APPLICATION OF AN ANALYTICAL METHOD TO MEASURE TEXTURE OF PECANS

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APPLICATION OF AN ANALYTICAL METHOD TO

MEASURE TEXTURE OF PECANS

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CHAPTER I

INTRODUCTION

Pecans are an important crop in Oklahoma as well as many other Southern states. They have a mild nutty flavor and crisp texture that compliments a variety of foods. The quality of the pecans can greatly affect their salability. Factors that affect pecan quality include color, odor, flavor, and texture. Despite their importance as a crop, little research has been done regarding the texture of pecans. It is widely accepted that moisture content, oil content, and other factors may affect texture of nuts and grains. In addition, new processes under development such as supercritical fluid extraction of oil may have an effect on texture. For this reason, having a sensitive and repeatable way to quantify pecan texture parameters is desirable.

Pecans, available in many varieties, are all members of the walnut family. Pecans are true nuts; botanically, a nut is a fruit seed enclosed in a leathery or woody covering, the pericarp, from which it is usually separable (Grolier, 1993). Only one seed is contained in the pericarp. While the food industry may consider a shelled pecan kernel to be "one pecan", it is actually only half of one seed.

Texture is one of several physical properties of food that are important for consumer acceptance. Consumers usually relate texture closely to freshness and quality. While off-colors and smells may indicate a spoiled food, bad texture may only indicate that a food is less desirable, not that it is dangerous or unfit for consumption (Szczesniak, 1990). For this reason, texture has traditionally been less important than other properties.

Recently, consumers have started to demand and expect better texture from their foods. In response to this, food producers and processors have become more aware of texture.

Food texture can be determined in several ways depending on the nature of the food sample. Liquid foods can be subjected to any number of different types of viscosity measurement techniques. These techniques include capillary, orifice and rotational viscometers. Each method has its own strengths and weaknesses and each can give the experimenter slightly different information about the sample. One challenge associated with the measurement of fluid samples is that they are substantially affected by temperature. For solid foods, most instruments use some combination of a loading mechanism and a force measuring system. These systems can range from the most simple hand operated puncture force tester to a "universal testing machine" or *Instron* which is mechanically driven and has highly accurate load and position sensors.

Texture Profile Analysis (TPA) is an instrumental food analysis method that utilizes the universal testing machine and is designed to quantify food texture parameters. It was shown by Ocón et al., 1995 to be suitable for pecan texture evaluation and separating the properties of several cultivars of pecans. The method is commonly performed using a universal testing machine although it was originally developed for the General Foods Texturometer (Rao and Rizvi, 1995). The method generates values for up to seven parameters that describe food texture.

CHAPTER II

LITERATURE REVIEW

Pecan Moisture

Moisture content of pecans is monitored and adjusted at various stages of pecan processing. After pecans are harvested, they are dried in their shell to approximately 4.5% wet-basis moisture content to preserve quality. Prior to shelling, pecan moisture is raised from a storage condition of about 4% to about 8% to reduce breakage caused by the sheller (Santerre, 1994). After shelling, the pecan kernels must be dried quickly to preserve consumer quality. If moisture content is not reduced sufficiently, pecans are susceptible to mold and bacteria growth. The optimum storage moisture content for shelled pecans is 3.0-4.0%. If pecans are too dry (below 2.0%), cracks can develop on the surface of the pecans and this can permit oxygen to penetrate deeper into the pecan and speed oxidation. Excessive drying also pulls oils to the surface where it is even more susceptible to oxidative rancidity. This can reduce the shelf life and quality of pecans. Although the wet basis moisture content is usually used to describe pecan water content, water activity is the main determining factor for mold and bacteria growth (Santerre, 1994). Water activity is harder to quantify since it depends on both the water and lipid (oil) content of the pecans. Water activity is the ratio of the vapor pressure of the food sample to the vapor pressure of pure water (Jelen, 1985). The higher the number, the more water is available to molds and bacteria. Since most spoilage bacteria will not grow below a water activity of 0.90, pecans are usually safe from bacterial spoilage (Jelen, 1985). However, pecans must have a water activity below 0.68 to prevent mold growth.

Depending on the oil content of the pecan, this corresponds to a moisture content of 4.5 to 5.7%(Santerre, 1994).

Pecan Storage and Rancidity

Shelled pecans can be stored at room temperature for short periods of time. However, extended storage can adversely affect pecan quality. Rancidity is the most apparent quality loss parameter associated with storage. Rancidity is the oxidation of the oil contained within the pecan. Pecans contain approximately 70% oil by weight and 90% of this oil is unsaturated (Santerre, 1994). Unsaturated lipids are far more susceptible to oxidation than are saturated lipids.

Several approaches have been tried to increase pecan shelf life. Reducing temperature to below -20°C has been shown to stop quality degradation for up to 25 years (Santerre, 1994). From a consumer's standpoint, freezing is a good way to keep fresh pecans on hand year round. Commercial freezing is a relatively expensive and energy intensive storage method and it is not always practical. In addition, when removed from cold storage, pecans have a tendency to absorb water that condenses on the thawing kernels. When pecans are used in cookies or breakfast cereals, other methods of extending shelf life are necessary.

Another way to reduce rancidity is to reduce the available oxygen. Several methods of limiting oxygen exposure have been examined. One of these methods involved flushing the container before sealing with a reduced oxygen gas mixture. Alternative fill gases that have been researched are nitrogen and carbon dioxide. Storage in vacuum and applying edible coatings have also been examined for their effects on rancidity rates.

Since rancidity is caused by the oxidation of oil within the pecan, a pecan with less oil could potentially be less susceptible to rancidity. Reducing the oil in pecans has recently become of interest for health reasons. A lower fat pecan could potentially be more acceptable to consumers who are trying to reduce the calories and fat in their diet. If reduced oil and extension of shelf life can be shown to be attainable, a "premium" pecan could be marketed that met both of these criteria. Assuming the problem of rancidity in extended room temperature storage of pecans can be overcome, other pecan property changes may become more pronounced or noticeable after a long storage time. Texture is one such quality parameter that may be affected by extended storage. Also, the packaging or oil reduction method itself might have an impact on pecan quality.

Food Texture Analysis

Texture is an important physical property exhibited by all foods, whether solid or fluid. However, it is not a concept that is easy to define. Bourne (1982) collected definitions of texture from a number of sources and generated a list of themes that are commonly associated with texture. These themes included the following partial list of ideas.

1. Texture is a group of several physical properties that derive from the structure of the food.
2. Texture is under the mechanical or rheological subheading of food physical properties.
3. Texture is detected by the human sense of touch (Bourne, 1982).

A much simplified definition states that food texture "is how a food feels in the mouth on manipulation and mastication, and how it handles during transport, preparation and on the plate"(Szczesniak, 1990).

Analysis of texture has traditionally taken one of two distinct paths; "sensory" and "objective" evaluation (Giese, 1995). Sensory analysis involves the use of human subjects, usually in the form of a taste panel, who are asked to evaluate the food sample based on their senses of touch, smell, taste, and sight. Objective analysis uses instruments to measure specific physical attributes of food samples. Each of these methods has distinct advantages and disadvantages. Sensory data are useful in determining preferences for different foods. For example, taste panels are good at performing comparative tests and detecting differences between samples. In addition, taste panels can often tell which food sample has the best combination of texture parameters to give the optimum quality. However, the use of taste panels in texture evaluation is difficult to standardize and is frequently subject to bias (Lees, 1975). Humans are not good at assigning food samples a value on an absolute scale. Taste panel participants may also require extensive training before they can accurately describe or quantify the food properties that they can sense. To take advantage of the strengths of a taste panel trial, sensory tests are often established to allow participants to rank food samples for several independent parameters.

Objective data have the advantage of increased repeatability, sensitivity and precision since the properties are measured by instruments instead of humans. However, it can be difficult to draw practical conclusions from objective data. For example, unless people can tell the difference in the hardness between two groups of pecans, it is of little value to have an instrument that can measure this property.

In the food industry, objective tests are often used for quality control of their product. A taste panel may be used to initially develop the product based on peoples expectations and preferences for that food, but once the ideal properties are determined, instruments can monitor the product more effectively on a day-to-day basis.

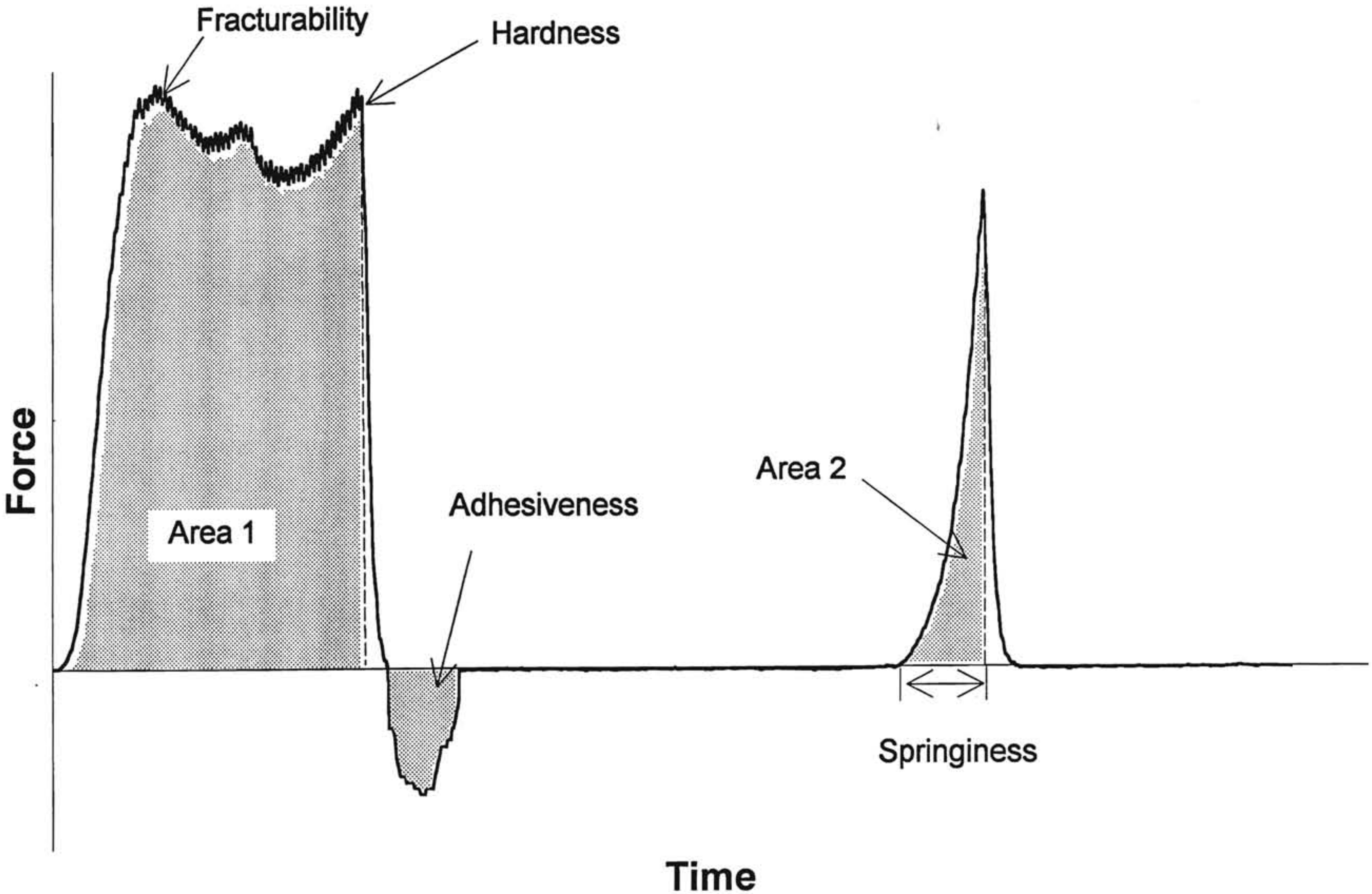
Most of the current tests that are available to measure physical properties were developed by engineers and scientists to evaluate construction materials. Many of these tests can be conducted with a universal testing machine which can apply any one of many different loading conditions. Depending on the physical attributes to be evaluated and the nature of the sample, compression, tensile, bending, shear, and cutting tests are examples of loading conditions that can be performed by an *Instron*. These tests usually are performed with loads less than initial failure of the material. This differs from food texture evaluation where the investigator is equally interested in the properties after the initial failure. According to Bourne (1982), "food texture measurement might be considered more a study of the *weakness* of materials rather than the strength of materials." While the same measuring instruments can be used for materials science and food texture evaluation, different methods of analysis are often used to determine texture. Texture Profile Analysis is one such method.

Texture Profile Analysis

Texture Profile Analysis was developed by scientists at the General Foods Corporation Technical Center (Bourne, 1982). They compressed, in a General Foods Texturometer, a bite-sized piece of food two times to the same compression point to generate a curve for force versus time. From this curve, seven texture related parameters were calculated. Since two complete compressions were used, the test was more sensitive than a simple compression test to the properties of the sample after its initial failure or deformation. The Universal Testing Machine (*Instron*) was adapted to perform TPA by M.C. Bourne in 1968 (Breene, 1975). Bourne (1968) describes the changes necessary to apply the universal testing machine to TPA. When areas were computed, only the compression portion of the curve was used and the area under the decompression portion was excluded. When the texturometer was used, the entire curve area was computed. Operational differences in the two machines produced force-versus-time curves of different shape but the concept remained the same. The GF Texturometer has jaws that are driven by an eccentric wheel. This imparts a sinusoidal motion to the jaws which are on a lever and fulcrum arrangement. Since the jaw speed slows as the maximum compression distance is reached, the curves generated by the GF Texturometer tend to have rounded peaks (Bourne, 1968). In contrast, the crosshead of a universal testing machine is driven by lead screws at a constant speed. At the end of a compression stroke the crosshead abruptly stops and can reverse direction. This is sometimes referred to as "rectilinear" motion. The resulting force-versus-time curve usually has sharper peaks and steeper slopes than the curve from a texturometer. The use of each instrument has its own advantages and disadvantages. The sinusoidal movement of the Texturometer more accurately imitates the natural chewing action of the mouth. However, since the speed is not constant, units of area and displacement are nonlinearly related to time. Use of the universal testing machine allows for linear conversion from time to displacement units. Therefore, areas under the curve are true measures of work energy (Bourne, 1968).

The texture parameters with relevant areas and points are obtained from a TPA curve shown in Figure 1. Hardness is the maximum force obtained in the first

Figure 1: General TPA force versus time curve.



compression stroke. Fracturability is the force at the first significant break point in the first compression stroke. Identifying the significant break point is a subjective determination as to what is or is not significant. Cohesiveness is defined as the area under the second compression stroke (Area 2) divided by the area under the first compression stroke (Area 1). Springiness is the distance that the specimen recovers in the time between the first and second compression strokes. Although shown on the graph in units of time (seconds), springiness is usually converted to length units for analysis. Adhesiveness is the negative area between the first and second compression strokes. Adhesiveness is a significant parameter for foods such as peanut butter which tend to stick to solid surfaces. Chewiness and gumminess are obtained from combinations of the other parameters. Gumminess is the product of hardness and cohesiveness. As measured by taste panel tests, it is designed to represent the "denseness that persists through mastication" (Bourne, 1982). Chewiness is the product of hardness, cohesiveness, and springiness. It is adapted from a taste panel parameter defined as the number of chews or the time to chew a food sample before swallowing (Bourne, 1982). Table I shows the units of the TPA parameters derived from a compression test on a Universal Testing Machine.

TPA was originally designed to correlate with human taste panel testing. Szczesniak (1962) tested this correlation by having nine taste panel members rank 5 to 9 different foods for the following TPA parameters; hardness, brittleness (now called fracturability), chewiness, adhesiveness, and gumminess. All of these parameters showed a good linear or curvilinear relationship between the instrument's output and the sensory ratings. The conclusions stated that the taste panel was able to distinguish between and

Table I: TPA parameters, variables and dimensions as described by Bourne, 1982.

Parameter	**Measured Variable**	**Dimensions**
Hardness	Force	mlt^{-2}
Cohesiveness	Ratio of areas	Dimensionless
Springiness	Distance	l
Adhesiveness	Area	ml^2t^{-2}
Fracturability	Force	mlt^{-2}
Chewiness	Area	ml^2t^{-2}
Gumminess	Force	mlt^{-2}

quantify the mechanical parameters and that the objective methods were able to measure the same intensity of textural characteristics as those perceived by the taste panel. Therefore, the assumption was made that TPA was an acceptable method of quantifying food texture.

Pecan Texture Analysis

Ocón et al (1995) examined several ways of determining pecan texture differences with cultivar. Comparisons were made between instrumental and taste panel tests. All instrumental methods made use of the universal testing machine. Specific tests included a 50% compression, TPA, puncture, and bending. The results showed that compression, TPA, and puncture were suitable to measure texture. Bending was unable to reliably detect pecan texture differences when the other methods detected statistical differences. Puncture and compression tests provided only one parameter (peak force) to describe texture. TPA had several parameters that describe different aspects of pecan texture. This meant that the TPA procedure allowed for more flexibility in the analysis of data because parameters could be included or deleted based on the goals of the experiment.

Objectives

This experiment was conducted to examine pecan texture under a variety of conditions using texture profile analysis (TPA). The goals for this experiment were as follows:

1. Show that TPA can measure pecan texture differences and if so, determine which are the best parameters.
2. Determine if vertical or horizontal placement of the sample in the universal

testing machine produces any differences in texture parameters.

3. Determine if pecan moisture content has an effect on texture.

4. Determine if pecan oil removal has an effect on texture.

5. Determine if there were detectable texture changes over storage time.

6. Determine any texture changes due to oxygen concentration in bags during storage.

Experimental Design

For this experiment, TPA was used because it provides several parameters to describe texture. The test method followed the general procedure described by Ocón et al., 1995. The independent variables or treatments in this experiment were pecan moisture content, oil content, storage time, and storage gas. All of these were examined for their effect on pecan texture. Analysis of variance and Duncan's multiple range test were used to indicate statistical differences.

CHAPTER III

MATERIALS, EQUIPMENT, AND METHODS

Pecan Kernels

Pecan halves were obtained from commercial growers in Oklahoma and hand sorted to remove any broken or damaged kernels. Experiments were designed with different treatments to induce what was expected to be differences or changes in texture. One set of experiments involved manipulation of moisture content using a combination of desiccant and environmental chambers. One experiment involved creating pecans with four different levels of oil content. A third experiment involved storing untreated and reduced oil pecans for 9 months in sealed bags filled with three different oxygen levels. . In each experiment, pecans were chosen from the same cultivar and harvest. After harvest they were kept frozen until the start of the experiment.

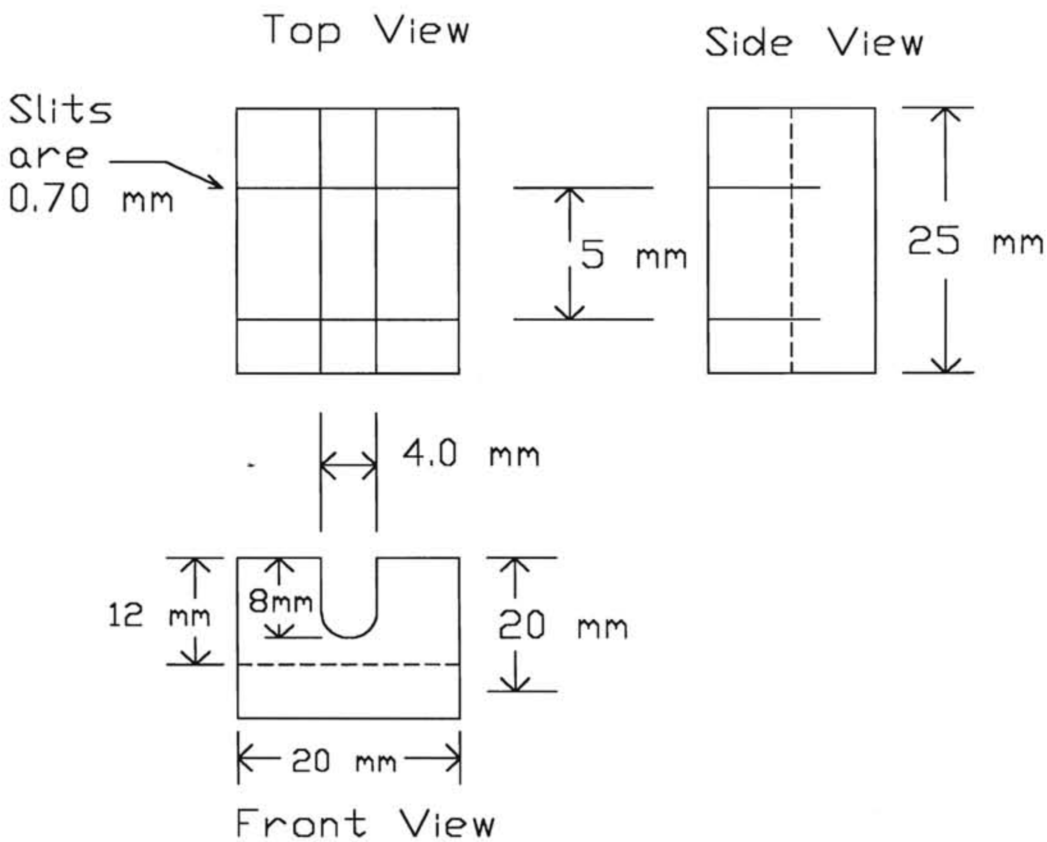
Texture Analysis

Texture Profile Analysis (TPA) used for texture analysis of the pecan samples was similar, but with a few minor changes, to the method described by Ocón et al, 1995. A different procedure was used to remove a core sample from the pecan. The cork borer was inserted lengthwise through one side of the pecan. Ocón et al (1995) inserted the cork borer perpendicular to a pecan half that was placed on a flat surface. This change was made because the native pecans used in this experiment were not "thick" enough to obtain a 5.0 mm tall cylinder with the perpendicular sampling procedure. The second major change was made to the orientation of the pecan cylinder in the universal testing machine. Ocón et al (1995) placed the samples in the machine horizontally with the longitudinal axis of the sample. This is not the standard loading position for a compression-type test. In this experiment, the samples were oriented vertically so that the compression plates of the machine pressed against the flat surfaces of the pecan cylinder.

