1.17	2.27±1.33	2.06±0.41
40	38.5±25	34.1±29	34.9±15	5.7±3.4	5.4±4.5	4.0±2.04	1.62±0.83	1.74±1.32	1.46±0.78

b) held under ambient conditions

Time	Peak Frequency 1			Peak Frequency 2			Peak Frequency 3		
	FR	MO	OV	FR	MO	OV	FR	MO	OV
10	42.7±27	26.7±18	58.2±62	4.4±2.2	3.6±3.05	5.3±6.02	1.43±0.85	1.07±0.93	2.1±2.24
20	42.1±29	26.8±28	36.2±21	4.8±3.5	2.9±1.8	2.9±2.2	1.63±0.92	1.12±0.95	0.99±0.74
30	39.4±28	31.5±25	25.1±23	10±10.4	3.3±3.2	2.6±1.7	2.95±3.18	1.26±1.05	1.14±0.7
40	57.1±40	24.6±20	20.5±5	6.2±4.3	3.2±1.3	2.6±1.3	2.08±1.53	1.06±0.95	1.02±0.39

Values are $\hat{y} \pm$ s. d.;

FR = Deep-fat fryer; MO = Microwave oven; OV = Convection oven;

Table 5.9   Effects of cooking method, storage conditions and holding time on the peak force and total energy of breaded fried chicken nuggets

Main effects	DF	Mean Sum of Squares	
		Peak Force	**Total Energy**
M	2	13.59*	793.58*
C	1	2.80*	177.55*
C * T	3	0.15	8.71
C * T * M	6	0.24	0.20
Error	88		

* indicates a significant difference for the main effect at 0.05 level

DF=Degrees of freedom

M = Cooking method

C = Storage condition

T = Holding time

Table 5.10 Mean values of peak force (N/g) and total energy (N/g) for each cooking method

Cooking method	Mean value ($\hat{y}$ ± s.d.)	
	Peak Force	**Total Energy**
Deep-fat fryer	33.84 ± 7.95	296.46 ± 65.14
Microwave oven	22.66 ± 5.00	216.11 ± 72.39
Oven	25.99 ± 6.57	226.41 ± 64.75

Table 5.11 **Correlation between instrumental and sensory measurements of crispness in breaded fried chicken nuggets (y = ax + b)**

Instrumental parameters	a	b	R^2
Peak Force			
All data points	3.35	5.19	0.64
Fryer	0.05	5.53	0.58
Convection oven	0.06	2.38	0.10
Microwave oven	-0.02	1.77	0.24
Total Energy			
All data points	0.37	-5.14	0.50
Fryer	0.02	6.61	0.07
Convection oven	0.01	3.69	0.01
Microwave oven	-0.02	1.65	0.16
Ultrasonic Velocity			
All data points	0.0127	-0.67	0.83
Fryer	0.0036	5.30	0.87
Convection oven	0.0042	2.38	0.94
Microwave oven	0.0014	0.99	0.85
Transmission Loss			
All data points	-7.64	8.83	0.55
Fryer	-1.24	7.80	0.13
Convection oven	-1.76	1.37	0.85
Microwave oven	-0.14	5.19	0.02
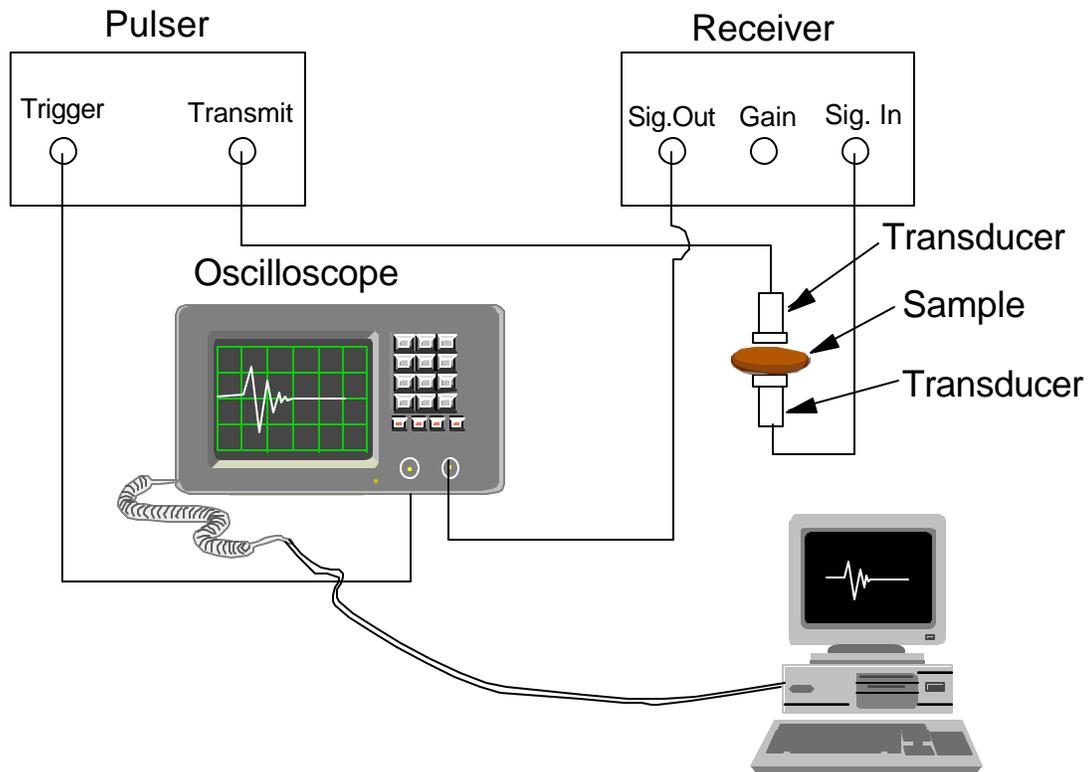
Fig.5.1   Schematic   diagram   of   the   instrumentation   setup   for   250-kHz   ultrasonic

