EFFECT OF INITIAL MOISTURE CONTENT BEFORE FREEZING AND THAWING RATE ON PECAN TEXTURE DETERMINED BY INSTRUMENTAL TEXTURE PROFILE ANALYSIS (TPA) AND SENSORY EVALUATION

By

BERNADETH BIDARIMURTI SURJADINATA

Bachelor of Science

Oklahoma State University

Stillwater, Oklahoma

1999

Submitted to the Faculty of the
Graduate College of the
Oklahoma State University
in partial fulfillment of
the requirements for
the Degree of
MASTER OF SCIENCE
December, 2000

EFFECT OF INITIAL MOISTURE CONTENT BEFORE FREEZING AND THAWING RATE ON PECAN TEXTURE DETERMINED BY INSTRUMENTAL TEXTURE PROFILE ANALYSIS (TPA) AND SENSORY EVALUATION

Thesis Approved:

Gerald H. Brusewitz
Thesis Adviser

Niels Maness

Danielle Bellmer

Alfred Carlozzi
Dean of the Graduate College

ACKNOWLEDGEMENTS

I would like to express my gratitude to my advisor and my graduate committee chairman, Dr. Gerald Brusewitz, for his guidance, inspiration, and understanding during my graduate study, and for his enormous patience in correcting this thesis. A very special thanks to Dr. Danielle Bellmer, member of my graduate committee, for her valuable expertise and for providing me with a lot of assistance when I worked in her laboratory. I also would like to extend my appreciation to Dr. Niels O. Maness, the third member of my committee, for his kind suggestions and help regarding my project.

I wish to thank Kathleen Rutledge, her staff and the sensory panelists from 21st Sensory, Inc, in Bartlesville, Oklahoma, for doing the sensory evaluation part of this project. Their expertise, friendliness, and generous help have made the work much easier.

Special thanks are given to the students who work in Dr. Bellmer's laboratory, Lynn Lye, Muluken Tilahun, Melissa Pierce, and Sylviana Sutiadji, for their cooperation, help, and friendship. All of them, in some way have made this research more fun and enjoyable. In addition, thanks to Yu Zou, Mimin Adhikary, and the Department of Biosystems and Agricultural Engineering for the various aspects of support during my study at Oklahoma State University.

Thanks to God who has given me blessings and strengths in good times and in bad. Thank you for making me able to achieve my goals and for giving me a wonderful life. I am also deeply grateful to Malone Bowen whose love, understanding, and continuous support have made a difference in my life. Thank you so much for believing in and encouraging me in so many ways. Also, thanks to Fr. Joe Townsend, my friends from the Catholic Students Association of St. John's Parish in Stillwater, Oklahoma, and all my other personal friends. I would never be able to do all of this without your continuous support and prayers.

At last but not least, I would like to dedicate this thesis to my wonderful parents (Djohan Surjadinata and Elisabeth Nuryta Angkola) and my dearest sister (Angela Surjadinata). I am wholeheartedly thankful for your unconditional love, encouragement, support, guidance, and prayers throughout my life. I will never be able to thank you enough.

TABLE OF CONTENTS

Chapter		Page

Chapter **Page**

LIST OF TABLES

LIST OF FIGURES

Figure **Page**

CHAPTER I

INTRODUCTION

Pecans are very popular compared to most other nuts and they are consumed all year round because of their rich flavor, crisp texture and unique aroma. All of these characteristics make pecans suitable for many varieties of food products, such as pies, ice cream, snack food, candies, etc. Pecans are commonly shelled prior to sale but these shelled kernels are unstable if they are not stored properly because they are vulnerable to insects, molds, staling, and rancidity. Pecans should be frozen to preserve their flavor and aroma (Heaton et al., 1977).

Pecan quality consists of several factors such as color, flavor, texture, and aroma. Much is known about flavor, color and aroma. There is limited information about fresh or frozen pecan texture although it is a food physical property considered by consumers. Consumers usually relate good texture to freshness and quality while bad texture often indicates that the food is less desirable, not that it is dangerous or unfit for consumption (Szczesniak, 1990). However, recently, consumers have started to demand better texture of their foods.

Many people have made an assumption that freezing pecans will maintain their flavor as well as their texture, but it has not been proven in published research. As more and better instruments and techniques have become available to measure texture, it is now possible to detect minute differences or changes in food quality during processing. It is understood that many changes in texture could occur during freezing, storage, and thawing of foods. That is why Anzaldua-Moralez et al., 1999 used the instrumental Texture Profile Analysis (TPA) to measure the effect of freezing rate, storage temperature, and thawing rate on the texture of pecans. They found out that freezing temperature influences freezing rate and it had less effect on TPA parameters than either freezing or thawing rate.

Food texture can be measured by an instrument or sensory panel. Numerous instruments have been used to measure food related to texture. Bourne, 1978, developed TPA to measure texture and Ocon et al., 1995 found TPA suitable for pecan texture evaluation. This method can generate up to seven of the food texture parameters from one double compression test. Sensory evaluation is done by trained panelists who rank the samples by comparing them to some food texture standards. Some studies conduct both sensory evaluation and instrumental measurements to obtain correlations between the two methods. There are several factors that could affect these correlations: similarity of the mechanisms of the two sets of measurements, the nature of the test material that includes its heterogeneity and rheological characteristics, and selection of sensory attributes and scales (Szczesniak, 1987).

Objectives

This study was conducted to examine the effect of freezing and thawing on pecan texture by using both instrumental TPA and sensory evaluation. The specific goals were as follows:

1. Determine if initial moisture content before freezing has an effect on texture.

2. Determine if thawing rate has an effect on texture.

3. Determine if multiple freeze/thaw cycles have an effect on texture.

4. Correlate texture results between instrumental TPA and sensory evaluation.

CHAPTER II

LITERATURE REVIEW

Pecan Industry

Compared with other nuts, pecans are very popular to use as a food ingredient. They have tender crunchy texture, pleasing aroma, and appetizing flavor. All of these characteristics make pecans desirable for making bakery products, candies, dairy products, and snack goods. Pecans are very versatile because they can be used as halves, pieces, or ground into butter; and may also be salted, coated with sugar, spiced or buttered. The shelled kernels, also known as halves, are mostly sold to consumers as raw pecans but some may be roasted as specialty products. The consumption is year-round because of the versatility and expanded uses for pecans (Heaton et al., 1977).

The production of pecans in the United States has increased steadily since 1925 and now is commercially significant. In the late 1970s, the average annual yield was over 200 million pounds (Heaton et al., 1977). Pecan trees are native crops in North America. They primarily grow in the southern third of the United States and Mexico (Florkowski and Hubbard, 1994).

Post Harvest Process

Pecan nuts are harvested from late September to mid December (Forbus and Senter, 1976). They have to be graded, packaged, and stored under controlled conditions so they can be shelled and marketed year-round (Heaton et al., 1977). After harvest, the pecan nut can be separated into three structural components: the kernel, the shell, and the red-brown tissue found within the shell (Kays, 1982).

<u>Handling</u>

In the early 1920s, equipment was developed for sizing, conditioning, cracking, shelling, screening, drying, grading, and packaging pecans. To improve the yield during shelling in commercial plants, pecans are "conditioned" before cracking and shelling (Heaton and Woodroof, 1961). The process that is commonly used involves soaking the pecans in large vats of water containing 1000 ppm chlorine for 1-2 hours. After that, they are drained and held for 12-24 hours before cracking. Another faster alternative is to soak the pecans in 85°C water for only 3-5 minutes and then hold them for 12-24 hours before cracking (Forbus and Senter, 1976).

This conditioning process increases the moisture content of the kernels from about 3% up to about 8%. After cracking, the pecans need to be dried again as rapidly as possible to below 4.5% to preserve the quality during storage (Heaton et al., 1977). Conditioning requires a long time, a large amount of labor and equipment because it is a batch-type instead of a continuous process, and a large amount of floor space in the plant for storing the in-process products (Forbus and Senter, 1976).

Storage

A large proportion of the pecan crop is stored frozen in warehouses until it is ready to be removed for shelling or to be delivered to consumers (Heaton et al., 1977) and the quality of pecans declines during post harvest handling and storage. This is largely due to the environmental conditions in which they are held (Beaudry et al., 1985). According to Kays (1982), the kernel's moisture content, the storage temperature, and the storage gas atmosphere are very important environmental factors. They all affect the growth of fungi and insects on stored pecan nuts, as well as the chemical changes in the nuts. At the time of harvest, pecan kernels with low naturally occurring moisture and low superficial moisture (i.e. moisture originated from sources other than the tree) are less likely to have mold than the ones with high natural moisture, or low natural moisture but high superficial moisture (Beuchat and Heaton, 1980). Therefore, drying the kernels to below 4.5% moisture and storing at below freezing temperature (0°C) in 65-75% relative humidity environment will protect them from quality deterioration. Besides that, drying will cause the kernels to shrink away from the shells, thus it will be helpful in the separation during cracking and shelling processes (Beuchat and Heaton, 1980).

Pecan meats that are cut into pieces have a shorter shelf life than whole kernels (Heaton and Woodroof, 1961) and they are more susceptible to infestation of insects, molds, staling, and rancidity during storage (Heaton et al., 1977, Forbus and Senter, 1976). Pecans that will be held up to one year should be stored at 0°C and at least –18°C for the ones held longer. Frozen storage will decrease staling and rancidity, thus extend the shelf life (Heaton et al., 1970). This low temperature will also eliminate the need for readjusting the moisture content of the kernels immediately before cracking and shelling (Beuchat and Heaton, 1980) because refrigeration systems will dry the pecans if held long enough in the storage. Another way to prevent mold spoilage is to seal the pecan nuts under nitrogen and carbon dioxide gases, regardless of the relative humidity of the atmosphere (Heaton et al., 1977). To control insect infestation, pecan kernels have to be stored at 9°C or lower (Brison, 1974) and at higher temperature, methyl bromide or a combination of ethylene dichloride and carbon tetrachloride are usually used to inhibit growth of insects (Thompson et al., 1951).

To achieve the best quality, pecans should be stored at the optimum moisture of 3.5% (Heaton and Woodroof, 1965). Determining the moisture content of pecan kernels can be done by drying 5 grams of 1 mm thick pieces in a forced-air oven at 105°C for 3.5 hours (Heaton and Shewfelt, 1976).

The term water activity (a_w) is also commonly used to define preservation of quality by preventing mold growth. The lower the water activity, the less the amount of mold and bacteria (Santerre, 1994). He defined water activity as the ratio of the vapor pressure of the system to the vapor pressure of pure water. Depending on the oil content (Beuchat, 1978), the minimum a_w range for mold growth is 0.68-0.70; pecans at 4.5% moisture content are equilibrated to $a_w = 0.68$ (Beuchat and Heaton, 1980).

Quality of Pecan

The quality of pecan kernels is usually determined by color, flavor, texture, and absence of insects and mold (Heaton and Woodroof, 1961, 1967). Temperature, oxygen concentration, and the moisture content of the kernels are the most critical factors for maintaining good quality pecans. Storage at low temperatures enhances the desirable color and flavor (Heaton et al., 1977).

Kernel Color

It is common to use the surface color of pecan kernels to measure the overall quality (Kays, 1987). The kernels that have light color are preferred by the consumer (Senter et al., 1984b). For growers, there are two main reasons why the kernel color is important:

1. The grower has control of many pre and post harvest factors that may influence the color.
2. Kernel color strongly affects the market value of the crop (Kays, 1987).

Kernel Flavor

Taste and odor both contribute to the characteristic flavor of pecans. The kernels with the highest oil content usually have the best flavor because the oil makes the pecans taste and smell better. Therefore, the oil content of the kernels plays an important role in rating pecan flavor (Kays, 1987).

To improve the flavor during short storage, pecan kernels can be exposed to heating treatments up to about 156°C, which will cause the inactivation of enzymatic systems in the kernels (Senter et al., 1984a). However, to maintain the fresh and acceptable flavor for extended periods, pecan kernels have to be stored at reduced temperature (Heaton and Woodroof, 1967).

Kernel Texture

There have been few studies done on pecan texture although it plays an important role in determining the quality. People generally assume that the texture of pecans and peanuts are the same but this is not true since peanuts are more homogeneous. Unlike peanuts that are legumes, pecans are true nuts (Ocon et al., 1995) and they belong to the walnut family. The botanical definition of a nut is a fruit seed enclosed in a leathery or woody covering, the pericarp, from which it is usually separable (Grolier, 1983).

Since the quality of food products depends very much on the raw material's texture, the texture of pecans is an important attribute for food processors (Brennan et al., 1976). It is also very critical for acceptance by the consumers (Bourne, 1982) because the pecan meats have to be tender enough to chew easily and tough enough to endure handling (Heaton and Woodroof, 1967). The optimum moisture for good texture pecans is 3.5 to 4%. Below this range, the kernels are too brittle for handling without injury and above this range they will stale rapidly because of increased enzymatic activity (Heaton and Woodroof, 1965).

Food Texture

According to Jansen (1969), many changes occur in the texture of foods during freezing, storage and thawing. Structural features such as the cell wall thickness, the size and shape of the cell, and the volume of the intercellular spaces play critical roles in determining texture. For example, the moisture within the tissue expands during freezing, forming ice crystals that burst cellular walls and membranes. This is how freezing mostly affects a food's texture. Therefore, fast freezing is better because of the formation of small, less damaging ice crystals compared to slow freezing which forms a smaller number of larger crystals (Schur, 1987).

Desirable texture varies between foods. In fruit, good texture may be a product with high turgor and in vegetables it may be both proper turgor and freedom from tough fibers (Jansen, 1969). In handling and processing of frozen fruits and vegetables, it is important to understand the factors that influence the texture. The changes in texture of these foods may occur during cooking, freezing, storage, and/or thawing (Schur, 1987, Jansen, 1969 and Guadogni, 1969). There are many kinds of texture changes but to date, only limited progress has been made in the elimination of texture defects (Jansen, 1969).

Frozen Foods

Pre-freezing Treatments

The freezing process is usually successful if it includes pre-freezing treatments because if conducted properly, the benefits of pre-treatments will compensate for any undesirable effects during freezing. These pre-treatments are different depending on the products. Possible pre-treatments include blanching for vegetables, control chilling for animal tissue, and exposure to chemical solutions for fruit.

Enzymatic browning usually occurs in fruits such as peaches, apples, and pears. The development of this brown color is caused by oxidation of phenolic compounds by o-diphenol oxidase, also known as polyphenoloxizase. Since most fruits are consumed uncooked, control of enzymes by blanching, which is done on vegetables, is usually unacceptable. Instead, additives such as citric and malic acid, sulfur dioxide, sulfites, or sulfurous acid can control tissue browning because they inhibit the activity of enzymes, alter enzyme substrate, or limit contact of oxygen with phenolic substances (Fennema et al., 1973).

Cut fruit, especially those with light colors must be protected against enzymatic browning during the interval between cutting and freezing. Immersion in a dilute solution of 1-3% sodium chloride is often used. Another alternative is immersing the fruits in 0.25% $NaHSO_3$ solution for 45 seconds followed by 0.2% K_2HPO4 solution (pH 8.8) for 5 minutes (Fennema et al., 1973).

Just like fruit, the enzymes in vegetables must be controlled so undesirable effects are avoided during freezing, storage, and thawing. Therefore, prior to freezing, all vegetables are blanched or soaked in addition to operations such as washing, grading, cutting, and packaging. Blanching involves a mild heat treatment by exposing the product to hot water or steam. The treatment ranges from 88°C for a few minutes to 100°C for less than one minute (Olson et al., 1968). This heat treatment will inactivate enzymes that can cause undesirable changes is color, flavor, texture, and nutritive content such as vitamins A, B_1, B_2, and C during subsequent freezing, storage, and thawing.

Freezing Process

Freezing is the best method known at the present time to preserve fresh color, taste, aroma, and nutritive content of many foods (Guadogni, 1969). The freezing process almost always produces some unwanted effects while accomplishing its primary function of preventing bacteria growth and retarding chemical changes. However, if freezing is conducted properly, the damaging effects are far less than normally occur during storage and probably somewhat less than during thawing (Fennema et al., 1973).

Freezing involves lowering the product's temperature, usually down to -18°C or below. Temperature reduction usually causes two undesirable effects. The first one is chilling injury, also known as physiological cold injury. Prior to freezing, susceptible products must be stored for an extended period of time at damaging refrigerated temperature for chilling injury to occur and influence the quality of frozen foods. However, it is easy to avoid chilling injury (Fennema et al., 1973).

Thermal shock, also known as temperature shock or cold shock, can occur by very rapid decreases in temperature, above and possibly even below freezing and can have a lethal effect on some organisms. Presumably, it is caused by fast temperature changes since organisms that are susceptible to thermal shock can frequently tolerate slower cooling. Unless there is cracking of food tissues, which sometimes occurs during very rapid freezing to very low temperature, there is no evidence that quality of frozen food is impaired by thermal shock (Fennema et al., 1973).

Crystallization is the formation of a systematically organized solid phase from a solution, melt, or vapor (Garrett and Rosenbaum, 1958). An understanding of this formation must be regarded as essential to anyone who is attempting to devise new methods to minimize freezing damage because liquid-solid transformations are responsible for most detrimental changes that occur during freezing. The crystallization process consists of the following:

1. Nucleation, which is the combining of molecules into an ordered particle of a size sufficient to survive and serve as a site for crystal growth.
2. Crystal growth, which is the enlargement of the nucleus by the orderly addition of molecules (Fennema et al., 1973).

Physical changes that may occur during frozen storage are the formation of eutectics (intermingled crystals of ice and sucrose hydrate form in constant proportion), freezer burn, and recrystallization. Limited information is available concerning the influence of eutectics on the quality of foods or the viability of biological specimens. Freezer burn is a surface defect that is initiated by sublimation of ice. This defect usually occurs during frozen storage on improperly packed animal or vegetable tissue. The term recrystallization means any changes in the quantity, size, shape, or orientation of crystals following the completion of initial solidification. These changes can occur because the systems tend toward a state of equilibrium wherein free energy is minimized and the chemical potential is equalized among all phases.

Chemical changes that may happen during frozen storage are lipid oxidation, enzymatic browning, flavor deterioration, protein insolubilization, degradation of chlorophyll and vitamins. Changes also can occur leading to viability loss in living specimens.

Thawing Process

Rapid thawing is essential to maintain the viability of many kinds of biological specimens. Therefore, thawing procedures deserve considerable attention. Compared to freezing, thawing must be regarded as a greater potential source of damage but changes during frozen storage still cause greater quality loss than thawing (Fennema et al., 1973). However, for pecan texture, freezing and thawing rates have been shown to have more influence than storage temperature (Anzaldua-Morales et al., 1999)

Although thawing affects the quality of some foods, it is usually secondary in importance, especially for foods that have been exposed to abusive storage conditions. This is because the time involved in thawing is short (minutes to hours) compared to a normal period of frozen storage (weeks to months) (Fennema et al., 1973).

If it possible to assume that the time and temperature pattern of thawing was simply a reverse of freezing, then what has been said about freezing could be applied similarly to thawing. Unfortunately, that is not the case because the pattern of thawing is different from freezing. During rapid commercial freezing, temperature differences range up to about 200°C, whereas the maximum differences during thawing are lower i.e., about 100°C for meat and vegetables and much less for fruits and living specimens.

Compared to freezing, there are some problems that involve thawing products that transmit heat energy primarily by conduction. They are summarized as follows:

1. When conducted under comparable temperature differentials, thawing is intrinsically slower than freezing.
2. In practice, the temperature differential during thawing is less than that during freezing.
3. The time and temperature pattern characteristic of thawing is potentially more critical than that of freezing.
4. The people in charge of thawing food materials are usually less skilled and sometimes unconcerned about the correct procedures than the people directing the freezing operations (Fennema et al., 1973).

There have been some studies to determine how thawing affects the texture of frozen fruit. Tomatoes, for example, are called the "hardest to freeze" commodities because their firm texture is gone and the product is soft and mushy after thawing. Another example is frozen strawberries; either whole berries or those sliced and added with sugar, are far different from fresh strawberries with respect to texture. After thawing the product is frequently called strawberry sauce or "mush" (Jansen, 1969). To get more acceptable thawed products such as tomatoes and strawberries, these fruit have to be immersed in liquid nitrogen before freezing (Anonymous, 1964).

Texture Measuring Device

According to Kramer (1973), texture is one of three primary sensory properties of foods that relates entirely to the sense of touch and feel and is potentially capable of precise measurement objectively by mechanical means in fundamental units of mass or force.

There are five necessary elements for all food texture-measuring devices (Szczesniak, 1966):

1. Driving mechanism, which varies from a simple weight and pulley arrangement to a sophisticated variable speed drive electric motor or hydraulic system.
2. Probe element, which comes in contact with food; flat plunger, shearing jaws, tooth-shaped attachment, piercing rod, spindle, or cutting blade.
3. Force, can be simple or composite; applied in a vertical, horizontal, or levered manner of the cutting, piercing, puncturing, compressing, grinding, shearing, or pulley type.
4. Sensing element, ranging from a simple spring to a complicated strain gauge, proving ring dynamometer or transducers may also be used.
5. Read-out system, which can be a maximum force dial, an oscilloscope, or a recorder tracing the force-distance relationship.

The most popular test is the Texture Profile Analysis (TPA), which was first developed for use on the General Foods Texturometer by a group at the General Foods Corporation Technical Center. This test compresses a bite-size piece of food two times in a reciprocating motion that imitates the action of the human jaw and produces a force versus time curve (Figure 1) that provides several textural parameters (Table I) that correlate well with sensory evaluation parameters (Friedman et al., 1963 and Szczesniak et al., 1963).

Table I. TPA parameters and measured variables.

Parameter	Definition
Hardness	Force (F_2)
Fracturability	Force (F_1)
Cohesiveness	Ratio of areas ($A_{4:6}/A_{1:3}$)
Adhesiveness*	Area 3:4 ($A_{3:4}$)
Springiness	Ratio of lengths ($L_{4:5}/L_{1:2}$)
Gumminess	F_3 x Cohesiveness
Chewiness	Gumminess x Springiness
Resilience	Ratio of areas ($A_{2:3}/A_{1:2}$)

* Negligible for all pecan specimens because it is not a reliable parameter to use to evaluate pecans (Ocon et al., 1995).