Pecans being a biological material vary in size, geometry, and other physical properties. Since the goal of this experiment was to test for pecan texture differences after a variety of treatments, the ideal test would minimize the effects caused by natural variability. Alternative methods of testing could have used an intact pecan half subjected to a variety of different loading conditions. These conditions included flat plate compression, snap bending, puncture, and shear loading test. All of these options have the advantage of minimal sample preparation time but introduce the added unknown of sample shape and compression area. Ocón et al (1995) results showed there was less variability due to size and geometry when testing a core sample of ideal geometric shape. It was decided that the extra effort necessary to remove a core sample was justified. The chosen method compressed a pecan core sample between two parallel plates. This required the additional step of removing the sample from a pecan half. A core sample was removed from each pecan half using a #1 sized cork borer. The pecan was placed on a flat surface and held with one hand while the cork borer was pushed through the pecan lengthwise. This produced a cylinder the length of the pecan with a 3 mm diameter. An aluminum trough (Figure 2) was constructed to hold this cylinder and razor blades were used to cut it to a standard 5-mm length.

Ocón et al, 1995, placed the cylindrical sample horizontally into the universal testing machine. Although most cylinder compression tests are performed with the cylinder oriented vertically. The first experiment (ORT-MC) was used to determine if

Figure 2: Schematic of trough used to cut pecan samples to a standard length.



horizontal or vertical orientation produced different results along with testing for moisture content effect.

Equipment

The instrument used to conduct the TPA experiments was an *Instron* model 1122 Universal Testing Machine (Instron, Canton, MA) with an *Instron* 50 kg compression load cell. A personal computer, linked to the machine, controlled the crosshead movement and collected data on-line. This was accomplished by using the software program "TestWorks for Windows" (Sintech, Research Triangle Park, NC). Equations were written for TestWorks that converted the 1000 digitized data points from the force versus time curve into six standardized TPA parameters. The data were then manipulated using a spreadsheet and analyzed for statistical significance using SAS. A test weight of 5.00 lb. (2.27 kg) was used at the start of each test day to check proper calibration of the load cell.

TPA Test Procedure

The cylindrical core sample of 5 mm height and 3 mm diameter was inserted vertically into the universal testing machine. The first moisture content experiment (ORT-MC) was replicated using horizontal sample orientation. The crosshead of the machine was lowered until the top plate just touched the pecan sample. The sample was compressed between two parallel plates at 1.0 cm/min. To obtain 50% compression, in vertical sample orientation compression distance was 2.5 mm and 1.5 mm for horizontal sample orientation. The top plate lost contact with the sample for about 20 seconds and so after the first retraction step no additional waiting time was allowed between the end of the first move segment and start of the second segment. Including a longer waiting time might have allowed the pecan sample to recover more of its original height which would have lead to higher values of springiness and possibly cohesiveness.

Standardization of TPA Procedure

A test was designed to examine the TPA method to ensure that it could be standardized and repeatable. Due to natural variability of biological materials, a sample of man-made material was needed that is more homogenous to produce repeatable results. A small steel compression spring was chosen to represent a predictable, repeatable sample. The selected spring had approximately the same force magnitude (1.5 kg at 2.5 mm of compression) as was expected for most pecan samples. The plates of the universal testing machine were first brought together until they just touched the spring to remove any "slack" in the spring. The force versus time curve generated by the spring was converted into six TPA parameters for examination of the TPA method. Theoretically, a spring has a linear force-to-compression relationship and no hysteresis between compression and decompression strokes. By examining the definitions for the six TPA parameters used in this study, several expectations can be made for an ideal TPA procedure performed on a spring. First, the maximum force for the first and second compressions should be the same. Second, cohesiveness (the ratio of the second compression area divided by the first compression area) should have a value of 1.0 since the spring is not permanently deformed. Fracturability should have a value of 0.0 since the plot of the first compression should be linear. Finally, since the spring is not permanently deformed, springiness should have a value of 2.5 mm which is the complete compression distance. Gumminess and chewiness are products of previous parameters so there is no obvious predictable value for them.

Figure 3 shows the force versus time curve for a spring including all 1000 data points. As expected, all compression and decompression strokes are linear. Any noise or background interference with the signal appeared to be insignificant in magnitude. The values for the maximum force on the first and second compressions were very similar (1.449kg and 1.446kg respectively with a 0.21% difference). The measured cohesiveness value was 0.997 compared to the theoretical value of 1.0. Measured springiness was 2.504mm compared to an ideal of 2.50mm and, fracturability was measured to be 0.0kg, the same as the ideal. All of these values indicate that the TPA method and the equipment used is a good choice to measure texture. The spring test was conducted at the beginning of each test day to assure proper calibration of the equipment and operating methodology.

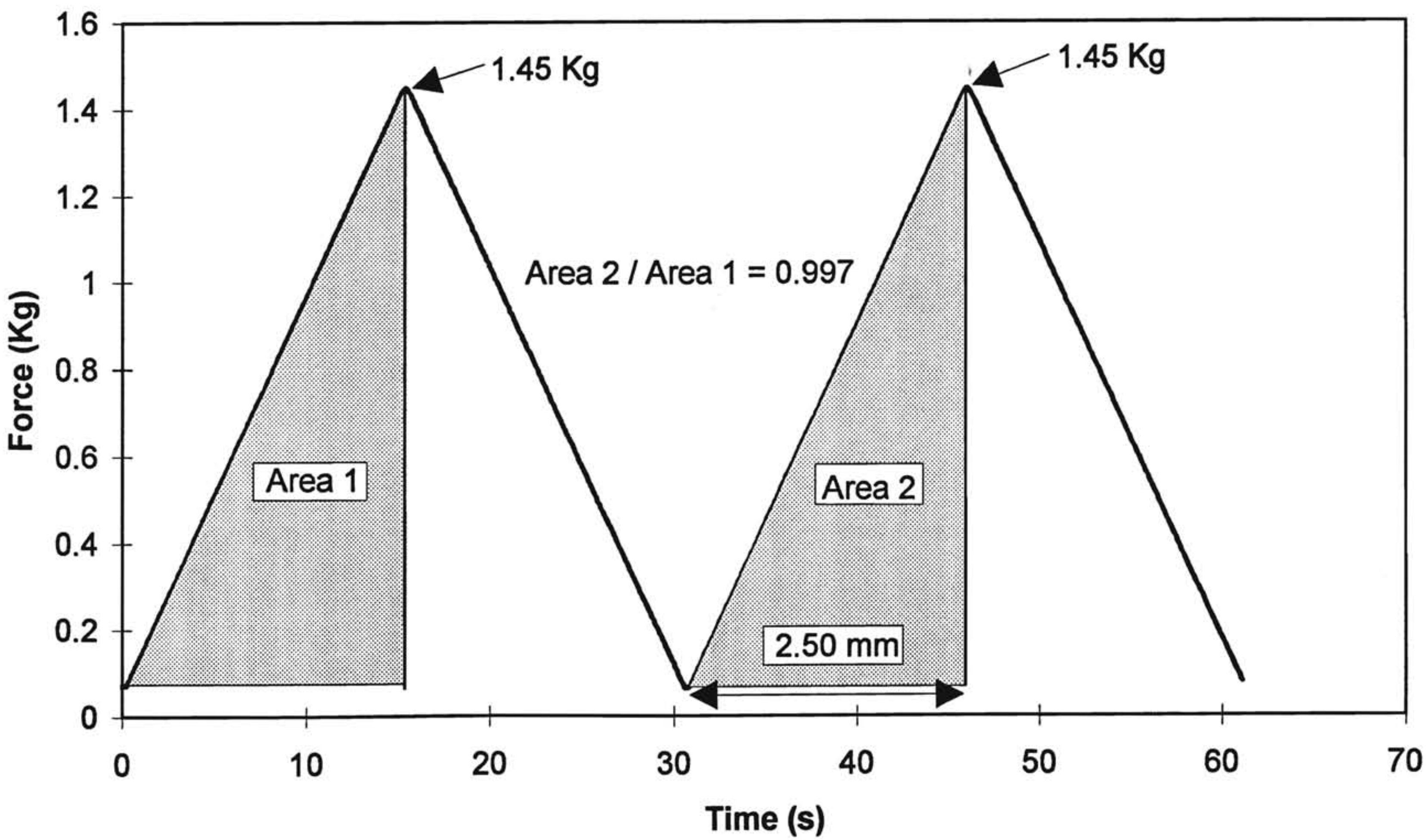
Sample Preparation Procedures

Four separate experiments were conducted to prepare pecan samples for the TPA procedure described above. Each experiment had independent unique sample preparation procedures.

<u>Moisture Content and Orientation Experiment (ORT-MC) using Stuart Pecans:</u>

The first step in this experiment was to achieve pecans with a range of moisture contents. The common moisture content for shelled commercial pecans is 3.0% to 4.0%(Santerre, 1994). The desired moisture range for this experiment would include pecans both above and below this level. The initial moisture content of the batch of pecans obtained from a local supplier was determined using an oven drying method.

Figure 3: TPA method performed on a spring to evaluate the testing method. Both compression strokes were 2.5 mm.



A tray of pecan halves of known weight was dried in an oven at 130 ± 3°C for six hours. The remaining pecans were divided into six trays and the weight of pecans in each tray was recorded. Two environmental chambers, one at 29°C and 95% humidity and the other at 24°C and 55% humidity and a desiccating chamber were used to force the pecans to the desired moisture content in a timely manner. The moisture content was determined based on the weight change of each batch of pecans. Once a suitable moisture content range was achieved, the pecans were sealed in Zip-Loc™ freezer bags and allowed to equilibrate for 24 hours before testing. Fifteen pecans from each moisture level were tested in vertical and in horizontal orientation. This resulted in a 2 by 6 factorial experiment (two sample orientations by six moisture levels).

Moisture Content # 2 Experiment (MC2) using Wichita Pecans:

A single batch of Wichita pecans was obtained from a local supplier and hand sorted to remove any broken pieces. In the previous experiment, the final moisture content before testing was approached from the adsorbing (adding moisture) or desorbing side (removing moisture) depending on the desired endpoint. This experiment was designed to approach the final moisture content only from the adsorbing direction. This was done to eliminate any unknown hysteresis effects on texture caused by approaching the final moisture from different directions. The same oven drying procedure as in the ORT-MC experiment (130 ± 3°C for 6 hours) was used to determine the initial moisture content of the pecans. Weight changes of trays over time in an environmental chamber set at 29°C and 95% humidity were used to estimate the final moisture content. Pecans to be tested at lower moisture contents were stored in the chamber for only a few minutes before being sealed in Zip-Loc™ freezer bags. Samples held in the chamber for a few hours reached moisture contents of 5% to 6% MC and the highest moisture content pecans were stored in the chamber for up to 24 hours. To verify this moisture content, samples from each tray were oven dried following TPA evaluation. Fifteen kernels were tested from each tray after a 24-hour tempering period in Zip-Loc™ freezer bags.

Oil Level Experiment using Native Pecans:

Supercritical carbon dioxide fluid extraction was used to reduce the oil content of native pecans. Different oil contents were attained by varying the time of the extraction process. TPA was performed on 15 kernels from three reduced oil levels plus a non-extracted group which was used as a control. A SPE-ED™ model 680 bar supercritical CO_2 extraction unit by Applied Separations (Allentown, Pa) was used to reduce the oil content of the pecans. A 300 ml extraction vessel (Thar Designs, Pittsburg, PA) was used to hold the pecans in the supercritical environment. A vessel temperature of 75°C, pressure of 62.0 MPa, flow rate of CO_2 of 2.0 to 7.5 standard liters per minute, and a extraction time from 60 to 275 minutes were used to lower oil content (Alexander, 1996). After extraction, the pecans were sealed in Zip-Loc™ freezer bags and refrigerated until texture analysis was performed. To determine the initial oil content of the pecans, a quantitative extraction was used that followed the procedure described in Maness et. al. (1995).

Modified Atmosphere Storage Experiment using Native Pecans:

A single cultivar of native pecans obtained from a commercial supplier (Young) was hand sorted to remove any broken or damaged kernels. They were then frozen in plastic liners at -20°C until the start of this experiment. They were brought out of the freezer and placed above a desiccant for 4 days. Half of the pecans were extracted using supercritical fluid extraction. The pecans were extracted for 2 hours using a SFE-703 extraction unit (Dionex Corporation, Sunnyvale, California) using the following procedure. Eight pecan halves were placed into each of four 50 ml extraction vessels. The oven extraction temperature was 40°C and the 500 ml/min. restrictor temperature was 150°C. The vessels were pressurized to 250 atm for 2 minutes and then pressurized to 500 atm for another 2 minutes before being brought up to the full extraction pressure of 680 atm for 120 minutes. The flow rate of CO_2 flow through the vessel was 1000 ml/min of expanded gas. Throughout all of the extractions, the total flow volume ranged from 120 to 145 liters. Quantitative oil extraction (Maness et. al, 1995)was used to determine the amount of oil that was removed from the pecan samples. The results indicated a 15% reduction in oil content. Because of the small capacity of the SFE equipment and the large volume of pecans required for testing, extraction took place over 2.5 months. Following extraction, pecans were stored in bulk at -20°C in Zip-Loc™ freezer bags until a sufficient amount of pecans had been extracted to proceed with the packaging and storage of the pecans.

In preparation for storage, 30 pecans were picked from the batch, weighed, and placed in a bag for sealing. A Multivac-A316 vacuum packaging machine (Multivac, Inc., Kansas City, MO) was used to evacuate the ambient air in the bags down to 0.37 kPa and fill the bags with bottled gas (Air Products and Chemicals of Chicago, IL) consisting of 2%, 10%, or 21% oxygen with the balance of nitrogen at a pressure of 88.2 kPa before sealing the bag and returning it to ambient pressure. This replaced almost all of the ambient air in the bags with dry gas of a known oxygen content. The bags used in the study were 13 micron Saran coated Mylar (polyester) laminated to 63.5 micron polyethylene (The Packaging Group, Woodridge, Ontario) and had a water vapor permeability of 0.06 g/100 cm^2 per 24 hours and an oxygen permeability of 0.09 cm^3/cm^2 per 24 hours. The sealed area of the bags measured 10 cm by 13 cm when placed on a flat surface. There were fifteen sealed bags at each oil level and oxygen condition to allow three bags to be tested at each of five storage times from zero to 48 weeks. The bags were stored in an environmental chamber of circulating air at 75°F and 55% humidity without any light. At each 12-week interval, pecans were removed and tested for weight, texture, color and chemical composition.

The design for this experiment was a 2 by 3 by 4 factorial (two oil levels, three oxygen content levels, and four storage times) with three bags used as repetitions. It was assumed that the storage bag would have no significant effect on any texture parameter. Once this assumption is validated, storage bag will be treated as a replicate in the factorial experiment. Each factor was examined for its effect on texture. Interaction was also examined to determine if simple effects or main effects could be used for analysis. With no interaction effect, the main effects were used because they analyzed a single variable across all levels of other variables (oil level at each storage time and gas treatment). The SAS procedure "GLM" was used to perform an analysis of variance on the data.

CHAPTER IV

RESULTS AND DISCUSSION

ORT-MC Experiment

In the first experiment designed to test the effects of kernel orientation and moisture content on pecan texture, the pecans from the field had 3.0% MC before conditioning and ended at six levels ranging from 0.93% to 6.27%. Table II shows the means for 15 pecans of the TPA parameters for the vertical orientation of the sample and Table III contains the means for horizontal orientation.

The software package SAS was used to perform analysis of variance on the ORT-MC data. The SAS procedure "GLM" (general linear model) was used along with the "by" option so that each TPA parameter could be independently evaluated for both pecan specimen orientation. There were strong statistical differences ($P<0.01$) for all parameters for the vertical orientation. There were also differences for horizontal orientation for all TPA parameters except for fracturability where $P=0.29$. This lack of a significant difference could be caused by one of two situations. Either no fracturability difference was present or the texture evaluation method was not sensitive enough to detect the difference. Since the same method performed on a vertically oriented sample detected a texture difference, it is more likely that the method could not detect a real texture difference than that no texture difference was present. Duncan's multiple range test was used to rank the means of each parameter and to separate the means according to statistical difference ($\alpha = 0.05$). Statistical difference is indicated by different letters

Table II: Means of TPA parameters for ORT-MC experiment for vertical orientation of pecan samples.

Moisture Content, %	TPA Parameter Hardness kg	Gumminess kg	Chewiness kg-mm	Cohesiveness kg-mm/kg-mm	Springiness mm	Fracturability kg
0.93	1.017c*	0.096c	0.085bc	0.096c	0.882a	0.850b
1.55	0.974c	0.123ab	0.107a	0.127a	0.854a	0.432c
3.45	1.224b	0.144a	0.096ab	0.117ab	0.664b	0.264c
4.29	1.285b	0.140a	0.072cd	0.109b	0.515c	0.215c
4.97	1.259b	0.113bc	0.057d	0.090c	0.496c	0.854b
6.27	1.478a	0.092c	0.065d	0.062d	0.696b	1.438a

* means in a column with the same letter are not significantly different (Duncans, α=0.05)

Table III: Means of TPA parameters for ORT-MC experiment for horizontal orientation of pecan samples.

Moisture Content, %	Hardness kg	Gumminess kg	Chewiness kg-mm	Cohesiveness kg-mm/kg-mm	Springiness mm	Fracturability kg
	TPA Parameter					
0.93	1.034bc*	0.125c	0.066bc	0.120c	0.491a	0.639a
1.55	0.978c	0.143bc	0.074ab	0.153ab	0.515a	0.614a
3.45	1.073bc	0.174ab	0.089a	0.167a	0.511a	0.343a
4.29	1.199ab	0.180a	0.072b	0.156ab	0.397b	0.656a
4.97	1.131bc	0.166ab	0.067bc	0.147abc	0.399b	0.302a
6.27	1.363a	0.173ab	0.051c	0.126bc	0.301c	0.640a

* means in a column with the same letter are not significantly different (Duncans, α=0.05)

within columns in Table II and Table III. Chewiness and cohesiveness had more differences (a,b,c,d) for vertical than for horizontal (a,b,c) sample orientation.

To determine if vertical orientation was any "better" than horizontal orientation, the coefficient of variability (CV) was computed for both sets of data (Table IV). The CV was used because it measures variation within treatments and adjusts for differences in mean magnitude; thus allowing all of the TPA parameters to be compared directly. For all six TPA parameters computed in this experiment, the vertical orientation showed a lower CV value, 34% versus 39% for horizontal. In addition, linear slopes were computed for the relationship between the TPA parameters and moisture content. Slopes were calculated independently for both vertical and horizontal sample orientations. The slopes for each parameter and orientation are shown in Table V. The slope magnitudes for the vertical tests were higher for five of the six TPA parameters. The slope for hardness was the highest of these five. The slope for cohesiveness was 18 times higher for vertical than for horizontal. Based on the value of slope, coefficient of variability, and Duncan's multiple range test, the vertical orientation provided the best results and thus was used for the remainder of the experiments.

Although TPA can provide up to seven parameters for texture analysis, analysis would be simplified with fewer parameters. Adhesiveness was eliminated first for all experiments because negative areas between the first and second compression strokes were negligible for all pecan specimens. Also, Ocón et. al. (1995) advised that adhesiveness was not a reliable parameter to use to evaluate pecans. Each TPA parameter was plotted against moisture content as shown in figures 4 through 9. Fracturability (Figure 9) seemed to be the next worst parameter as its slope was close to 0.0 and its CV

Table IV: Coefficient of variation of TPA parameters for ORT-MC experiment. Data are separated by vertical and horizontal orientation.

	TPA Parameter					
Moisture Content, %	Hardness kg	Gumminess kg	Chewiness kg-mm	Cohesiveness kg-mm/kg-mm	Springiness mm	Fracturability kg
			Vertical Orientation			
0.926	22.1	22.4	28.3	24.3	13.4	45.5
1.545	21.4	32.8	39.4	20.3	12.3	113.3
3.45	16.6	25.3	26.1	12.7	6.9	171.6
4.29	19.9	23.4	26.5	14.0	9.7	215.9
4.97	18.9	19.4	26.2	7.2	13.4	66.1
6.27	14.1	22.2	34.4	16.3	17.1	14.5
average	18.8	24.3	30.1	15.8	12.1	104.5
			Horizontal Orientation			
0.926	21.5	44.6	46.6	36.0	30.5	71.1
1.545	40.4	35.5	36.2	25.7	8.2	99.7
3.45	18.6	13.6	16.5	20.3	6.8	147.9
4.29	20.4	17.8	21.2	26.8	10.2	100.8
4.97	17.8	30.8	36.2	27.9	13.1	149.9
6.27	20.1	29.4	24.4	20.4	15.6	100.4
average	23.1	28.6	30.2	26.2	14.1	111.6

Table V: Slopes and r^2 of TPA parameters when linearly regressed against percent moisture content for ORT-MC experiment.