transducers in through-transmission mode
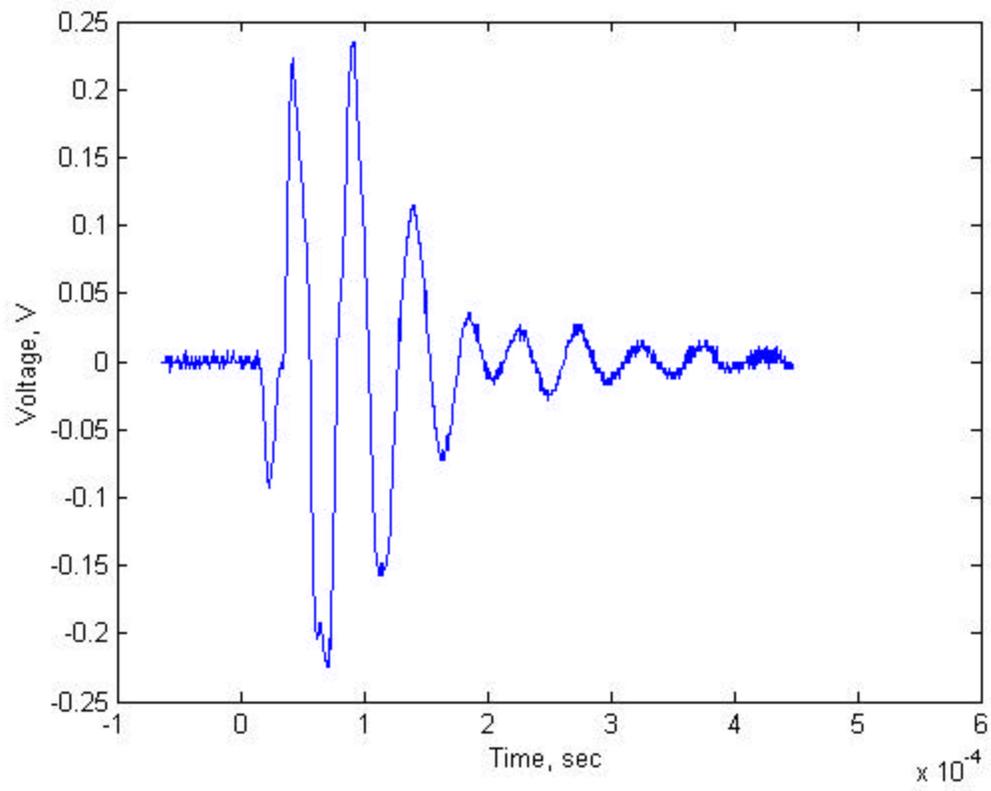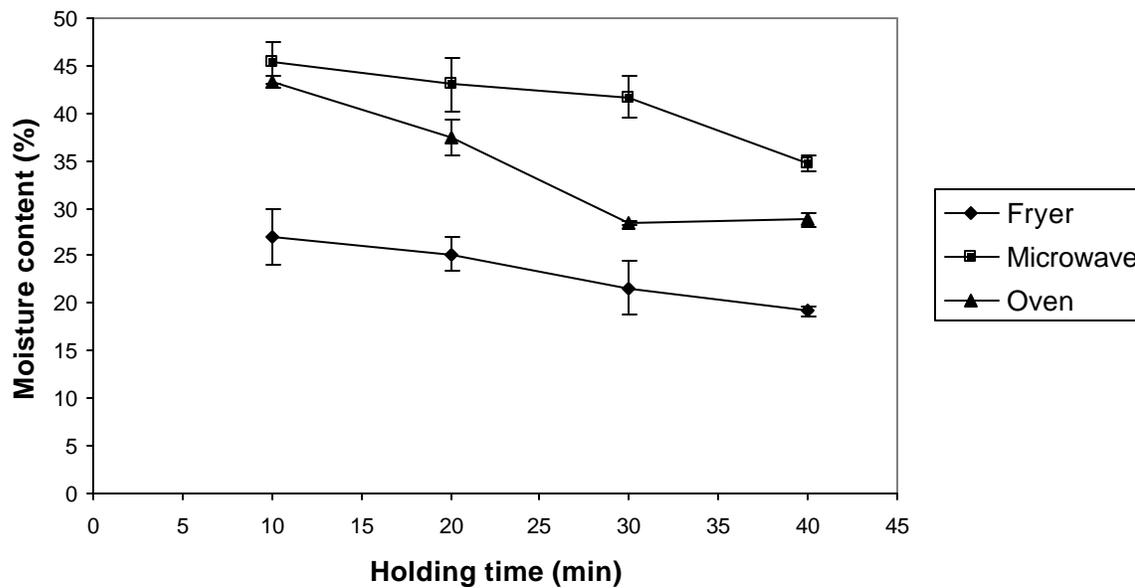
Fig. 5.2 Time domain plot of transmitted ultrasound
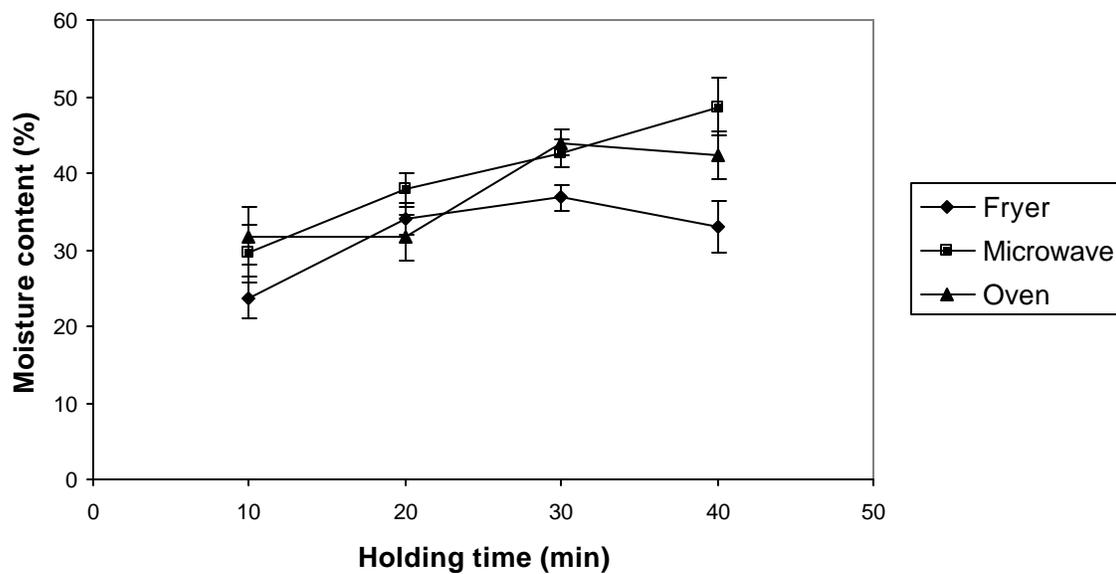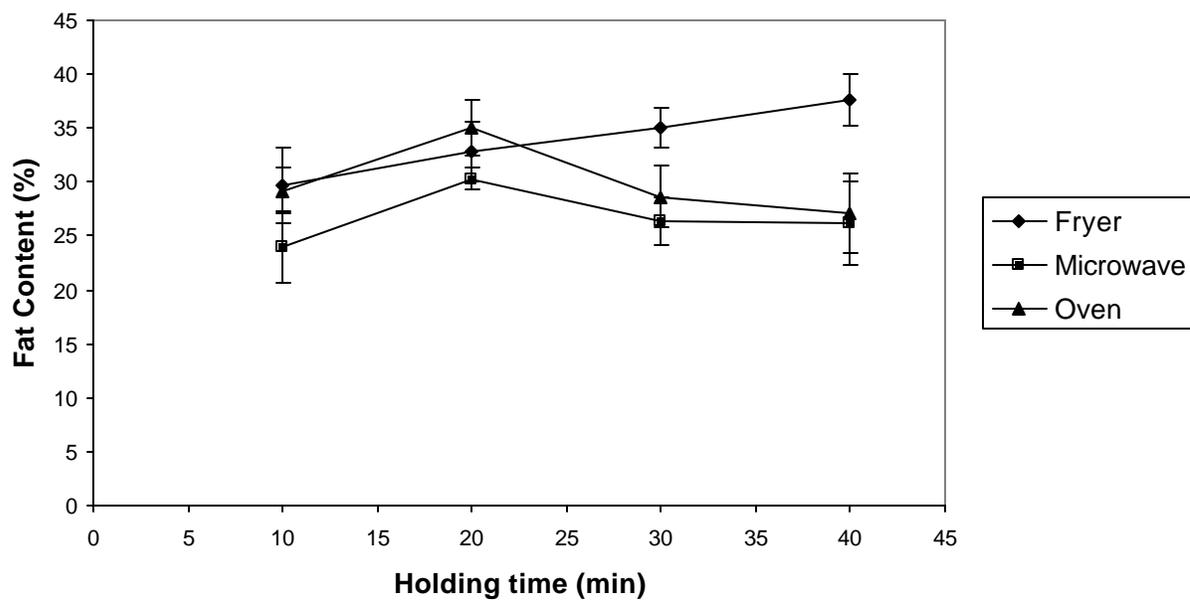
a)

b)