Correlations between Sensory and TPA

Texture, by definition, is a sensory property and just like flavor, is a multi-parameter attribute (Szczesniak, 1987). Both sensory evaluation techniques and instrumental measurements are used in food research to assess these texture parameters (Meullenet et al., 1998). Correlations between these two techniques are generally used because of reasons such as: the need for quality control instruments, desire to predict consumer responses, the need to understand what is being perceived in sensory

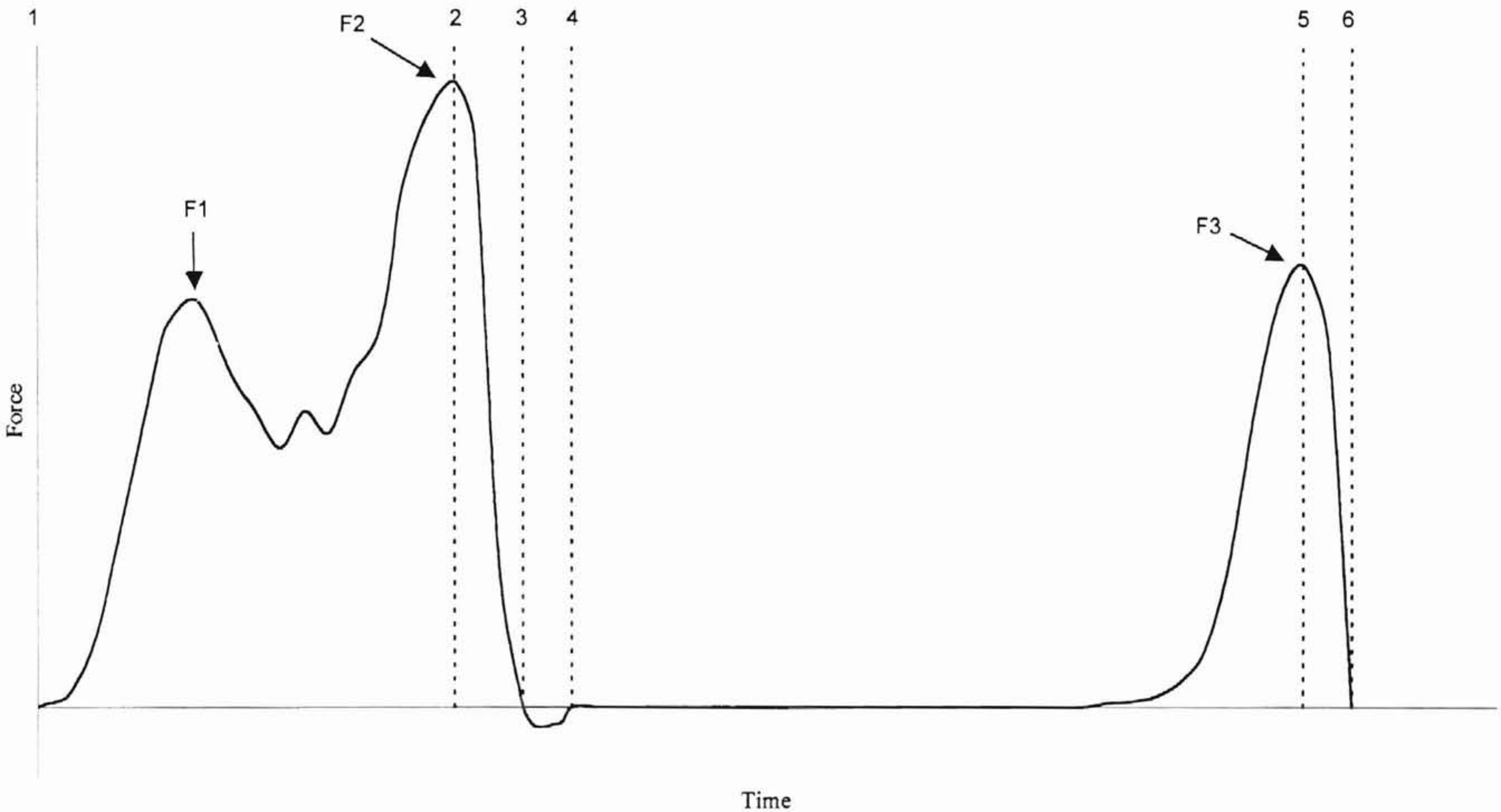

Figure 1. General TPA curve of force versus time

texture assessment, or the need to develop improved instrumental test methods. There is much interest in designing a texture testing that could both predict consumer acceptance and replace descriptive panels. This is because sensory evaluation involves a large amount of time in training, high cost and often gives poor results (Szczesniak, 1987).

The heterogeneity of food samples may influence the nature and degree of correlation between sensory and instrumental measurements (Szczesniak, 1968). Some other key factors that could lead to poor correlations between sensory and instrumental data are improper execution of sensory tests, inadequate knowledge of what the instrumental tests actually measure, sampling errors, and misinterpretation of the statistics of the results. When correlations between the two techniques do not meet expectations, the fault is usually directed at poor sensory testing rather than toward inappropriate selection of instrumental test or statistical analysis (Meullenet et al., 1998).

CHAPTER III

MATERIALS AND METHODS

Pecan Kernels

Western Scheley pecan halves, never frozen, used in this research were obtained from the Young Pecan Company and grown in Las Cruces, NM. They were kept in the refrigerator at 5°C until used for the freezing experiments. Before beginning the freezing and thawing treatments, the pecans were humidified to achieve the desired moisture contents and create uniformity.

Experimental Methods

Initial Moisture Content

Pecans were placed in a single layer on a screen bottom tray inside an environmental chamber for 24 hours at 25°C. To get the two desired moisture contents, the chamber was set at 45% and 75% relative humidity. Afterward, the pecans were dried in a forced convection oven at 130°C for 5-6 hours to determine the moisture content. The final moisture contents were 3.0% and 5.0% (Table II) for 45% and 75% relative humidity, respectively.

Table II. Determination of initial moisture content before freezing by weight of samples before and after drying (chamber's temperature = 25°C)

Chamber Relative Humidity (%)	Pan (gr)	Before		After		Moisture Content (%)	Average Moisture Content (%)
		Pan+Sample (gr)	Sample (gr)	Pan+Sample (gr)	Sample (gr)		
	6.1	26.3	20.2	25.6	19.5	3.5	
45	6.1	26.4	20.3	25.9	19.8	2.5	3.0
	6.0	26.0	20.0	25.4	19.4	3.0	
	6.2	26.7	20.5	25.7	19.5	4.9	
75	6.1	26.7	20.6	25.6	19.5	5.3	5.0
	6.1	26.4	20.3	25.4	19.3	4.9	

Freezing Treatment

After being humidified, the pecans were taken out of the chamber and sealed in Zip-Loc™ freezer bags, 100 grams each bag. The bags were filled such that the pecans could be placed in a single layer in a freezer (Model V706N-1R) by American Motors, Michigan, at about –15°C (+1/-3°C). The bags were placed on wire racks and a fan was added to provide air movement for rapid freezing.

A thermocouple, which was glued into the center of a 12-mm x 10-mm x 3-mm wood block, was placed inside each bag. The purpose of the wood block was to simulate thermal response of a pecan kernel because it gives more uniform reading compared to an actual kernel (Anzaldua-Morales et al., 1999). The reading was taken every five minutes until subsequent changes were less than 1°C. The pecans were left in the freezer for about 24 hours.

Thawing Treatment

Four different thawing methods were created to get different thawing rates. The two faster rates were created by blowing forced air at 25°C and a velocity of 5.5 m/s or 3.3 m/s over the bags of pecans. The pecans, sealed inside the plastic bags, were laid in a single layer inside a 813 mm x 216 mm x 25.4 mm box (Figure 2) so air could flow over them.

The two slow rates were created by placing the bags in between two layers of insulation, so there was no airflow. Fiberglass blanket insulation that was about 25mm thick was used to achieve the slowest rate and 10 mm thick bubble wrap was used for insulation to get the medium rate. The room temperature was 23-25°C during thawing of the pecans. After thawed, they were stored at the same room temperature for 1-3 days until texture measurements.

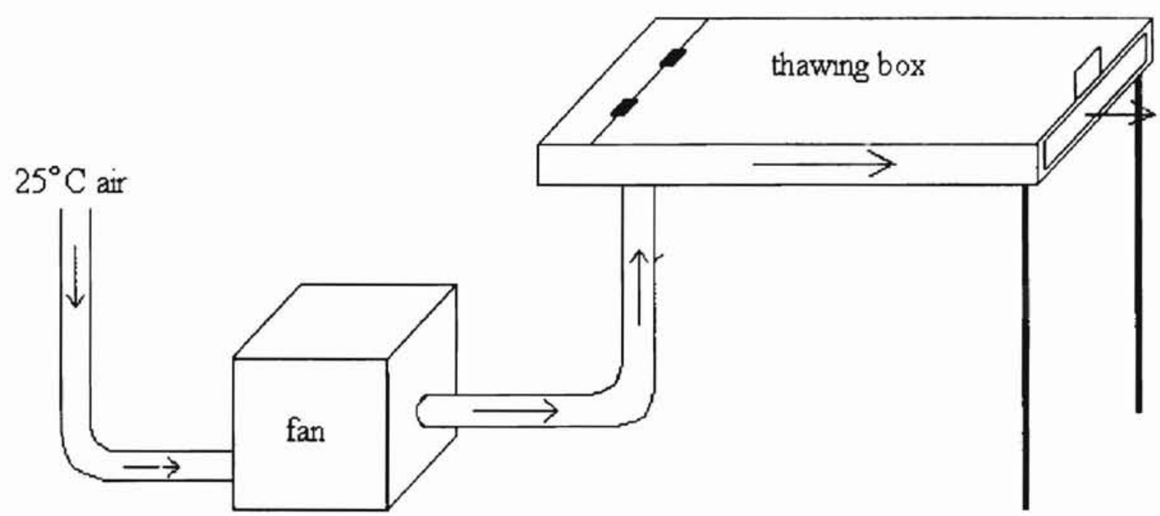

Figure 2. Schematic of the thawing box.

Texture Measurement

There were two methods used in determining the pecan texture parameters: instrumental Texture Profile Analysis (TPA) and sensory evaluation.

<u>Instrumental Texture Profile Analysis (TPA)</u>

The instrumental Texture Profile Analysis was done using a commercial Texture Analyzer (Model TA-XT2i) by Stable Micro Systems, New York. It has a 25-kg load capacity and the settings were: 80% compression, pre-test and post-test speed of 5 mm/s, and crosshead speed of 0.2 mm/s.

To get uniform shape samples, a cylindrical shaped core (3 mm diameter) was removed from the kernel by using a cork borer # 1 and cut to 5 mm in length with a sharp razor blade to obtain square ends. These samples were placed on a small aluminum plate and covered with plastic wrap before texture measurement so they were not exposed to room air. The sample was then placed vertically on the flat plate of the texture analyzer and was compressed twice by a 25 mm diameter flat end cylindrical probe. The samples were handled with forceps during cutting and placement into the texture analyzer.

The standard TPA parameters hardness, fracturability, cohesiveness, gumminess, resilience, springiness, and chewiness were calculated from the TPA curve (Figure 1). Twenty replicates (from 20 different pecan halves) were taken for each treatment.

Sensory Evaluation

Sensory evaluation was done by a commercial firm 21st Sensory, Inc., in Bartlesville, Oklahoma and this had to be approved by the Oklahoma State University Institutional Review Board (Appendix A.1). The pecans were frozen and thawed at the same time as the ones to be measured by the texture analyzer. They were then placed and sealed inside plastic bags (500 grams each bag). After all of the thawing treatments were done, these bags of pecans were then laid horizontally on top of each other inside a cardboard box. Styrofoam packing peanuts were placed inside the box for insulation; the box was sealed and transported the next morning by automobile to the company.

There were twelve highly trained panelists who measured four texture attributes (hardness, fracturability, cohesiveness, and denseness) for two replicates of each treatment. The samples were randomly coded with three digit numbers and presented in monadic and sequential order. The panelists used a 15-point intensity scale with 15.0 having the strongest effect and 0.0 indicating no effect. The standards and the ballot form used by the panelists as references are shown in Appendix A.2 and A.3. The definitions of the texture attributes analyzed used by the sensory panel were:

- Hardness/toughness is the required force to bite through sample with molars.
- Fracturability is the measured force to break or fracture the sample with molars.
- Cohesiveness is the amount of deformation of the sample during one chew using the molars.
- Denseness is the measure of compactness of the cross section of the sample while biting completely through with the molars.

Experimental Design

The independent treatments in this study were the pecan's initial moisture content before freezing and thawing rate. The effects of these treatments were determined during three separate experiments.

Experiment 1

Pecans harvested in 1998 were used to create a total of eight treatments at two moisture contents and four thawing rates. Texture was measured by instrumental TPA only.

Experiment 2

Pecans harvested in 1999 were used to create two moisture contents and two thawing rates at levels similar to the extremes in experiment 1. Two control treatments (at each moisture content) were created whereby pecans were moisture adjusted but not frozen and thawed. In this second experiment there was a total of six treatments.

Both instrumental TPA and sensory evaluation were used to measure texture parameters. The TPA measured all of the parameters but in the sensory evaluation, only hardness, fracturability, and cohesiveness were measured because these parameters have been shown to have a high correlation to those of instrumental TPA (Meullenet et al., 1998, Meullenet and Gross, 1999, and Truong et al., 1997). Denseness was measured because it was suggested by the agent that did the sensory evaluation at 21st Sensory.

Experiment 3

Pecans harvested in 1999 and treated like those in experiment 2, at two initial moisture contents were subjected to multiple freezing/thawing. These pecans were left in a freezer for 24-48 hours. Thawing was done by the slowest method because it is the one that closely related to real life application, i.e. fiberglass blanket insulation, which took about 4-5 hours. Samples were taken for instrumental TPA after being subjected to 3,6, 9, and 12 freeze/thaw cycles stretched over 4, 8, 13, and 18 days.

Statistical Analysis

Analysis of variance was carried out using the General Linear Model (GLM) procedure of SAS version 7.0. Multiple comparisons of means were also tested by Tukey's method with significant difference, α, of 0.05.

CHAPTER IV

RESULTS

Experiment 1

The times for the pecans in the first experiment to thaw from about –15 to 15°C were 29, 35, 78, and 162 minutes for fastest, fast, medium and slow rates, respectively. The means for the eight treatments of the TPA parameters are shown in Table III for the 20 replicates

Each TPA parameter was plotted against thawing rates as shown in Figures 3 to 9 for the variables thawing rate and moisture content. Since there is no interaction between the two variables, the different letters on the plot indicate when means are significantly different ($\alpha=0.05$) between the two moisture contents and the four thawing rates. There were statistical differences ($p<0.05$) for the thawing rate for most of the parameters, such as hardness, cohesiveness, gumminess, resilience, springiness, and chewiness. However, from those plots of TPA parameters versus thawing rates, it is clear that there is not much difference among fastest, fast, and medium rate but they are very different from the slow rate. The values for most of the parameters (hardness, cohesiveness, gumminess, resilience, and chewiness) for slow thawing rate are lower than the other thawing rates and this is true for both moisture contents.

Also, for the moisture content, the TPA parameters cohesiveness, springiness, resilience, and chewiness show very strong significant differences ($p<0.0001$). This means that the initial moisture content before freezing has greater effect than the

Table III. Means of TPA parameters for experiment 1 (n=20).

Initial MC (%)	Thawing Rate	Time to thaw -15°C to15°C (min)	TPA Parameters Hardness (N)	Fracturability (N)	Cohesiveness (mJ/mJ)	Gumminess (N.mJ/mJ)	Resilience (mJ/mJ)	Springiness (mm)	Chewiness (N.mm)
3.0	Fastest	29	21.26	14.11	0.0953	1.588	0.0329	0.299	0.469
	Fast	35	20.92	13.97	0.0958	1.579	0.0326	0.315	0.495
	Medium	78	21.71	15.34	0.0956	1.653	0.0333	0.311	0.510
	Slow	162	17.56	13.27	0.0827	1.101	0.0275	0.323	0.356
5.0	Fastest	29	19.81	12.94	0.0973	1.411	0.0283	0.392	0.738
	Fast	35	22.31	14.37	0.0808	1.446	0.0300	0.463	0.665
	Medium	78	20.92	13.17	0.0807	1.377	0.0292	0.476	0.654
	Slow	162	19.37	13.99	0.0769	1.230	0.0263	0.441	0.542

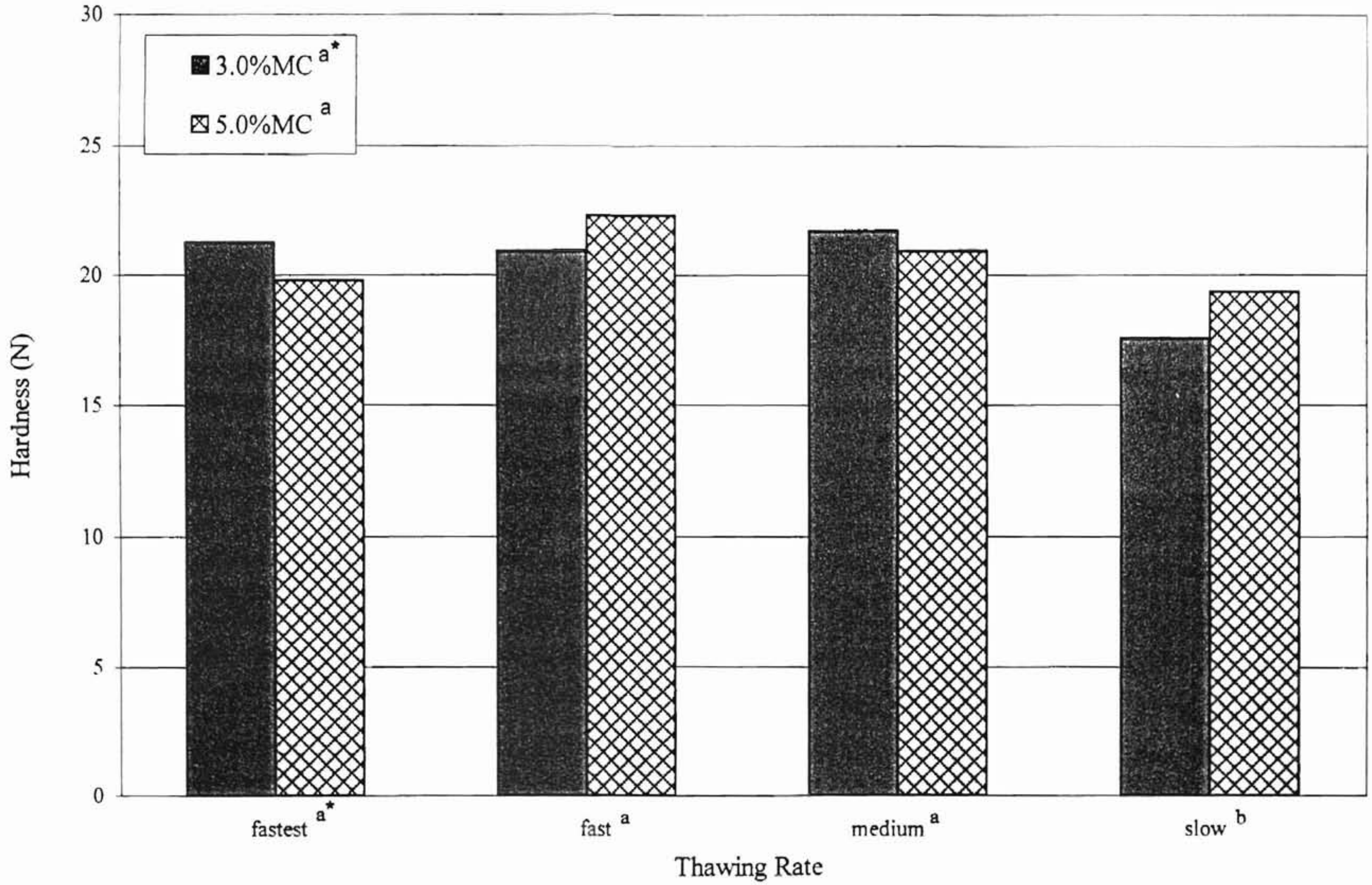

Figure 3. Instrumental TPA hardness versus thawing rate for experiment 1.

* Treatments with different letters are significantly different ($\alpha = 0.05$).

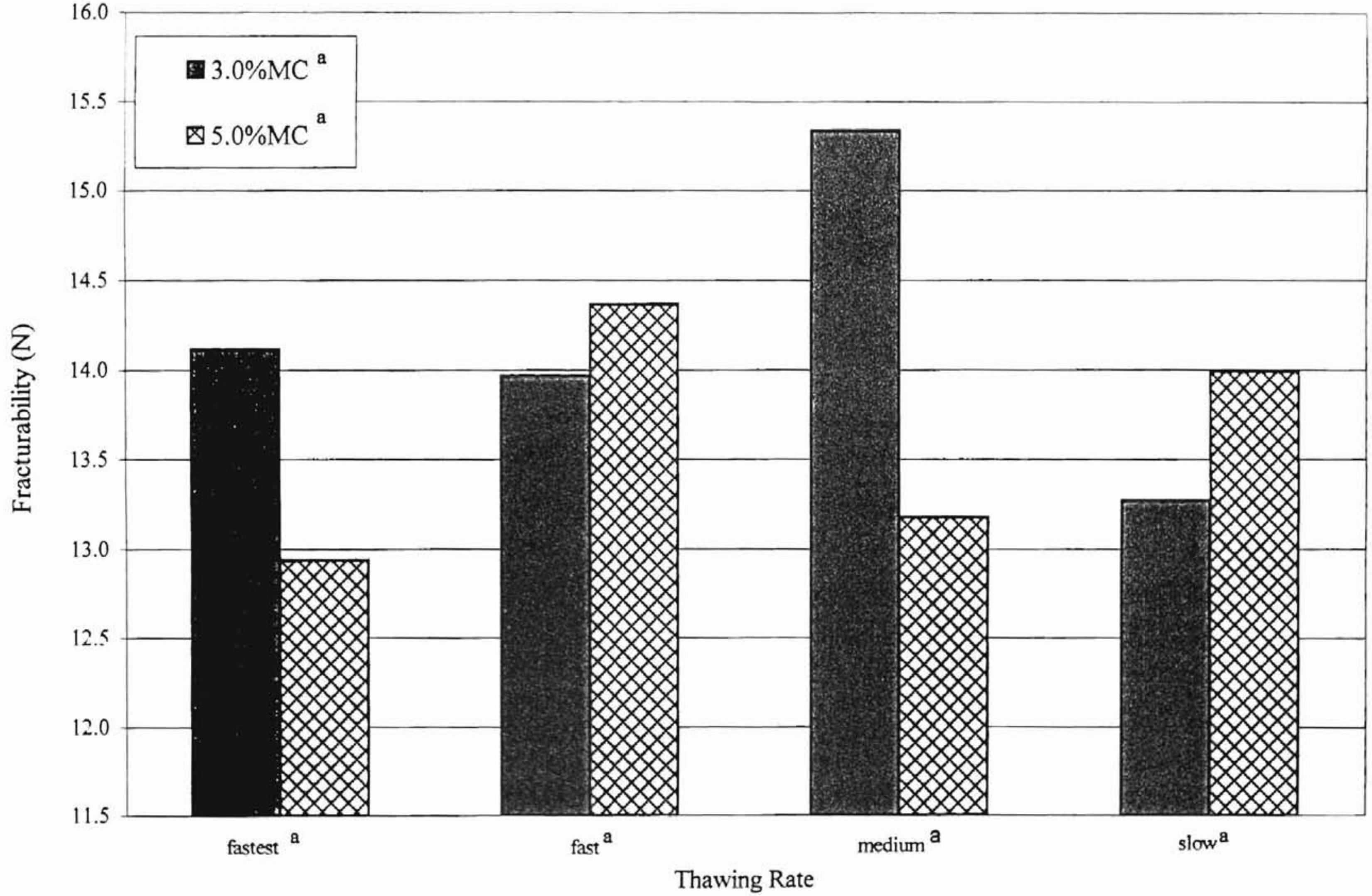

Figure 4. Instrumental TPA fracturability versus thawing rate for experiment 1.