TPA Parameter	Vertical		Horizontal	
	slope	r^2	slope	r^2
Hardness	0.088	0.355	0.060	0.154
Gumminess	-0.001	0.002	0.009	0.113
Chewiness	-0.007	0.189	-0.003	0.041
Cohesiveness	-0.007	0.267	0.000	0.000
Springiness	-0.058	0.400	-0.036	0.419
Fracturability	0.099	0.093	-0.018	0.004

Figure 4: Hardness versus moisture content for horizontal and vertical orientation in ORT-MC experiment.

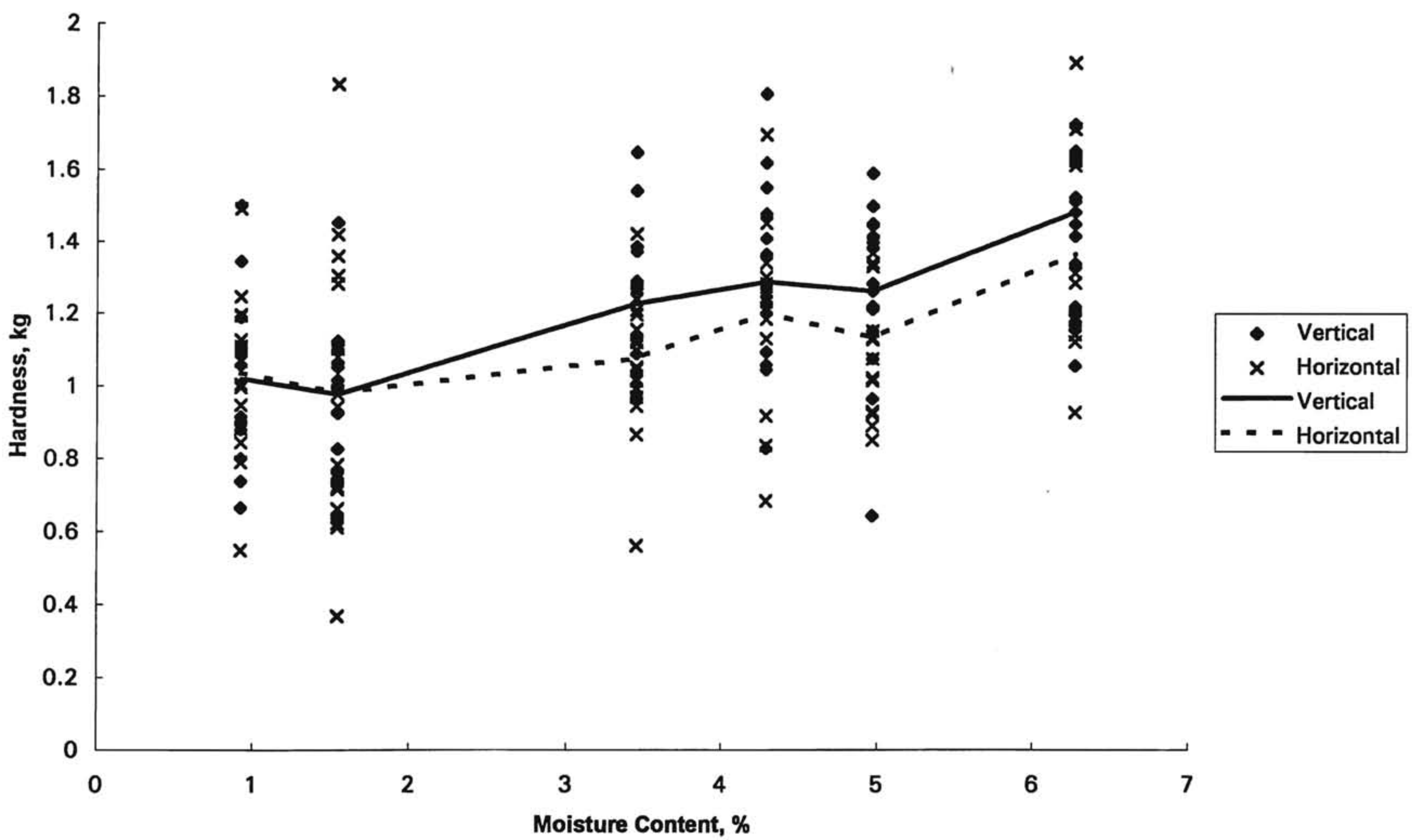


Figure 5: Gumminess versus moisture content for horizontal and vertical orientation in ORT-MC experiment.

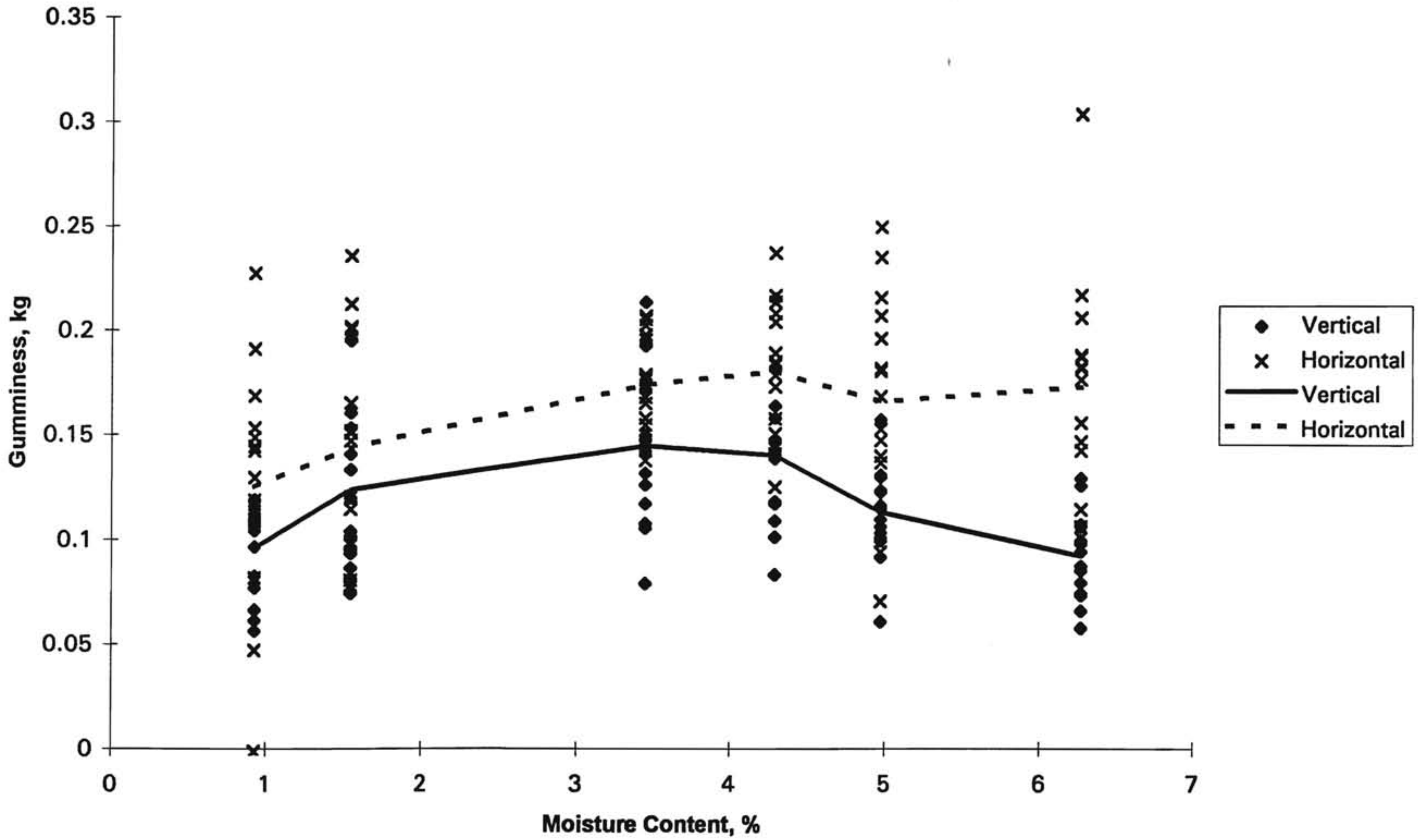


Figure 6: Chewiness versus moisture content for horizontal and vertical orientation in ORT-MC experiment.

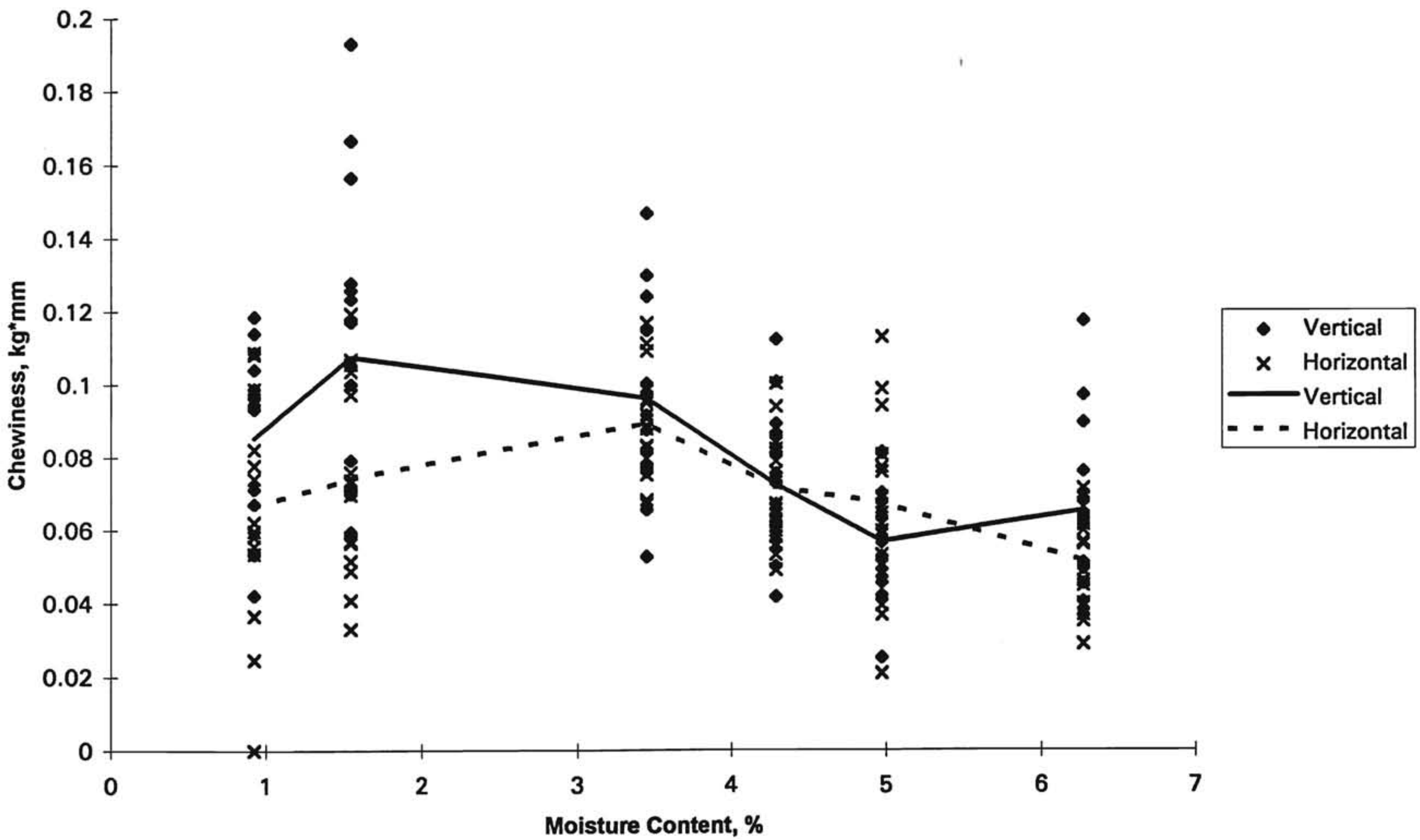


Figure 7: Cohesiveness versus moisture content for horizontal and vertical orientation in ORT-MC experiment.

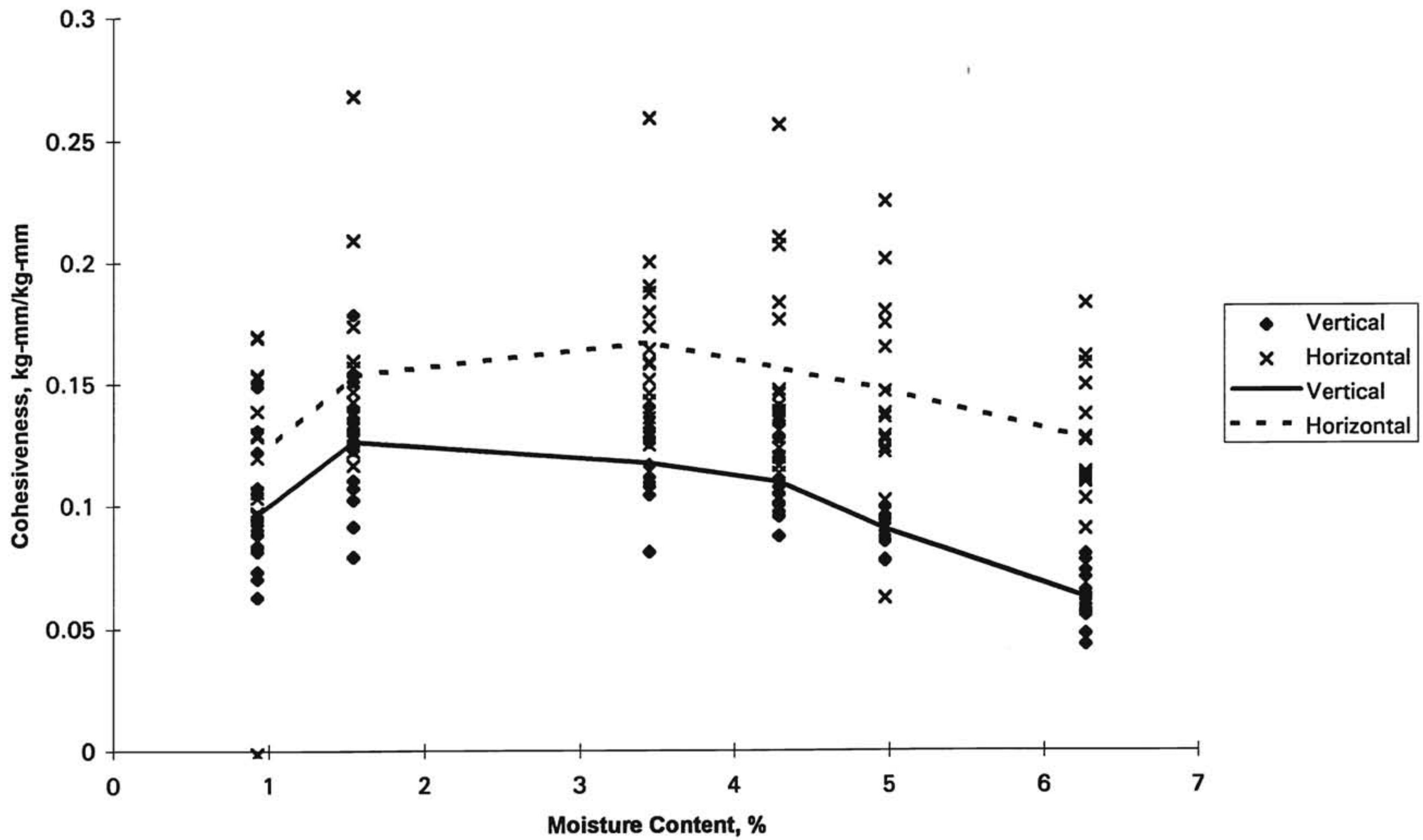


Figure 8: Springiness versus moisture content for horizontal and vertical orientation in ORT-MC experiment.

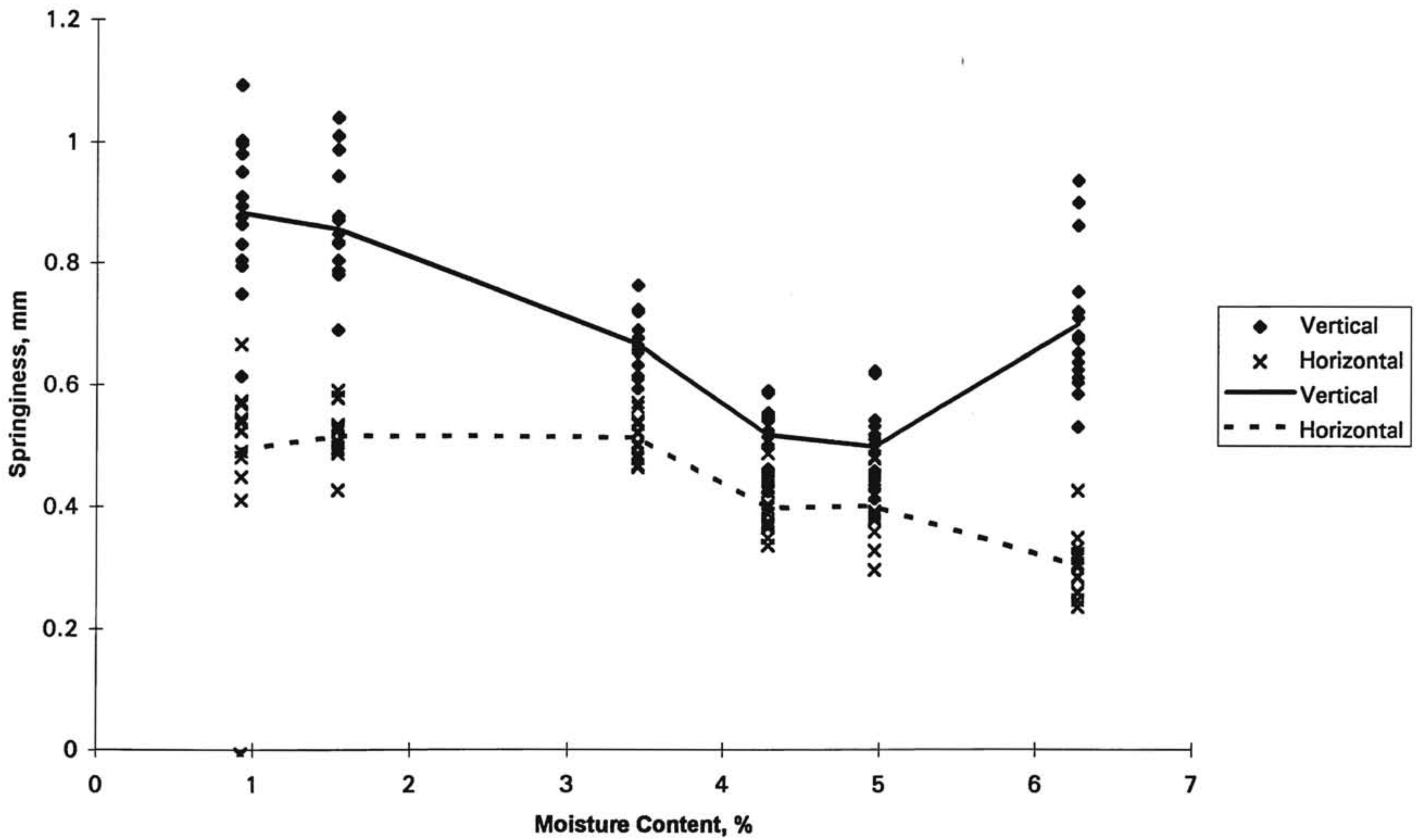
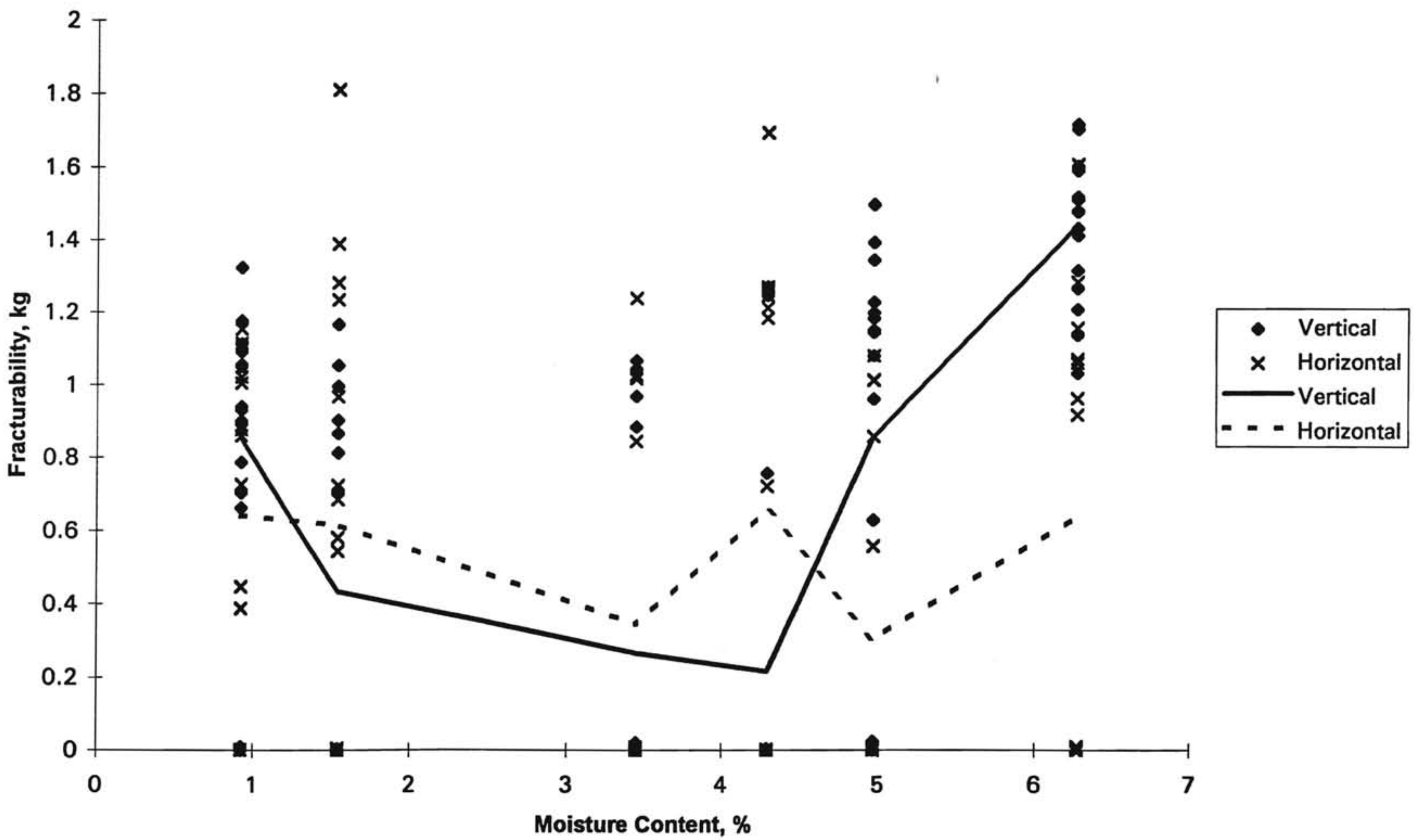


Figure 9: Fracturability versus moisture content for horizontal and vertical orientation in ORT-MC experiment.



was over 100%. In an effort to improve the analysis of fracturability, the force at the first significant fracture was replaced by the percent of pecans at a certain condition that fracture (Figure 10). In this experiment, this analysis still failed to reveal any apparent trend. The most sensitive to a change in moisture content and least variable parameters were hardness, cohesiveness, and springiness. Gumminess and chewiness were intermediate between the best and worst parameters. They had a higher variability than the best three parameters but still detected a statistical significant difference.