Fig.5.3 Effect of holding time on the moisture content of the crust

    a) – under a heat lamp

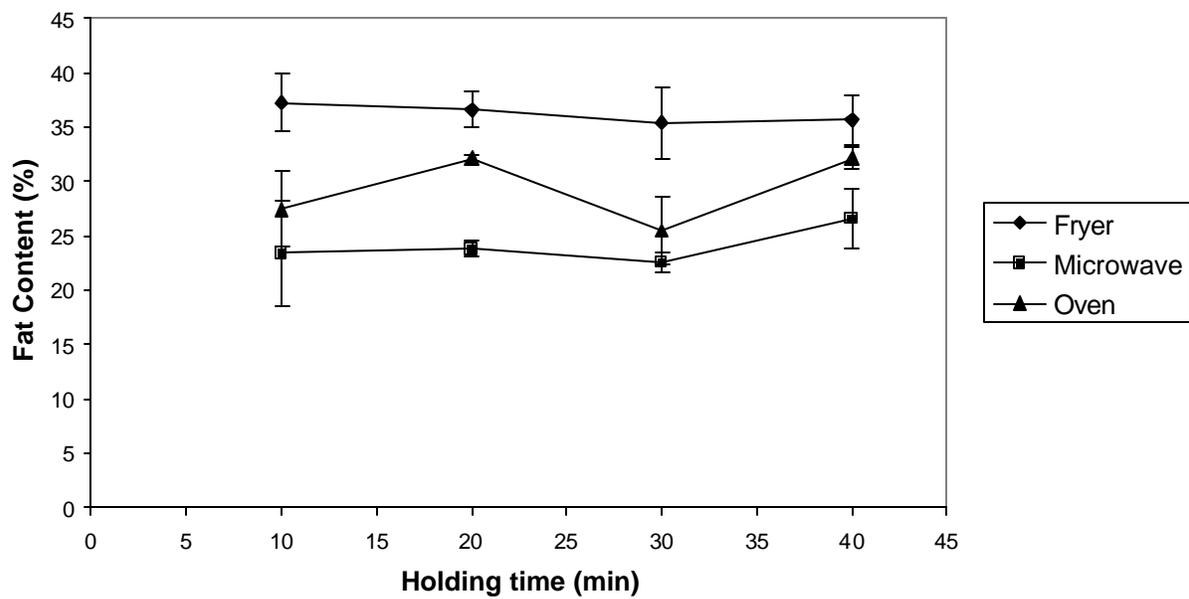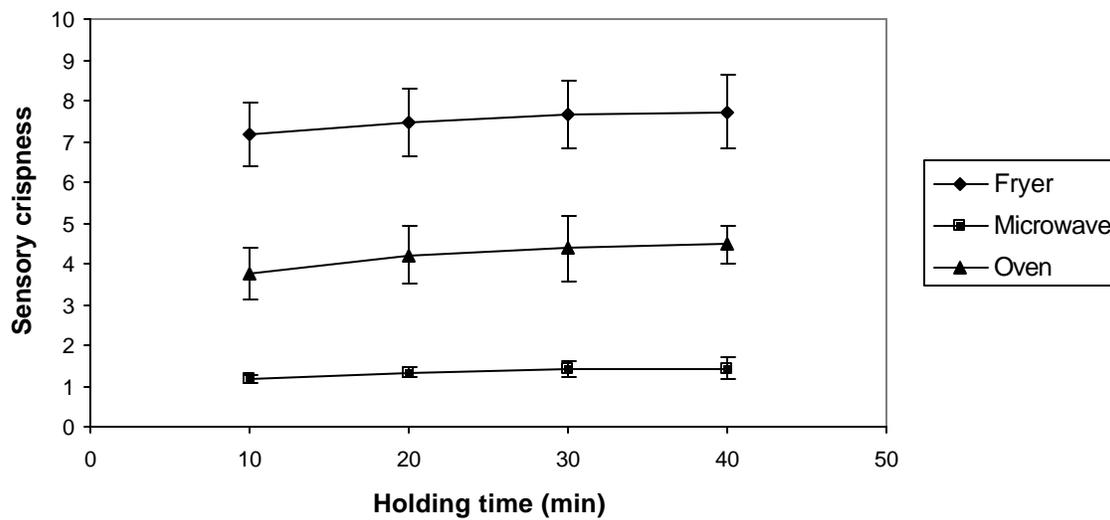   b) – under ambient conditions

a)

b)

Fig. 5.4 Effect of holding time on the fat content of the crust: (a) under a heat lamp; and

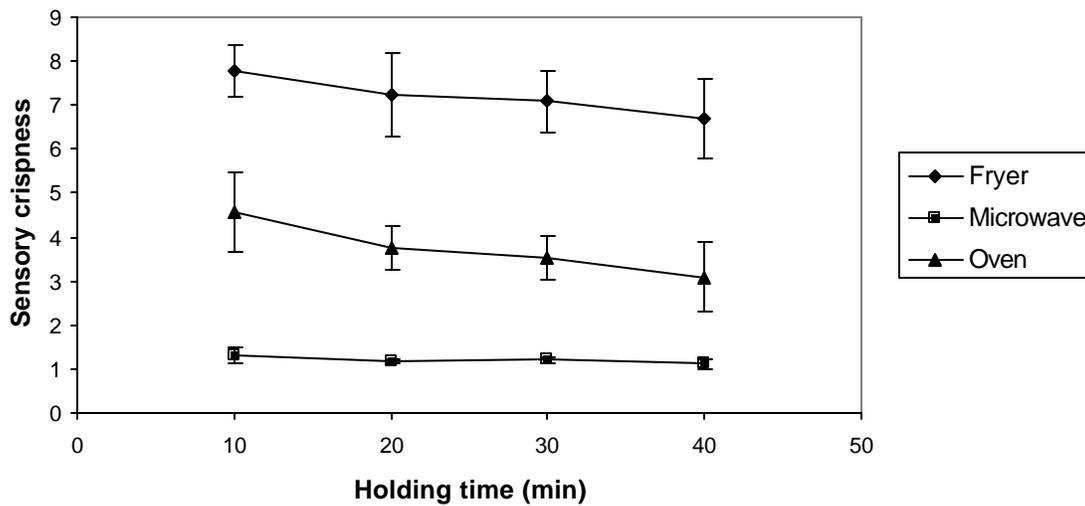(b) under ambient conditions

a)

b)