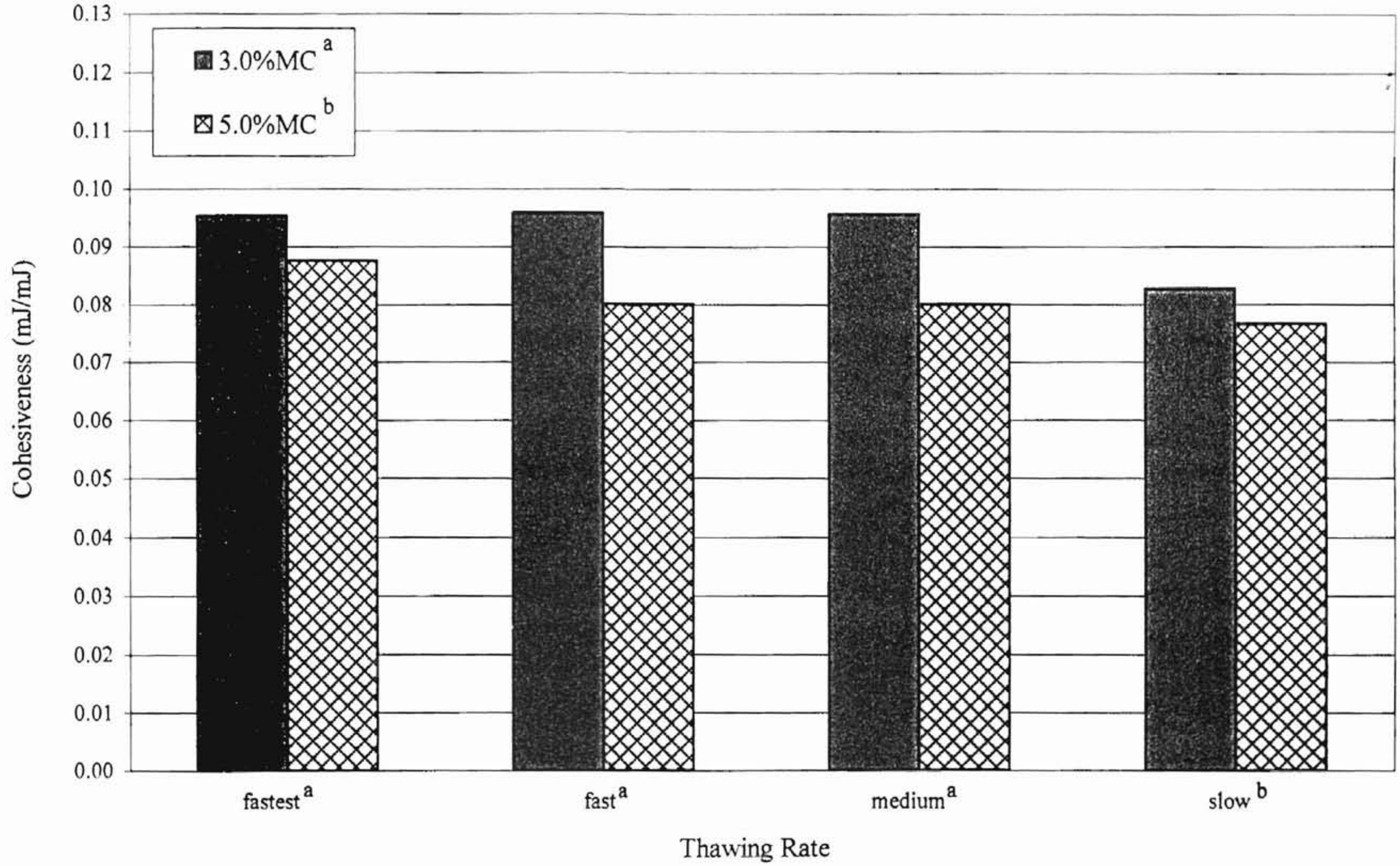

Figure 5. Instrumental TPA cohesiveness versus thawing rate for experiment 1.

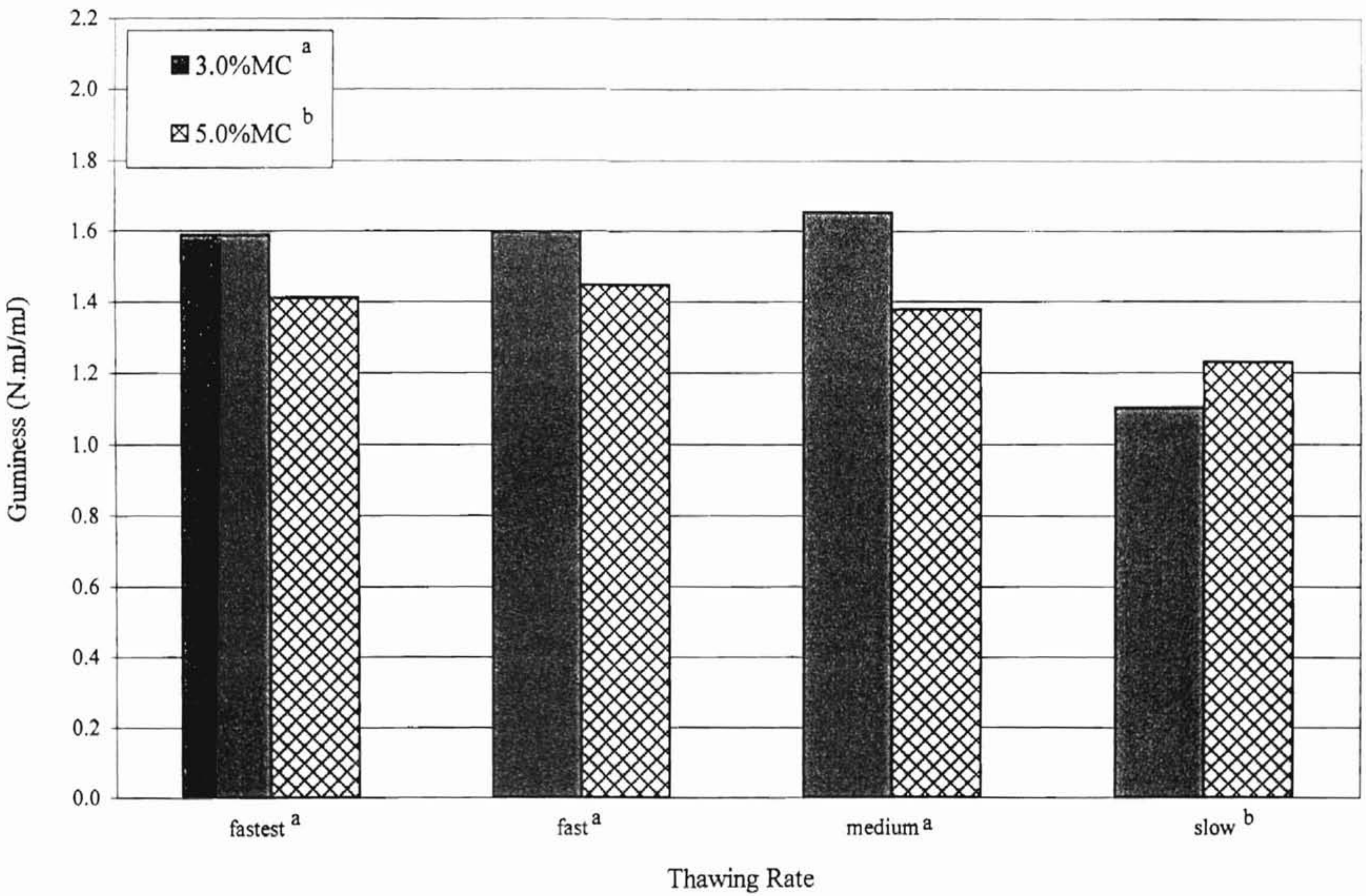

Figure 6. Instrumental TPA gumminess versus thawing rate for experment 1.

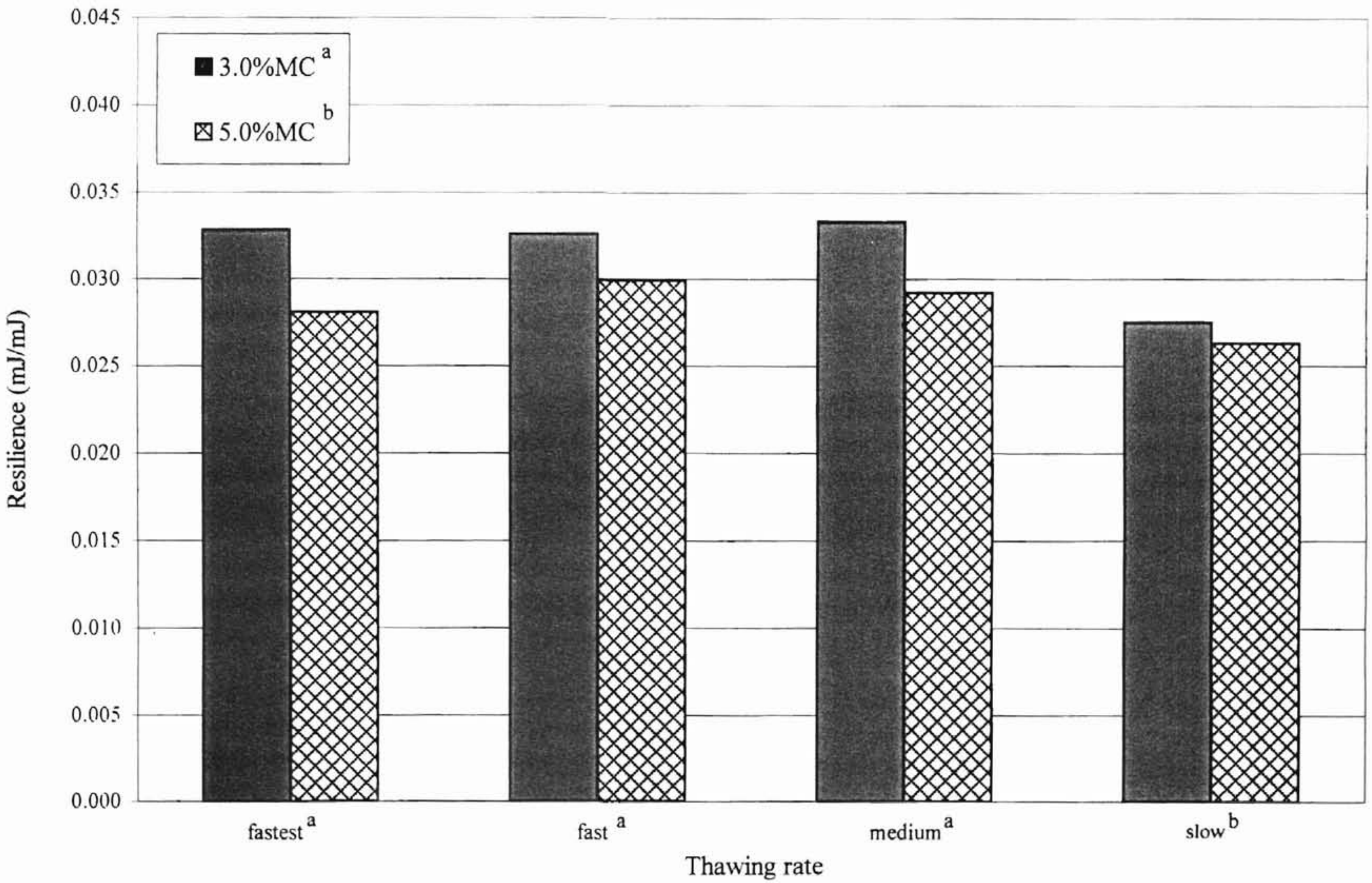

Figure 7. Instrumental TPA resilence versus thawing rate for experiment 1.

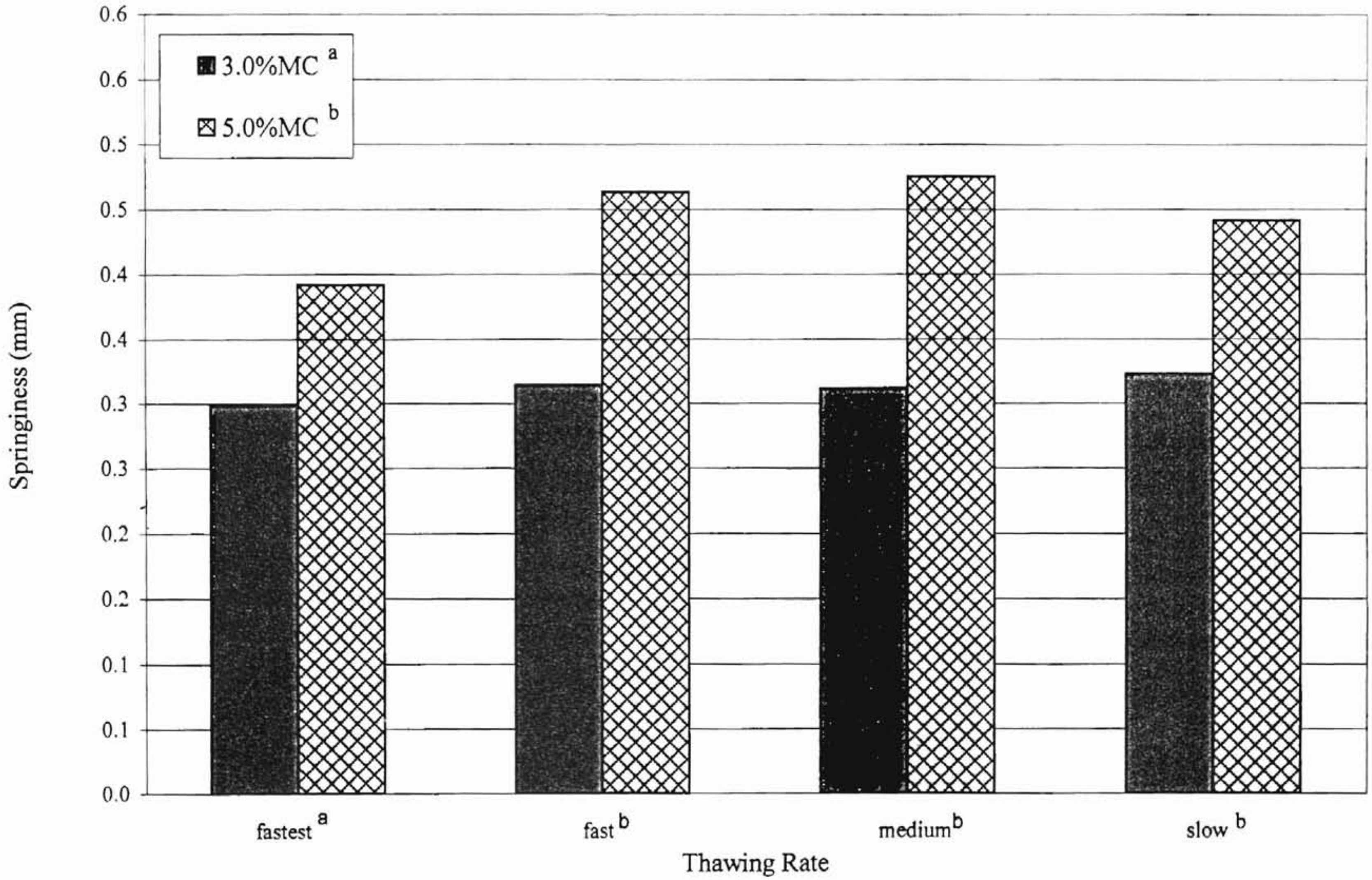

Figure 8. Instrumental TPA springiness versus thawing rate for experiment 1.

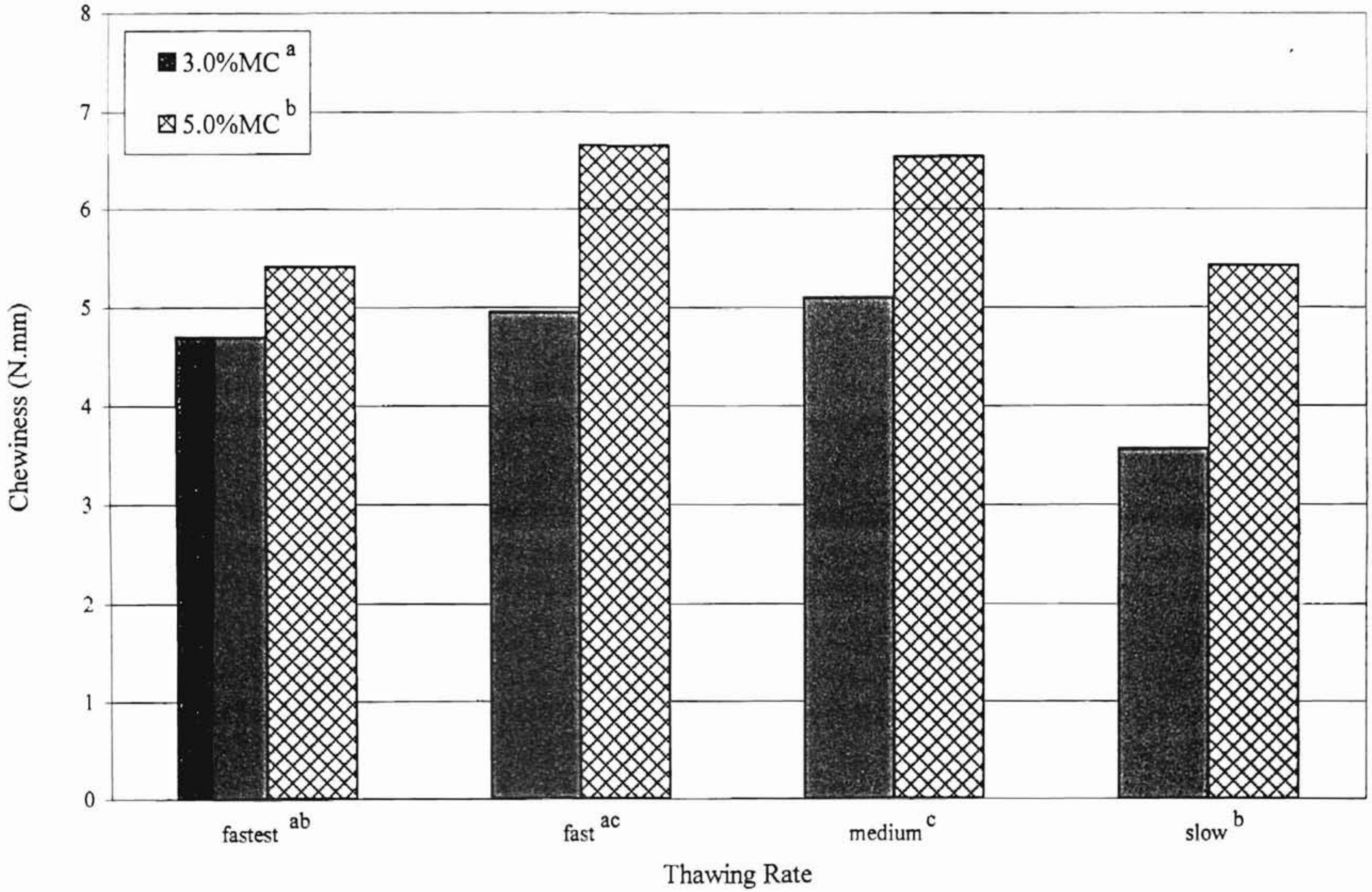

Figure 9. Instrumental TPA chewiness versus thawing rate for experiment 1.

thawing rate on some of the texture parameters.

The standard deviations and coefficients of variability (C.V.) for all of the TPA parameters are shown in Appendix B. For hardness, fracturability, cohesiveness, resilience and springiness, the C.V.'s range from 8.5 to 23%. The C.V.'s for gumminess and chewiness are higher, ranging from 16 to 36%. An explanation for this is that these two TPA parameters are computed by using one of the other five, which use measured data.

Experiment 2

The means for the TPA parameters for experiment 2 are shown in Table IV. A comparison of experiments 1 and 2 are presented in Table V for the same treatments. The results for parameters hardness, fracturability, and cohesiveness for experiments 1 and 2 are very similar, with differences ranging from 0.67 to 22.78%. This means that these three parameters are consistent because the pecans that were used in experiments 1 and 2 were harvested in different years. Chewiness has the highest % difference among the other parameters, which is as high as 68.61%. This could be caused by the computation used to get this parameter, as explained in the previous section. For gumminess, resilience, and springiness, the differences ranged from 7.3 to 57.5%.

The means for sensory evaluation parameters are shown in Table VI. It is clear that the two moisture contents affected the texture parameters significantly. However, the sensory panelists could not detect any differences between the fastest and slow thawing rate (Figures 11, 13, and 15). Refer to Appendix C for the results for the other parameters.

Table IV. Means of TPA parameters for experiment 2 (n=20).

Initial MC (%)	Thawing Rate	Time to thaw -15°C to15°C (min)	TPA Parameters						
			Hardness (N)	Fracturability (N)	Cohesiveness (mJ/mJ)	Gumminess (N.mJ/mJ)	Resilience (mJ/mJ)	Springiness (mm)	Chewiness (N.mm)
3.0	Control*	0	21.49	15.95	0.0652	1.686	0.0254	0.364	0.625
	Fastest	29	23.14	16.79	0.0983	1.845	0.0478	0.351	0.661
	Slow	162	20.49	15.43	0.0677	1.655	0.0332	0.383	0.634
5.0	Control*	0	19.98	14.70	0.0833	1.645	0.0311	0.247	0.415
	Fastest	29	20.71	13.89	0.0774	1.636	0.0355	0.219	0.361
	Slow	162	19.50	13.80	0.0684	1.556	0.0283	0.244	0.385

*Control = never frozen pecans

Table V. Comparisons of means of TPA parameters from experiments 1 and 2.