By examination of the graphs, certain generalizations can be drawn about pecan texture as it relates to moisture content. Only data for vertical orientation were used because this orientation had more response and less variable results than horizontal orientation. First, hardness (Figure 4) increased with increasing moisture content. Second, cohesiveness decreased (Figure 7) as moisture content increased, except at the lowest moisture level but this is well below the practical moisture level of most commercially stored pecans. Springiness (Figure 8) decreased with increasing moisture for all but the highest moisture level. While other trends may be contained in the data, these were the three that could be shown with the most certainty.

<u>MC2 Experiment</u>

In the MC2 experiment, the pecans initially had 3.5% moisture content and were raised to 4.67% to 8.08%. Each TPA parameter, for vertical orientation only, showed strong statistical difference ($P<0.01$) across the range of moisture contents. The Duncan's multiple range test was then used to separate the means according to statistical difference ($\alpha = 0.05$). Table VI shows the mean values and statistical significance of each parameter using moisture content as the independent variable. Table VII shows the coefficient of

Figure 10: Percent of pecans that fracture versus moisture content for horizontal and vertical orientation in ORT-MC experiment.

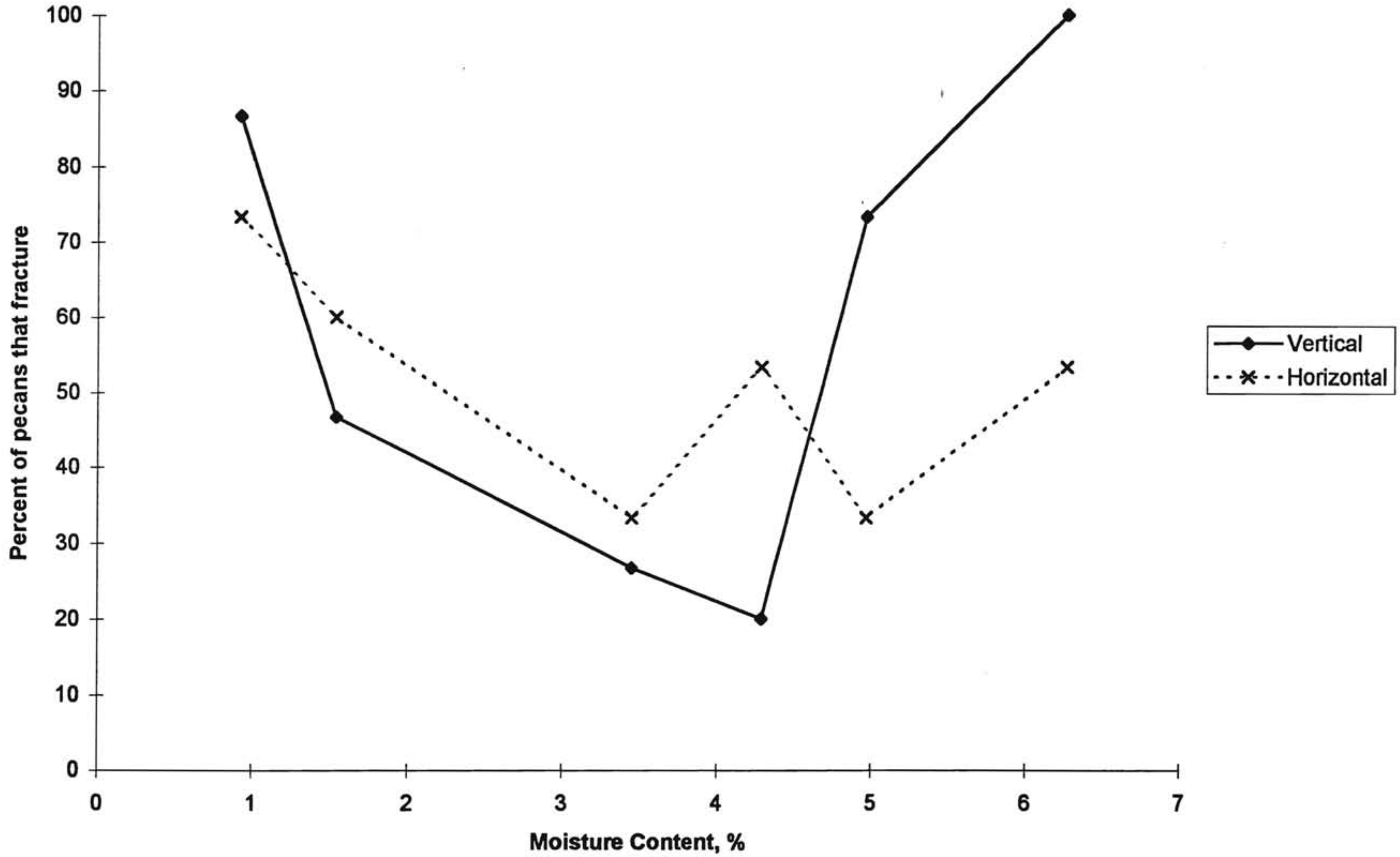


Table VI: Means of TPA parameters for MC2 experiment.

Moisture Content, %	Hardness kg	Gumminess kg	Chewiness kg-mm	Cohesiveness kg-mm/kg-mm	Springiness mm	Fracturability kg
	TPA Parameter					
4.67	1.557c*	0.164a	0.102a	0.105a	0.629a	1.072d
4.95	1.711bc	0.0166a	0.099a	0.097a	0.592a	1.089d
5.66	1.727bc	0.139b	0.071b	0.080b	0.510b	1.360cd
6.43	1.758bc	0.136bc	0.064bc	0.076b	0.476bc	1.533bc
6.94	1.867ab	0.106de	0.045d	0.057c	0.427c	1.853ab
7.84	1.992a	0.112cd	0.053cd	0.055c	0.452bc	1.979a
8.08	1.679bc	0.083e	0.040d	0.050c	0.483bc	1.63abc

* means (n=15) in a column with the same letter are not significantly different (Duncans, α=0.05)

Table VII: Coefficients of variability, linear slopes and r^2 for MC2 experiment.

	TPA Parameter					
Moisture Content, %	Hardness kg	Gumminess kg	Chewiness kg-mm	Cohesiveness kg-mm/kg-mm	Springiness mm	Fracturability kg
4.67	13.34	20.48	19.19	11.27	7.74	52.89
4.95	12.27	21.88	28.11	17.27	10.68	63.00
5.66	16.52	22.32	31.80	8.70	12.95	45.47
6.43	14.86	26.52	31.30	19.13	17.86	31.18
6.94	10.24	12.60	24.55	12.77	18.49	10.72
7.84	17.52	40.27	55.36	24.16	17.22	17.19
8.08	15.29	16.38	21.95	12.85	17.34	16.57
average	14.29	22.92	30.32	15.16	14.61	33.86
Slope	0.065	-0.022	-0. 017	-0.016	-0.046	0.235
r^2	0.390	0.416	0.494	0.715	0.338	0.263

variability of each TPA parameter and slope of the regression line with moisture content. These data were used to confirm the results of the ORT-MC experiment which showed that hardness, cohesiveness, and springiness had the lowest average coefficients of variability (14%-15% compared to 23%-34% for the other three parameters). Slope values, other than zero, for these three parameters indicate that pecan texture tends to change with moisture content.

Graphs are shown in Figures 11 through 16 of each TPA parameter versus moisture content. Cohesiveness (Figure 14) showed the strongest, most consistent trend with moisture content range. Each 1% increase in moisture decreased cohesiveness by 0.6 on the average. Springiness (Figure 15) also showed the negative-sloped trend from 4.5% to 7.0% MC. Hardness (Figure 11) increased with moisture content from 4.5% to 7.8% MC. Since only the one highest moisture level experienced a reduced hardness value, it is doubtful that this was the beginning of a new changing trend and since there were 15 replicates is unlikely caused by random error. This deviation from the general trend at the highest moisture could possibly have been caused by the moisture re-wetting process. Fracturability (Figure 16) also displayed this characteristic. All fracturability values increased as moisture content increased except at the highest moisture level. Figure 17 shows that the three highest moisture levels (7.0%-8.2%) exhibited 100% fracturability while the lower levels (4.7%-6.5%) had 70% to 80% of the pecans fractured. These results show that pecans are more likely to fracture at higher than at lower moisture contents.

Since gumminess and chewiness are multiples of other TPA parameters, their values and trends are strongly dependent on individual parameters that have already been

Figure 11: Hardness versus moisture content for MC2 experiment.

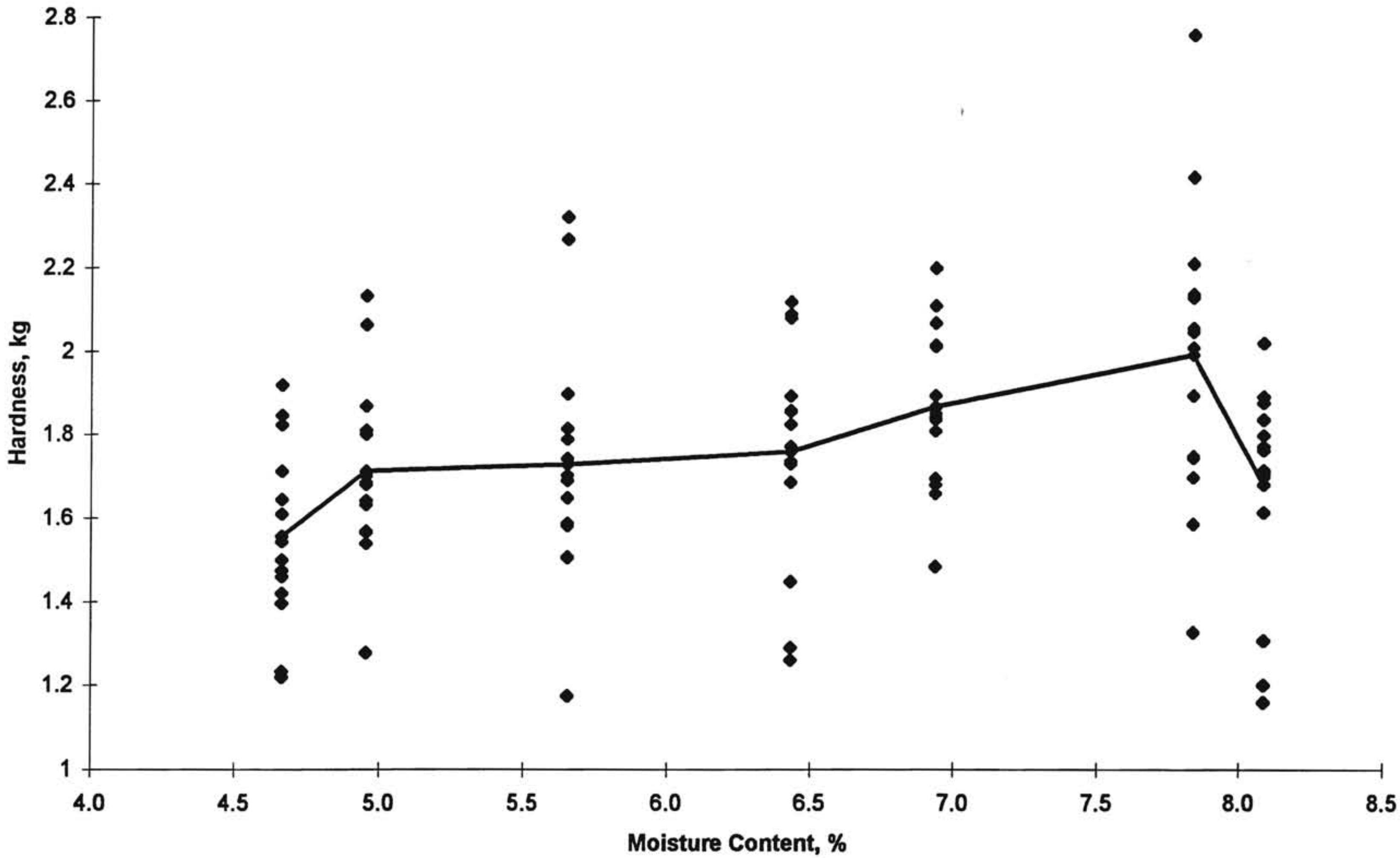


Figure 12: Gumminess versus moisture content for MC2 experiment.

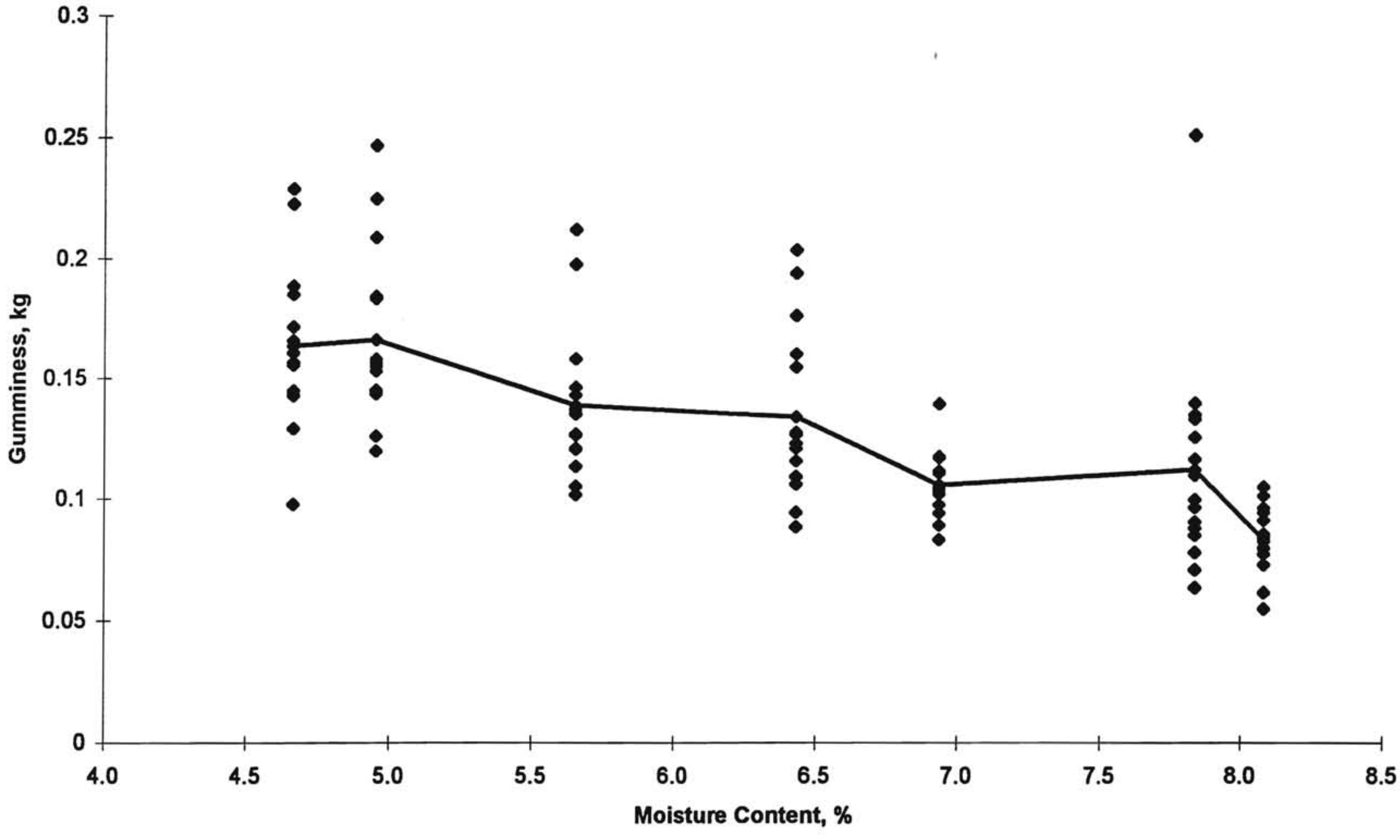


Figure 13: Chewiness versus moisture content for MC2 experiment.

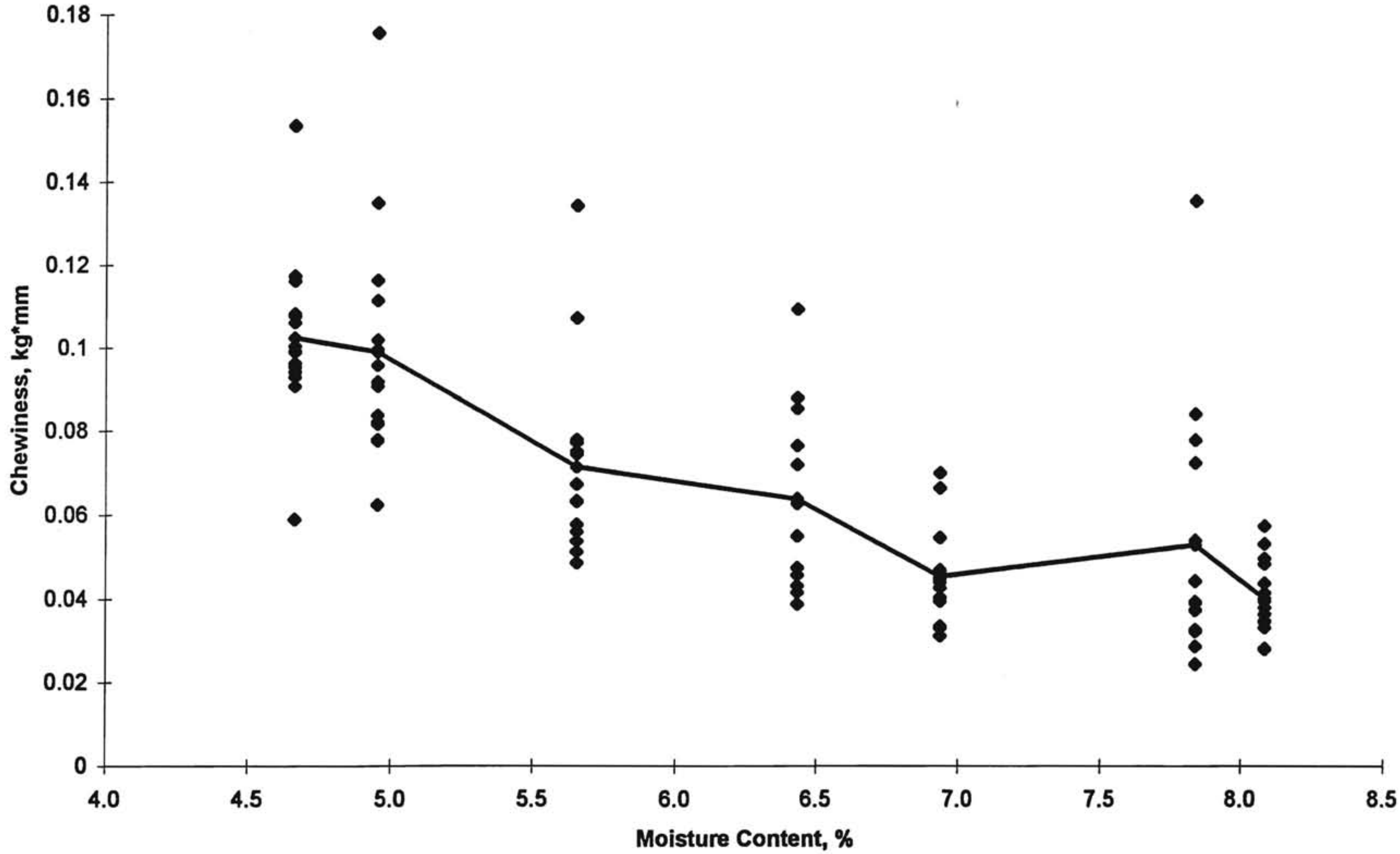


Figure 14: Cohesiveness versus moisture content for MC2 experiment.