Fig.5.5   Effect of holding time on the mean sensory crispness intensity ratings of

breaded fried chicken nuggets for each cooking method

    a) under a heat lamp
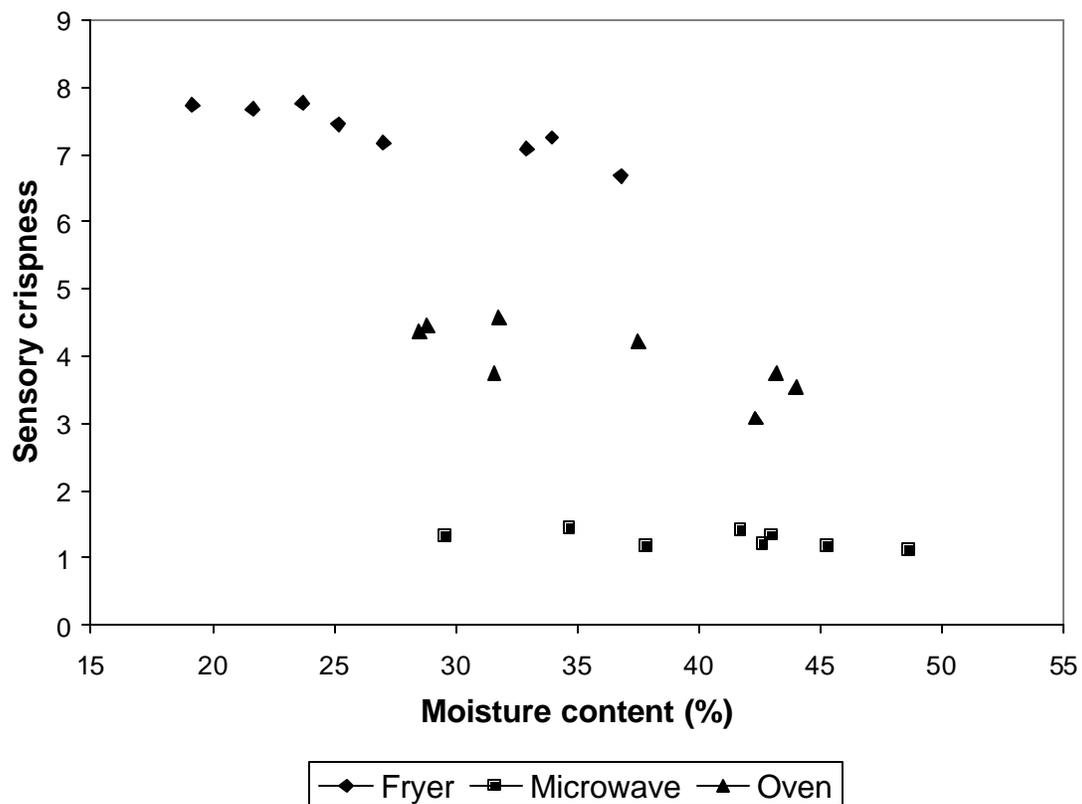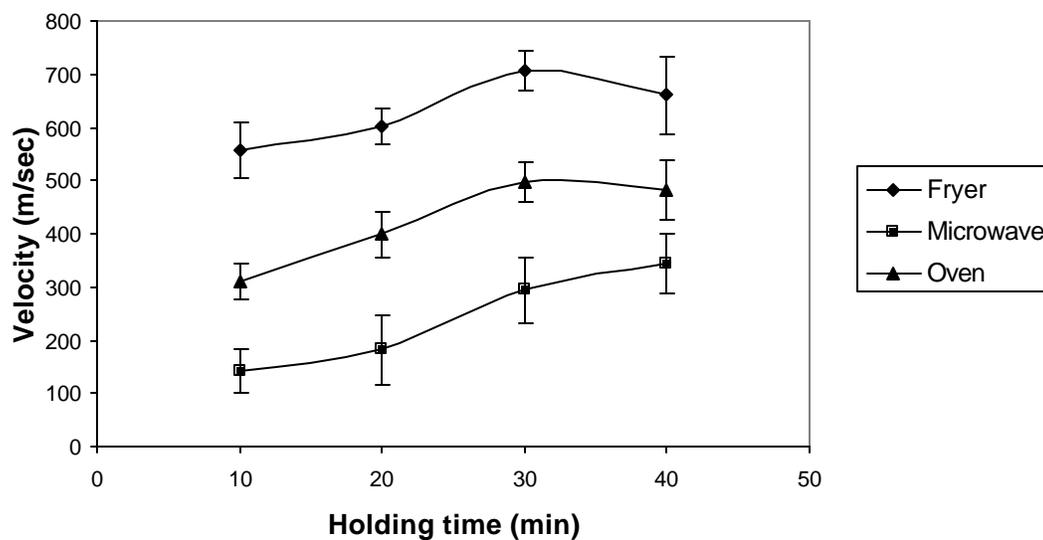
    b) under ambient conditions

Fig. 5.6 Relating moisture content to sensory crispness
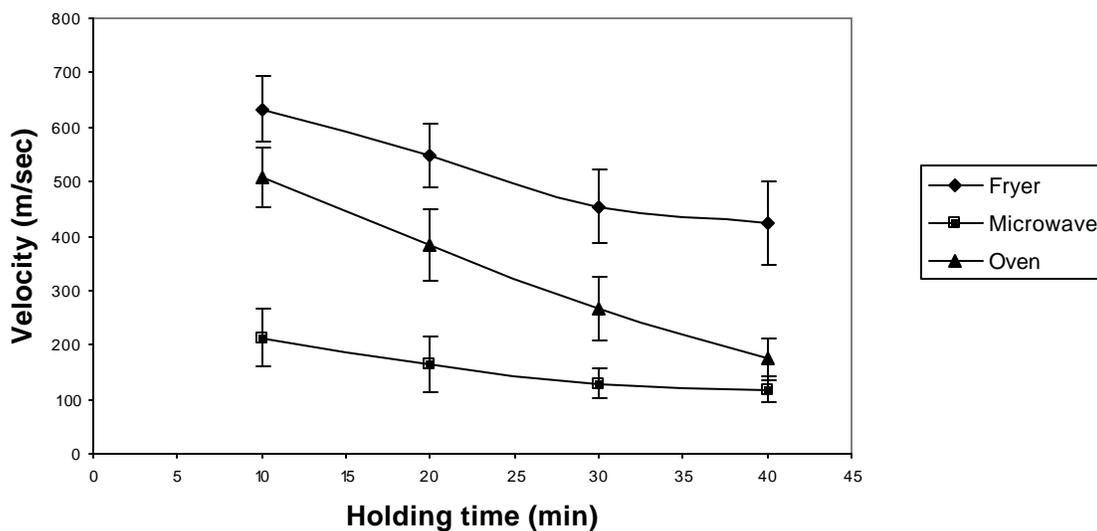
a)

b)