Moisture Content (%)	Thawing Rate	Experiment	TPA Parameters						
			Hardness (N)	Fracturability (N)	Cohesiveness (mJ/mJ)	Gumminess (N.mJ/mJ)	Resilience (mJ/mJ)	Springiness (mm)	Chewiness (N.mm)
3.0	Fastest	1	21.26	14.11	0.0953	1.588	0.0329	0.299	0.469
		2	23.14	16.79	0.0983	1.845	0.0478	0.351	0.661
		% difference	8.47	17.35	3.10	14.97	36.93	16.00	33.98
3.0	Slow	1	17.56	13.27	0.0827	1.101	0.0275	0.323	0.356
		2	20.49	15.43	0.0677	1.655	0.0332	0.383	0.634
		% difference	15.40	15.05	19.95	40.20	18.78	17.00	56.16
5.0	Fastest	1	19.81	12.94	0.0973	1.411	0.0283	0.392	0.738
		2	20.71	13.89	0.0774	1.636	0.0355	0.219	0.361
		% difference	4.44	7.08	22.78	14.77	22.57	56.63	68.61
5.0	Slow	1	19.37	13.99	0.0769	1.230	0.0263	0.441	0.542
		2	19.50	13.80	0.0684	1.556	0.0283	0.244	0.385
		% difference	0.67	1.37	11.70	23.40	7.33	57.52	33.87

Table VI. Means of sensory parameters for experiment 2 with a scale from 0.0 to 15.0 (n=24).

Initial MC (%)	Thawing Rate	Time to thaw -15°C to15°C (min)	Sensory Parameters			
			Hardness	Fracturability	Cohesiveness	Denseness
3.0	Control	0	6.708	5.500	6.708	7.033
	Fastest	29	6.750	5.471	3.646	7.000
	Slow	162	6.771	5.221	3.458	6.908
5.0	Control	0	7.808	3.375	7.808	8.125
	Fastest	29	7.758	3.542	6.304	8.117
	Slow	162	7.746	3.417	6.471	8.133

For both TPA and sensory texture measurements, the initial moisture content before freezing again had significant effect on the texture parameters but thawing rate did not (Figures 10,12, and 14). This confirmed the results from the first experiment.

Fracturability had the best similarity between TPA and sensory evaluation (Figures 12 and 13). They both showed that the treatments with lower initial moisture content have higher fracturability values, which means that they are more brittle. As for thawing rates, the slow rate had the lowest fracturability compared to the control and fastest rate. Hardness and cohesiveness are different from each other (Figures 10, 11, 14 and 15), by both TPA and sensory evaluation. For TPA, 3.0% MC is harder and more cohesive than 5.0%MC but the opposite trend occurs in sensory evaluation. There are a few possible explanations for this. The two methods have different definitions of texture terms. For example, the sensory panelists measure the pecan's hardness as toughness and the instrument measured hardness as maximum force. A second possible explanation is that the two methods use different kernel orientation during measurement. A sample for TPA is placed vertically on the flat plate while the panelists for sensory evaluation bite the kernels horizontally with their molars. Another possible cause of different results is the difference of physical characteristics of the samples. For instrumental TPA measurement, the sample is cut out of the interior of the pecan's meat without the skin as contrasted to sensory evaluation where the panelists bite through the skin and meat of the entire intact pecan kernel.

From the statistical analysis of the TPA results, the moisture content strongly affected the texture parameters ($p<0.001$) except for cohesiveness ($p=0.829$) and gumminess ($p=0.073$).

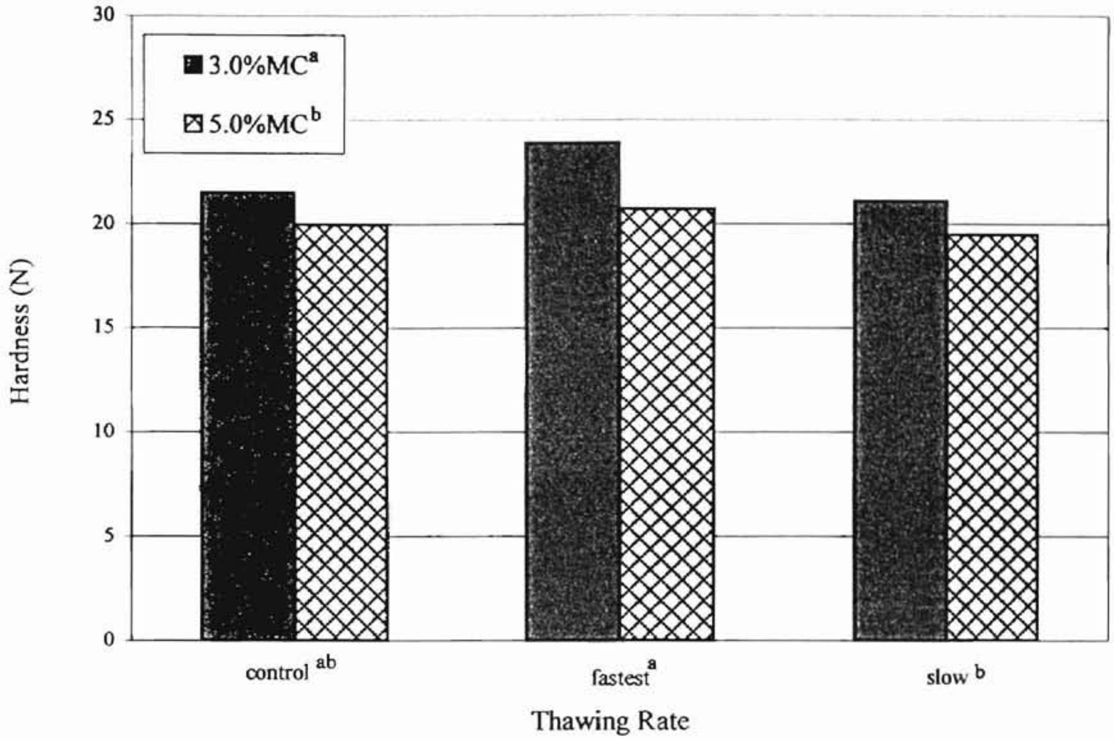

Figure 10. Instrumental TPA hardness versus thawing rate for experiment 2.

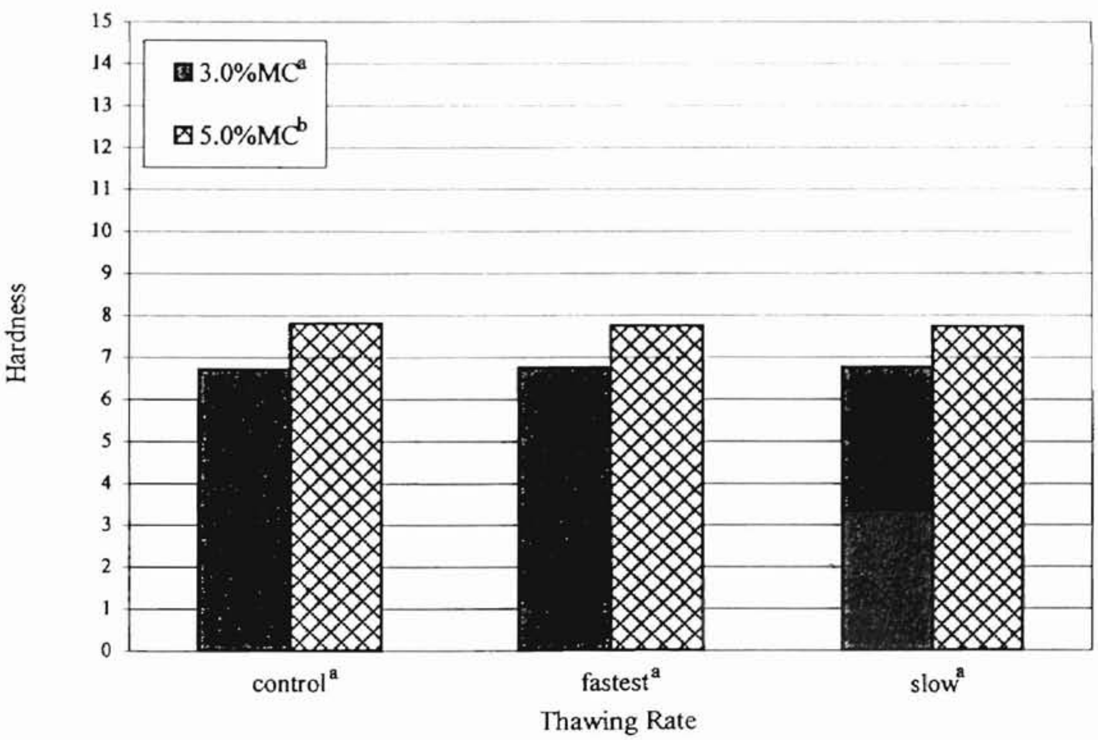

Figure 11. Sensory evaluation hardness versus thawing rate for experiment 2.

[ab] Treatments with different letters are significantly different (α=0.05).

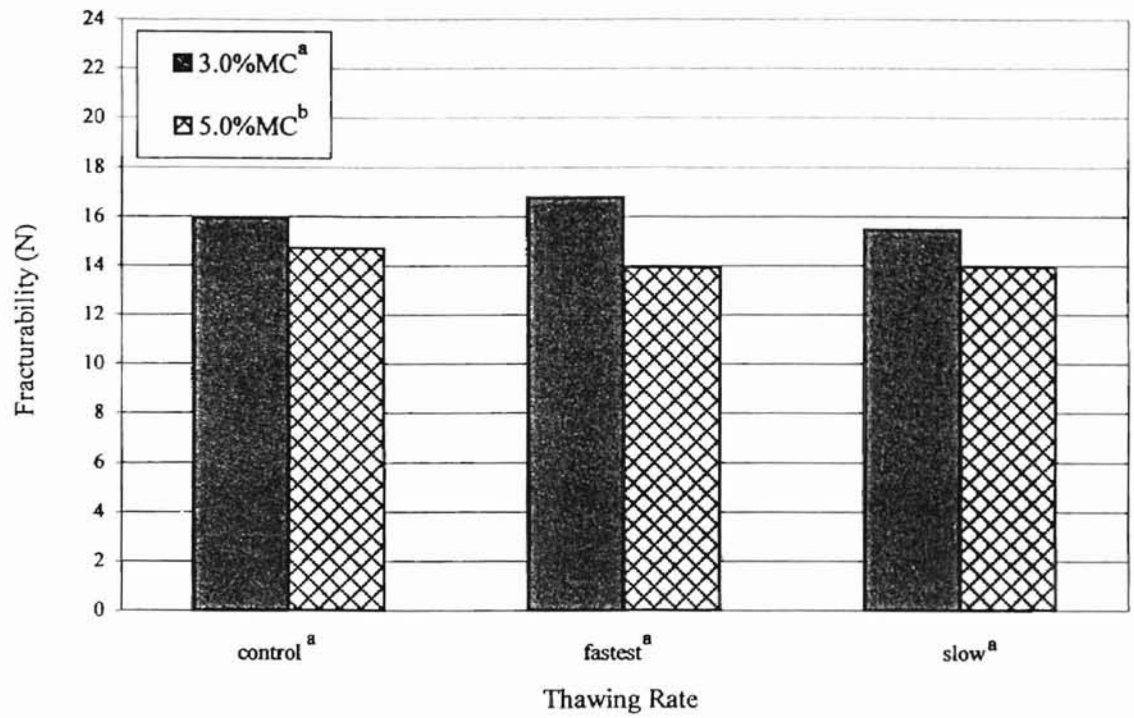

Figure 12. Instrumental TPA fracturability versus thawing rate for experiment 2.

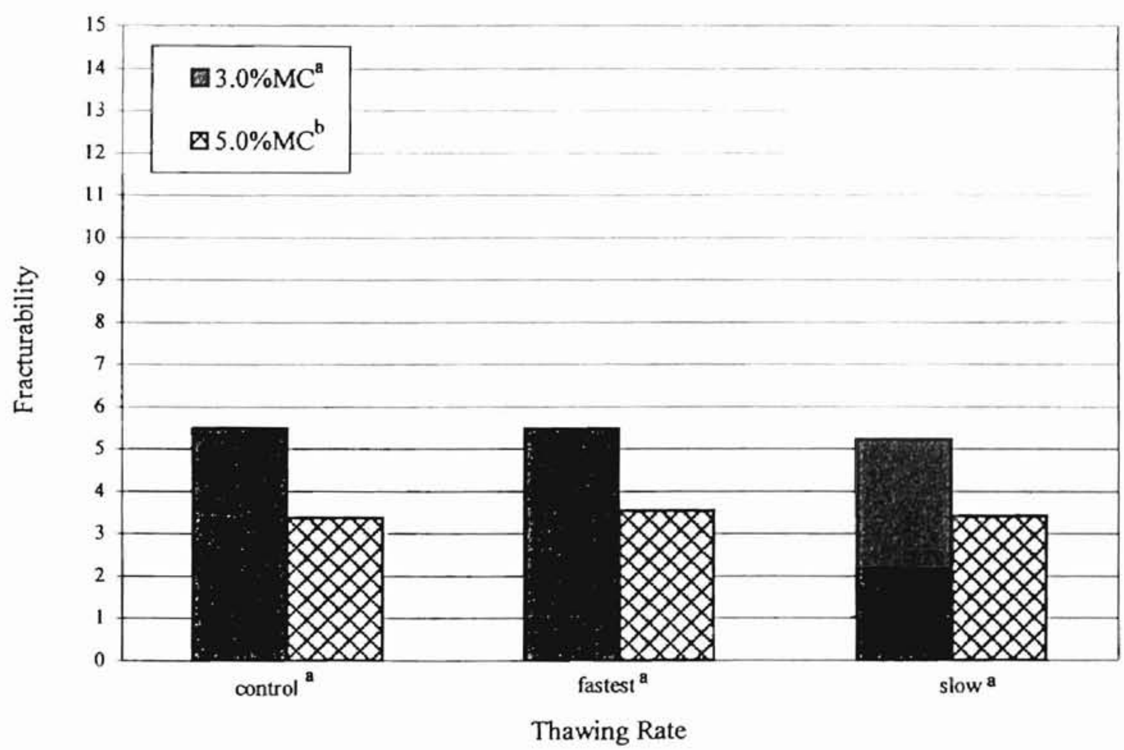

Figure 13. Sensory evaluation fracturability versus thawing rate for experiment 2.

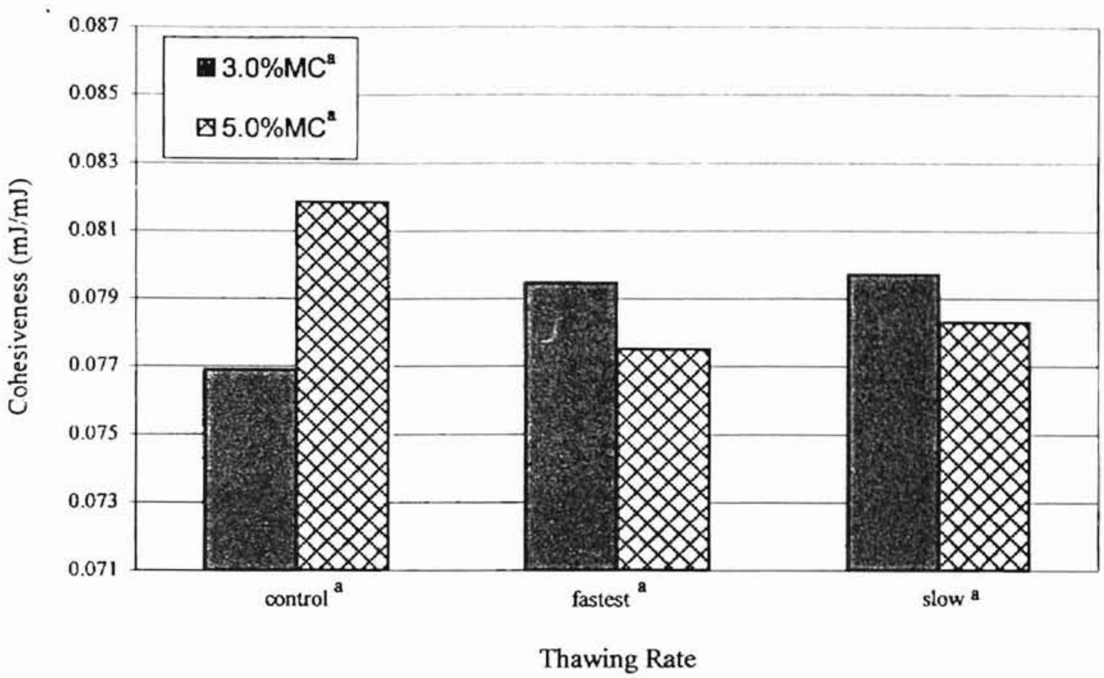

Figure 14. Instrumental TPA cohesiveness versus thawing rate for experiment 2.

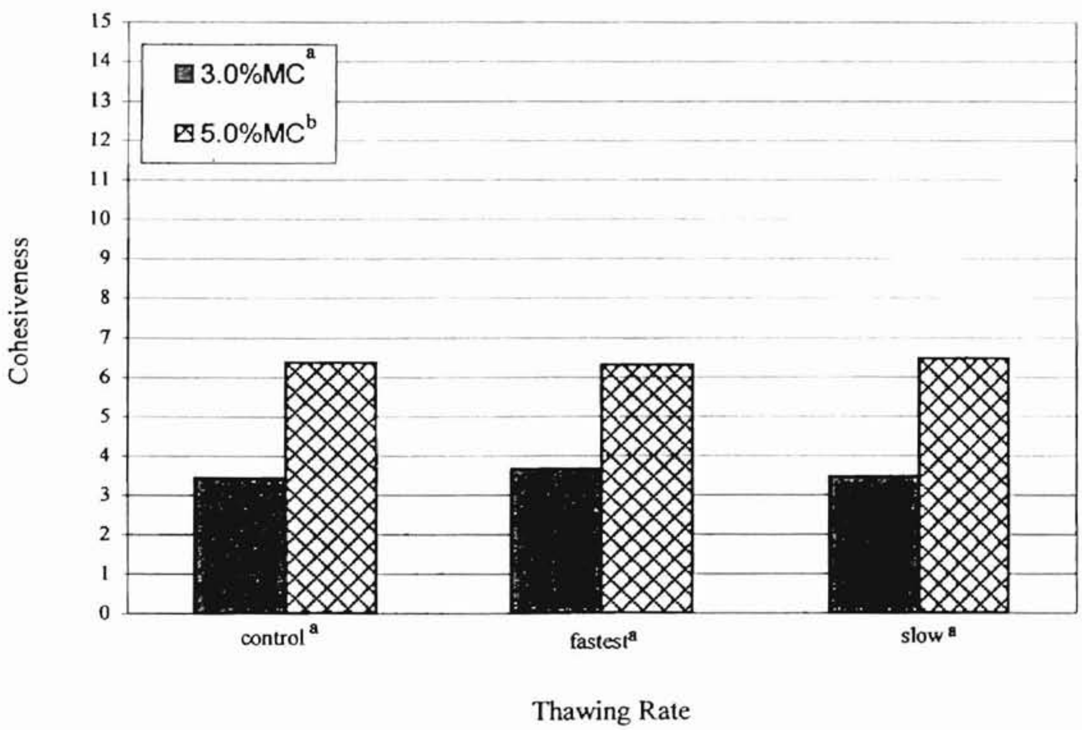

Figure 15. Sensory evaluation cohesiveness versus thawing rate for experiment 2.

The thawing rate only showed differences for hardness ($p=0.048$), springiness ($p=0.013$), and resilience ($p=0.009$) and for the other parameters, there was no significant difference ($p>0.05$). For the sensory evaluation, the results show very significant difference for all of the TPA parameters for both moisture contents ($p<0.0001$) but there is no difference between frozen/thawed and never frozen/thawed pecans with p value almost equal to 1.0. Just like experiment 1, the results for this second experiment also showed that there is no interaction among the moisture content and the thawing rate for both TPA and sensory evaluation ($p>0.05$).

Appendices C.1 through C.6 show that the C.V.'s for instrumental TPA hardness, fracturability, and springiness are low (<23%). Cohesiveness and resilience have the highest C.V. among all of the parameters, the values ranging from 95% to 148%, except for the ones for control at 5.0% MC, which are 13 and 14%, for cohesiveness and resilience, respectively. For sensory evaluation, the C.V.'s are very low (< 26.40%), which means that the sensory panelists were consistent with their ranking.

There are several factors that can be considered in comparing instrumental TPA to sensory texture evaluation. TPA requires only a small number of kernels, takes only a small amount of time to run the test, and the computer can process the data simultaneously for all parameters with low operating cost and more precise data (up to five digits). The disadvantages are that it requires uniformity of samples and since pecan kernels have irregular shape, it can be difficult and time consuming to get uniformly shaped samples. Sensory evaluation requires a larger number of pecans, takes a few hours to get data for a limited number of parameters, costs a considerable amount of money and the panelists can only provide data with up to two digits of precision. Another disadvantage of sensory evaluation is that the panelists have to be trained and it can take months before they can really do valuable evaluation. The advantages are the samples do not have to be cut into uniform shape so there is less time needed to prepare the samples. In general for measurement of texture, instrumental TPA is more efficient and provides better results than sensory evaluation.

Regression analysis was performed by Minitab release 12 to fit the data to the following model:

$$Y = c_1 + c_2 MC + c_3 TR \qquad (1)$$

Where: Y is the response variable (texture parameter); c_1, c_2, and c_3 are the regression coefficients; MC is the initial moisture content (%) before freezing; and TR is the thawing rate (time to thaw, minute). For fracturability, the regression models are as follows:

$$\text{Fracturability}_{TPA} = 19.06 - 1.13MC + 0.00474TR \qquad (2)$$

$$\text{Fracturability}_{SE} = 8.28 - 0.93MC - 0.00141TR \qquad (3)$$

Where: TPA is instrumental TPA and SE is sensory evaluation. When the values of 3.0% moisture content and fastest thawing rate (29 minutes) were substituted into Equation 2 and 3, the regression models become:

$$\text{Fracturability}_{TPA} = 19.06 - 3.39 + 0.14 = 15.81 \text{ N} \qquad (4)$$

$$\text{Fracturability}_{SE} = 8.28 - 2.80 + 0.04 = 5.52 \qquad (5)$$

From Equations 4 and 5, moisture content (second term) contributes a higher number to the value of fracturability than thawing rate (third term). This confirmed the statistical analysis results above that moisture content had greater effect on pecan's texture than thawing rate. The regression coefficients for other parameters for both TPA and sensory evaluation are available in Tables VII and VIII. These coefficients are suitable to predict the values of the seven texture parameters if the pecans have 3.0 to 5.0% MC and it takes 29 to 162 minutes to thaw the frozen kernels. Sensory parameters fit the model with r^2 ranging from 0.44 to 0.79 and TPA fracturability, springiness, and chewiness fit the model with r^2 ranging from 0.002 to 0.63.