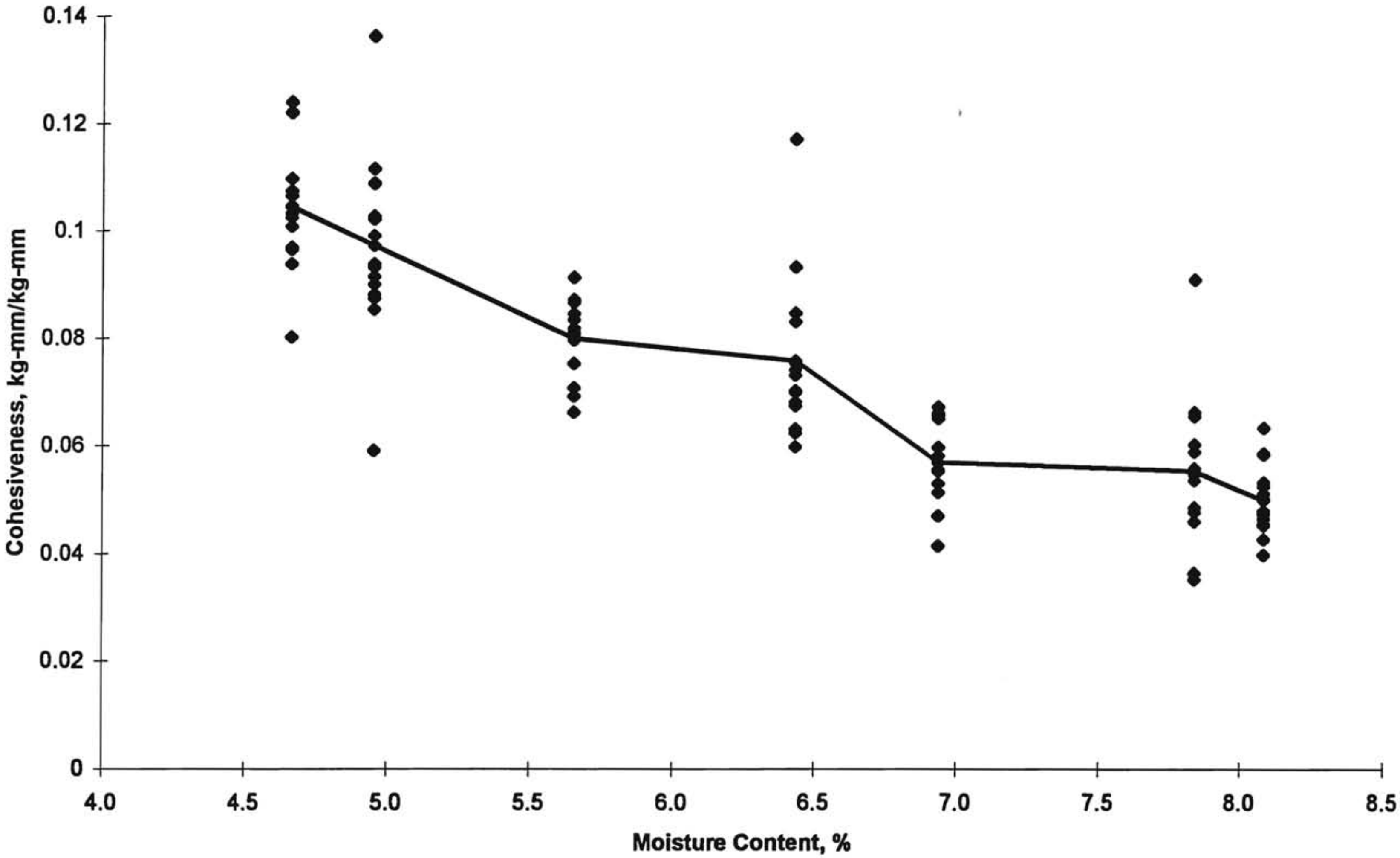


Figure 15: Springiness versus moisture content for MC2 experiment.

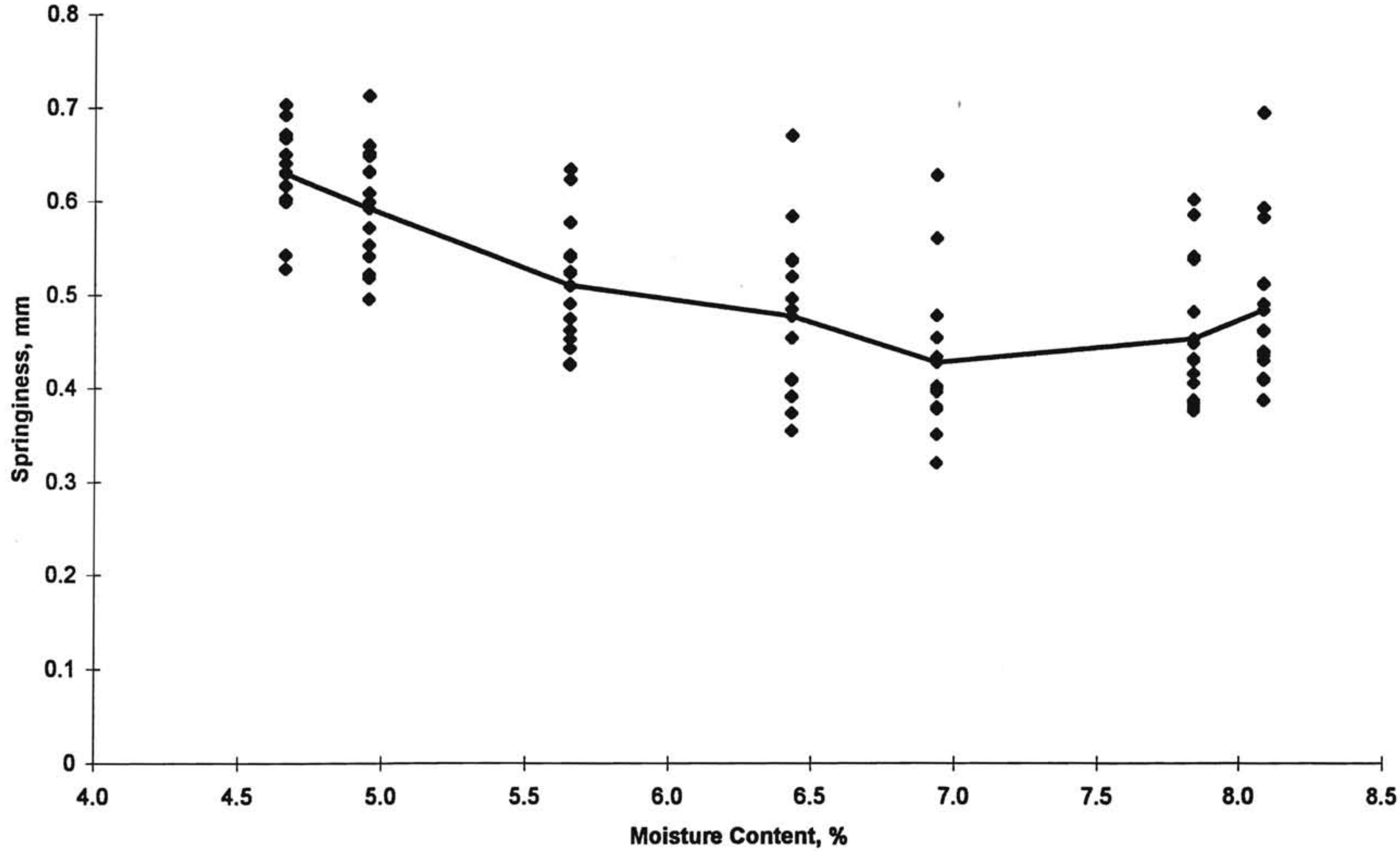


Figure 16: Fracturability versus moisture content for MC2 experiment.

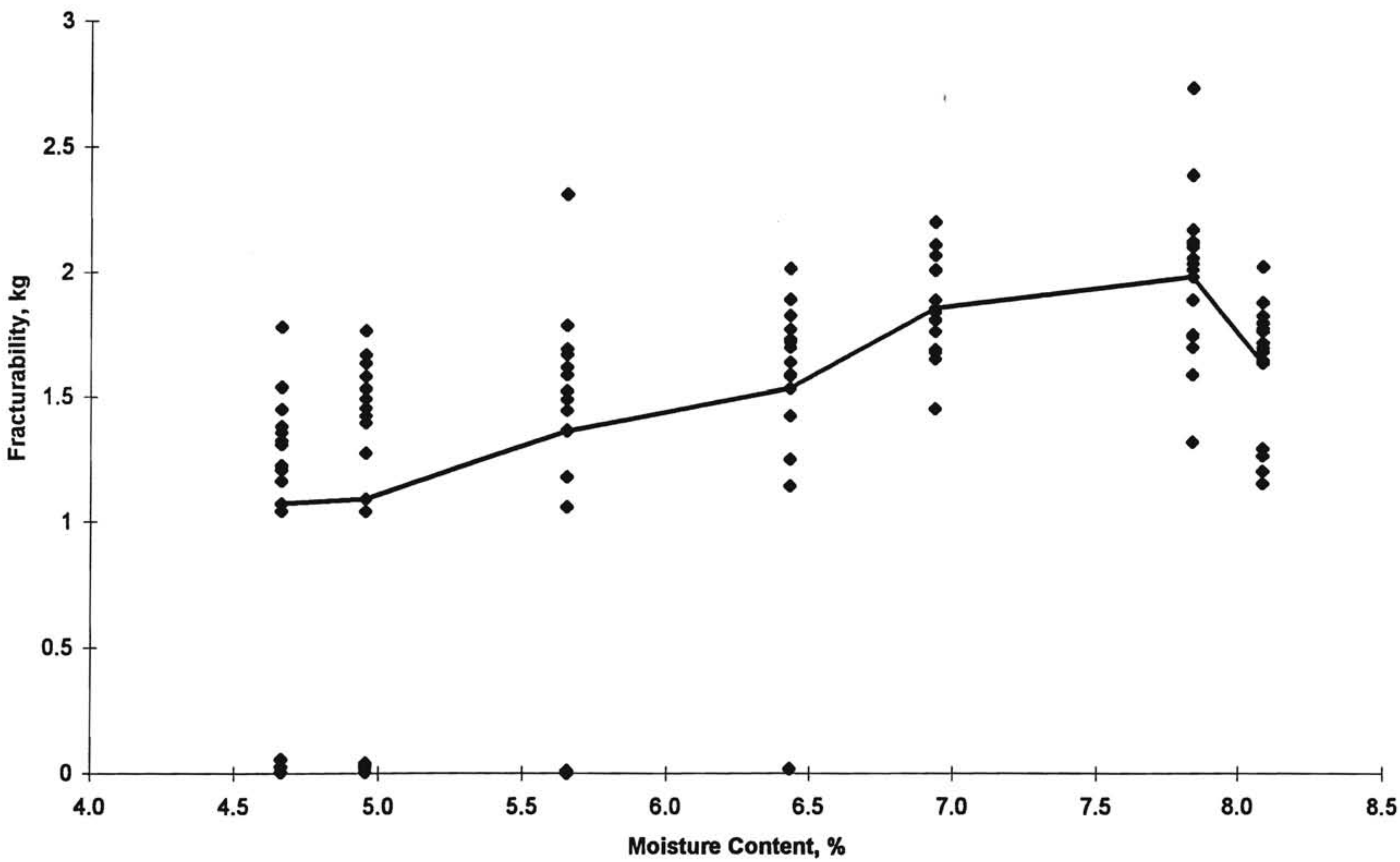
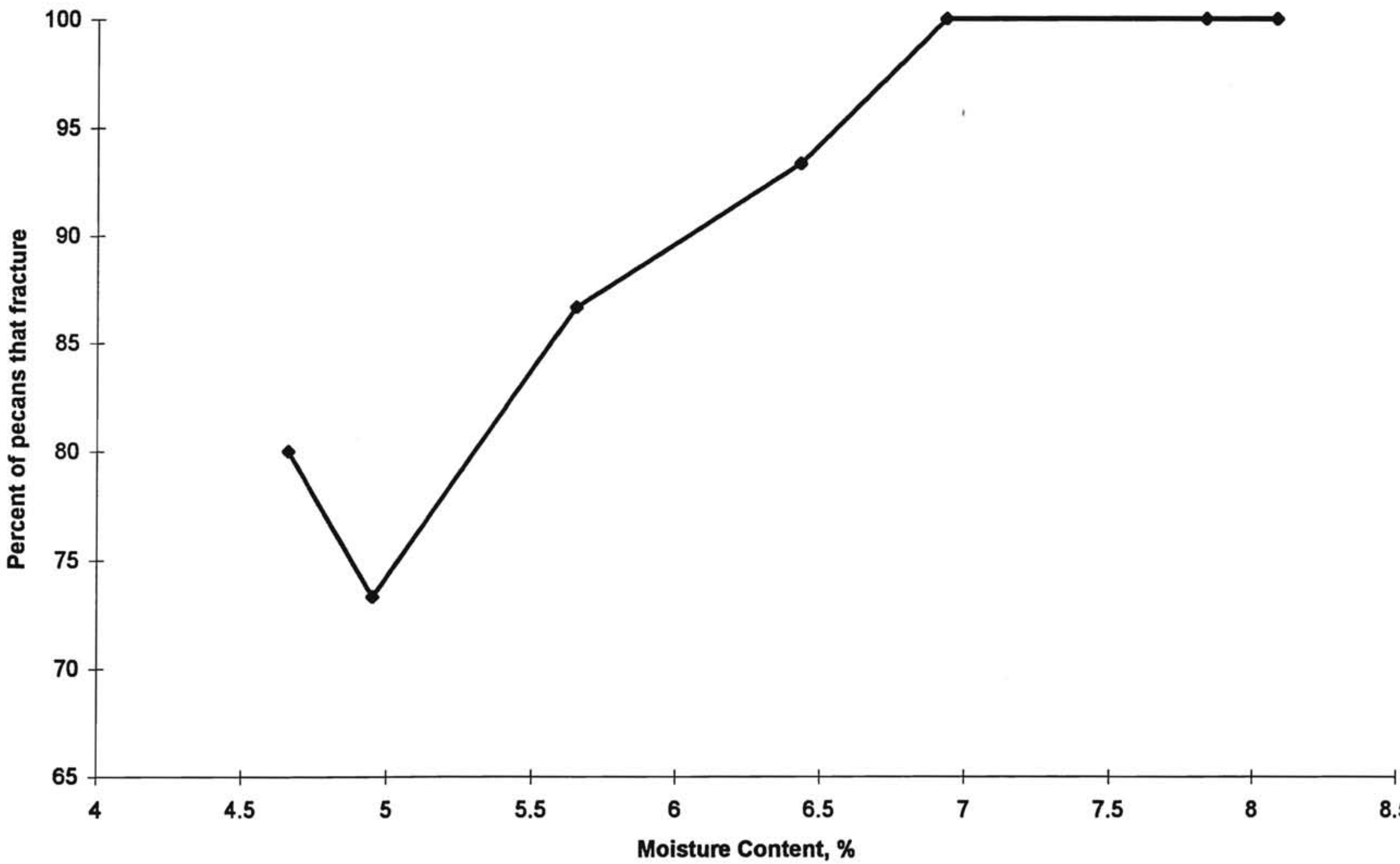


Figure 17: Percent of pecans that fracture versus moisture content for MC2 experiment.



discussed. Combining parameters is likely to increase the variability. Both parameters still showed decreasing values (Figures 12 and 13) with increasing moisture content.

Discussion of Moisture Effects on Pecan Texture

The moisture content ranges for these two experiments, although different, did overlap between 4.7% and 6.3%MC. In this range the trends of each parameter were expected to be similar but values could differ between cultivars and due to the use of different sample moisture preparation procedures. Graphs of the three best parameters (hardness, cohesiveness, and springiness) were used to compare the results of the two experiments.

Cohesiveness had the most similarities between the results of the two experiments. The slopes and magnitudes of the cohesiveness values showed a definite decrease with increasing MC% (Figure 18). Hardness increased with MC over all but the extremes of both experiments (Figure 19). Springiness did not correlate well between the two experiments within the overlap range, but the general trend for both data sets indicates a decrease in springiness with increasing MC% (Figure 20). Similarities between the results add weight to the conclusions reached independently in each experiment.

The methods used to obtain the desired moisture contents appear to effect the TPA parameter values, especially at extreme high and low moisture pecans. By desiccating one batch of pecans to 0.93% MC, fissures were observed in the surface of the pecans and obtaining a core sample using a cork borer was difficult because the pecans tended to break apart during handling. For the pecans at the opposite moisture content extreme, a core sample was difficult to obtain because the pecans were flexible and tended to bend as the cork borer was inserted.

Figure 19: Comparison of means of hardness for ORT-MC and MC2 experiments.

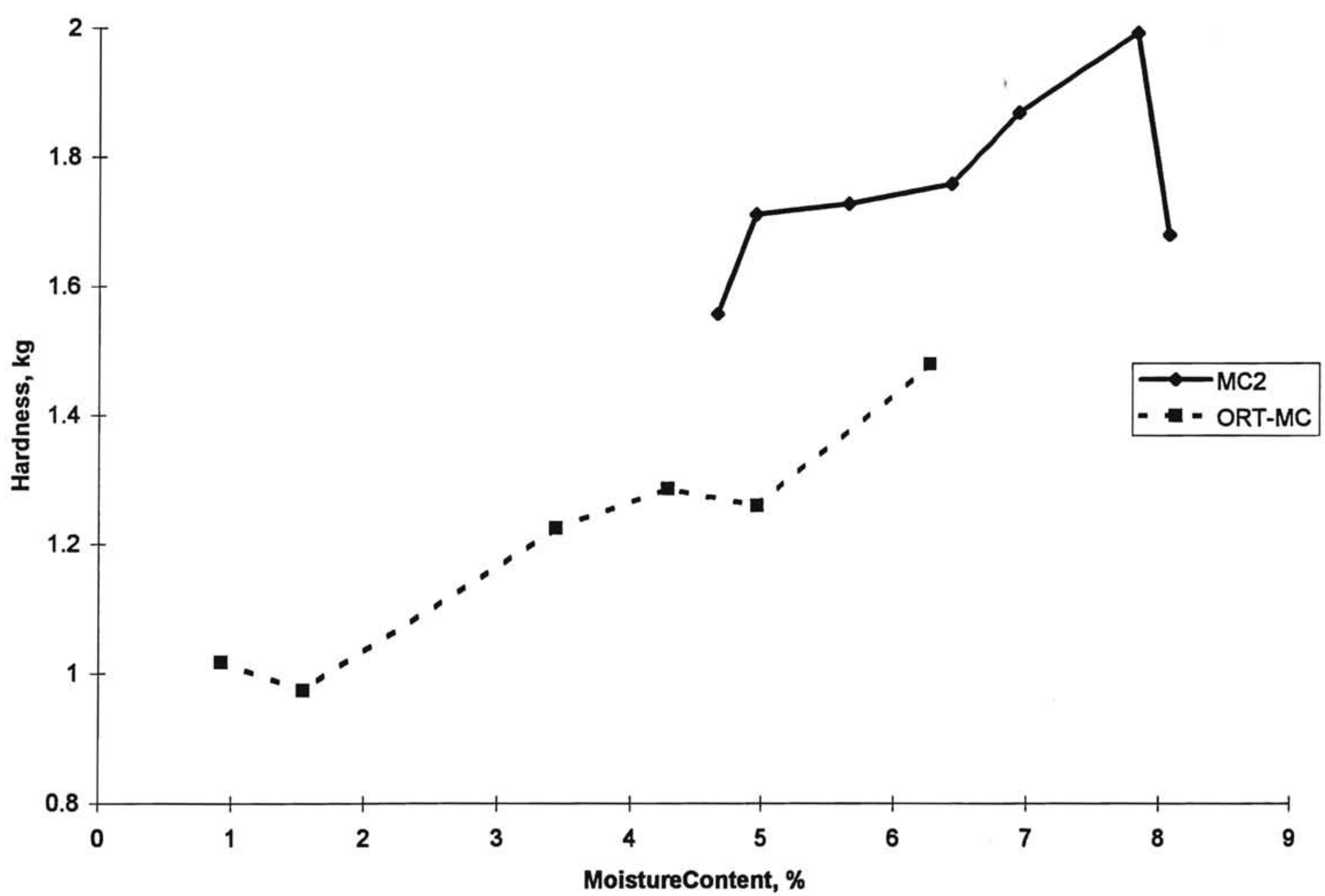
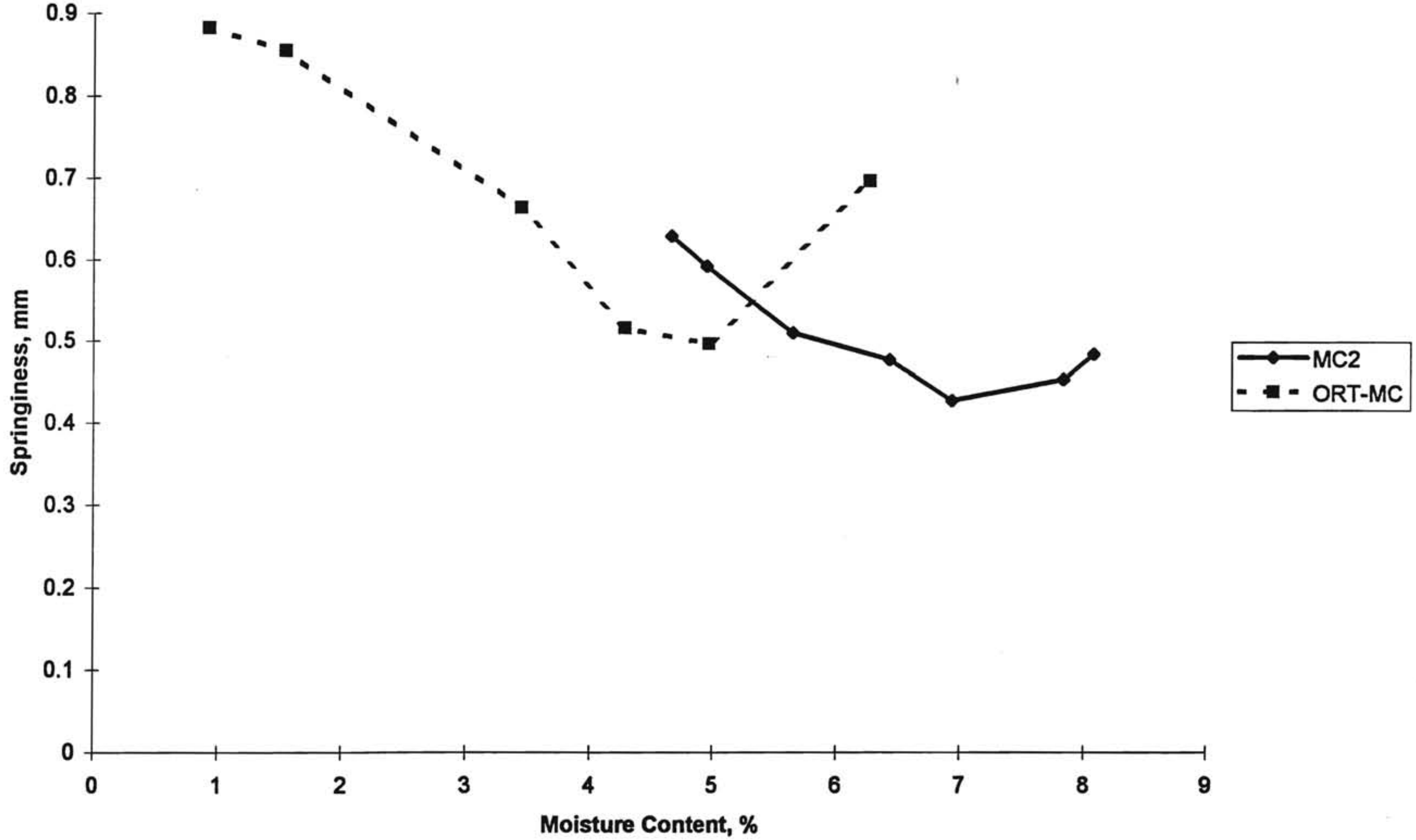


Figure 20: Comparison of means of springiness for ORT-MC and MC2 experiments.