Fig.5.7 Effect of holding time on ultrasonic velocity for each cooking method

    a)   under a heat lamp
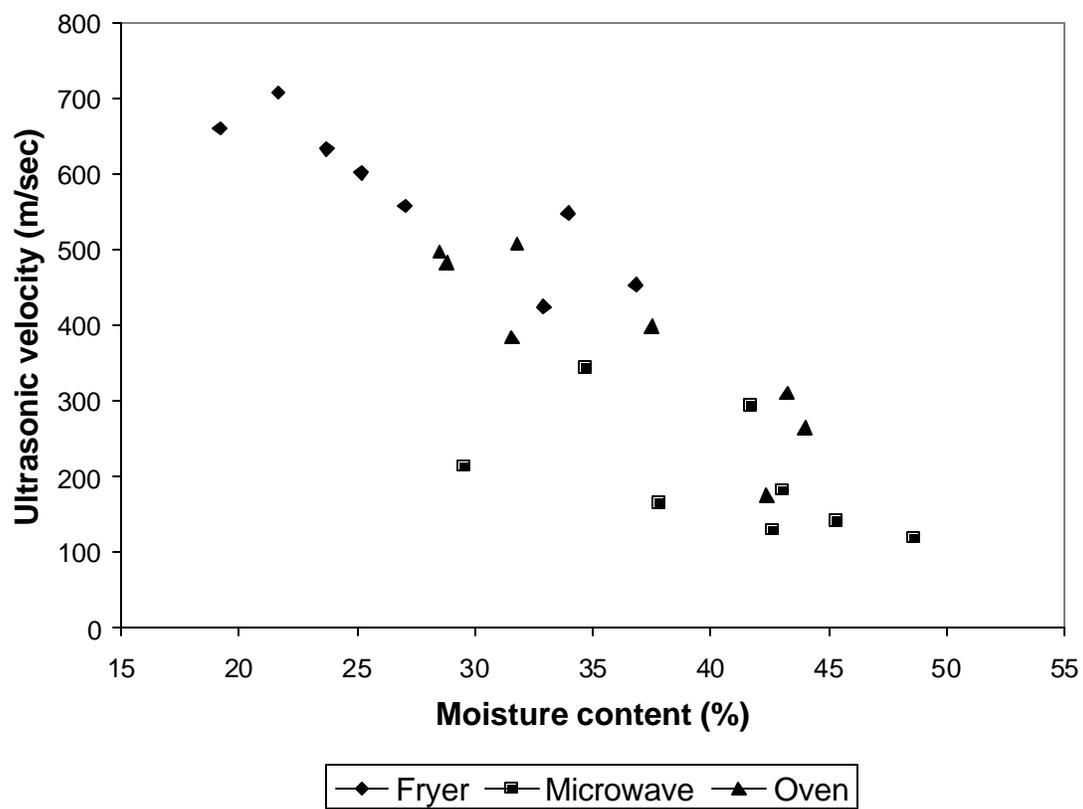
    b)   under ambient conditions

Fig. 5.8 Relating moisture content to ultrasonic velocity
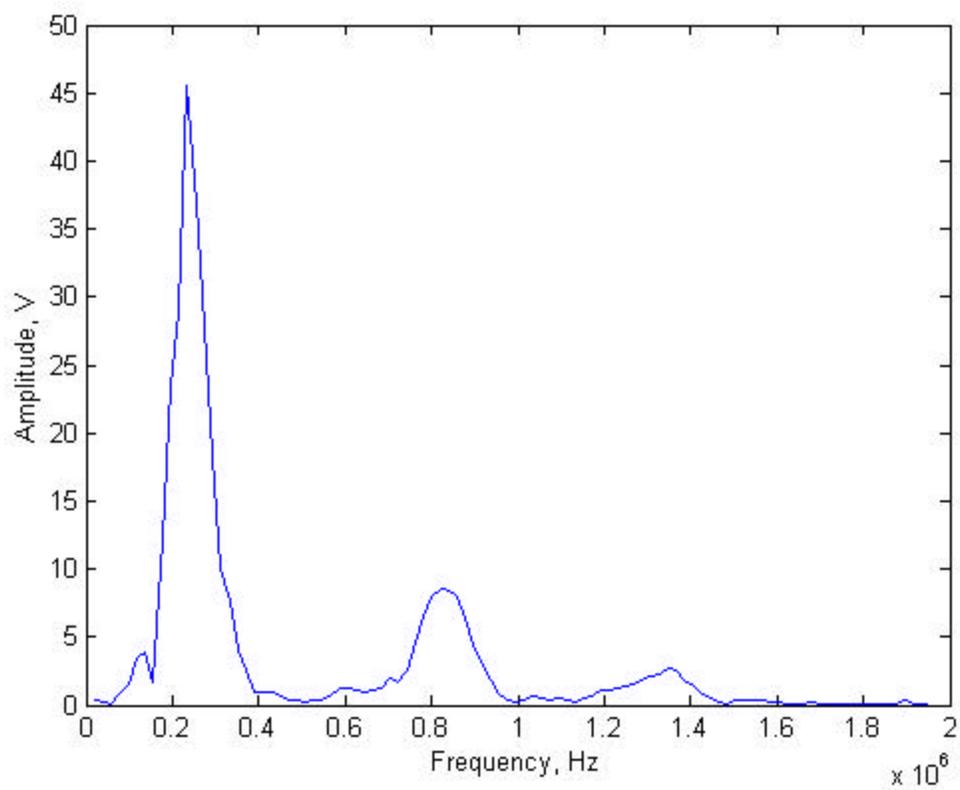
Fig. 5.9 Frequency domain plot of transmitted ultrasound

a)
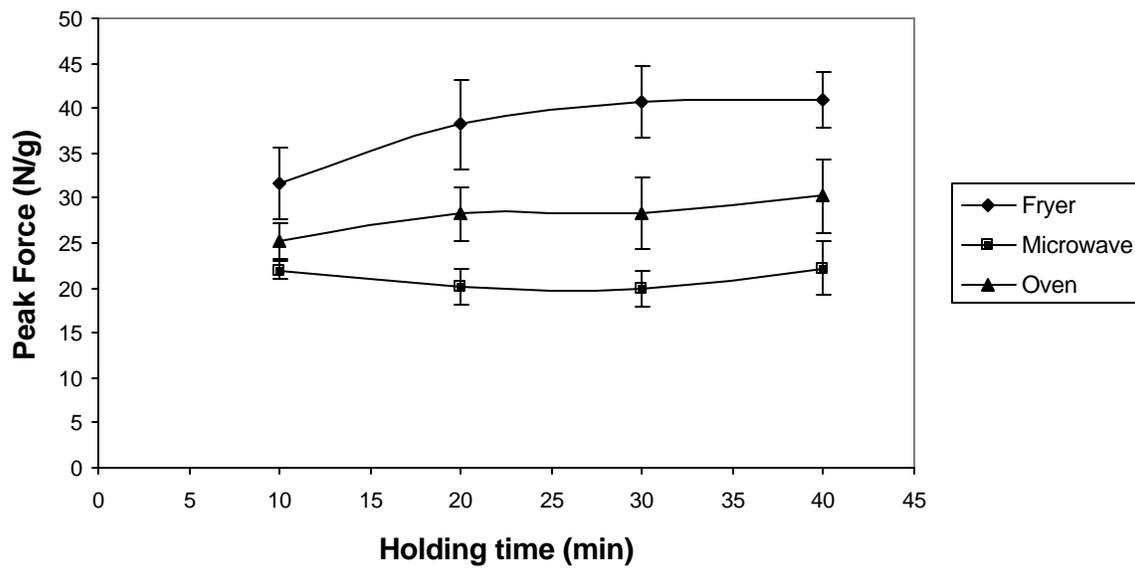
b)
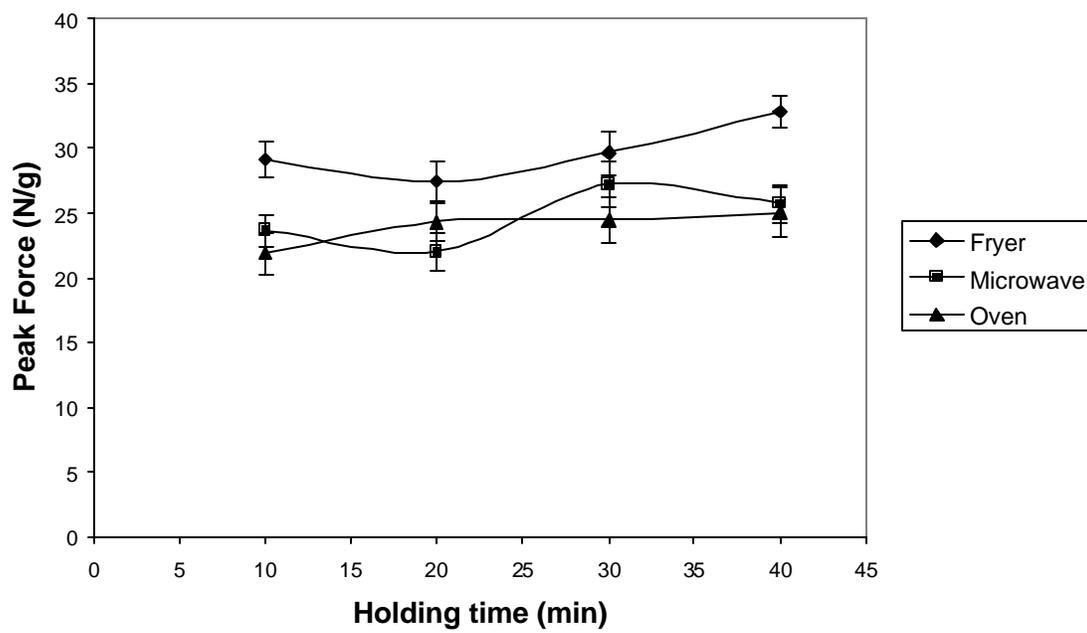
Fig.5.10 Effect of holding time on peak force for each cooking method