The results of first and second experiments showed that it is better to store the pecans at low moisture content to keep it fresh, free from fungi or insects, and to preserve the desired texture. However, too low of moisture content can cause the pecan kernels to break easily; Heaton and Woodroof (1965) suggest the optimum moisture content is 4.0-4.5%. For thawing pecans slowly, as usually done commercially, texture is affected more than at faster rates. If pecans have low moisture content, thawing rate makes no difference, while if moisture content is higher, i.e. 5.0%, then the pecans should be thawed at medium to fast rates to maintain good texture. Thawing rate is less important compared to freezing rate as mentioned by Anzaldua-Morales et al., 1999.

Experiment 3

The analysis of variance showed very significant differences for all of the parameters for moisture ($p \leq 0.0001$) and for most of the parameters for the number of freeze/thaw cycles, except for cohesiveness ($p=0.0836$) and resilience ($p=0.118$). There were also interactions between moisture content and freeze/thaw cycles for hardness

Table VII. Regression coefficients for TPA parameters (Y) as a function of initial moisture content before freezing (MC) and thawing rate (TR)* for experiment 2.

TPA Parameter	c_1	c_2	c_3	r^2
Hardness	23.86	-0.8560	0.005410	0.053
Fracturability	19.06	-1.1300	0.004740	0.215
Cohesiveness	0.08	-0.0002	-0.000007	0.002
Gumminess	1.94	-0.0768	0.000412	0.023
Resilience	0.04	-0.0014	0.000001	0.043
Springiness	0.57	-0.0681	-0.000026	0.633
Chewiness	1.04	-0.1370	0.000190	0.315

*Mathematical model: $Y = c_1 + c_2MC + c_3TR$

Table VIII. Regression coefficients for sensory parameters (Y) as a function of initial moisture content before freezing (MC) and thawing rate (TR)* for experiment 2.

Sensory Parameter	c_1	c_2	c_3	r^2
Hardness	5.27	0.4958	0.000031	0.490
Fracturability	8.28	-0.9333	-0.001409	0.753
Cohesiveness	-0.69	1.4177	-0.000078	0.789
Denseness	5.22	0.5854	-0.000282	0.444

*Mathematical model: $Y = c_1 + c_2MC + c_3TR$

(p=0.0257), cohesiveness (p=0.001), gumminess (p=0.0292), resilience (p=0.0036), and springiness (p=0.0317). The results from the third experiment showed that multiple freeze/thaw cycling affected the texture parameters, especially the pecans with higher moisture content.

The means for the seven TPA parameters are shown in Table IX, which shows that gumminess and chewiness have greater changes between the cycles. At the lower moisture content, there were more changes for hardness, fracturability, gumminess, and chewiness between cycles 1 and 3. However at 5.0% MC, hardness, fracturability, and springiness have the greater changes between cycles 9 and 12.

TPA parameters hardness, fracturability and cohesiveness were plotted against number of freeze/thaw cycles (Figures 16, 17, and 18). These plots show similar trends, where the slopes have negative values for all three parameters except for cohesiveness at 3.0% MC. For hardness and fracturability, the slopes for 5.0% MC are steeper than the ones at 3.0%, which means that the multiple freeze/thaw cycles have more effect on the pecans at higher moisture content. The data show that all the TPA parameters decrease as the freeze/thaw cycle increases and that values for 3.0% MC were higher that the ones for 5.0% MC.

The data for this third experiment are presented in Appendix D. The coefficients of variability were less than 20% for hardness, fracturability, and springiness at 3.0% MC. The C.V. for chewiness for all cycles at 3.0% MC has the highest values, ranging from 34 to 49%. For 5.0%MC pecans, the C.V. of hardness, fracturability, cohesiveness, and resilience for 3, 6, and 9 cycles are lower than 20%.

Table IX. Means of TPA parameters for experiment 3 (n=20).

Initial MC (%)	Freeze/Thaw Cycle (#)	TPA Parameters Hardness (N)	Fracturability (N)	Cohesiveness (mJ/mJ)	Gumminess (N.mJ/mJ)	Resilience (mJ/mJ)	Springiness (mm)	Chewiness (N.mm)
3.0	0	21.49	15.95	0.0652	1.686	0.0254	0.364	0.625
	1	20.49	15.43	0.0677	1.655	0.0332	0.383	0.634
	3	21.54	17.76	0.0769	1.255	0.0345	0.346	0.440
	6	21.15	17.62	0.0851	1.487	0.0350	0.322	0.482
	9	20.24	15.66	0.0831	1.324	0.0341	0.366	0.487
	12	19.85	14.84	0.0375	1.241	0.0375	0.319	0.404
5.0	0	19.98	14.70	0.0833	1.645	0.0311	0.247	0.415
	1	19.50	13.80	0.0684	1.556	0.0283	0.244	0.385
	3	18.99	16.52	0.0731	1.142	0.0320	0.218	0.246
	6	18.04	15.43	0.0694	1.035	0.0305	0.196	0.203
	9	16.55	13.96	0.0668	0.888	0.0247	0.213	0.192
	12	14.99	11.14	0.0649	0.782	0.0257	0.254	0.194

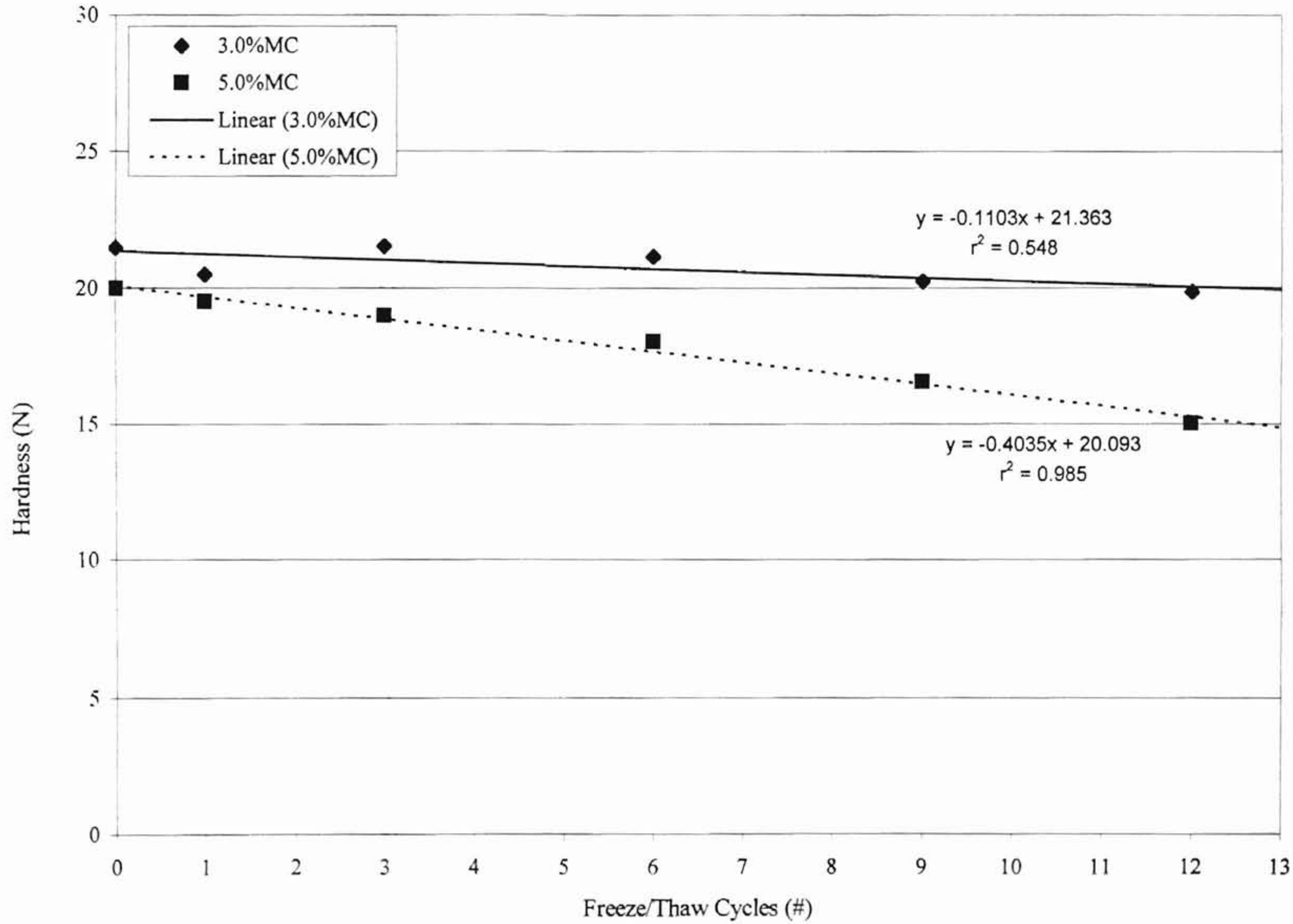

Figure 16. TPA hardness versus number of freeze/thaw cycles at slow thawing rate for experiment 3.

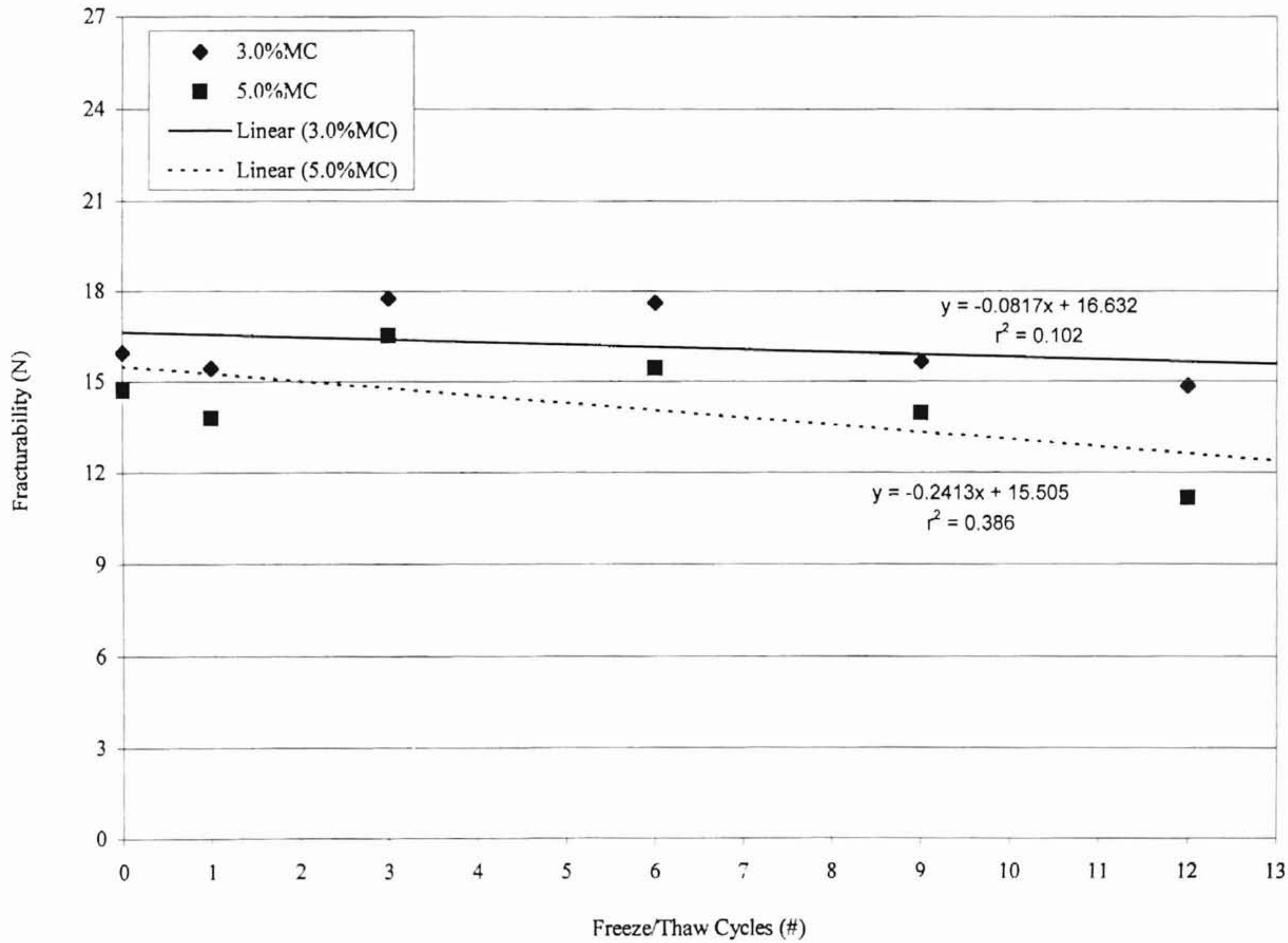

Figure 17.TPA fracturability versus number of freeze/thaw cycles at slow thawing rate for experiment 3.

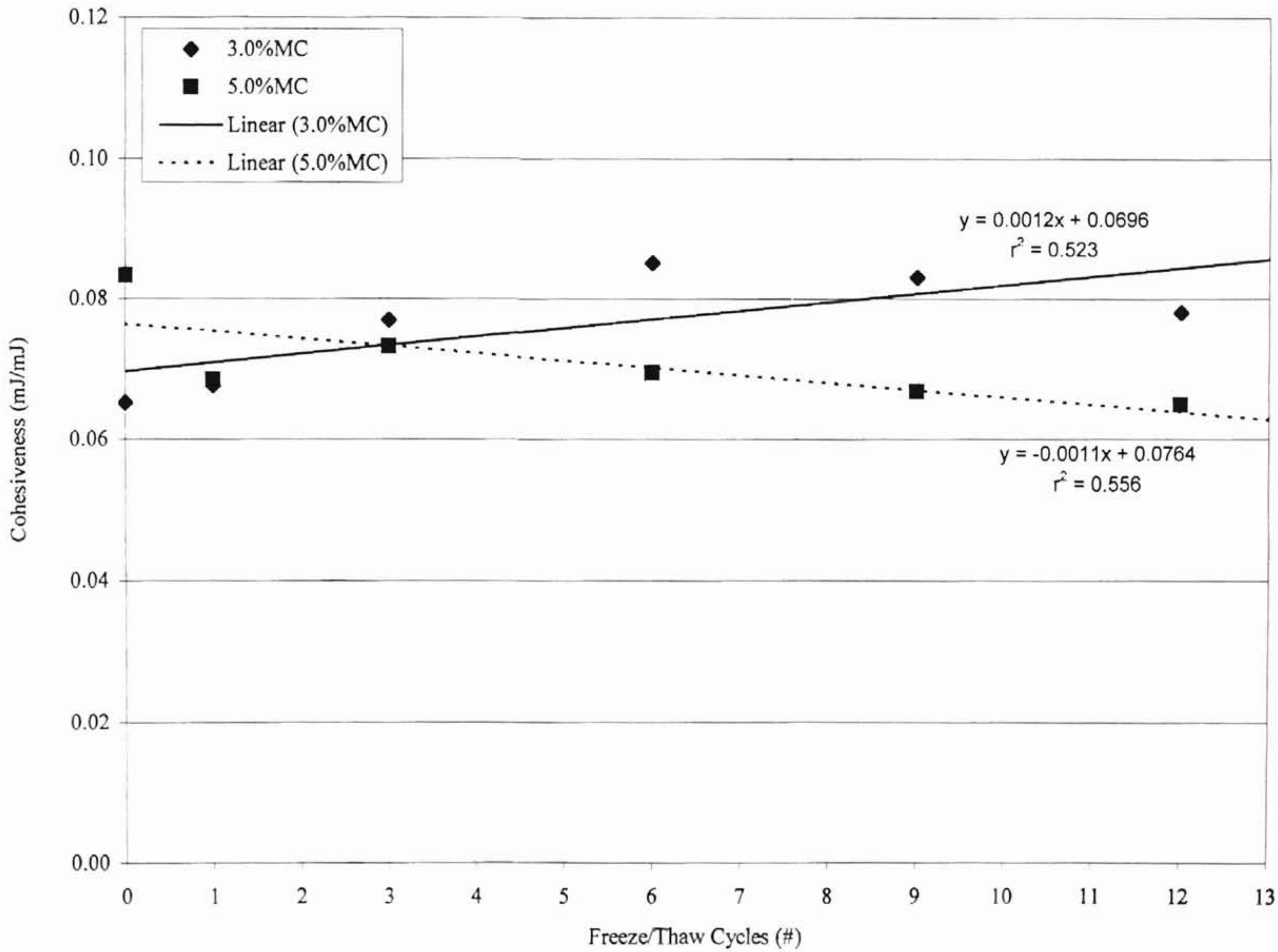

Figure 18. TPA cohesiveness versus number of freeze/thaw cycles at slow thawing rate for experiment 3

Gumminess and chewiness had highest C.V.'s ranging from 16 to 39%. However, for 12 freeze/thaw cycles, springiness had the highest C.V. (51%) among all other parameters.

CHAPTER V

CONCLUSIONS

This study was conducted to obtain further information on how to better preserve pecan's texture as affected by initial moisture content before freezing and the rate of thawing. Texture parameters were measured by two methods, instrumental TPA and sensory evaluation. The conclusions that can be drawn are as follows:

1. Initial moisture content before freezing has significant effect on all of the sensory evaluation parameters and most of the instrumental TPA texture parameters (hardness, fracturability, springiness, resilence, and chewiness) with $p \leq 0.001$.
2. Thawing rate has only minor effect on pecan texture; the only instrumental TPA parameters that were affected were hardness ($p=0.048$), springiness ($p=0.013$), and resilence ($p=0.009$). The sensory panel could not detect any differences between the thawing rate treatments.
3. The slowest thawing rate affects more texture parameters than the medium and faster thawing rates.
4. Equations were developed to explain texture parameters as a function of moisture content and thawing rate. TPA fracturability, springiness, and chewiness fit a linear equation with r^2 ranging from 0.002 to 0.63 and all of the sensory parameters, hardness, fracturability, cohesiveness, and denseness, fit the model with r^2 ranging from 0.44 to 0.79.

5. Multiple freeze/thaw cycles affect pecan texture significantly ($p \leq 0.001$), especially for pecans at higher moisture content. The change is a non-linear decrease with number of cycles.
6. Instrumental TPA is better, more efficient and has greater sensitivity than sensory evaluation of pecan texture. Sensory fracturability correlates best with TPA fracturability.
7. TPA hardness and fracturability have lower coefficients of variability (<23%) than the other parameters (cohesiveness, gumminess, springiness, resilence, and chewiness). The other five parameters have medium to high coefficients of variability (up to 148%). All of the sensory parameters have coefficients of variability below 26.4%.

CHAPTER VI

RECOMMENDATIONS FOR FUTURE STUDIES

This study found that initial moisture content before freezing has a great effect on the pecan's texture. Since there were only two moisture contents used in this experiment, further research can be done with more moisture contents between 3.0-5.0% because that is the optimum range for good quality pecans.

Another recommendation is to study the reduced oil pecan's texture since all of the kernels used in this study were full oil. The oil extraction can be done either before or after freezing and thawing. Then experiments could be conducted to determine if freezing or thawing has any effect on the texture of the kernels that have less oil.

Pecans sold in the market are often in the shells and this research only used pecans that had been shelled. So, further studies could be conducted on un-shelled pecans after freezing, storing, and thawing.

REFERENCES

Anonymous. 1964. Exciting breakthrough: freezing sliced tomatoes. Food Engineering. 36(1): 56-57.

Anzaldua-Morales, A., G.H. Brusewitz, and J.A. Anderson. 1999. Pecan texture as affected by freezing rates, storage temperature, and thawing rates. Journal of Food Science. 64(2): 332-335.

ASAE Standard. 1997. Moisture measurement – peanuts. S410.1. pp. 576-586.

Beaudry, R.M., J.A. Payne, and J.J. Kays. 1985. Variation in the respiration of harvested pecans due to genotype and kernel moisture level. HortScience. 20(4): 752-754.

Beuchat, L.R. 1978. Relationship of water activity to moisture content in tree nuts. Journal of Food Science. 48(3): 754-755.

Beuchat, L.R. and E.K. Heaton. 1980. Factors influencing fungal quality of pecan stored at refrigeration temperatures. Journal of Food Science. 45(1): 251-254.

Bourne, M.C. 1978. Texture Profile Analysis. Food Technology. 32(7): 62-72.

Bourne, M.C. 1982. Food texture and viscosity: concept and measurement. Academic Press, Inc. New York.

Brennan, J.G., J.R. Butters, N.D. Cowell, and A.E.V. Lilly. 1976. Food Engineering Operations. 2nd ed. Applied Science Publishers, Ltd. London.

Brison, F.R. 1974. Pecan Culture. Capital printing. Austin, Texas. pp 193-202.

Florkowski, W.J. and E E. Hubbard. 1994. Structure and the performance of pecan market. In Santere, C.R. (Ed.), Pecan Technology. New York: Chapman & Hall. pp. 134-150.

Forbus, W.R. and S.D. Senter. 1976. Conditioning pecans with steam to improve shelling efficiency and storage stability. Journal of Food Science. 41(4): 794-798.

Fennema, O.R., W.D. Powrie, and E.H. Morth. 1973. Low-temperature preservation of foods and living matter. Marcel Dekker, Inc. New York.

Friedman, H.H., J.E. Whitney, and A.S. Szczesniak. 1963. The texturometer, a new instrument for objective texture measurement. Journal of Food Science. 28(4): 390-396.

Garrett, D.E. and G.P. Rossenbaum. 1958. For your next purification: crystallization. Chemical Engineering. 65(16): 125-140.

Grolier, 1983. New Grolier Multimedia Encyclopedia, Release 6, Version 6.03. Grolier Inc. Danbury, CT.

Guadogni, D.G. 1969. Quality and stability in frozen fruits and juices. In Van Arsdel, W.B., M.J. Copley, and R.L. Olson (Ed.), Quality ad stability of frozen foods, time-temperature tolerance and its significance. New York: John Wiley & Sons. pp. 85-116.

Heaton, E.K. and A.L. Shewfelt. 1976. Pecan quality effect of light exposure on pecan kernel color and flavor. Lebensm. –Wiss. U. –Technol. 9: 201-206.

Heaton, E.K., A.L. Shewfelt, A.E. Bodenhop, and L.R. Beuchat. 1977. Pecans: handling, storage, processing and utilization. University of Georgia, Agricultural Experiment Station. Research Bulletin. 197:79.

Heaton, E.K. and J.G. Woodroof. 1961. Pecans for processing. University of Georgia, Agricultural Experiment Station. Research Bulletin. 80:77.