Oil Level Experiment

The initial oil content, by quantitative oil extraction, of the pecans was determined to be 63.9%. Pecan oil content reduction by supercritical carbon dioxide fluid extraction ranged from 0% (not extracted) to 27.4%. The final oil content by weight of the pecans was 63.9%, 57.3%, 49.8%, and 46.4%. All of the TPA parameters except for fracturability ($P=0.50$) showed significant differences with oil content ($P<0.01$). Duncan's multiple range test was used to separate the means within each TPA parameter ($\alpha = 0.05$). Table VIII shows the statistical significance of each parameter with the percent of oil removed as the independent variable. Since four oil contents were tested, at most the means could be statistically separated into four levels. All of the parameters except fracturability were separable into three levels. Table IX shows the coefficient of variability and linear regression slopes for each oil reduction level and TPA parameter. As in the previous experiments, fracturability had the largest variability (62%) of the TPA parameters. Cohesiveness, springiness, and hardness had the three lowest average coefficients of variability (31%, 18%, and 29% respectively). Graphs (Figures 21 through 27) of each TPA parameter against the percentage of oil reduction allowed for a general view of the overall trends.

The hardness parameter (Figure 21) decreased at higher amounts of removed oil. This relationship was nearly linear. Cohesiveness (Figure 24) values were significantly different but the changes were not linear. The 10.35% oil reduction level had the largest cohesiveness value. Cohesiveness was less at all other oil reduction levels. It appears that a slight oil reduction treatment increases the cohesiveness but further oil reduction reduces

Table VIII: Means of TPA parameters for oil level experiment.

Oil Removed %	Hardness kg	Gumminess kg	Chewiness kg-mm	Cohesiveness kg-mm/kg-mm	Springiness mm	Fracturability kg
	TPA Parameter					
0.00*	1.431a**	0.147a	0.106b	0.101b	0.727c	0.803a
10.35	1.114b	0.160a	0.184a	0.143a	1.139a	0.597a
22.07	0.748c	0.072b	0.083b	0.099b	1.083ab	0.642a
27.37	0.594c	0.041c	0.041c	0.073c	0.940b	0.580a

* 0.0% removed = 63.9% oil content; 10.35% removed = 57.29% oil content; 22.07% removed = 49.80% oil content; 27.39% removed = 46.41% oil content.

** means (n=15)in a column with the same letter are not significantly different (Duncans, α=0.05)

Table IX: Coefficients of variability, linear slopes, and r^2 for oil level experiment.

	Coefficient of Variability					
Oil Removed %	Hardness kg	Gumminess kg	Chewiness kg-mm	Cohesiveness kg-mm/kg-mm	Springiness mm	Fracturability kg
0	22.67	31.88	28.97	12.37	9.91	74.00
10.35	20.82	28.83	37.23	16.38	12.80	87.58
22.07	32.02	43.34	58.91	40.17	29.03	46.16
27.37	39.93	50.16	59.72	54.50	21.69	42.14
average	28.86	38.55	46.21	30.86	18.36	62.47
Slope	-0.0307	-0.0042	-0.0030	-0.0013	0.0073	-0.0066
r^2	0.640	0.529	0.208	0.115	0.094	0.026

Figure 21: Hardness versus percent oil removed for Oil Level experiment.

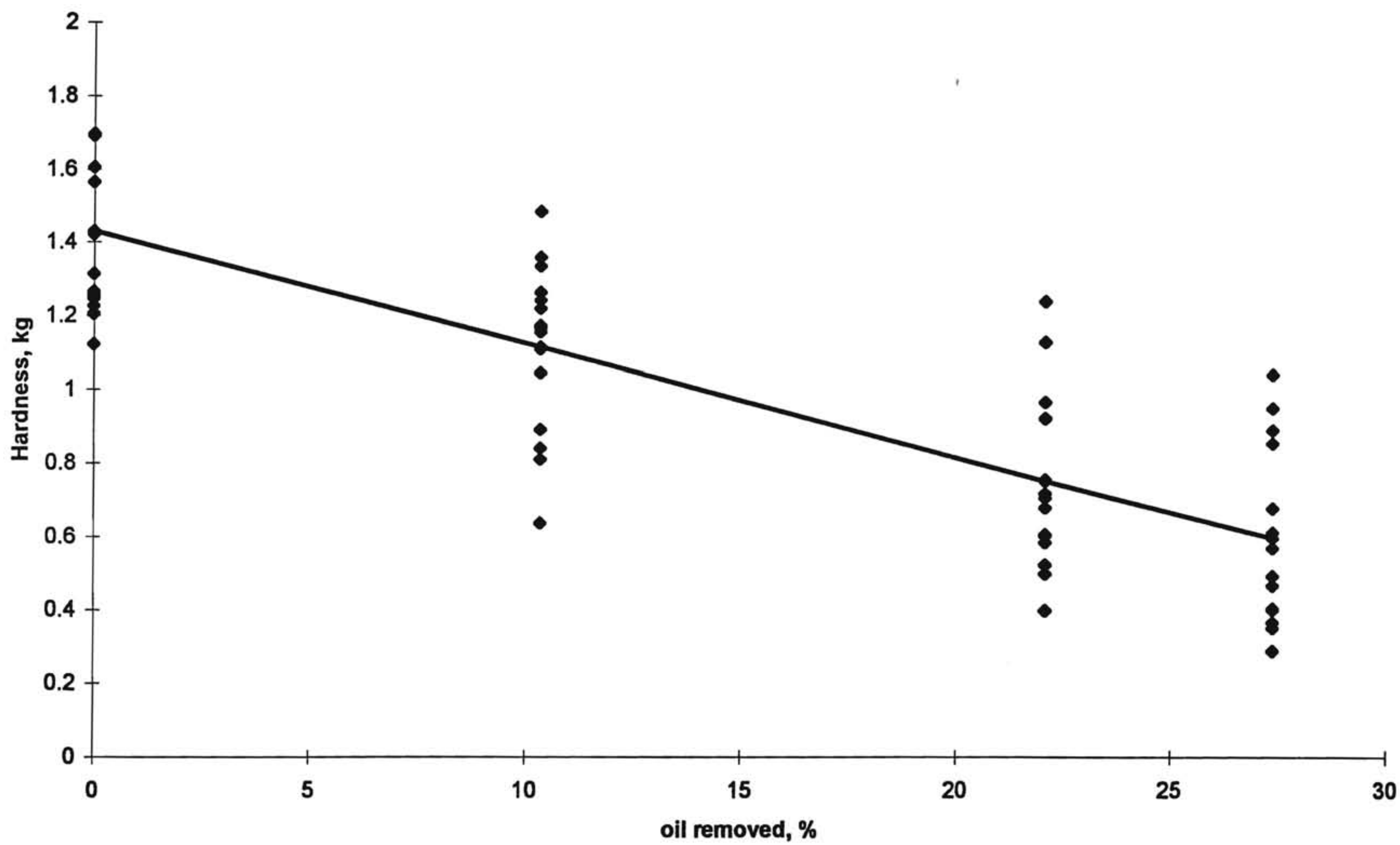


Figure 22: Gumminess versus percent oil removed for Oil Level experiment.

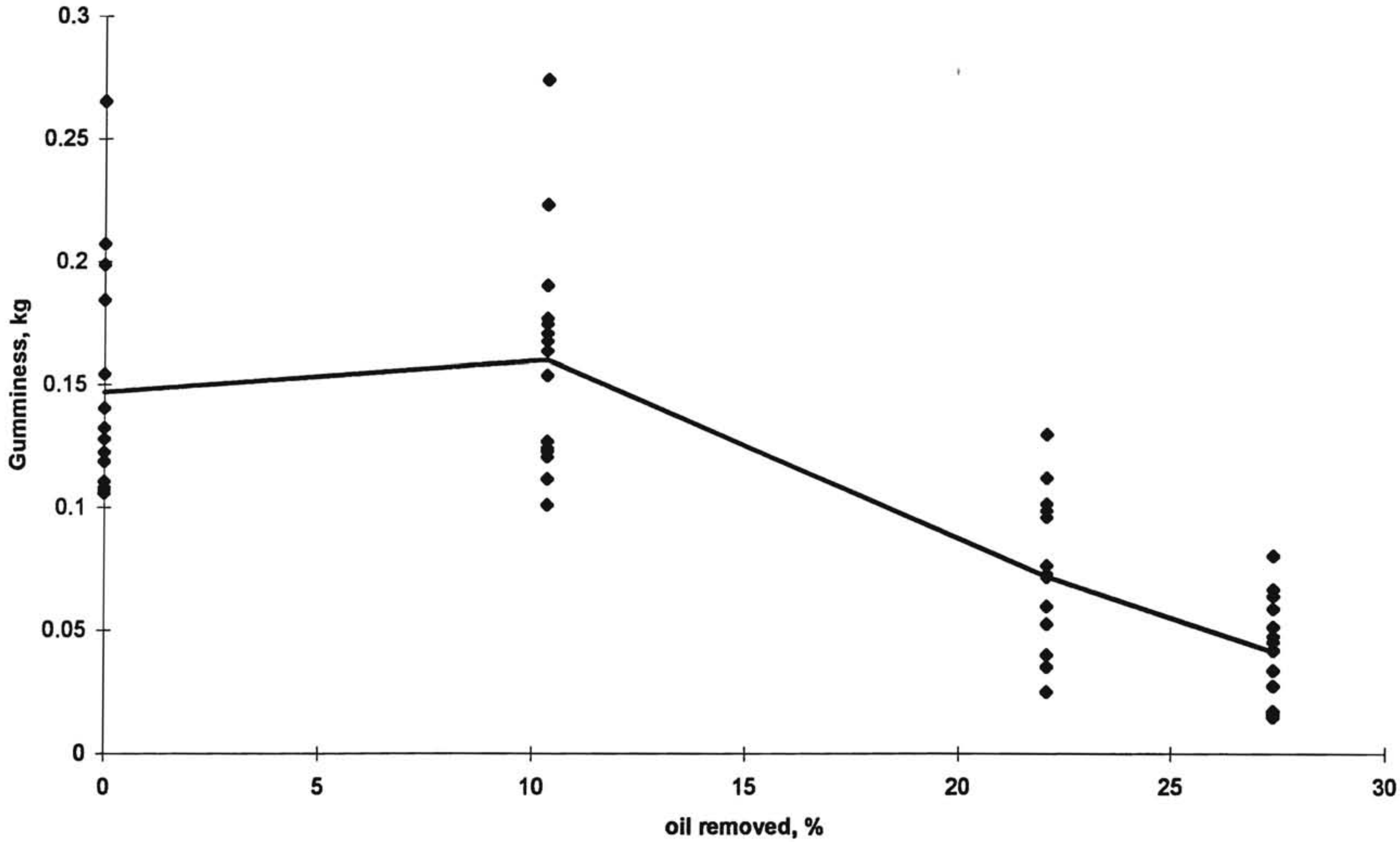


Figure 23: Chewiness versus percent oil removed for Oil Level experiment.

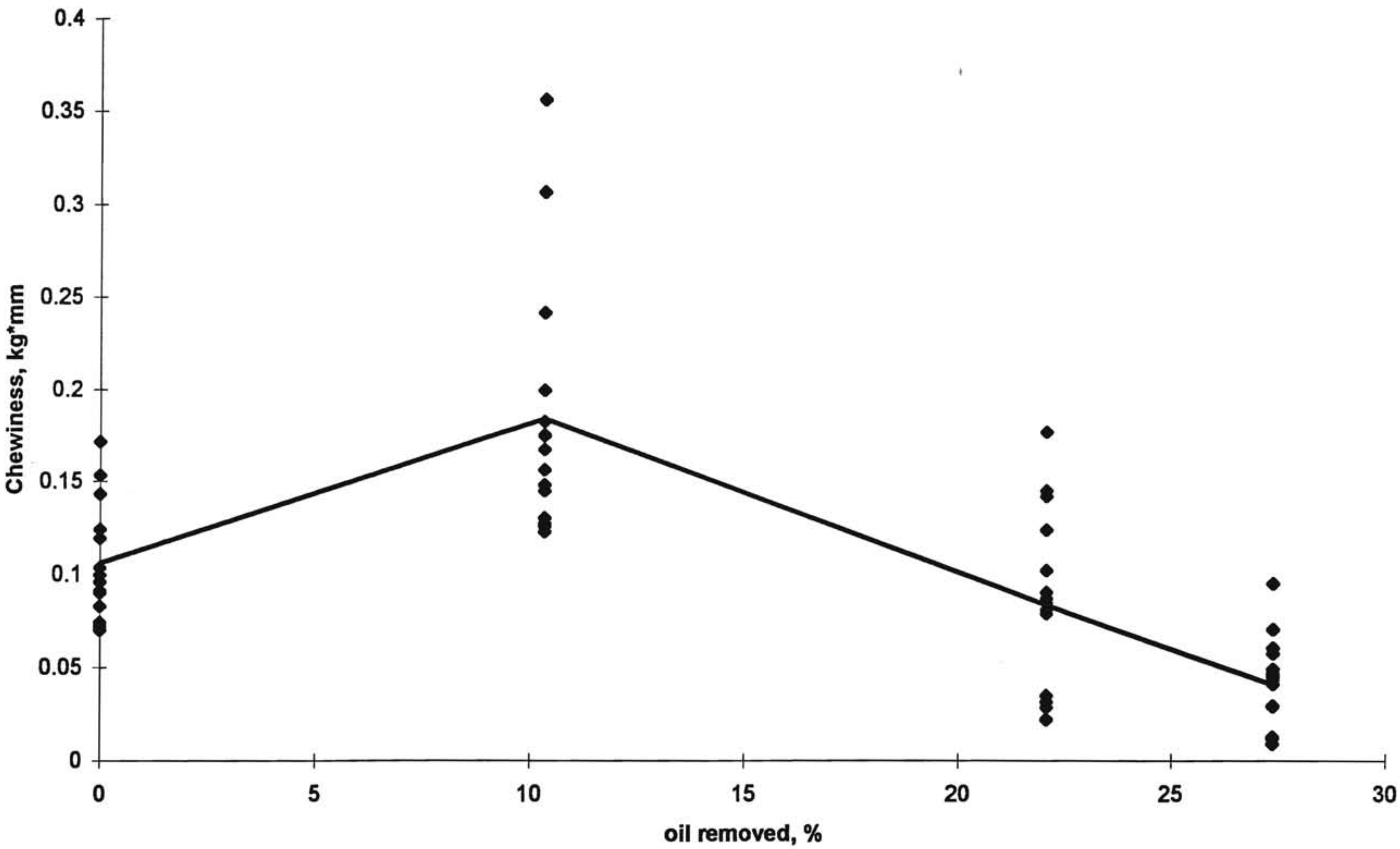


Figure 24: Cohesiveness versus percent oil removed for Oil Level experiment.

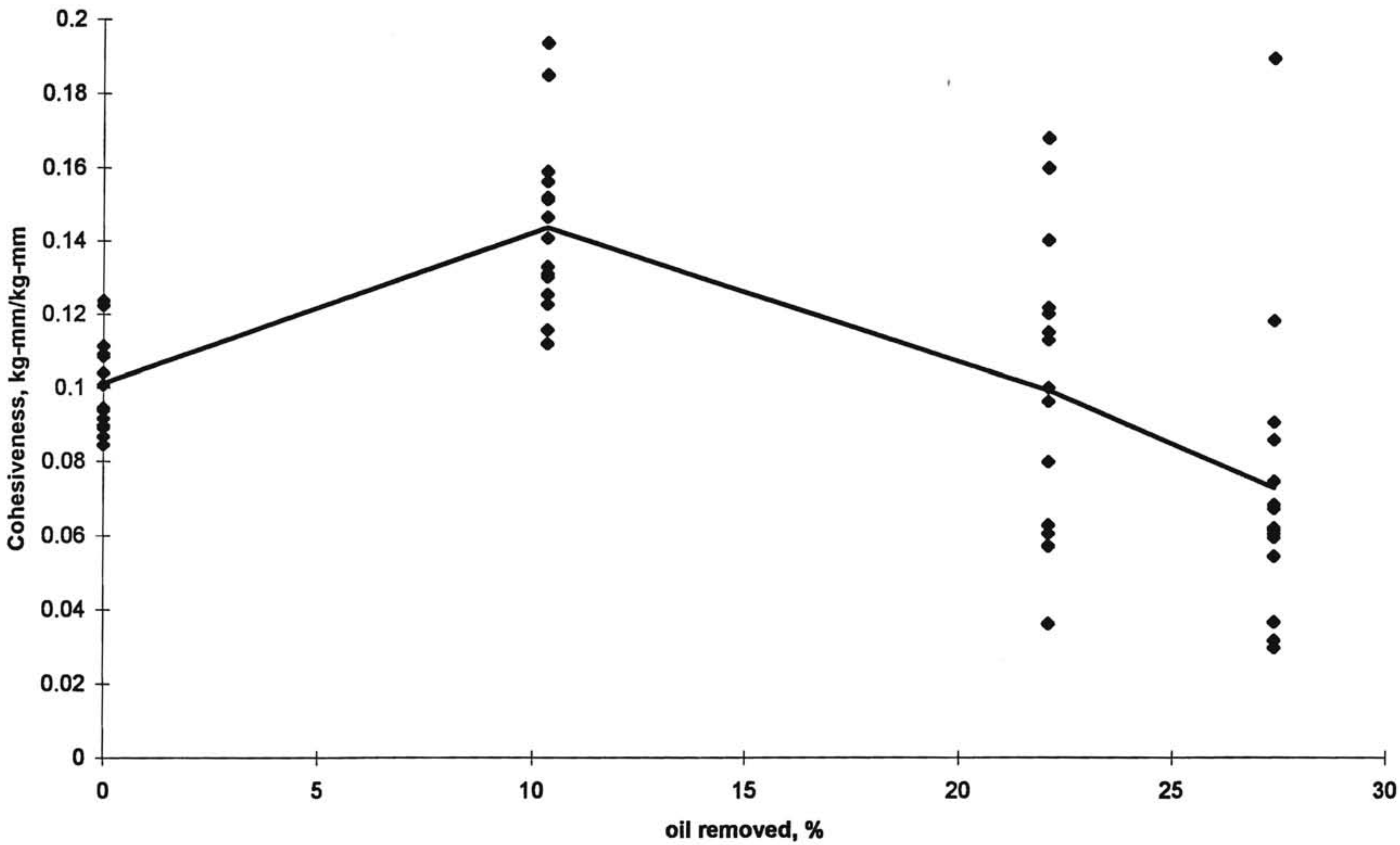


Figure 25: Springiness versus percent oil removed for Oil Level experiment.