    a)   under a heat lamp

    b)   under ambient conditions

Fig. 5.11　Total energy for breaded fried chicken nuggets kept under different storage conditions
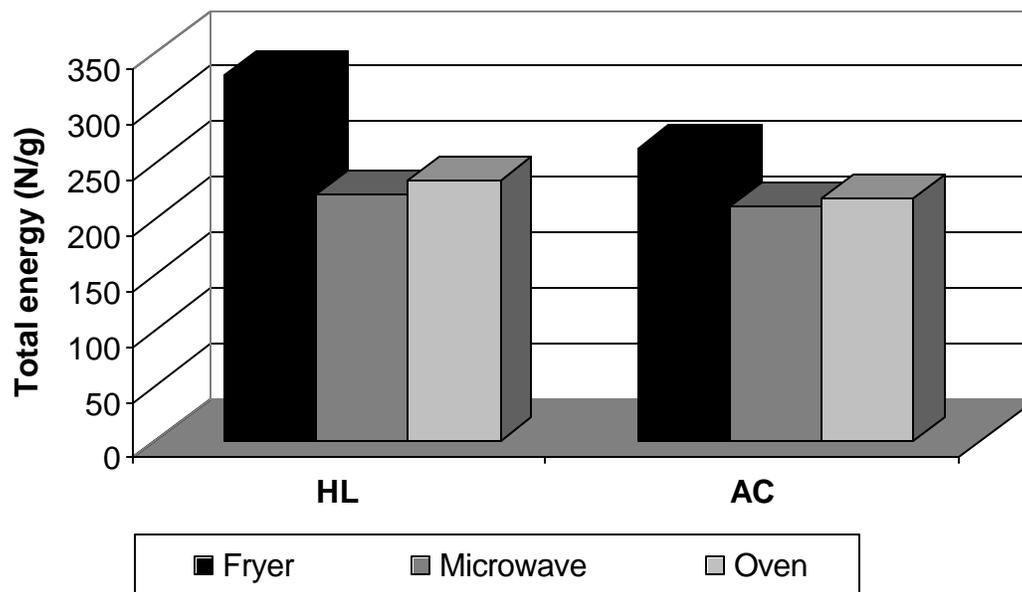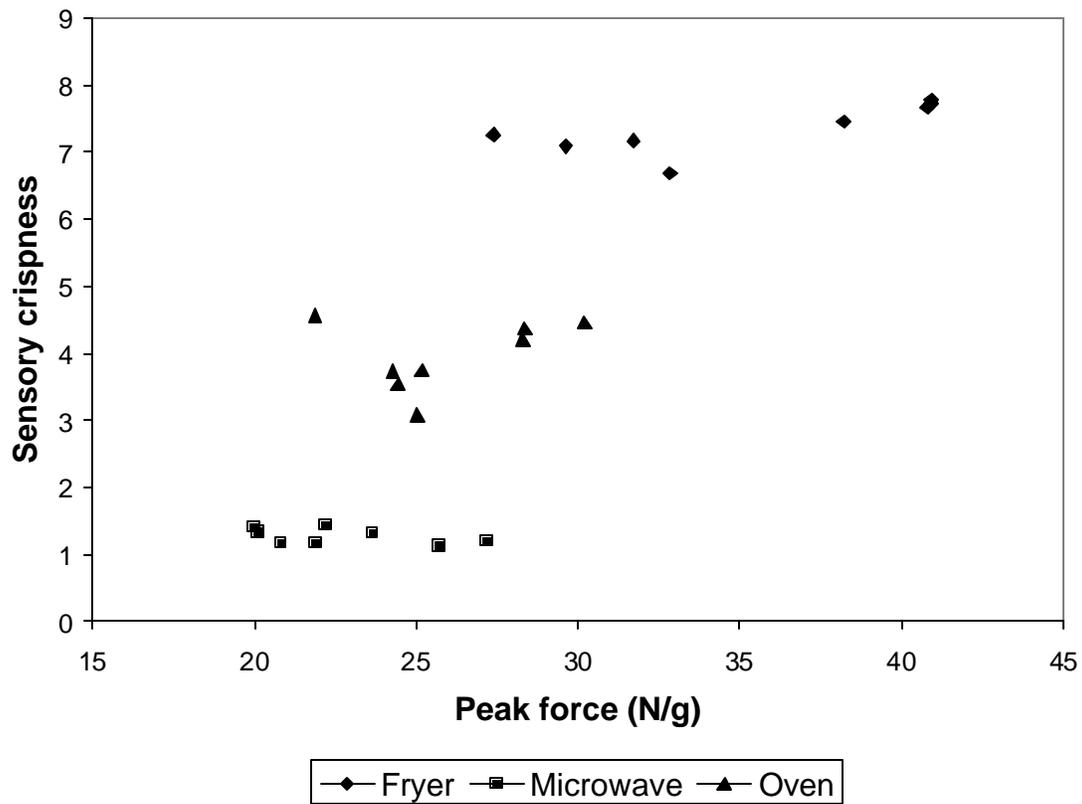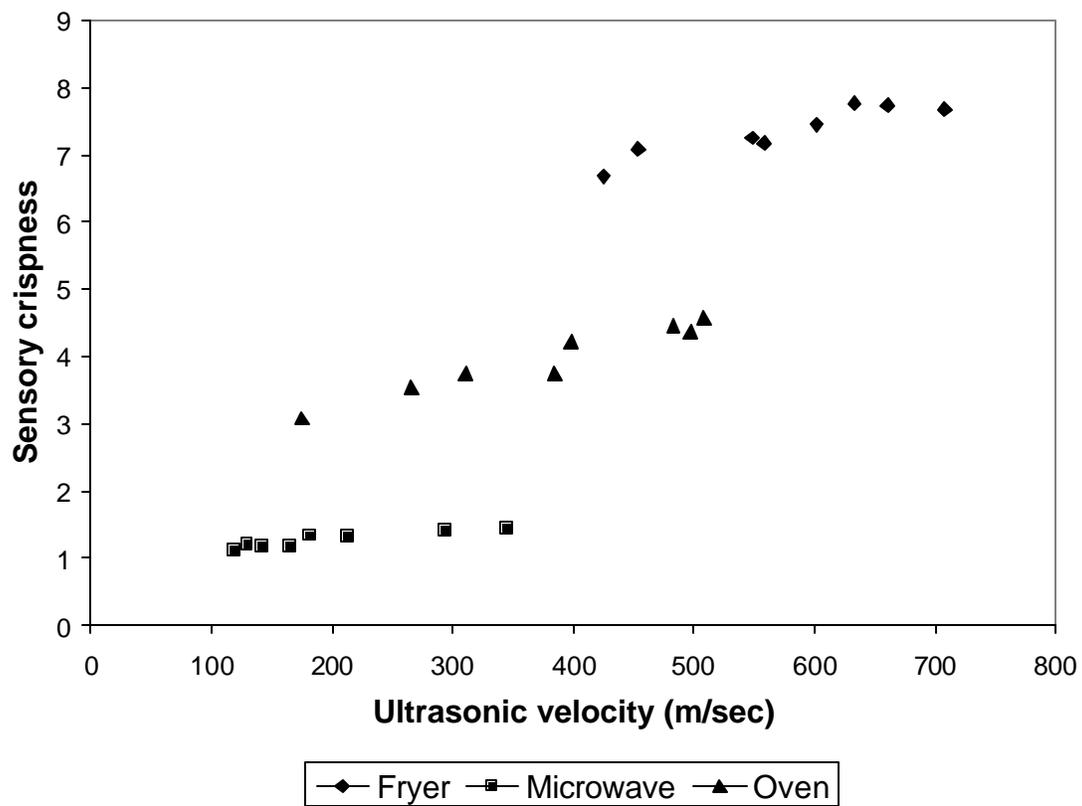
Fig. 5.12 Relating peak force to sensory crispness