Heaton E.K. and J.G. Woodroof. 1965. Importance of proper drying of pecans. Southeast Pecan Growers Association. 58: 119-129.

Heaton E.K. and J.G. Woodroof. 1967. Controlling quality in pecans. Pecan Journal of Nut World. 46:30.

Jansen, E.F. 1969. Quality-related chemical and physical changes in frozen foods. In Van Arsdel, W.B., M.J. Copley, and R.L. Olson (Ed.), Quality and stability of frozen foods, time-temperature tolerance and its significance. New York: John Wiley & Sons. pp. 19-42.

Kays, S.J.1982. Storage of pecan kernels under wholesale and retail conditions. In Richardson, D.G. and M. Meheriuk (Ed.), Controlled atmospheres for storage and transport of perishable agricultural commodities. Oregon: Timber Press. pp. 367.

Kays, S.J. 1987. Pecan quality as affected by pre-, post harvest handling, storage and marketing conditions (Part 2). Pecan South. 21(2) 22-26.

Kramer, A. 1973. Food Texture – definition, measurement and relation to other food quality attributes. In Kramer A. and A.S. Szczesnick (ed.), Texture measurement of foods. Dordrecht, Netherlands: Reidel Publ. pp. 1-9.

Li, M., D.D. Bellmer, and G.H. Brusewitz. 1999. Pecan kernel breakage and oil extracted by supercritical CO2 as affected by moisture content. Journal of Food Science. 64(6): 1084-1088.

Meullenet, J-F.C., J.A. Carpenter, B.G. Lyon, and C.E. Lyon. 1998. Relationship between sensory and instrumental texture profile attributes. Journal of Sensory Studies. 13(1): 77-93.

Meullenet, J-F.C. and J. Gross. 1999. Instrumental single and double compression tests to predict sensory texture characteristics of foods. Journal of Texture Studies. 30(2): 167-180.

Ocon, A., A. Anzaldua-Morales, A. Quintero, and G. Gastelum. 1995. Texture of pecans measured by sensory and instrumental means. Journal of Food Science. 60(6): 1333-1336.

Olson, R.L. and W.C. Dietrich. 1968. Vegetables: characteristics and the stability of the frozen product. In Tressler, D.K., W.B. Van Arsdel and M.J. Copley (Ed.), The freezing preservation of foods. 4th ed. Vol.2. Connecticut: Avi Pub. Co. pp. 83-106.

Santerre, C.R. 1994. Pecan Technology. Chapman & Hall, Inc. New York.

Schur, S. 1987. Texture integrity: challenge for research and development. In Moskowitz, H.R. (Ed.), Food texture, instrumental and sensory measurement. New York: Marcel Dekker, Inc. pp. 273-292.

Senter, S.D., W.R. Forbus, JR., S.O. Nelson, R.L. Wilson, JR., and R.J. Horvat. 1984a. Effects of dielectric and steam heating treatments on the storage stability of pecan kernels. Journal of Food Science. 49(3): 893-895.

Senter, S.D., W.R. Forbus, JR., S.O. Nelson, and R.J. Horvat. 1984b. Effects of dielectric and steam heating treatments on the pre-storage and storage color characteristics of pecan kernels. Journal of Food Science. 49(5): 1532-1534.

Shult, M.J and Brusewitz, G.H. 1999. Pecan instrumental texture measurement as affected by oil and moisture contents. Applied Engineering in Agriculture. 14(5):507-512.

Szczesniak, A.S. 1966. Texture measurements. Food Technology. 20(10):1292-1298.

Szczesniak, A.S. 1968. Correlations between objective and sensory texture measurements. Food Technology. 22(8): 981-985.

Szczesniak, A.S. 1987. Correlating sensory with instrumental texture measurements, an overview of recent development. Journal of Texture Studies. 18(1): 1-15.

Szczesniak, A.S. 1990. Texture: is it still an overlooked food attribute? Food Technology. 44(9):86-95.

Szczesniak, A.S., M.A. Brandt, and H.H. Friedman. 1963. Development of standard rating scales for mechanical parameters of texture and correlation between the objective and sensory method of texture evaluation. Journal of Food Science. 28 (4): 397-403.

Thompson, H., S.R. Cecil, and J.G. Woodroof. 1951. Storage of edible peanuts. University of Georgia, Agricultural Experiment Station. Research Bulletin. 268:42.

Truong, D.D., W.M. Walter, Jr., D.D. Hamman. 1997. Relationship between instrumental and sensory parameters of cooked sweetpotato texture. Journal of Texture Studies. 28(2): 163-185.

User Guide. 1995. Texture Expert for Windows. Version1.0. Stable Micro Systems Ltd. England. no. 2.

APPENDIX

APPENDIX A.1

OKLAHOMA STATE UNIVERSITY
INSTITUTIONAL REVIEW BOARD

Date:	January 18, 2000	IRB #:	EG-00-003
Proposal Title:	"SENSORY (TASTE) EVALUATION ON PECAN'S TEXTURE"		
Principal Investigator(s):	Gerald Brusevitz Bernadeth Surjadinata		
Reviewed and Processed as:	Exempt		

Approval Status Recommended by Reviewer(s): Approved

Signature:

Carol Olson, Director of University Research Compliance

January 18, 2000
Date

Approvals are valid for one calendar year, after which time a request for continuation must be submitted. Any modification to the research project approved by the IRB must be submitted for approval with the advisor's signature. The IRB office MUST be notified in writing when a project is complete. Approved projects are subject to monitor by the IRB. Expedited and exempt projects may be reviewed by the full Institutional Review Board.

APPENDIX A.2

Sensory Evaluation Lexicon

Hardness: measure the force required to bite through sample with molars.

Reference: Graham Crackers 4.5, Mario Spanish Queen Olives 6.0, Pringles 7.5, Crunchy Cheetos 8.0, Peanuts 9.5.

Fracturability: measure the force with which the sample breaks or fractures.

Reference: Graham Crackers 4.5, Keebler Cookie Stix 6.0, Plain Melba Toasts 7.0, Pringles 8.5.

Cohesiveness: measure the amount that the sample deforms rather than breaks with one chew using molars.

Reference: Corn Muffin 1.0, Yellow American Cheese 5.0, Rice Krispie Treat 6.5, Soft Pretzel 8.0, Raisins 10.0.

Denseness: measure the compactness of the cross section of sample while biting completely through with the molars.

Reference: Graham Crackers 3.5, Crunchy Cheetos 5.0, Malted Milk Balls 6.0, Pringles 7.0, Yellow American Cheese 9.5.

APPENDIX A.3

Sensory Evaluation Ballot

Name________________________________#__________Date_____________

Replicate 1

First Chew (1x through with molars)

Sensory Parameter	#	#	#	#	#	#
Fracturability						
Hardness/Toughness						
Denseness						
Cohesiveness						

Comments:

Replicate 2

First Chew (1x through with molars)

Sensory Parameter	#	#	#	#	#	#
Fracturability						
Hardness/Toughness						
Denseness						
Cohesiveness						

Comments:

APPENDIX B.1

Experiment 1 results for fastest thawing rate at 3.0% MC

Replicate	Hardness (N)	Fracturability (N)	Cohesiveness (mJ/mJ)	Gumminess (N.mJ/mJ)	Resilience (mJ/mJ)	Springiness (mm)	Chewiness (N.mm)
1	21.99	17.30	0.0843	1.350	0.0314	0.230	0.310
2	23.20	13.26	0.1069	1.735	0.0405	0.250	0.433
3	22.28	13.29	0.1164	2.157	0.0341	0.283	0.611
4	22.04	14.79	0.1068	2.002	0.0371	0.292	0.585
5	24.54	14.62	0.1180	2.316	0.0423	0.292	0.677
6	19.40	14.96	0.0836	1.333	0.0254	0.465	0.620
7	25.33	13.58	0.1107	2.229	0.0415	0.297	0.662
8	16.86	14.18	0.0978	1.332	0.0275	0.327	0.436
9	20.09	14.22	0.0773	1.144	0.0301	0.311	0.356
10	17.16	14.44	0.1025	1.495	0.0242	0.231	0.346
11	16.51	11.47	0.0847	1.093	0.0280	0.365	0.399
12	24.64	13.41	0.1021	2.014	0.0406	0.306	0.617
13	20.00	14.90	0.0844	1.283	0.0278	0.272	0.348
14	15.63	14.19	0.0810	1.010	0.0238	0.292	0.295
15	18.35	12.74	0.0798	1.100	0.0266	0.306	0.337
16	18.39	12.04	0.0811	1.105	0.0291	0.322	0.356
17	24.27	14.55	0.1110	2.122	0.0370	0.306	0.649
18	23.31	13.38	0.0988	1.731	0.0368	0.275	0.476
19	23.75	17.43	0.0718	1.143	0.0309	0.288	0.329
20	27.53	13.52	0.1065	2.060	0.0420	0.264	0.543
Mean	21.26	14.11	0.0953	1.588	0.0328	0.299	0.469
Std. Dev.	3.295	1.410	0.0141	0.442	0.0062	0.049	0.133
C.V.(%)	15.49	9.99	14.77	27.82	18.97	16.49	28.26

APPENDIX B.2

Experiment 1 results for fast thawing rate at 3.0% MC

Replicate	Hardness (N)	Fracturability (N)	Cohesiveness (mJ/mJ)	Gumminess (N.mJ/mJ)	Resilience (mJ/mJ)	Springiness (mm)	Chewiness (N.mm)
1	19.98	14.76	0.0991	1.597	0.0285	0.338	0.540
2	20.86	13.17	0.0808	1.158	0.0301	0.296	0.343
3	20.76	13.37	0.0949	1.582	0.0338	0.275	0.435
4	21.21	13.35	0.1057	1.813	0.0315	0.322	0.583
5	20.78	13.99	0.0897	1.377	0.0323	0.327	0.450
6	19.20	14.84	0.0888	1.331	0.0277	0.253	0.337
7	19.79	12.12	0.0886	1.389	0.0409	0.474	0.659
8	19.72	14.10	0.0869	1.401	0.0295	0.316	0.443
9	17.12	13.80	0.1085	1.338	0.0260	0.306	0.409
10	21.93	16.63	0.1045	1.809	0.0388	0.297	0.537
11	21.69	14.71	0.1043	1.772	0.0329	0.264	0.467
12	18.75	12.57	0.1107	1.665	0.0308	0.311	0.519
13	23.59	13.66	0.0812	1.491	0.0390	0.372	0.554
14	26.27	11.27	0.0972	1.877	0.0424	0.316	0.594
15	21.91	18.73	0.0937	1.603	0.0291	0.284	0.455
16	22.06	12.96	0.0945	1.611	0.0365	0.327	0.527
17	25.93	14.47	0.1134	2.386	0.0364	0.301	0.719
18	22.88	13.24	0.1049	1.866	0.0304	0.301	0.562
19	18.26	14.31	0.0874	1.228	0.0267	0.264	0.324
20	15.74	13.31	0.0812	1.287	0.0289	0.345	0.444
Mean	20.92	13.97	0.0958	1.579	0.0326	0.315	0.495
Std. Dev.	2.534	1.554	0.0100	0.283	0.0047	0.046	0.101
C.V.(%)	12.11	11.12	10.39	17.90	14.50	14.76	20.49

APPENDIX B.3

Experiment 1 results for medium thawing rate at 3.0% MC

Replicate	Hardness (N)	Fracturability (N)	Cohesiveness (mJ/mJ)	Gumminess (N.mJ/mJ)	Resilience (mJ/mJ)	Springiness (mm)	Chewiness (N.mm)
1	23.40	15.01	0.1278	2.536	0.0555	0.297	0.753
2	25.23	20.35	0.0867	1.752	0.0358	0.392	0.687
3	21.40	17.27	0.0809	1.320	0.0313	0.358	0.472
4	25.43	15.42	0.0943	1.674	0.0367	0.333	0.557
5	21.04	15.73	0.1008	1.680	0.0295	0.232	0.389
6	24.65	18.59	0.0925	1.870	0.0329	0.365	0.682
7	26.77	12.23	0.1008	2.177	0.0418	0.292	0.636
8	17.08	14.24	0.0762	0.978	0.0264	0.358	0.350
9	15.80	13.61	0.0726	0.808	0.0233	0.358	0.289
10	16.91	13.49	0.0722	0.944	0.0264	0.311	0.294
11	28.11	17.00	0.1199	2.731	0.0393	0.264	0.720
12	17.81	12.67	0.0999	1.307	0.0330	0.253	0.331
13	20.86	16.98	0.0914	1.459	0.0271	0.288	0.420
14	26.32	15.98	0.1020	2.203	0.0426	0.358	0.789
15	15.52	12.60	0.1015	1.233	0.0281	0.283	0.349
16	19.46	11.34	0.0940	1.402	0.0272	0.316	0.444
17	24.71	16.55	0.1087	2.201	0.0339	0.306	0.674
18	21.31	18.24	0.0832	1.382	0.0290	0.306	0.423
19	23.67	13.97	0.1099	1.988	0.0383	0.264	0.524
20	18.76	15.51	0.0964	1.414	0.0278	0.292	0.413
Mean	21.71	15.34	0.0956	1.653	0.0333	0.311	0.510
Std. Dev.	3.784	2.293	0.0143	0.515	0.0074	0.042	0.160
C.V.(%)	17.43	14.95	14.96	31.15	22.23	13.49	31.36

APPENDIX B.4

Experiment 1 results for slow thawing rate at 3.0% MC

Replicate	Hardness (N)	Fracturability (N)	Cohesiveness (mJ/mJ)	Gumminess (N.mJ/mJ)	Resilience (mJ/mJ)	Springiness (mm)	Chewiness (N.mm)
1	21.25	12.53	0.1166	1.549	0.0360	0.376	0.583
2	10.91	11.95	0.0633	0.478	0.0194	0.345	0.165
3	12.71	11.36	0.0714	0.483	0.0181	0.275	0.133
4	18.58	13.93	0.0903	1.482	0.0325	0.295	0.438
5	18.28	12.99	0.0871	1.232	0.0285	0.429	0.529
6	12.65	11.05	0.0834	0.760	0.0233	0.284	0.216
7	20.25	12.27	0.0836	1.328	0.0356	0.316	0.420
8	16.08	11.87	0.0716	0.917	0.0256	0.404	0.370
9	17.50	14.52	0.0737	1.009	0.0285	0.387	0.390
10	19.20	15.67	0.0896	1.388	0.0307	0.398	0.552
11	18.83	13.58	0.0841	1.212	0.0279	0.271	0.329
12	20.15	16.91	0.1024	1.697	0.0347	0.246	0.418
13	17.10	13.78	0.0647	0.723	0.0205	0.382	0.276
14	13.18	12.30	0.0808	0.865	0.0199	0.279	0.242
15	19.57	14.79	0.0599	0.592	0.0201	0.254	0.151
16	18.44	12.08	0.0912	1.317	0.0289	0.264	0.347
17	17.58	13.53	0.0809	1.130	0.0279	0.298	0.337
18	21.15	13.44	0.0844	1.333	0.0364	0.339	0.452
19	18.07	12.39	0.0925	1.323	0.0280	0.287	0.380
20	19.70	14.42	0.0819	1.208	0.0280	0.322	0.389
Mean	17.56	13.27	0.0827	1.101	0.0275	0.323	0.356
Std. Dev.	2.910	1.451	0.0130	0.347	0.0057	0.055	0.126
C.V.(%)	16.57	10.94	15.75	31.52	20.66	16.93	35.28

APPENDIX B.5

Experiment 1 results for fastest thawing rate at 5.0% MC

Replicate	Hardness (N)	Fracturability (N)	Cohesiveness (mJ/mJ)	Gumminess (N.mJ/mJ)	Resilience (mJ/mJ)	Springiness (mm)	Chewiness (N.mm)
1	18.21	11.41	0.1080	1.569	0.0289	0.365	0.572
2	22.30	11.08	0.1094	1.921	0.0319	0.264	0.507
3	20.12	13.44	0.1001	1.635	0.0305	0.339	0.554
4	22.56	15.16	0.1003	1.799	0.0297	0.333	0.600
5	18.62	12.40	0.0849	1.307	0.0307	0.441	0.576
6	20.83	14.89	0.0966	1.583	0.0303	0.358	0.567
7	15.11	8.14	0.0762	0.915	0.0225	0.452	0.414
8	13.63	10.82	0.0719	0.769	0.0206	0.432	0.332
9	17.62	9.49	0.0876	1.247	0.0251	0.322	0.401
10	15.71	15.40	0.0657	0.795	0.0230	0.404	0.321
11	19.96	14.61	0.0801	1.300	0.0265	0.387	0.503
12	23.11	18.43	0.0811	1.475	0.0298	0.396	0.583
13	23.27	13.17	0.1186	2.340	0.0332	0.311	0.728
14	20.60	15.00	0.0751	1.252	0.0271	0.432	0.541
15	23.18	14.91	0.0837	1.618	0.0298	0.421	0.682
16	19.21	14.08	0.0723	1.010	0.0257	0.380	0.384
17	20.38	10.55	0.0735	1.198	0.0258	0.432	0.517
18	19.66	12.47	0.0920	1.454	0.0293	0.404	0.587
19	21.08	10.89	0.0921	1.585	0.0337	0.453	0.717
20	20.99	12.39	0.0834	1.441	0.0285	0.512	0.738
Mean	19.81	12.94	0.0876	1.411	0.0281	0.392	0.541
Std.Dev.	2.640	2.380	0.0139	0.373	0.0034	0.058	0.121
C.V.(%)	13.33	18.40	15.88	26.42	12.22	14.71	22.28

APPENDIX B.6

Experiment 1 results for fast thawing rate at 5.0% MC

Replicate	Hardness (N)	Fracturability (N)	Cohesiveness (mJ/mJ)	Gumminess (N.mJ/mJ)	Resilience (mJ/mJ)	Springiness (mm)	Chewiness (N.mm)
1	25.61	16.13	0.0913	1.939	0.0338	0.462	0.896
2	21.00	16.17	0.0794	1.320	0.0250	0.316	0.418
3	19.48	14.05	0.0680	1.054	0.0276	0.527	0.556
4	24.83	16.36	0.0743	1.488	0.0344	0.542	0.806
5	20.33	14.83	0.0806	1.371	0.0297	0.421	0.578
6	20.15	12.95	0.0869	1.426	0.0307	0.462	0.659
7	19.89	13.82	0.0780	1.281	0.0265	0.452	0.578
8	22.02	13.46	0.0887	1.571	0.0293	0.404	0.634
9	20.19	12.74	0.0700	1.101	0.0263	0.542	0.597
10	23.64	16.63	0.0697	1.288	0.0305	0.557	0.717
11	19.11	13.40	0.0788	1.208	0.0272	0.441	0.532
12	23.00	12.57	0.0852	1.599	0.0290	0.442	0.706
13	25.47	15.14	0.0928	1.951	0.0357	0.372	0.725
14	26.29	17.32	0.0818	1.665	0.0310	0.463	0.771
15	20.46	13.36	0.0768	1.282	0.0279	0.463	0.594
16	23.63	15.30	0.0806	1.562	0.0310	0.486	0.758
17	24.39	12.74	0.0854	1.652	0.0359	0.512	0.846
18	21.44	15.61	0.0810	1.467	0.0282	0.442	0.648
19	19.33	12.99	0.0720	1.122	0.0245	0.500	0.561
20	25.88	11.80	0.0799	1.573	0.0346	0.463	0.729
Mean	22.31	14.37	0.0801	1.446	0.0299	0.463	0.665
Std.Dev.	2.411	1.574	0.0068	0.244	0.0034	0.058	0.115
C.V.(%)	10.81	10.96	8.55	16.91	11.33	12.43	17.33

APPENDIX B.7

Experiment 1 results for medium thawing rate at 5.0% MC

Replicate	Hardness (N)	Fracturability (N)	Cohesiveness (mJ/mJ)	Gumminess (N.mJ/mJ)	Resilience (mJ/mJ)	Springiness (mm)	Chewiness (N.mm)
1	19.73	14.61	0.0663	1.053	0.0249	0.559	0.589
2	24.50	13.95	0.0919	1.876	0.0384	0.463	0.869
3	23.87	15.68	0.0887	1.788	0.0334	0.486	0.869
4	20.84	15.27	0.0805	1.370	0.0259	0.432	0.592
5	24.30	12.30	0.0852	1.714	0.0337	0.464	0.795
6	18.53	11.09	0.0748	1.127	0.0292	0.592	0.668
7	18.28	11.12	0.0771	1.165	0.0268	0.475	0.553
8	20.92	11.78	0.0872	1.552	0.0328	0.514	0.797
9	19.06	13.46	0.0804	1.214	0.0267	0.412	0.500
10	17.92	12.10	0.0699	1.024	0.0255	0.474	0.486
11	21.22	11.56	0.0791	1.377	0.0291	0.453	0.623
12	23.18	15.19	0.0822	1.522	0.0324	0.474	0.722
13	17.37	13.64	0.0618	0.818	0.0231	0.442	0.361
14	23.80	18.27	0.0752	1.397	0.0285	0.396	0.553
15	19.27	11.48	0.0771	1.199	0.0248	0.432	0.518
16	23.47	14.55	0.0800	1.513	0.0347	0.486	0.735
17	21.98	13.27	0.0858	1.563	0.0286	0.441	0.688
18	19.12	11.64	0.0718	1.112	0.0263	0.487	0.542
19	21.95	11.93	0.1026	1.870	0.0311	0.514	0.961
20	19.17	10.62	0.0823	1.286	0.0278	0.512	0.659
Mean	20.92	13.17	0.0800	1.377	0.0292	0.475	0.654
Std.Dev.	2.272	1.922	0.0090	0.289	0.0039	0.046	0.148
C.V.(%)	10.86	14.59	11.20	20.96	13.34	9.73	22.63