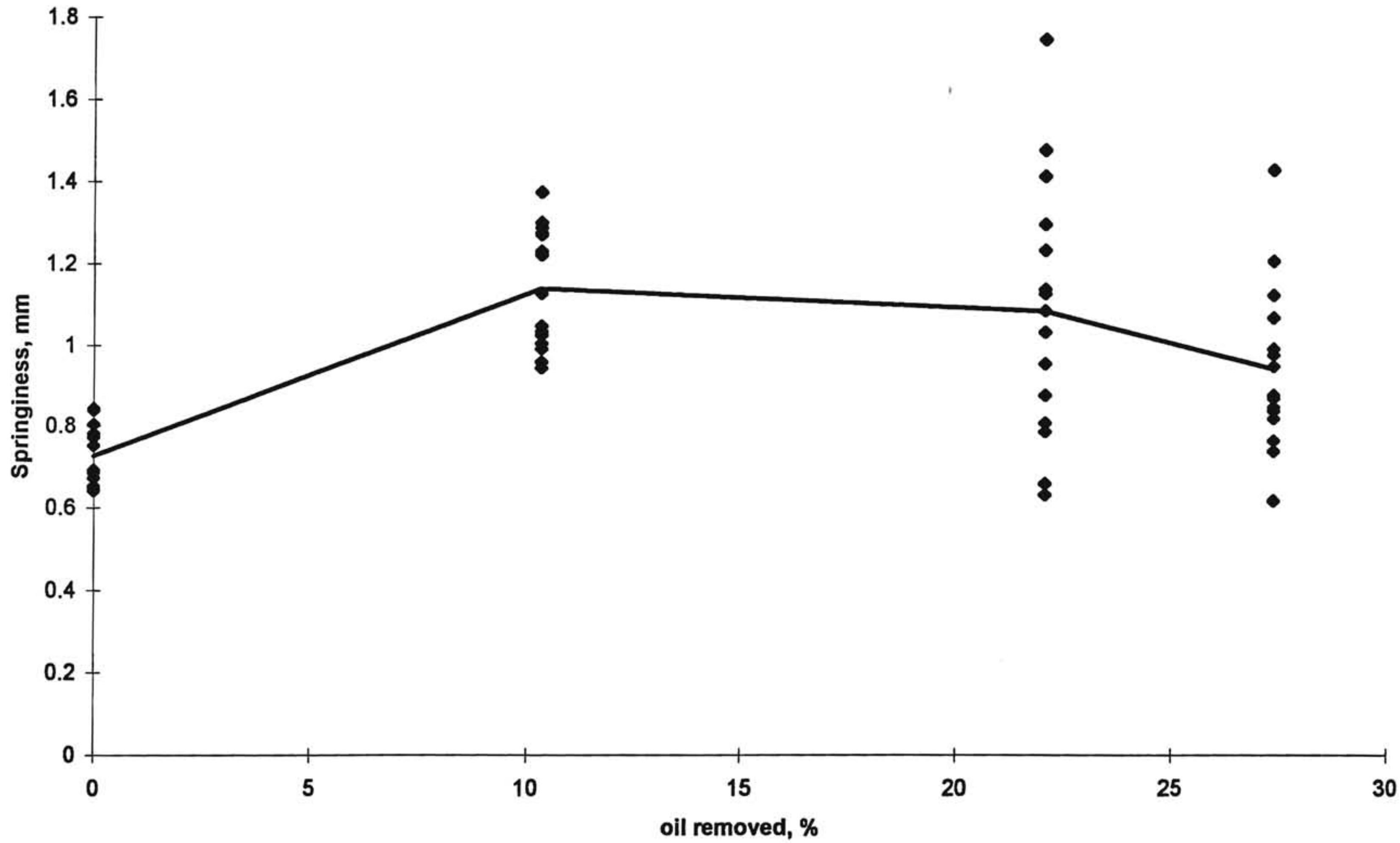


Figure 26: Fracturability versus percent oil removed for Oil Level experiment.

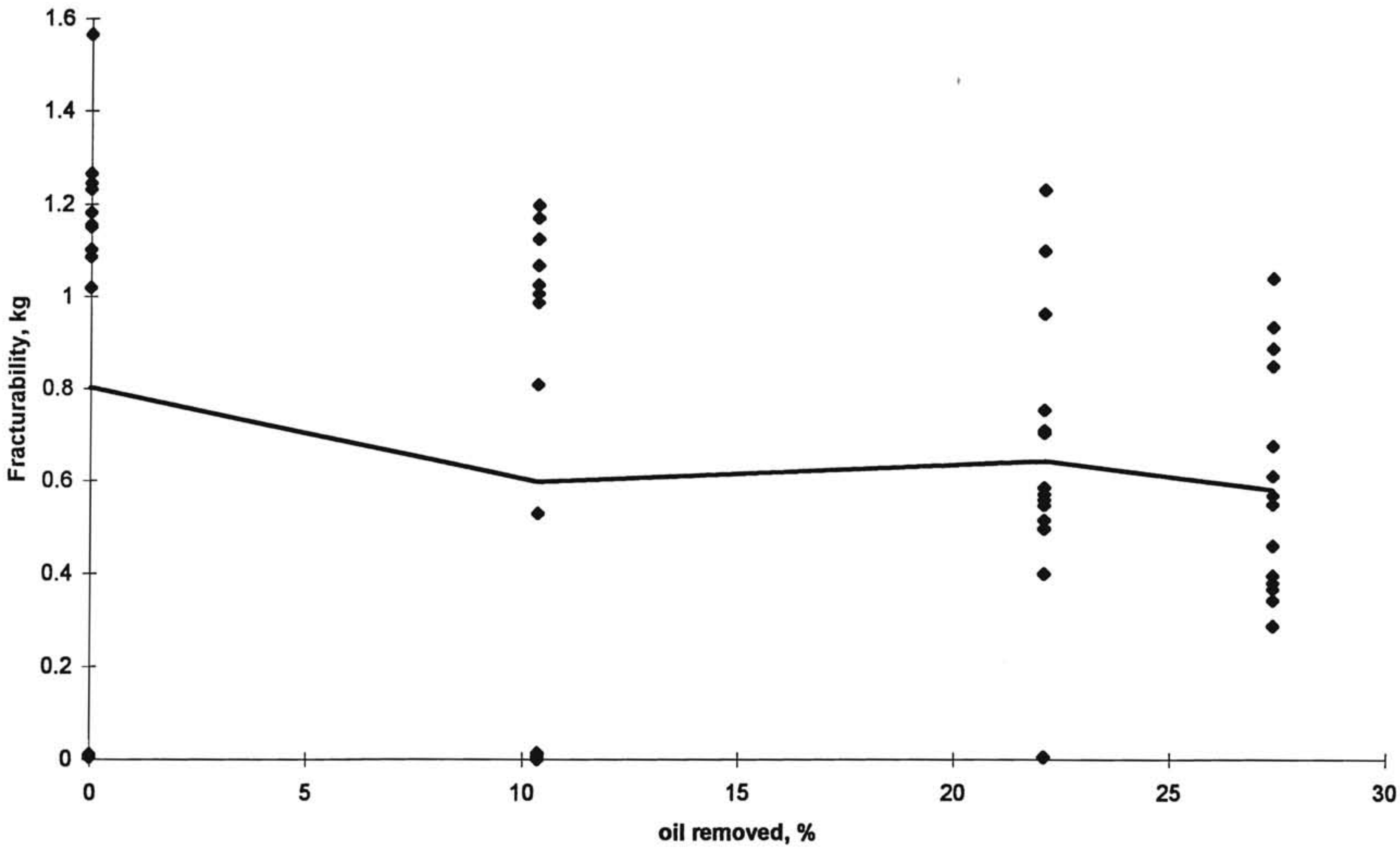
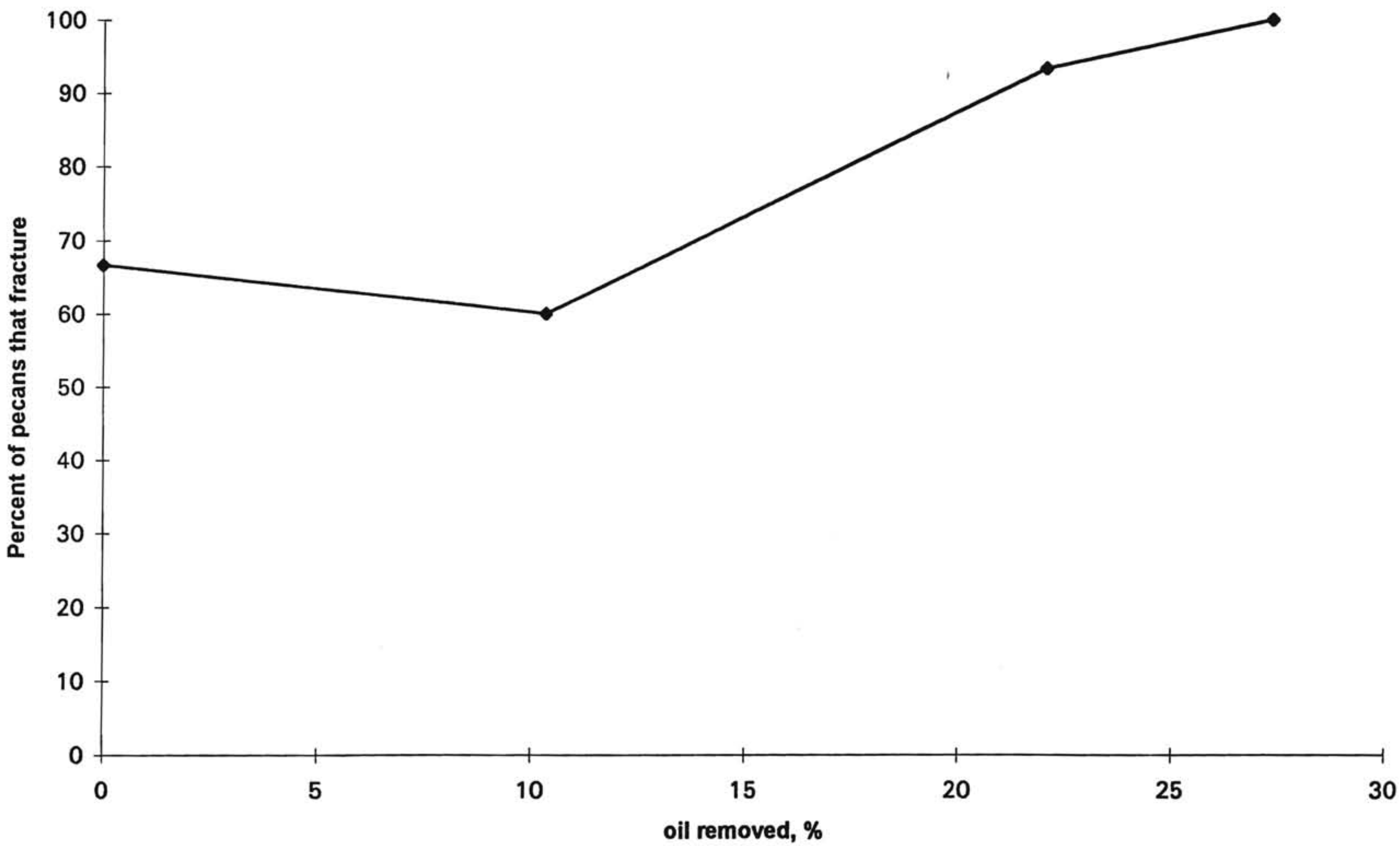


Figure 27: Percent of pecans that fracture versus percent oil removed for Oil Level experiment.



cohesiveness. Gumminess (Figure 22) and chewiness (Figure 23) show similar trends as expected since they are multiples of cohesiveness. Although fracturability (Figure 26) showed no significant treatment effects, the percentage of pecans exhibiting fracturability (Figure 27) increased as oil level decreased. Springiness had a low value and small variability at the full oil level. At the 10.35% oil reduction level, springiness was sharply higher and then decreased only slightly as the oil level decreased. The variabilities at the 22.1% and 27.4% oil reduction levels were much higher (29% and 22% respectively) than at the lower oil reduction levels (10% to 13%).

Modified Atmosphere Storage Experiment

The oil content of the full oil and reduced oil pecans, by quantitative oil extraction, was determined to be 63% and 50% respectively. This indicated a 15% oil reduction by supercritical fluid extraction. The data when analyzed to determine the effect of bags showed no significant main effect or interaction on hardness; thus the bag effect was treated as a replicate for the examination of the effect of oil level, oxygen level, and storage time. Oil level and storage time but not bag oxygen content had significant effects on hardness ($P<0.01$, Table X). Hardness was the only parameter that had no significant interactions. Reduced oil significantly reduced the hardness of the pecans. This result is consistent with the previous oil level experiment where increased oil reduction was found to reduce pecan hardness. Hardness increased with longer storage times. Duncan's multiple range test with $\alpha=0.05$ only separated the 36 week storage time as significantly different from the three shorter times.

Table X: Pecan hardness as affected by oil level, oxygen content, and storage time.

	Mean Hardness, kg	P value	N
Oil Level		0.0001	144
Reduced oil	1.326b*		
Full oil	1.530a		
Oxygen Content		0.2459	96
2%	1.462a		
10%	1.434a		
21%	1.389a		
Storage Time (weeks)		0.0001	96
36	1.587a		
25	1.435b		
12	1.359b		
0	1.331b		

* means with same letter are not significantly different (Duncans $\alpha = 0.05$)

All of the other TPA parameters exhibited significant interactions in addition to main effects. Therefore, analysis of these parameters was carried out on the simple effects using the "by" command in SAS.

Storage bag showed no significant effect on gumminess so the storage bag was again treated as a replicate. Gumminess showed a significant oxygen content ($P = 0.040$) and storage time ($P<0.0001$) effect but also had a significant interaction between oil content and storage time ($P=0.0014$, Table XI). Since oxygen content was not involved in the interaction, its analysis used only main effects. As oxygen content in the storage bags increased, gumminess decreased for each oxygen level. There was a significant storage time effect for lower oil pecans but not for full oil pecans. The pecans stored for 36 weeks had significantly higher gumminess values than the other three storage times. Oil level was examined for its effect on gumminess at each of the four storage times. Significant time effects were found for reduced oil pecans after 36 weeks of storage. At 36 weeks of storage, lower oil pecans had a significantly higher gumminess value than did the full oil pecans.

The results of chewiness at each oxygen content, storage time, and oil level show that all three had significant main effects (Table XII). Oxygen content of 2 % had a significantly higher chewiness than did the 10% and 21% oxygen content levels. There was a significant interaction in the main effects between oil level and storage time. Storage time alone did not significantly affect the chewiness of full oil pecans. Reduced oil pecans showed a strong storage time effect ($P<0.0001$) at 36 weeks of storage. The low oil pecans stored 36 weeks were significantly higher in chewiness than at the other storage times. This storage time was also the only time that oil level had an effect on

Table XI: Gumminess as affected by oil level and storage time.

	Oxygen Content, %	Mean Gumminess, Kg		N
	2	0.209a*		96
	10	0.197ab		
	21	0.187b		
Lower Oil	Storage Time, weeks			
	36	0.263m**	y+	36
	25	0.180n	z	
	12	0.179n	z	
	0	0.178n	z	
Full Oil	Storage Time, weeks			
	36	0.210m	z	36
	25	0.178n	z	
	12	0.198mn	z	
	0	0.194mn	z	

*Means with same letter (a,b) are not significantly different with respect to oxygen content (Duncans $\alpha = 0.05$).

** Means with same letter (m,n) are not significantly different with respect to storage time at each oil level (Duncans $\alpha = 0.05$).

+ Means with same letter (y,z) are not significantly different with respect to oil level at each storage time (Duncans $\alpha = 0.05$).

Table XII: Chewiness as affected by oil level and storage time.

	Storage Time, weeks	Mean Chewiness, Kg-mm		N
Lower Oil	36	0.329a*	y+	36
	25	0.204b	z	
	12	0.208b	z	
	0	0.211b	z	
Full Oil	Storage Time, weeks			
	36	0.186ab	z	36
	25	0.175b	z	
	12	0.213a	z	
	0	0.198ab	z	

*Means with same letter (a,b) are not significantly different with respect to storage time at each oil level (Duncans $\alpha = 0.05$).

+ Means with same letter (y,z) are not significantly different with respect to oil level at each storage time (Duncans $\alpha = 0.05$).

chewiness. At 36 weeks of storage, low oil pecans had a significantly higher chewiness than did the full oil pecans.

Springiness had significant storage time and oil level main effects but also had a significant interaction between time and oil level. Table XIII shows the simple effects for storage time by oil level and for oil level by storage time. Storage time had no significant effect on reduced oil pecans but did affect full oil pecans. At the full oil level, springiness was statistically unchanged between 0 and 12 weeks of storage and then it decreased at 25 and 36 weeks. At all storage times, lower oil pecans had significantly higher springiness values.

In analysis of the other TPA parameters, the storage bag did not have a significant main effect or main interaction with any other independent variable. Fracturability showed an interaction between storage time and bag when main effects were examined. Because of this, it was necessary to statistically test for a bag effect at each storage time. The results showed that bag did not have a significant simple effect on fracturability at any storage time. When storage time was evaluated, it did have a significant effect on bags "b" and "c" but not on bag "a". Since bag did not have a significant main effect, and it did not have a significant simple effect at any storage time, the assumption that bag should be treated as a replicate was kept for the fracturability texture parameter.

Without a separate term for bag in the model, oil level and storage time were found to have significant main effects on fracturability (Table XIV). Full oil pecans had a significantly lower fracturability (0.64 kg) than did reduced oil pecans (0.97 kg). The effect of storage time on fracturability was significant but it did not exhibit a obvious trend.

Table XIII: Springiness as affected by oil level and storage time.

Lower Oil	Storage Time, weeks	Mean Springiness, mm		N
	36	1.212a*	y+	36
	25	1.121b	y	
	12	1.150ab	y	
	0	1.176ab	y	
Full Oil	Storage Time, weeks			
	36	0.880c	z	36
	25	0.973b	z	
	12	1.064a	z	
	0	1.018ab	z	

*Means with same letter (a,b) are not significantly different with respect to storage time at each oil level (Duncans $\alpha = 0.05$).

+ Means with same letter (y,z) are not significantly different with respect to oil level at each storage time (Duncans $\alpha = 0.05$).

Table XIV: Fracturability as affected by oil level, oxygen content, and storage time.

	Mean Fracturability, kg	P value	N
Oil level		0.0001	144
Reduced oil	0.975b		
Full oil	0.638a		
Oxygen Content		0.2410	96
2%	0.741a		
10%	0.873a		
21%	0.805a		
Storage Time (weeks)		0.0001	72
36	0.600c		
25	1.150a		
12	0.812b		
0	0.663bc		

* means with same letter are not significantly different (Duncans $\alpha = 0.05$)

Cohesiveness, like fracturability, had no main storage bag effect but did have a significant interaction between bag and oxygen content and between bag and storage time. To validate the assumption that the storage bag had no significant effect and could be treated as a replicate, the bag effect was examined at each oxygen content and at each storage time. None of these results showed a significant effect and so bags were treated as replicates.

Cohesiveness was significantly affected by oil level and storage time and there was also an interaction between these two variables. Oil level was examined at each storage time and storage time was examined at full and reduced oil levels to test for significant simple effects (Table XV). Storage time had a significant effect on cohesiveness for both full and reduced oil pecans. However, the effects were not the same. Reduced oil pecans had the highest cohesiveness value at 36 weeks of storage. The three shorter storage times were not significantly different from each other. Full oil pecans showed a significant difference only at 25 weeks of storage. Pecans stored shorter or longer times were not significantly different. At each storage time, reduced oil pecans had a higher cohesiveness value than did full oil pecans. This effect was significant at all storage times except for 12 weeks.

Table XV: Cohesiveness as affected by oil level and storage time.

Lower Oil	Storage Time, weeks	Mean Cohesiveness, kg-mm/kg-mm		N
	36	0.174a*	y+	36
	25	0.136b	y	
	12	0.143b	y	
	0	0.151b	y	
Full Oil	Storage Time, weeks			
	36	0.125a	z	36
	25	0.115b	y	
	12	0.134a	z	
	0	0.131a	z	

*Means with same letter (a,b) are not significantly different with respect to storage time at each oil level (Duncans $\alpha = 0.05$).

+ Means with same letter (y,z) are not significantly different with respect to oil level at each storage time (Duncans $\alpha = 0.05$).

CHAPTER V

CONCLUSIONS

The first goal of this study was to show that TPA can measure texture differences in pecans. In all four experiments, statistical differences were detected in pecans that had been subjected to a treatment that was presumed to change texture. Lacking independent analysis, such as a human sensory evaluation, the assumption must be made that the induced texture changes were real before conclusions can be made about the ability of the TPA method to measure those changes. Based on this assumption and the statistical analysis of the data, it can be concluded that TPA successfully measured texture differences in pecans.

An extension of the first objective was to determine which TPA parameters "best" described pecan texture. Of the seven commonly used parameters, it is expected that some will be more descriptive and less variable than others. Ranking the parameters from "best" to "worst" would depend on several factors. Variability should be low in relation to the magnitude of the response. The parameter should be sensitive to actual differences in pecan texture. Finally, the parameter should have a practical comparison to descriptions given by human taste panels.

Since adhesiveness did not exist on the recorded force versus deformation curves, it was eliminated as a parameter. Because of its high variability, fracturability was not as valuable in describing pecan texture as other parameters. The percentage of pecans in a group that fracture was also examined as an additional new parameter. Since it required that a group of replicates be combined into one parameter, no statistical parameter is available that would describe its variability. It did however provide some insight into why the fracturability parameter was particularly high or low.