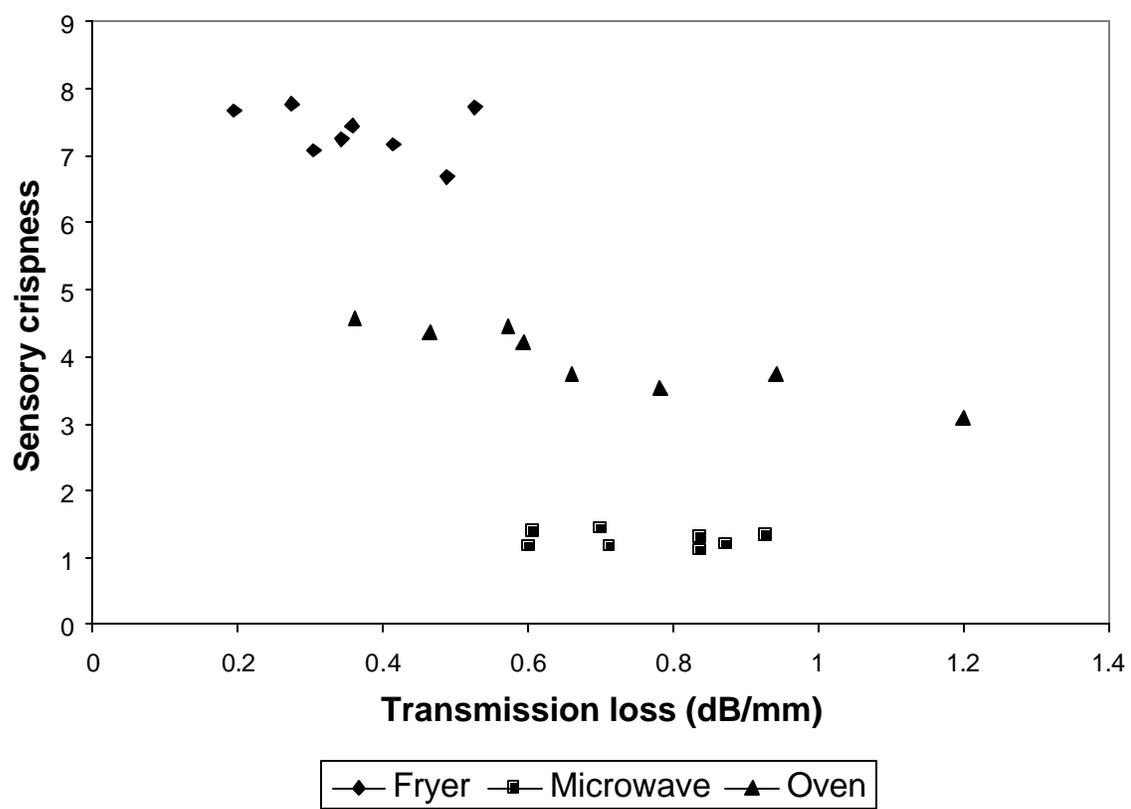Fig. 5.13 Relating ultrasonic velocity to sensory crispness

Fig. 5.14 Relating transmission loss to sensory crispness

SECTION VI

SUMMARY AND CONCLUSIONS

SUMMARY

Crispness is one of the most important textural characteristics in breaded fried foods. Though many experiments have been dedicated to determining crispness, the best measurements are still inconclusive. There is a need for developing an objective method that can accurately measure and quantify crispness for breaded fried foods having moist core.

In this study, the mechanical and ultrasonic techniques were investigated and used for crispness evaluation of breaded fried chicken nuggets cooked by different methods and held under either a heat lamp or ambient conditions. An Instron universal testing machine was used to measure the mechanical properties of breaded fried chicken nuggets. For the ultrasonic measurements, the ultrasonic non-destructive evaluation system was used. The system included a high power burst pulser, a broadband receiver, a digital storage oscilloscope, 250-kHz dry-coupling ultrasonic transducers, and a microcomputer system for data acquisition and analysis. The equipment setup was in the through-transmission mode because breaded fried chicken nugget is highly atttenuative material.

Ultrasonic velocity, transmission loss, peak frequencies and its amplitudes, peak force and total energy were determined for each sample. Correlation between instrumental measurements and sensory measurements showed that the ultrasonic method can be used to measure and explain sensory crispness in breaded fried chicken nuggets. Ultrasonic velocity had high correlation with sensory crispness ($R^2 = 0.83$). This indicates that sensory crispness could be reasonably well predicted by the ultrasonic velocity.

CONCLUSIONS

The following conclusions were derived from this study:

1. The ultrasonic transmission through the breaded fried chicken nugget using the 250-kHz transducers was successful.

2. The moisture and fat contents significantly changed among the samples cooked by different methods. The moisture content decreased with increasing holding time under a heat lamp as the samples became crispier.

3. Sensory crispness of breaded fried chicken nuggets was significantly affected by cooking method, storage conditions and holding time.

4. The relationship between sensory crispness and instrumental parameters suggests that the ultrasonic method can be used to measure and explain sensory crispness in breaded fried chicken nuggets.

5. The ultrasonic velocity had high correlation with sensory crispness ($R^2 = 0.83$). Ultrasonic velocity increased with increasing holding time under a heat lamp as the samples became crispier, which can be attributed to moisture loss.