APPENDIX B.8

Experiment 1 results for slow thawing rate at 5.0% MC

Replicate	Hardness (N)	Fracturability (N)	Cohesiveness (mJ/mJ)	Gumminess (N.mJ/mJ)	Resilience (mJ/mJ)	Springiness (mm)	Chewiness (N.mm)
1	17.88	16.86	0.0855	1.301	0.0247	0.412	0.536
2	17.23	13.50	0.0723	1.018	0.0332	0.387	0.394
3	21.09	15.20	0.0727	1.271	0.0294	0.546	0.694
4	21.95	13.66	0.0831	1.554	0.0308	0.432	0.671
5	19.21	16.04	0.0819	1.326	0.0249	0.404	0.535
6	20.45	15.61	0.0783	1.374	0.0261	0.432	0.593
7	19.03	15.21	0.0793	1.231	0.0290	0.487	0.600
8	16.53	13.15	0.0704	0.974	0.0234	0.463	0.451
9	16.34	12.30	0.0573	0.741	0.0174	0.463	0.343
10	18.70	14.10	0.0839	1.304	0.0253	0.432	0.563
11	20.61	15.11	0.0756	1.267	0.0253	0.452	0.573
12	18.59	13.37	0.0681	1.053	0.0219	0.421	0.444
13	21.71	13.20	0.0822	1.414	0.0304	0.463	0.655
14	18.10	13.29	0.0841	1.227	0.0268	0.345	0.424
15	18.01	12.99	0.0658	0.977	0.0227	0.442	0.431
16	20.14	13.78	0.0734	1.158	0.0238	0.462	0.535
17	19.44	13.50	0.0718	1.129	0.0241	0.421	0.476
18	21.18	14.16	0.0754	1.360	0.0299	0.526	0.716
19	19.93	11.52	0.0837	1.350	0.0279	0.388	0.524
20	21.31	13.20	0.0869	1.566	0.0297	0.442	0.692
Mean	19.37	13.99	0.0766	1.230	0.0263	0.441	0.542
Std.Dev.	1.649	1.278	0.0075	0.198	0.0036	0.045	0.106
C.V.(%)	8.52	9.14	9.80	16.14	13.86	10.22	19.47

APPENDIX C.1

Experiment 2 results for control at 3.0% MC for instrumental TPA

Replicate	Hardness (N)	Fracturability (N)	Cohesiveness (mJ/mJ)	Gumminess (N.mJ/mJ)	Resilience (mJ/mJ)	Springiness (mm)	Chewiness (N.mm)
1	25.11	17.98	0.0863	2.168	0.0450	0.397	0.861
2	21.54	15.32	0.0744	1.602	0.0370	0.363	0.582
3	25.61	16.45	0.0793	2.030	0.0399	0.366	0.743
4	27.94	16.87	0.0960	2.682	0.0490	0.382	1.025
5	33.06	17.41	0.0863	2.852	0.0543	0.322	0.918
6	20.07	12.04	0.0905	1.816	0.0304	0.406	0.737
7	22.06	16.66	0.0971	2.141	0.0330	0.373	0.799
8	25.55	16.97	0.1021	2.608	0.0431	0.503	1.312
9	18.28	16.73	0.0691	1.262	0.0267	0.316	0.399
10	26.00	20.26	0.0820	2.132	0.0391	0.355	0.757
11	16.99	14.87	0.0473	1.033	0.0242	0.344	0.355
12	19.14	15.03	0.0608	1.228	0.0199	0.347	0.426
13	16.61	16.04	0.0642	1.414	0.0284	0.376	0.532
14	18.49	11.37	0.0851	1.366	0.0291	0.384	0.525
15	18.31	17.97	0.0739	1.242	0.0244	0.362	0.450
16	15.66	14.26	0.0678	0.914	0.0257	0.363	0.332
17	20.59	17.86	0.0584	0.741	0.0243	0.286	0.212
18	19.51	14.14	0.0360	1.715	0.0152	0.364	0.624
19	18.64	12.35	0.0879	1.484	0.0340	0.349	0.518
20	20.66	18.38	0.0796	1.289	0.0314	0.314	0.405
Mean	21.49	15.95	0.0652	1.686	0.0254	0.364	0.625
Std. Dev.	4.309	2.230	0.0624	0.586	0.0377	0.043	0.263
C.V. (%)	20.05	13.98	95.68	34.74	148.01	11.79	41.97

APPENDIX C.2

Experiment 2 results for fastest thawing rate at 3.0% MC for instrumental TPA

Replicate	Hardness (N)	Fracturability (N)	Cohesiveness (mJ/mJ)	Gumminess (N.mJ/mJ)	Resilience (mJ/mJ)	Springiness (mm)	Chewiness (N.mm)
1	23.56	15.34	0.0702	1.653	0.0439	0.367	0.607
2	30.24	18.70	0.0921	2.786	0.0450	0.388	1.080
3	16.81	14.73	0.0782	1.315	0.0267	0.368	0.484
4	18.47	15.12	0.0639	1.180	0.0340	0.333	0.393
5	18.20	17.72	0.0685	1.246	0.0366	0.351	0.437
6	30.68	19.25	0.0833	2.556	0.0462	0.391	0.998
7	27.31	18.13	0.0709	1.935	0.0387	0.323	0.625
8	32.09	26.28	0.0877	2.813	0.0508	0.383	1.076
9	24.31	18.28	0.0634	1.541	0.0411	0.292	0.450
10	16.51	15.10	0.1151	0.970	0.0516	0.308	0.299
11	20.17	19.79	0.0588	1.399	0.0288	0.344	0.481
12	20.22	12.53	0.0694	1.818	0.0268	0.383	0.697
13	18.83	16.96	0.0899	1.042	0.0371	0.243	0.253
14	21.83	18.53	0.0554	1.217	0.0295	0.343	0.417
15	16.59	13.48	0.0558	1.252	0.0307	0.367	0.460
16	18.14	12.95	0.0602	1.562	0.0268	0.411	0.642
17	28.70	14.64	0.0755	3.408	0.0285	0.366	1.246
18	20.84	19.29	0.0861	1.406	0.0274	0.349	0.491
19	30.50	13.85	0.1187	2.997	0.0508	0.355	1.064
20	28.83	15.17	0.0675	2.800	0.0297	0.362	1.015
Mean	23.14	16.79	0.0983	1.845	0.0478	0.351	0.661
Std. Dev.	5.315	3.120	0.0971	0.737	0.0506	0.037	0.296
C.V.(%)	22.97	18.58	98.85	39.94	105.87	10.65	44.82

APPENDIX C.3

Experiment 2 results for slow thawing rate at 3.0% MC for instrumental TPA

Replicate	Hardness (N)	Fracturability (N)	Cohesiveness (mJ/mJ)	Gumminess (N.mJ/mJ)	Resilience (mJ/mJ)	Springiness (mm)	Chewiness (N.mm)
1	17.43	15.88	0.0740	1.289	0.0307	0.359	0.463
2	21.27	17.37	0.0816	1.736	0.0298	0.342	0.593
3	18.58	16.63	0.0668	1.241	0.0260	0.659	0.817
4	18.74	14.30	0.0797	1.493	0.0312	0.413	0.616
5	22.84	15.53	0.0810	1.851	0.0319	0.377	0.698
6	20.61	17.05	0.0787	1.622	0.0326	0.353	0.573
7	18.31	12.26	0.0826	1.512	0.0365	0.379	0.573
8	17.13	15.55	0.0838	1.435	0.0292	0.379	0.544
9	21.62	16.65	0.0682	1.474	0.0352	0.366	0.539
10	19.10	14.45	0.0658	1.256	0.0323	0.384	0.482
11	19.09	16.58	0.0647	1.235	0.0299	0.311	0.384
12	25.24	19.58	0.0989	2.495	0.0374	0.377	0.941
13	23.99	17.91	0.0696	1.670	0.0376	0.273	0.456
14	22.27	11.84	0.0962	2.142	0.0456	0.409	0.875
15	16.94	12.60	0.0620	1.600	0.0288	0.410	0.656
16	18.18	17.62	0.0862	1.186	0.0516	0.394	0.467
17	20.64	14.28	0.0945	2.041	0.0351	0.375	0.766
18	26.77	15.03	0.0653	2.936	0.0303	0.428	1.256
19	21.05	15.35	0.0989	1.426	0.0351	0.331	0.472
20	20.01	12.26	0.1097	1.450	0.0472	0.346	0.501
Mean	20.49	15.43	0.0677	1.655	0.0332	0.383	0.634
Std. Dev.	2.639	2.047	0.0725	0.440	0.0340	0.073	0.205
C.V. (%)	12.88	13.26	106.97	26.57	102.51	18.96	32.34

APPENDIX C.4

Experiment 2 results for control at 5.0% MC for instrumental TPA

Replicate	Hardness (N)	Fracturability (N)	Cohesiveness (mJ/mJ)	Gumminess (N.mJ/mJ)	Resilience (mJ/mJ)	Springiness (mm)	Chewiness (N.mm)
1	17.75	14.20	0.0758	1.346	0.0296	0.181	0.243
2	15.78	11.63	0.0627	0.990	0.0236	0.198	0.196
3	23.43	15.52	0.0744	1.743	0.0332	0.194	0.338
4	24.35	18.53	0.0722	1.757	0.0332	0.196	0.345
5	21.73	15.19	0.1144	2.486	0.0355	0.349	0.868
6	19.07	9.29	0.0826	1.706	0.0282	0.243	0.415
7	18.80	12.43	0.0894	1.787	0.0337	0.298	0.533
8	19.08	16.62	0.0951	1.365	0.0295	0.248	0.338
9	23.69	14.45	0.0715	2.054	0.0288	0.286	0.588
10	20.89	16.79	0.0867	1.591	0.0368	0.215	0.342
11	22.40	15.40	0.0762	2.067	0.0274	0.268	0.554
12	18.76	13.30	0.0923	1.503	0.0390	0.254	0.382
13	16.97	13.65	0.0801	1.362	0.0311	0.260	0.353
14	15.26	15.26	0.0803	1.229	0.0301	0.229	0.281
15	16.25	13.04	0.0806	1.315	0.0258	0.310	0.408
16	22.34	16.33	0.0809	2.094	0.0245	0.283	0.593
17	23.42	10.20	0.0937	2.157	0.0344	0.256	0.552
18	21.79	17.68	0.0921	1.670	0.0391	0.226	0.377
19	17.54	17.54	0.0767	1.312	0.0295	0.231	0.303
20	20.34	17.05	0.0874	1.358	0.0282	0.210	0.286
Mean	19.98	14.70	0.0833	1.645	0.0311	0.247	0.415
Std.Dev.	2.772	2.447	0.0109	0.370	0.0043	0.0425	0.154
C.V.(%)	13.87	16.64	13.13	22.50	13.97	17.22	37.04

APPENDIX C.5

Experiment 2 results for fastest thawing rate at 5.0% MC for instrumental TPA

Replicate	Hardness (N)	Fracturability (N)	Cohesiveness (mJ/mJ)	Gumminess (N.mJ/mJ)	Resilience (mJ/mJ)	Springiness (mm)	Chewiness (N.mm)
1	15.13	15.19	0.0651	0.985	0.0288	0.152	0.150
2	22.95	15.62	0.0728	1.671	0.0389	0.180	0.302
3	17.16	14.88	0.0576	0.989	0.0279	0.175	0.173
4	19.19	14.24	0.0724	1.390	0.0297	0.206	0.287
5	21.17	13.55	0.0843	1.784	0.0335	0.222	0.396
6	23.14	11.23	0.0847	1.959	0.0422	0.194	0.380
7	21.51	13.01	0.0832	1.790	0.0347	0.258	0.462
8	17.42	12.94	0.0766	1.334	0.0331	0.211	0.281
9	16.39	12.70	0.0778	1.276	0.0368	0.213	0.271
10	27.16	15.21	0.0954	2.592	0.0428	0.258	0.667
11	18.05	13.43	0.0777	1.770	0.0307	0.374	0.663
12	15.88	15.30	0.0981	0.964	0.0288	0.196	0.189
13	25.14	13.14	0.0607	2.261	0.0240	0.208	0.470
14	26.09	17.15	0.0900	1.916	0.0447	0.193	0.370
15	14.12	11.85	0.0734	0.908	0.0347	0.307	0.278
16	25.22	15.80	0.0643	2.096	0.0250	0.207	0.434
17	22.83	11.21	0.0737	2.052	0.0357	0.233	0.478
18	23.19	14.92	0.0831	1.619	0.0412	0.205	0.333
19	21.35	14.27	0.0899	1.653	0.0439	0.179	0.296
20	21.12	12.24	0.0698	1.717	0.0313	0.202	0.346
Mean	20.71	13.89	0.0774	1.636	0.0355	0.219	0.361
Std.Dev.	3.761	1.583	0.0813	0.450	0.0366	0.0487	0.136
C.V. (%)	18.16	11.40	105.04	27.50	103.18	22.27	37.78

APPENDIX C.6

Experiment 2 results for slow thawing rate at 5.0% MC for instrumental TPA

Replicate	Hardness (N)	Fracturability (N)	Cohesiveness (mJ/mJ)	Gumminess (N.mJ/mJ)	Resilience (mJ/mJ)	Springiness (mm)	Chewiness (N.mm)
1	19.72	10.71	0.0735	1.450	0.0328	0.210	0.305
2	14.97	13.75	0.0609	0.912	0.0235	0.238	0.217
3	19.68	12.49	0.0735	1.446	0.0290	0.229	0.330
4	24.15	13.45	0.1000	2.415	0.0348	0.293	0.708
5	17.20	12.40	0.0841	1.447	0.0328	0.253	0.366
6	27.10	14.26	0.0871	2.360	0.0405	0.225	0.532
7	20.99	14.33	0.0821	1.723	0.0342	0.207	0.356
8	21.70	17.20	0.0846	1.834	0.0320	0.272	0.499
9	16.96	14.06	0.0691	1.172	0.0279	0.196	0.230
10	15.95	15.22	0.0716	1.142	0.0232	0.230	0.262
11	18.39	15.09	0.0822	1.511	0.0277	0.252	0.381
12	18.69	15.90	0.0749	1.399	0.0296	0.230	0.322
13	16.94	11.84	0.0692	1.172	0.0269	0.226	0.265
14	19.81	14.59	0.0834	1.652	0.0317	0.275	0.454
15	14.85	9.24	0.1002	1.034	0.0485	0.197	0.204
16	20.69	15.31	0.0696	1.670	0.0354	0.229	0.383
17	22.41	13.20	0.0622	2.013	0.0248	0.281	0.566
18	18.80	15.51	0.0807	1.440	0.0342	0.277	0.399
19	18.95	13.97	0.0898	1.296	0.0381	0.286	0.370
20	21.99	13.43	0.0766	2.025	0.0291	0.269	0.544
Mean	19.50	13.80	0.0684	1.556	0.0283	0.244	0.385
Std. Dev.	2.987	1.797	0.0921	0.402	0.0360	0.0298	0.129
C.V.(%)	15.32	13.02	134.57	25.86	127.25	12.22	33.46

APPENDIX C.7

Experiment 2 results for control as treatment at 3.0 % MC for sensory evaluation

Replicate	Hardness	Fracturability	Cohesiveness	Denseness
1	6.5	5.5	2.5	7.0
2	7.0	5.5	4.0	7.0
3	7.5	5.5	3.0	7.0
4	6.0	4.0	3.5	7.0
5	7.5	6.0	3.0	7.5
6	7.5	6.0	3.5	8.0
7	7.0	5.5	3.0	7.5
8	7.0	4.5	5.0	7.0
9	7.0	6.5	3.5	8.0
10	6.5	6.0	4.0	6.5
11	7.0	4.5	4.0	8.0
12	5.0	5.5	2.5	6.0
13	6.5	5.5	2.5	7.0
14	7.0	5.5	4.0	7.0
15	5.5	5.0	3.0	7.5
16	7.5	5.5	4.0	6.5
17	6.5	6.5	4.0	6.0
18	7.0	6.0	3.5	6.8
19	7.5	5.0	3.0	7.5
20	7.0	4.5	4.0	7.0
21	7.0	6.5	3.0	7.0
22	6.5	5.5	4.0	7.0
23	6.5	5.5	3.0	7.0
24	5.0	6.0	2.5	6.0
Mean	6.708	5.500	6.708	7.033
Std.Dev.	0.706	0.645	0.918	0.560
C.V. (%)	10.52	11.74	13.69	7.96

APPENDIX C.8

Experiment 2 results for fastest thawing rate at 3.0% MC for sensory evaluation

Replicate	Hardness	Fracturability	Cohesiveness	Denseness
1	6.5	5.8	3.0	7.0
2	6.5	6.0	3.0	6.5
3	6.5	5.0	3.0	7.0
4	7.0	5.5	4.0	7.0
5	6.5	6.5	3.5	6.0
6	7.0	5.0	4.0	7.0
7	7.0	5.0	2.5	7.5
8	7.0	5.0	4.0	6.5
9	8.0	6.0	5.0	8.5
10	6.0	5.5	3.5	7.0
11	6.5	5.5	3.5	7.5
12	6.0	5.5	4.0	6.5
13	7.0	5.0	3.0	7.5
14	7.0	5.5	3.5	7.0
15	7.0	4.5	4.0	7.0
16	6.5	5.5	6.0	7.0
17	6.0	5.5	3.0	6.0
18	7.5	6.0	5.5	7.0
19	7.0	5.0	2.5	7.0
20	7.5	5.0	3.5	7.5
21	7.0	6.5	3.5	8.0
22	6.5	5.5	4.0	6.5
23	7.0	5.5	3.5	7.5
24	5.5	5.5	2.5	6.0
Mean	6.750	5.471	3.646	7.000
Std.Dev.	0.540	0.482	0.860	0.595
C.V. (%)	8.00	8.81	23.58	8.50

APPENDIX C.9

Experiment 2 results for slow thawing rate at 3.0% MC for sensory evaluation

Replicate	Hardness	Fracturability	Cohesiveness	Denseness
1	7.0	5.5	3.0	7.5
2	7.0	5.5	3.5	7.0
3	8.0	4.5	3.0	7.0
4	6.5	4.0	4.0	6.5
5	6.5	5.0	4.5	6.5
6	7.0	5.0	3.5	7.0
7	6.5	5.0	3.0	7.5
8	7.0	5.0	3.0	6.5
9	7.0	6.5	3.5	7.0
10	6.5	5.5	4.0	7.0
11	6.5	5.5	3.0	7.0
12	5.5	5.0	2.5	6.0
13	6.5	5.8	3.0	7.0
14	8.0	5.0	3.0	6.5
15	7.0	4.0	3.5	7.5
16	6.5	4.5	4.0	7.0
17	6.5	5.5	3.0	6.5
18	7.0	5.5	4.5	7.3
19	7.0	5.5	2.5	7.0
20	7.0	5.0	3.5	7.0
21	6.5	6.0	4.5	7.0
22	6.5	6.0	4.5	6.5
23	7.0	5.0	3.5	7.5
24	6.0	5.5	3.0	6.5
Mean	6.771	5.221	3.458	6.908
Std.Dev.	0.5200	0.5852	0.6110	0.3894
C.V. (%)	7.68	11.21	17.67	5.64

APPENDIX C.10

Experiment 2 results for control as treatment at 5.0% MC for sensory evaluation

Replicate	Hardness	Fracturability	Cohesiveness	Denseness
1	8.0	3.0	6.0	9.0
2	8.5	3.5	6.5	9.0
3	6.5	4.5	6.0	7.5
4	8.2	3.5	7.0	7.8
5	7.0	4.5	6.0	7.5
6	7.5	2.5	5.0	8.0
7	7.5	3.5	6.5	9.0
8	8.0	3.0	6.5	7.5
9	7.5	3.5	7.0	8.5
10	8.0	3.0	7.0	8.0
11	8.2	3.0	7.0	9.3
12	8.0	3.0	6.5	7.5
13	8.0	3.0	6.0	9.0
14	7.5	4.5	5.0	7.5
15	8.5	3.5	7.0	7.0
16	8.0	3.0	7.0	8.0
17	7.0	4.5	6.0	7.5
18	8.0	2.5	5.0	7.7
19	8.0	2.5	6.8	9.2
20	8.0	3.0	6.0	7.5
21	8.0	3.0	7.0	8.5
22	8.5	3.0	7.5	8.0
23	7.5	3.5	6.5	9.0
24	7.5	4.5	6.0	7.5
Mean	7.808	3.375	7.808	8.125
Std.Dev.	0.4873	0.6495	0.7334	0.6887
C.V. (%)	6.24	19.25	9.39	8.48

APPENDIX C.11

Experiment 2 results for fastest thawing rate at 5.0% MC for sensory evaluation

Replicate	Hardness	Fracturability	Cohesiveness	Denseness
1	8.0	2.5	6.5	9.0
2	7.5	4.5	5.5	7.5
3	7.5	3.0	5.0	8.0
4	8.0	4.5	7.0	7.5
5	7.0	4.5	6.0	7.5
6	8.0	3.0	5.5	8.3
7	7.5	3.5	5.5	8.0
8	8.5	3.0	7.0	7.5
9	8.0	4.0	7.5	9.0
10	8.5	3.0	7.5	8.0
11	8.0	3.5	6.5	9.0
12	6.5	4.0	6.0	7.0
13	7.5	3.5	6.0	9.5
14	7.5	4.0	5.5	7.5
15	8.0	4.0	5.0	8.0
16	8.0	3.5	7.0	7.8
17	7.0	4.0	6.0	7.5
18	7.7	4.0	5.3	8.0
19	7.0	3.5	6.0	9.0
20	8.5	3.0	7.0	7.5
21	8.0	3.0	7.0	9.0
22	8.0	3.5	7.5	8.0
23	8.0	3.0	7.0	9.2
24	8.0	3.0	6.5	7.5
Mean	7.758	3.542	6.304	8.117
Std.Dev.	0.4974	0.5575	0.7845	0.6920
C.V. (%)	6.41	15.74	12.44	8.53

APPENDIX C.12

Experiment 2 results for slow thawing rate at 5.0% MC for sensory evaluation

Replicate	Hardness	Fracturability	Cohesiveness	Denseness
1	7.0	3.5	6.0	9.5
2	8.0	4.0	6.0	7.5
3	8.5	3.0	7.0	7.5
4	8.0	3.5	7.2	8.0
5	7.0	4.0	6.0	7.5
6	7.7	3.5	5.3	8.0
7	8.0	3.0	7.0	9.2
8	7.5	3.5	6.0	7.0
9	8.0	3.5	7.0	9.0
10	8.0	3.5	7.0	8.5
11	7.8	3.0	6.5	9.0
12	7.0	4.5	6.0	7.0
13	8.0	2.5	6.5	9.5
14	8.5	3.5	6.5	9.0
15	8.0	3.0	6.5	7.0
16	8.2	4.0	6.5	7.5
17	7.0	4.5	6.0	7.5
18	7.5	3.0	5.0	7.5
19	7.5	3.0	6.8	9.0
20	7.5	3.0	6.0	7.5
21	8.0	3.0	7.5	9.0
22	8.0	3.0	7.5	8.0
23	8.2	3.0	7.0	9.0
24	7.0	4.0	6.5	7.0
Mean	7.746	3.417	6.471	8.133
Std.Dev.	0.4637	0.5137	0.6208	0.8542
C.V. (%)	5.99	15.04	9.59	10.50