6. The values of the transmission loss were significantly different for samples cooked by different method. Samples cooked in a deep-fat fryer had lower values for the transmission loss than samples cooked in an oven and a microwave oven.

7. The peak frequencies in the frequency spectrum were found in a range of 216 – 252 kHz, 846 – 882 kHz, and 1368 – 1386 kHz, respectively. Samples held under a heat lamp had higher amplitudes corresponding to the peak frequencies than those stored under ambient conditions.

APPENDIX

WORKSHEET 1

Day   **No.**

Each panelist receives an eight samples of standard products to evaluate for crispness at same time. Each sample is coded with a 3-digit random number.

Type of test: Category Scales

Code	Sample
A	Quaker Low Fat Chewy Chunk, 1/3 bar
B	Keeblers partner Club Cracker, 1/2 cracker
C	Honey Maid Graham Cracker, 1" sq.
D	Cheerios oat Cereal, 1 oz.
F	Kellogg's Bran Flakes Cereal, 1 oz.
H	Cheddar Cheese Crackers, 1 oz.
G	Kellogg's Corn Flakes Cereal, 1 oz.
K	Devonsheer melba Toast, 1/2 cracker

Panelist No.	Order of presentation and serving code							
	1	2	3	4	5	6	7	8
1	A 862	C 756	D 544	B 681	F 199	G 918	K 335	H 477
2	B 681	A 862	C 756	F 199	K 335	H 477	G 918	D 544
3	C 756	B 681	F 199	K 335	G 918	A 862	H 477	D 544
4	D 544	A 862	B 681	C 756	H 477	K 335	F 199	G 918
5	A 862	B 681	K 335	H 477	C 756	D 544	G 918	F 199
6	F 199	G 918	D 544	C 756	H 477	K 335	B 681	A 862
7	K 335	H 477	G 918	F 199	B 681	D 544	C 756	A 862
8	G 918	F 199	K 335	H 477	D 544	C 756	A 862	B 681

WORKSHEET 2

Date   **No.**

Each panelist receives five samples of fried products obtained from local fast-food restaurants. Each sample is coded with a 3-digit random number.
Only one sample is presented at a time. When the panelist finished the evaluation of the first sample, the second sample is presented in the set of tray with the appropriate scorecard. Repear the procedure for the following samples.

Type of test: Category Scales

Code	Sample
A	Fried and breaded chicken nuggets
B	French fries
C	Fried and breaded onion rings
D	Chicken strips
K	Breaded chicken

Panelist No.	Order of presentation and serving code				
	1	2	3	4	5
1	A 332	C 691	B 549	D 855	K 714
2	B 549	A 332	K 714	C 691	D 855
3	K 714	B 549	D 855	A 332	C 691
4	C 691	D 855	A 332	K 714	B 549
5	D 855	K 714	C 691	B 549	A 332
6	A 332	B 549	C 691	D 855	K 714
7	K 714	D 855	B 549	C 691	A 332
8	B 549	K 714	C 691	D 855	A 332

WORKSHEET 3

Date   **No.**

Each panelist receives five samples of fried products obtained from local fast-food restaurants.
Each sample is coded with a 3-digit random number.
Only one sample is presented at a time. When the panelist finished the evaluation of the
first sample, the second sample is presented in the set of tray with the appropriate scorecard.
Repeat the procedure for the following samples.

Type of test: Category Scales

Code	Sample
A	Chicken strips stored under AC (10 min)
B	Chicken strips store under AC (20 min)
H	Chicken strips stored under HL (10 min)
D	Chicken strips stored under HL (20 min)
G	Chicken nuggets stored under HL (10 min)

Panelist No.	Order of presentation and serving code				
	1	2	3	4	5
1	A 332	H 855	G 112	D 714	B 549
2	A 332	H 855	G 112	D 714	B 549
3	A 332	H 855	G 112	D 714	B 549
4	A 332	H 855	G 112	D 714	B 549
5	A 332	H 855	G 112	D 714	B 549
6	A 332	H 855	G 112	D 714	B 549
7	A 332	H 855	G 112	D 714	B 549
8	A 332	H 855	G 112	D 714	B 549

WORKSHEET 4

Date   **No.**

Each panelist receives six samples of chicken strips obtained from KFC.
Each sample is coded with a 3-digit random number.
Three samples are presented at a time.
Next three samples are presented in the set of tray with the appropriate scorecard
at 10 min interval.
Red lighting is provided.

Type of test: Category Scales

Code	Sample	Serving code
AC-10	Chicken strips stored under AC (10 min)	332
HL-10	Chicken strips stored under HL (10 min)	112
HH-10	Chicken strips stored under HH (10 min)	855
AC-20	Chicken strips stored under AC (20 min)	714
HL-20	Chicken strips stored under HL (20 min)	623
HH-20	Chicken strips stored under HH (20 min)	477

Panelist No.	Order of presentation and serving code					
	1	2	3	4	5	6
1	AC-10 332	HL-10 112	HH-10 855	AC-20 714	HH-20 477	HL-20 623
2	HL-10 112	AC-10 332	HH-10 855	HH-20 477	AC-20 714	HL-20 623
3	AC-10 332	HH-10 855	HL-10 112	HL-20 623	HH-20 477	AC-20 714
4	HH-10 855	HL-10 112	AC-10 332	AC-20 714	HL-20 623	HH-20 477
5	HL-10 112	AC-10 332	HH-10 855	HH-20 477	AC-20 714	HL-20 623
6	AC-10 332	HH-10 855	HL-10 112	AC-20 714	HL-20 623	HH-20 477
7	HH-10 855	AC-10 332	HL-10 112	HL-20 623	HH-20 477	AC-20 714
8	HL-10 112	AC-10 332	HH-10 855	HL-20 623	HH-20 477	AC-20 714

SCORECARD

_____

CATEGORY SCALES

Date:

Name:

Type of Sample: Chicken nuggets

Characteristic Studied: Crispness
_____

Instructions

You have three samples on the tray in front of you.
Taste the samples from left to right and indicate
intensity of crispness by checking the appropriate space on the scale.
Try do not repeat the evaluation of previous samples.
Focus on the outer crust of samples.
_____

Sample code:

Attribute: Crispness

Not crisp/soggy_____ _____ _____ _____ _____ _____ _____ _____ _____Very crisp

Sample code:

Attribute: Crispness

Not crisp/soggy_____ _____ _____ _____ _____ _____ _____ _____ _____Very crisp

Sample code:

Attribute: Crispness

Not crisp/soggy_____ _____ _____ _____ _____ _____ _____ _____ _____Very crisp
_____

Comments:

VITA

Irina Antonova was born on April 28, 1974 in Moscow city, Russia. She graduated from high school in 1991, and then entered Moscow State University of Applied Biotechnology, majoring in Automation of Technological Processes and Productions. She graduated in June 1996 with a Master degree in Automation of Technological Processes and Productions. From 1996 to 1998 she worked as a graduate research assistant in the Automation of Biotechnological Systems Department at Moscow State University of Applied Biotechnology, Moscow, Russia.

In August of 1998, she entered Virginia Polytechnic Institute and State University to pursue a Master of Science degree in Biological Systems Engineering Department under the direction of Dr. P. Kumar Mallikarjunan, while she worked as a graduate research assistant. She completed the final exam for the degree in December 2001.