APPENDIX D.1

Experiment 3 results for 3 freeze/thaw cycles at 3.0% MC

Replicate	Hardness (N)	Fracturability (N)	Cohesineness (mJ/mJ)	Gumminess (N.mJ/mJ)	Resilience (mJ/mJ)	Springiness (mm)	Chewiness (N.mm)
1	21.72	19.13	0.0793	1.285	0.0352	0.359	0.461
2	25.13	21.63	0.0644	1.169	0.0365	0.267	0.312
3	19.55	12.97	0.0618	1.026	0.0262	0.361	0.370
4	21.94	21.34	0.0904	1.461	0.0323	0.379	0.554
5	22.20	15.38	0.0550	0.992	0.0227	0.338	0.335
6	18.29	17.23	0.1079	1.542	0.0377	0.431	0.665
7	17.81	12.93	0.0918	1.267	0.0323	0.393	0.498
8	19.68	18.53	0.0599	0.871	0.0301	0.311	0.271
9	26.33	25.72	0.0826	1.734	0.0465	0.366	0.635
10	20.40	16.41	0.0972	1.823	0.0318	0.405	0.738
11	20.39	17.69	0.0649	0.999	0.0266	0.402	0.401
12	19.76	16.83	0.0764	1.171	0.0350	0.339	0.397
13	20.51	20.40	0.0873	1.418	0.0348	0.493	0.699
14	18.16	15.06	0.0800	1.069	0.0331	0.358	0.383
15	21.26	16.64	0.0558	0.895	0.0373	0.260	0.233
16	28.75	20.91	0.0832	1.722	0.0534	0.232	0.400
17	24.07	16.40	0.0844	1.539	0.0372	0.324	0.499
18	20.89	14.73	0.1050	1.373	0.0504	0.348	0.478
19	22.90	19.70	0.0727	1.277	0.0325	0.263	0.336
20	21.08	15.51	0.0386	0.470	0.0179	0.281	0.132
Mean	21.54	17.76	0.0769	1.255	0.0345	0.346	0.440
Std. Dev.	2.716	3.113	0.0174	0.328	0.0083	0.0630	0.155
C.V.(%)	12.61	17.53	22.60	26.11	24.03	18.22	35.36

APPENDIX D.2

Experiment 3 results for 6 freeze/thaw cycles at 3.0% MC

Replicate	Hardness (N)	Fracturability (N)	Cohesineness (mJ/mJ)	Gumminess (N.mJ/mJ)	Resilience (mJ/mJ)	Springiness (mm)	Chewiness (N.mm)
1	19.81	15.50	0.0756	1.062	0.0293	0.312	0.331
2	15.28	12.73	0.0780	0.880	0.0256	0.401	0.353
3	16.82	13.54	0.0624	0.689	0.0298	0.274	0.189
4	19.41	13.91	0.1059	2.363	0.0477	0.409	0.967
5	22.74	19.08	0.0873	1.674	0.0457	0.196	0.328
6	21.51	20.38	0.0690	1.108	0.0243	0.305	0.338
7	20.95	18.92	0.1273	2.361	0.0596	0.180	0.425
8	23.03	17.43	0.0642	1.045	0.0280	0.286	0.299
9	21.39	16.49	0.0676	1.140	0.0235	0.389	0.444
10	23.67	21.26	0.0798	1.635	0.0320	0.327	0.535
11	19.43	19.38	0.0673	0.995	0.0285	0.300	0.299
12	26.31	20.84	0.1153	2.526	0.0518	0.368	0.929
13	21.52	17.66	0.0735	1.196	0.0325	0.314	0.376
14	18.01	14.07	0.0682	1.071	0.0320	0.342	0.366
15	24.69	21.95	0.0839	1.501	0.0362	0.306	0.459
16	24.59	20.00	0.1118	2.172	0.0430	0.366	0.795
17	18.08	16.66	0.0774	1.067	0.0298	0.384	0.410
18	17.84	11.72	0.0984	1.493	0.0321	0.276	0.412
19	26.38	23.27	0.1165	2.555	0.0359	0.394	1.007
20	21.52	17.66	0.0735	1.196	0.0325	0.314	0.376
Mean	21.15	17.62	0.0851	1.487	0.0350	0.322	0.482
Std. Dev.	3.021	3.185	0.0195	0.578	0.0094	0.0612	0.234
C.V.(%)	14.28	18.08	22.94	38.89	26.97	18.99	48.67

APPENDIX D.3

Experiment 3 results for 9 freeze/thaw cycles at 3.0% MC

Replicate	Hardness (N)	Fracturability (N)	Cohesineness (mJ/mJ)	Gumminess (N.mJ/mJ)	Resilience (mJ/mJ)	Springiness (mm)	Chewiness (N.mm)
1	22.33	16.05	0.0495	0.776	0.0245	0.368	0.286
2	18.19	12.90	0.0824	1.213	0.0306	0.418	0.507
3	18.77	15.15	0.0832	1.144	0.0355	0.428	0.490
4	20.44	16.06	0.0928	1.471	0.0348	0.428	0.630
5	20.34	18.35	0.1031	1.613	0.0407	0.418	0.674
6	20.00	15.87	0.1261	1.972	0.0277	0.341	0.672
7	17.90	13.19	0.0672	0.858	0.0329	0.313	0.269
8	28.97	23.54	0.0812	1.837	0.0416	0.297	0.546
9	19.62	18.96	0.0743	1.048	0.0337	0.380	0.398
10	22.11	19.35	0.0652	1.237	0.0330	0.329	0.407
11	18.01	17.47	0.0623	0.898	0.0250	0.290	0.260
12	25.20	20.20	0.1013	1.981	0.0448	0.395	0.782
13	18.20	12.05	0.0605	0.860	0.0307	0.314	0.270
14	22.74	14.12	0.0820	1.379	0.0373	0.329	0.454
15	16.90	12.06	0.0921	1.137	0.0264	0.373	0.424
16	17.11	13.13	0.0766	1.003	0.0298	0.313	0.314
17	18.01	11.12	0.1033	2.274	0.0515	0.364	0.828
18	19.56	14.06	0.0898	1.233	0.0389	0.370	0.456
19	20.51	18.49	0.0735	1.101	0.0239	0.429	0.472
20	19.92	11.05	0.0958	1.446	0.0380	0.416	0.601
Mean	20.24	15.66	0.0831	1.324	0.0341	0.366	0.487
Std. Dev.	2.855	3.312	0.0176	0.411	0.0071	0.0463	0.165
C.V.(%)	14.10	21.15	21.24	31.05	20.70	12.67	33.97

APPENDIX D.4

Experiment 3 results for 12 freeze/thaw cycles at 3.0% MC

Replicate	Hardness (N)	Fracturability (N)	Cohesineness (mJ/mJ)	Gumminess (N.mJ/mJ)	Resilience (mJ/mJ)	Springiness (mm)	Chewiness (N.mm)
1	16.54	11.06	0.0576	0.698	0.0301	0.267	0.186
2	23.30	20.54	0.0935	1.759	0.0480	0.363	0.639
3	18.74	14.05	0.0858	1.501	0.0488	0.279	0.419
4	23.37	14.05	0.0680	1.219	0.0439	0.278	0.339
5	21.88	15.05	0.0622	0.951	0.0295	0.273	0.260
6	20.95	19.05	0.0762	1.179	0.0361	0.330	0.389
7	20.71	14.05	0.1364	2.224	0.0569	0.415	0.923
8	16.79	11.05	0.0680	0.918	0.0324	0.305	0.280
9	18.11	12.37	0.0576	0.752	0.0268	0.287	0.216
10	20.76	10.43	0.0978	1.961	0.0366	0.321	0.629
11	16.60	14.98	0.0891	1.204	0.0268	0.372	0.448
12	20.01	18.37	0.0764	1.118	0.0301	0.350	0.391
13	18.16	15.45	0.0646	0.790	0.0306	0.327	0.258
14	22.71	15.05	0.0671	1.030	0.0385	0.320	0.330
15	18.43	16.32	0.0944	1.266	0.0326	0.387	0.490
16	24.50	15.35	0.0847	1.584	0.0445	0.333	0.528
17	19.63	14.04	0.0863	1.345	0.0332	0.390	0.525
18	19.41	18.85	0.0439	0.554	0.0324	0.258	0.143
19	18.77	12.83	0.0857	1.707	0.0566	0.193	0.329
20	17.61	13.92	0.0657	1.058	0.0359	0.330	0.349
Mean	19.85	14.84	0.0780	1.241	0.0375	0.319	0.404
Std. Dev.	2.318	2.676	0.0195	0.428	0.0090	0.052	0.179
C.V.(%)	11.68	18.03	24.94	34.49	23.99	16.30	44.39

APPENDIX D.5

Experiment 3 results for 3 freeze/thaw cycles at 5.0% MC

Replicate	Hardness (N)	Fracturability (N)	Cohesineness (mJ/mJ)	Gumminess (N.mJ/mJ)	Resilience (mJ/mJ)	Springiness (mm)	Chewiness (N.mm)
1	18.90	15.52	0.0787	1.323	0.0338	0.217	0.287
2	18.96	14.53	0.0711	1.068	0.0314	0.186	0.199
3	20.50	18.62	0.0782	1.313	0.0326	0.228	0.299
4	18.62	17.78	0.0728	1.103	0.0333	0.214	0.236
5	17.05	16.61	0.0596	0.804	0.0272	0.224	0.180
6	16.02	13.45	0.0758	1.015	0.0331	0.219	0.222
7	17.71	15.86	0.0621	0.919	0.0269	0.202	0.186
8	21.97	19.54	0.0728	1.282	0.0315	0.250	0.320
9	21.36	18.45	0.0750	1.353	0.0350	0.187	0.253
10	20.63	16.44	0.0684	1.166	0.0297	0.211	0.246
11	19.63	16.47	0.0734	1.210	0.0351	0.202	0.244
12	17.05	15.48	0.0577	0.808	0.0259	0.191	0.154
13	19.69	17.62	0.0924	1.565	0.0407	0.211	0.330
14	16.02	15.46	0.0803	1.000	0.0261	0.220	0.220
15	21.03	19.28	0.0810	1.360	0.0357	0.255	0.347
16	17.47	14.53	0.0734	1.024	0.0261	0.199	0.204
17	15.93	13.13	0.0723	0.779	0.0344	0.389	0.303
18	24.80	21.09	0.0806	1.720	0.0401	0.172	0.296
19	19.88	16.48	0.0724	1.178	0.0267	0.200	0.236
20	16.59	14.05	0.0640	0.854	0.0303	0.191	0.163
Mean	18.99	16.52	0.0731	1.142	0.032	0.218	0.246
Std. Dev.	2.275	2.087	0.0079	0.249	0.0043	0.0440	0.0556
C.V.(%)	11.98	12.64	10.86	21.80	13.67	20.13	22.58

APPENDIX D.6

Experiment 3 results for 6 freeze/thaw cycles at 5.0% MC

Replicate	Hardness (N)	Fracturability (N)	Cohesineness (mJ/mJ)	Gumminess (N.mJ/mJ)	Resilience (mJ/mJ)	Springiness (mm)	Chewiness (N.mm)
1	18.57	16.05	0.0658	1.034	0.0291	0.182	0.188
2	14.78	13.05	0.0588	0.725	0.0221	0.187	0.136
3	16.90	14.05	0.0631	0.846	0.0297	0.192	0.162
4	19.43	16.39	0.0646	1.041	0.0318	0.193	0.201
5	18.97	15.17	0.0697	1.140	0.0300	0.180	0.205
6	18.69	16.18	0.0743	1.196	0.0377	0.166	0.198
7	17.86	14.05	0.0803	1.251	0.0386	0.191	0.239
8	14.08	12.06	0.0595	0.659	0.0232	0.209	0.138
9	17.89	15.06	0.0639	0.882	0.0312	0.176	0.155
10	20.49	17.73	0.0689	1.156	0.0316	0.168	0.194
11	19.24	17.05	0.0574	0.837	0.0297	0.208	0.174
12	18.32	15.05	0.0650	1.017	0.0304	0.194	0.197
13	17.47	14.52	0.0670	0.963	0.0262	0.197	0.190
14	18.35	16.44	0.0740	1.091	0.0304	0.178	0.194
15	21.08	18.33	0.0699	1.232	0.0277	0.224	0.276
16	15.89	14.61	0.0770	1.048	0.0326	0.211	0.221
17	17.93	15.80	0.0810	1.140	0.0389	0.223	0.254
18	18.15	16.23	0.0745	1.085	0.0272	0.228	0.247
19	18.65	15.71	0.0783	1.245	0.0299	0.191	0.238
20	18.06	15.05	0.0755	1.104	0.0329	0.230	0.254
Mean	18.04	15.43	0.0694	1.035	0.0305	0.196	0.203
Std. Dev.	1.634	1.464	0.0070	0.165	0.0043	0.0190	0.0384
C.V.(%)	9.06	9.49	10.10	15.93	14.02	9.693	18.90

APPENDIX D.7

Experiment 3 results for 9 freeze/thaw cycles at 5.0% MC

Replicate	Hardness (N)	Fracturability (N)	Cohesineness (mJ/mJ)	Gumminess (N.mJ/mJ)	Resilience (mJ/mJ)	Springiness (mm)	Chewiness (N.mm)
1	16.90	14.66	0.0681	0.902	0.0278	0.218	0.197
2	16.27	12.58	0.0525	0.546	0.0216	0.187	0.102
3	14.84	12.01	0.0622	0.753	0.0237	0.197	0.148
4	17.96	14.05	0.0692	1.028	0.0246	0.198	0.204
5	22.10	19.12	0.0655	1.062	0.0262	0.186	0.198
6	14.26	11.97	0.0497	0.469	0.0205	0.197	0.092
7	19.21	16.04	0.0940	1.538	0.0304	0.296	0.455
8	15.55	13.73	0.0691	0.846	0.0219	0.217	0.184
9	17.01	12.96	0.0640	0.813	0.0215	0.214	0.174
10	19.89	17.01	0.0697	1.164	0.0279	0.174	0.202
11	16.97	12.05	0.0606	0.805	0.0243	0.206	0.166
12	13.07	11.30	0.0601	0.663	0.0274	0.186	0.123
13	17.59	15.09	0.0707	1.025	0.0248	0.219	0.225
14	17.46	13.31	0.0760	1.175	0.0261	0.220	0.258
15	14.84	11.05	0.0719	0.905	0.0242	0.238	0.215
16	16.58	14.49	0.0573	0.658	0.0190	0.239	0.157
17	12.55	10.43	0.0699	0.705	0.0253	0.218	0.154
18	15.82	15.33	0.0638	0.812	0.0231	0.240	0.195
19	14.70	14.64	0.0575	0.673	0.0220	0.197	0.133
20	17.43	17.41	0.0842	1.228	0.0307	0.207	0.254
Mean	16.55	13.96	0.0668	0.888	0.0247	0.213	0.192
Std. Dev.	2.220	2.229	0.0100	0.253	0.0031	0.0263	0.0746
C.V.(%)	13.41	15.97	14.97	28.46	12.44	12.35	38.90

APPENDIX D.8

Experiment 3 results for 12 freeze/thaw cycles at 5.0% MC

Replicate	Hardness (N)	Fracturability (N)	Cohesineness (mJ/mJ)	Gumminess (N.mJ/mJ)	Resilience (mJ/mJ)	Springiness (mm)	Chewiness (N.mm)
1	14.02	9.24	0.0514	0.546	0.0238	0.198	0.108
2	14.05	10.16	0.0580	0.624	0.0210	0.799	0.499
3	17.31	15.05	0.0766	1.082	0.0295	0.193	0.209
4	12.92	11.66	0.0624	0.630	0.0232	0.250	0.157
5	12.27	11.73	0.0550	0.521	0.0191	0.196	0.102
6	14.17	11.28	0.0704	0.782	0.0281	0.232	0.181
7	12.64	7.40	0.0722	0.656	0.0302	0.214	0.140
8	14.82	10.13	0.0691	0.822	0.0204	0.276	0.227
9	17.54	14.06	0.0622	0.882	0.0256	0.189	0.167
10	13.67	8.38	0.0579	0.801	0.0235	0.156	0.125
11	15.75	10.04	0.0746	0.983	0.0244	0.287	0.282
12	15.86	11.05	0.0740	0.999	0.0283	0.214	0.214
13	17.31	11.05	0.0601	0.861	0.0341	0.221	0.190
14	12.92	8.05	0.0672	0.642	0.0212	0.264	0.169
15	14.43	9.06	0.0572	0.473	0.0201	0.227	0.107
16	16.49	14.05	0.0705	0.936	0.0278	0.203	0.190
17	17.63	14.94	0.0623	0.925	0.0352	0.239	0.221
18	12.26	8.05	0.0623	0.594	0.0254	0.272	0.161
19	17.42	13.05	0.0729	1.028	0.0280	0.225	0.231
20	16.39	14.39	0.0624	0.861	0.0244	0.227	0.196
Mean	14.99	11.14	0.0649	0.782	0.0257	0.254	0.194
Std. Dev.	1.860	2.382	0.0071	0.180	0.0044	0.129	0.083
C.V.(%)	12.41	21.38	10.94	22.95	17.00	50.78	43.03

APPENDIX E.1

Experiment 3 analysis of variance for TPA hardness

Dependent variable: trt

Source	DF	Sum of Squares	Mean Square	F Value[1]	p > F
cy[2]	5	314.0034	62.8007	8.10	<.0001
mc[3]	1	465.3178	465.3178	60.02	<.0001
cy*mc[4]	5	101.0633	20.2127	2.61	0.0257
Error	228	1767.6614	7.7529		
Total	239	2648.0458			
	r^2	Coeff Var	Root MSE	trt Mean	
	0.3325	14.35	2.7844	19.4013	

APPENDIX E.2

Experiment 3 analysis of variance for TPA fracturability

Dependent variable: trt

Source	DF	Sum of Squares	Mean Square	F Value	p > F
cy	5	435.6270	87.1254	13.52	<.0001
mc	1	228.5987	228.5987	35.46	<.0001
cy*mc	5	42.9732	8.5946	1.33	0.2510
Error	228	1469.7167	6.4461		
Total	239	2176.9156			
	r^2	Coeff Var	Root MSE	trt Mean	
	0.3249	16.67	2.5389	15.2349	

[1] Significant for $p<0.05$
[2] cy = freeze/thaw cycles (0,1,3,6,9, and 12)
[3] mc = initial moisture content before freezing (3.0% and 5.0%)
[4] cy*mc = interaction of freeze/thaw cycles and moisture content

APPENDIX E.3

Experiment 3 analysis of variance for TPA cohesiveness

Dependent variable: trt

Source	DF	Sum of Squares	Mean Square	F Value[5]	p > F
cy[6]	5	0.0020	0.0004	1.97	0.0836
mc[7]	1	0.0032	0.0032	15.57	0.0001
cy*mc[8]	5	0.0044	0.0009	4.29	0.0010
Error	228	0.0463	0.0002		
Total	239	0.0559			
	r^2	Coeff Var	Root MSE	trt Mean	
	0.1705	18.67	0.0143	0.0763	

APPENDIX E.4

Experiment 3 analysis of variance for TPA gumminess

Dependent variable: trt

Source	DF	Sum of Squares	Mean Square	F Value	p > F
cy	5	14.3448	2.8689	18.03	<.0001
mc	1	4.2616	4.2616	26.78	<.0001
cy*mc	5	2.0217	0.4043	2.54	0.0292
Error	228	36.2832	0.1591		
Total	239	56.9114			
	r^2	Coeff Var	Root MSE	trt Mean	
	0.3625	30.50	0.3989	1.3079	

[5] Significant for $p<0.05$
[6] cy = freeze/thaw cycles (0,1,3,6,9, and 12)
[7] mc = initial moisture content before freezing (3.0% and 5.0%)
[8] cy*mc = interaction of freeze/thaw cycles and moisture content

APPENDIX E.5

Experiment 3 analysis of variance for TPA resilience

Dependent variable: trt

Source	DF	Sum of Squares	Mean Square	F Value[9]	p > F
cy[10]	5	0.0004	0.0001	1.78	<.1180
mc[11]	1	0.0018	0.0018	37.77	<.0001
cy*mc[12]	5	0.0009	0.0002	3.62	0.0036
Error	228	0.0109	0.00005		
Total	239	0.0140			
	r^2	Coeff Var	Root MSE	trt Mean	
	0.2211	21.61	0.0069	0.0320	

APPENDIX E.6

Experiment 3 analysis of variance for TPA springiness

Dependent variable: trt

Source	DF	Sum of Squares	Mean Square	F Value	p > F
cy	5	0.0720	0.0144	3.91	0.0020
mc	1	0.8808	0.8808	239.09	<.0001
cy*mc	5	0.0460	0.0092	2.50	0.0317
Error	228	0.8399	0.0037		
Total	239	1.8387			
	r^2	Coeff Var	Root MSE	trt Mean	
	0.5432	20.98	0.0607	0.2892	

[9] Significant for $p<0.05$
[10] cy = freeze/thaw cycles (0,1,3,6,9, and 12)
[11] mc = initial moisture content before freezing (3.0% and 5.0%)
[12] cy*mc = interaction of freeze/thaw cycles and moisture content

APPENDIX E.7

Experiment 3 analysis of variance for TPA chewiness

Dependent variable: trt

Source	DF	Sum of Squares	Mean Square	F Value[13]	p > F
cy[14]	5	1.8579	0.3715	13.81	<.0001
mc[15]	1	3.4416	3.4416	127.90	<.0001
cy*mc[16]	5	0.0856	0.0171	0.64	0.6720
Error	228	6.1353	0.0269		
Total	239	11.5204			
	r^2	Coeff Var	Root MSE	trt Mean	
	0.4674	41.83	0.1640	0.3921	

[13] Significant for $p<0.05$

[14] cy = number of freeze thaw cycles (0,1,3,6,9, and 12)

[15] mc = initial moisture content before freezing (3.0% and 5.0%)

[16] cy*mc = interaction of freeze/thaw cycles and moisture content

VITA

Bernadeth Bidarimurti Surjadinata

Candidate for the Degree of

Master of Science

Thesis: EFFECT OF INITIAL MOISTURE CONTENT BEFORE FREEZING AND THAWING RATE ON PECAN TEXTURE DETERMINED BY INSTRUMENTAL TEXTURE PROFILE ANALYSIS (TPA) AND SENSORY EVALUATION

Major Field: Biosystems Engineering

Biographical:

Personal Data: Born in Jakarta, Indonesia, on July 15, 1976, the daughter of Djohan Surjadinata and Elisabeth Nuryta Angkola.

Education: Graduated from Bunda Hati Kudus High School, Jakarta, Indonesia in May 1994; received Bachelor of Science degree in Biosystems Engineering from Oklahoma State University, Stillwater, Oklahoma in May 1999; completed the requirements for the Master of Science degree with a major in Biosystems Engineering at Oklahoma State University in December 2000.

Experience: Employed by the Biosystems and Agricultural Engineering Department at Oklahoma State University in Stillwater, Oklahoma as a research assistant, 1998 to present.

Professional Memberships: Tau Beta Pi, Gamma Sigma Delta, Alpha Epsilon, Pi Eta Sigma, Golden Key, Institute of Food Technologists, American Society of Agricultural Engineering.