The TPA parameters that best described pecan texture were hardness, cohesiveness, and springiness. All of these had a lower variability than the other parameters and showed significant differences when real pecan texture differences were expected to be present. Chewiness and gumminess were in between the best and worst parameters. Their variabilities were higher than the best parameters but still had statistically different means.

The measured TPA parameters were different depending on sample orientation (horizontal or vertical). Based on a combination of high sensitivity and low variability in TPA parameters, placing the cylindrical sample vertically gave better overall results than horizontal orientation. The average coefficient of variability for all TPA parameters was 12.8% lower when the test was performed on a vertically oriented sample. In addition, the regressed slopes of hardness and springiness were 37.8% and 46.1%, respectively, greater in magnitude.

The ORT-MC and MC2 experiments examined pecan texture as affected by moisture contents. Throughout most of the observed moisture range, from 0.9% to 8.1% MC, hardness increased 36.8% and 25.2% with moisture from the two experiments, ORT-MC and MC2, respectively. For all moistures above 1%, cohesiveness decreased 68.8% with increasing moisture in ORT-MC and 70.1% in MC2. Springiness changed a maximum of 56.0% and 38.3% with increasing moisture for ORT-MC and MC2, respectively. Based on analysis of these three parameters, there is conclusive objective evidence that pecan texture changed with moisture content. Furthermore, TPA was able to quantify trends in three parameters verifying this texture change.

Two experiments were conducted to determine if oil removal has an effect on pecan texture. In the first experiment (Oil level), the strongest trend was exhibited by the hardness parameter in which reductions in oil content reduced the pecan hardness. Cohesiveness and springiness also showed significant changes with changing oil content in this experiment. The second experiment (Oil-storage) also showed significant differences in all TPA parameters between the two oil content levels. As expected from the Oil level experiment, the lower oil pecans had a significantly lower (14.0%) hardness value. These experiments detected textural changes by TPA in pecans as oil content changes.

There were no significant changes in TPA hardness through the first 25 weeks of storage. At 36 weeks, the hardness was significantly greater (17.8%) from the three earlier storage times. Fracturability showed significant differences but did not indicate any obvious trend. Interactions in the data between storage time and oil level preclude conclusions from being made with respect to the effect of storage time alone.

Gumminess was the only parameter to detect a texture change based on the oxygen content in the storage bags. Since this significance was marginal (p=0.040) and none of the other parameters detected a texture change, it can be concluded that either the oxygen content did not affect pecan texture or the method was not sensitive enough to detect it. Since other treatments caused detectable TPA changes, it is more likely than not that oxygen content in the storage bags caused no or immeasurable changes in texture. The changes in texture caused by the storage time and oxygen content were less than changes due to the pecan's moisture and oil contents.

CHAPTER VI

RECOMMENDATIONS FOR FUTURE STUDY

All pecans used in this study were stored at -25°C between harvest and texture analysis. It would be helpful to determine any effect that freezing may have on pecan moisture and texture. It would be important to ensure that the moisture contents before and after freezing were the same since this experiment showed a definite texture change with moisture content.

It is possible that different pecan cultivars have different textural properties. An experiment is needed to determine differences between cultivars for different moisture and oil contents and after different storage times.

Supercritical carbon dioxide extraction is just one way of removing oil from pecans. An experiment could be conducted to see if pecan texture is affected by other methods used to lower oil content.

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APPENDIX

Appendix A.1
ORT-MC experiment results for vertical orientation at 0.93% MC.

Specimen Number	Hardness kg	Gumminess kg	Chewiness kg-mm	Cohesiveness kg-mm/kg-mm	Springiness mm	Fracturability kg
1	0.736	0.109	0.104	0.149	0.950	0.000
2	1.094	0.077	0.067	0.070	0.875	1.089
3	1.104	0.118	0.094	0.107	0.794	1.097
4	0.798	0.066	0.053	0.083	0.804	0.701
5	0.664	0.061	0.054	0.092	0.876	0.661
6	0.877	0.114	0.114	0.130	0.996	0.009
7	1.497	0.109	0.067	0.073	0.613	1.322
8	1.111	0.106	0.096	0.095	0.909	1.111
9	0.914	0.082	0.071	0.090	0.863	0.871
10	1.187	0.096	0.097	0.081	1.001	1.175
11	0.891	0.108	0.118	0.122	1.093	0.785
12	1.342	0.119	0.099	0.089	0.830	1.054
13	1.088	0.104	0.093	0.096	0.894	0.938
14	1.056	0.111	0.109	0.105	0.980	1.048
15	0.899	0.056	0.042	0.063	0.748	0.896

Appendix A.2
ORT-MC experiment results for horizontal orientation at 0.97% MC.

Specimen Number	Hardness kg	Gumminess kg	Chewiness kg-mm	Cohesiveness kg-mm/kg-mm	Springiness mm	Fracturability kg
1	1.107	0.106	0.056	0.096	0.523	1.019
2	1.245	0.191	0.108	0.153	0.566	1.102
3	1.192	0.142	0.058	0.119	0.409	0.858
4	1.489	0.227	0.109	0.152	0.479	0.002
5	1.194	0.153	0.082	0.128	0.536	1.151
6	0.842	0.082	0.037	0.097	0.448	0.001
7	1.066	0.110	0.060	0.103	0.543	0.913
8	1.099	-0.001	0.000	-0.001	-0.008	-0.002
9	1.002	0.129	0.074	0.129	0.571	1.002
10	1.125	0.118	0.062	0.105	0.524	1.112
11	0.879	0.148	0.099	0.169	0.664	0.874
12	0.787	0.109	0.053	0.138	0.489	0.446
13	0.945	0.144	0.078	0.153	0.538	0.724
14	0.993	0.168	0.096	0.169	0.570	0.000
15	0.547	0.047	0.025	0.086	0.521	0.387

Appendix A.3
ORT-MC experiment results for vertical orientation at 1.55% MC.

Specimen Number	Hardness kg	Gumminess kg	Chewiness kg-mm	Cohesiveness kg-mm/kg-mm	Springiness mm	Fracturability kg
1	0.644	0.081	0.071	0.126	0.870	0.001
2	1.094	0.086	0.059	0.079	0.688	1.051
3	1.111	0.140	0.123	0.126	0.876	0.863
4	1.097	0.196	0.193	0.178	0.986	-0.002
5	0.998	0.153	0.128	0.153	0.834	-0.005
6	0.761	0.093	0.079	0.122	0.848	0.708
7	0.921	0.101	0.070	0.110	0.688	0.900
8	0.725	0.074	0.058	0.102	0.786	-0.002
9	1.013	0.133	0.125	0.131	0.943	-0.002
10	0.743	0.104	0.105	0.140	1.009	0.000
11	1.050	0.141	0.117	0.134	0.831	0.004
12	1.120	0.120	0.100	0.107	0.834	0.993
13	0.825	0.075	0.059	0.091	0.779	0.810
14	1.450	0.195	0.156	0.134	0.803	1.164
15	1.062	0.160	0.166	0.151	1.039	0.001

Appendix A.4
ORT-MC experiment results for horizontal orientation at 1.55% MC.

Specimen Number	Hardness kg	Gumminess kg	Chewiness kg-mm	Cohesiveness kg-mm/kg-mm	Springiness mm	Fracturability kg
1	1.098	0.151	0.073	0.138	0.485	0.004
2	0.714	0.097	0.051	0.136	0.528	0.001
3	0.368	0.098	0.049	0.268	0.495	0.000
4	0.940	0.120	0.069	0.128	0.578	0.684
5	1.279	0.200	0.107	0.157	0.533	1.279
6	1.416	0.201	0.105	0.142	0.523	1.387
7	1.356	0.235	0.119	0.174	0.506	0.000
8	1.302	0.165	0.097	0.127	0.589	1.233
9	0.620	0.099	0.057	0.159	0.576	0.001
10	1.831	0.212	0.103	0.116	0.486	1.808
11	0.973	0.147	0.073	0.151	0.496	0.965
12	0.781	0.114	0.056	0.146	0.493	0.721
13	0.661	0.081	0.041	0.122	0.504	0.579
14	0.721	0.151	0.076	0.209	0.504	0.002
15	0.609	0.077	0.033	0.127	0.425	0.542

Appendix A.5
ORT-MC experiment results for vertical orientation at 3.45% MC.

Specimen Number	Hardness kg	Gumminess kg	Chewiness kg-mm	Cohesiveness kg-mm/kg-mm	Springiness mm	Fracturability kg
1	0.965	0.105	0.076	0.109	0.718	0.882
2	1.002	0.107	0.065	0.107	0.608	-0.003
3	1.643	0.213	0.147	0.130	0.688	-0.002
4	0.976	0.079	0.052	0.081	0.663	0.966
5	1.137	0.145	0.091	0.127	0.630	-0.005
6	1.277	0.142	0.087	0.111	0.613	-0.001
7	1.125	0.117	0.077	0.104	0.661	1.042
8	1.370	0.147	0.097	0.107	0.656	0.020
9	1.287	0.149	0.098	0.116	0.653	0.018
10	1.383	0.194	0.114	0.140	0.591	0.005
11	1.085	0.126	0.082	0.116	0.650	1.064
12	1.267	0.172	0.124	0.136	0.721	-0.003
13	1.538	0.192	0.130	0.125	0.674	-0.006
14	1.038	0.131	0.100	0.127	0.761	-0.006
15	1.275	0.148	0.100	0.116	0.675	-0.006

Appendix A.6
ORT-MC experiment results for horizontal orientation at 3.45% MC

Specimen Number	Hardness kg	Gumminess kg	Chewiness kg-mm	Cohesiveness kg-mm/kg-mm	Springiness mm	Fracturability kg
1	1.236	0.165	0.088	0.133	0.536	1.236
2	1.418	0.176	0.088	0.124	0.498	0.008
3	1.118	0.177	0.095	0.158	0.535	1.014
4	1.194	0.207	0.096	0.173	0.463	0.000
5	0.967	0.138	0.067	0.142	0.485	-0.001
6	1.050	0.142	0.068	0.135	0.478	1.025
7	1.207	0.198	0.111	0.164	0.561	0.002
8	1.044	0.158	0.079	0.151	0.503	0.842
9	0.863	0.155	0.083	0.179	0.534	-0.004
10	1.012	0.202	0.109	0.200	0.539	-0.001
11	0.559	0.145	0.075	0.259	0.518	-0.001
12	1.096	0.205	0.117	0.187	0.569	0.001
13	0.942	0.179	0.083	0.190	0.464	-0.005
14	1.240	0.195	0.091	0.158	0.468	0.004
15	1.153	0.168	0.087	0.146	0.521	1.023

Appendix A.7
ORT-MC experiment results for vertical orientation at 4.29% MC.

Specimen Number	Hardness kg	Gumminess kg	Chewiness kg-mm	Cohesiveness kg-mm/kg-mm	Springiness mm	Fracturability kg
1	1.363	0.142	0.073	0.105	0.513	-0.005
2	1.221	0.164	0.089	0.134	0.544	-0.008
3	1.055	0.147	0.086	0.139	0.588	-0.007
4	1.228	0.117	0.064	0.095	0.546	-0.003
5	1.090	0.138	0.075	0.127	0.544	-0.005
6	1.804	0.215	0.112	0.119	0.521	-0.005
7	1.546	0.182	0.100	0.118	0.551	-0.006
8	1.091	0.109	0.057	0.100	0.523	0.002
9	1.271	0.139	0.081	0.109	0.584	1.268
10	1.473	0.158	0.073	0.107	0.460	0.000
11	1.244	0.118	0.050	0.095	0.423	1.244
12	1.042	0.101	0.054	0.097	0.539	0.003
13	0.825	0.083	0.042	0.101	0.499	0.754
14	1.406	0.146	0.067	0.104	0.456	-0.005
15	1.615	0.141	0.062	0.087	0.441	0.003

Appendix A.8
ORT-MC experiment results for horizontal orientation at 4.29% MC

Specimen Number	Hardness kg	Gumminess kg	Chewiness kg-mm	Cohesiveness kg-mm/kg-mm	Springiness mm	Fracturability kg
1	1.299	0.150	0.060	0.116	0.396	1.263
2	1.260	0.183	0.079	0.145	0.429	1.260
3	1.210	0.158	0.058	0.130	0.368	1.210
4	1.128	0.237	0.100	0.210	0.423	-0.003
5	1.214	0.178	0.067	0.147	0.375	0.720
6	0.834	0.213	0.094	0.256	0.439	-0.001
7	1.692	0.208	0.076	0.123	0.364	1.692
8	1.337	0.185	0.062	0.138	0.335	0.001
9	1.280	0.173	0.067	0.135	0.386	1.269
10	1.449	0.204	0.082	0.141	0.403	0.002
11	1.272	0.143	0.053	0.113	0.370	1.244
12	1.230	0.217	0.084	0.176	0.388	0.001
13	0.915	0.189	0.084	0.207	0.443	0.000
14	0.682	0.125	0.061	0.183	0.485	0.001
15	1.182	0.141	0.049	0.119	0.348	1.182

Appendix A.9
ORT-MC experiment results for vertical orientation at 4.97% MC.

Specimen Number	Hardness kg	Gumminess kg	Chewiness kg-mm	Cohesiveness kg-mm/kg-mm	Springiness mm	Fracturability kg
1	1.379	0.130	0.070	0.094	0.540	1.143
2	1.260	0.116	0.058	0.092	0.500	1.078
3	1.586	0.157	0.081	0.099	0.516	0.002
4	1.148	0.110	0.068	0.095	0.620	1.148
5	1.217	0.106	0.056	0.087	0.530	0.022
6	1.209	0.103	0.053	0.085	0.509	1.182
7	1.496	0.115	0.049	0.077	0.425	1.496
8	1.447	0.123	0.047	0.085	0.383	-0.003
9	1.396	0.131	0.081	0.094	0.616	1.391
10	1.072	0.101	0.051	0.094	0.510	0.001
11	1.408	0.130	0.063	0.092	0.488	1.343
12	0.962	0.092	0.042	0.095	0.456	0.959
13	1.381	0.123	0.060	0.089	0.485	1.227
14	1.280	0.099	0.045	0.078	0.458	1.197
15	0.642	0.061	0.025	0.094	0.411	0.627

Appendix A.10
ORT-MC experiment results for horizontal orientation at 4.97% MC.

Specimen Number	Hardness kg	Gumminess kg	Chewiness kg-mm	Cohesiveness kg-mm/kg-mm	Springiness mm	Fracturability kg
1	1.426	0.235	0.113	0.164	0.480	0.002
2	1.365	0.168	0.066	0.123	0.391	0.008
3	0.926	0.094	0.039	0.102	0.418	0.856
4	1.131	0.070	0.021	0.062	0.295	0.001
5	1.125	0.137	0.061	0.121	0.449	1.010
6	1.072	0.215	0.077	0.201	0.358	0.000
7	1.011	0.182	0.080	0.180	0.443	0.005
8	0.887	0.112	0.037	0.126	0.326	0.556
9	0.848	0.152	0.059	0.180	0.390	0.003
10	1.337	0.196	0.076	0.146	0.386	0.001
11	1.428	0.249	0.094	0.175	0.376	0.000
12	0.919	0.207	0.098	0.225	0.476	0.002
13	1.148	0.147	0.064	0.128	0.438	0.004
14	1.328	0.180	0.069	0.136	0.381	1.078
15	1.018	0.140	0.053	0.137	0.379	1.012

Appendix A.11
ORT-MC experiment results for vertical orientation at 6.27% MC.

Specimen Number	Hardness kg	Gumminess kg	Chewiness kg-mm	Cohesiveness kg-mm/kg-mm	Springiness mm	Fracturability kg
1	1.619	0.125	0.117	0.077	0.934	1.593
2	1.445	0.079	0.068	0.055	0.860	1.431
3	1.520	0.085	0.045	0.056	0.528	1.516
4	1.152	0.073	0.049	0.063	0.672	1.135
5	1.479	0.087	0.051	0.059	0.582	1.475
6	1.052	0.066	0.040	0.063	0.610	1.030
7	1.718	0.074	0.050	0.043	0.678	1.702
8	1.715	0.107	0.076	0.062	0.707	1.715
9	1.412	0.099	0.089	0.070	0.898	1.411
10	1.215	0.058	0.037	0.047	0.635	1.206
11	1.619	0.129	0.097	0.080	0.750	1.264
12	1.626	0.106	0.064	0.065	0.601	1.600
13	1.624	0.099	0.062	0.061	0.622	1.597
14	1.335	0.098	0.070	0.073	0.718	1.314
15	1.646	0.094	0.061	0.057	0.650	1.589

Appendix A.12
ORT-MC experiment results for horizontal orientation at 6.27% MC.

Specimen Number	Hardness kg	Gumminess kg	Chewiness kg-mm	Cohesiveness kg-mm/kg-mm	Springiness mm	Fracturability kg
1	1.281	0.142	0.036	0.111	0.256	1.281
2	1.118	0.114	0.040	0.102	0.346	1.068
3	1.138	0.155	0.066	0.136	0.424	1.059
4	1.494	0.188	0.056	0.126	0.299	1.494
5	1.628	0.183	0.056	0.112	0.305	0.007
6	1.621	0.206	0.062	0.127	0.299	1.605
7	1.177	0.106	0.035	0.090	0.329	1.155
8	1.310	0.146	0.046	0.112	0.313	0.009
9	1.183	0.176	0.056	0.149	0.320	0.960
10	1.706	0.187	0.048	0.110	0.259	-0.003
11	1.889	0.304	0.071	0.161	0.234	0.002
12	1.606	0.181	0.044	0.113	0.245	0.002
13	1.185	0.217	0.061	0.183	0.281	-0.001
14	1.189	0.188	0.059	0.158	0.316	0.001
15	0.924	0.101	0.029	0.109	0.284	0.915

Appendix B.1

MC2 experiment results at 4.67% MC.

Specimen Number	Hardness kg	Gumminess kg	Chewiness kg-mm	Cohesiveness kg-mm/kg-mm	Springiness mm	Fracturability kg
1	1.823	0.223	0.117	0.122	0.528	0.055
2	1.610	0.172	0.108	0.107	0.630	1.323
3	1.395	0.143	0.093	0.103	0.650	1.162
4	1.474	0.143	0.095	0.097	0.667	1.381
5	1.712	0.161	0.096	0.094	0.599	1.538
6	1.232	0.129	0.091	0.105	0.702	1.221
7	1.419	0.156	0.108	0.110	0.692	1.356
8	1.556	0.161	0.099	0.103	0.617	1.042
9	1.499	0.145	0.094	0.097	0.649	1.223
10	1.846	0.229	0.154	0.124	0.671	0.004
11	1.919	0.185	0.100	0.097	0.542	1.779
12	1.644	0.166	0.106	0.101	0.640	1.308
13	1.219	0.098	0.059	0.080	0.602	1.206
14	1.459	0.157	0.099	0.108	0.631	1.450
15	1.543	0.188	0.116	0.122	0.616	0.026

Appendix B.2
MC2 experiment results at 4.95% MC.

Specimen Number	Hardness kg	Gumminess kg	Chewiness kg-mm	Cohesiveness kg-mm/kg-mm	Springiness mm	Fracturability kg
1	1.641	0.144	0.078	0.087	0.541	1.633
2	1.569	0.144	0.091	0.092	0.631	1.039
3	1.701	0.145	0.096	0.085	0.659	1.666
4	1.632	0.144	0.082	0.088	0.571	1.453
5	1.869	0.209	0.135	0.112	0.648	0.004
6	2.133	0.126	0.062	0.059	0.495	0.028
7	1.679	0.157	0.082	0.093	0.522	1.580
8	1.684	0.183	0.111	0.109	0.608	1.531
9	1.702	0.153	0.092	0.090	0.599	1.491
10	1.566	0.155	0.084	0.099	0.540	1.422
11	1.539	0.158	0.100	0.103	0.631	1.393
12	1.277	0.120	0.078	0.094	0.651	1.273
13	2.063	0.225	0.116	0.109	0.518	0.039
14	1.809	0.247	0.176	0.136	0.712	0.023
15	1.801	0.184	0.102	0.102	0.553	1.764

Appendix B.3
MC2 experiment results at 5.65% MC.

Specimen Number	Hardness kg	Gumminess kg	Chewiness kg-mm	Cohesiveness kg-mm/kg-mm	Springiness mm	Fracturability kg
1	1.648	0.135	0.078	0.082	0.577	1.618
2	1.587	0.105	0.049	0.066	0.462	1.587
3	1.174	0.102	0.063	0.087	0.623	1.058
4	1.581	0.127	0.056	0.080	0.442	1.522
5	1.813	0.146	0.075	0.081	0.509	1.669
6	1.897	0.158	0.075	0.083	0.475	0.008
7	2.268	0.198	0.107	0.087	0.542	0.001
8	1.505	0.113	0.051	0.075	0.452	1.490
9	1.788	0.126	0.054	0.071	0.425	1.785
10	1.691	0.143	0.077	0.085	0.540	1.691
11	1.506	0.121	0.063	0.080	0.523	1.445
12	1.702	0.136	0.058	0.080	0.426	1.668
13	2.321	0.212	0.134	0.091	0.634	2.310
14	1.689	0.137	0.067	0.081	0.491	1.366
15	1.742	0.121	0.063	0.069	0.525	1.176

Appendix B.4
MC2 experiment results at 6.43% MC.

Specimen Number	Hardness kg	Gumminess kg	Chewiness kg-mm	Cohesiveness kg-mm/kg-mm	Springiness mm	Fracturability kg
1	1.771	0.106	0.042	0.060	0.391	1.771
2	1.729	0.121	0.055	0.070	0.454	1.637
3	2.118	0.176	0.072	0.083	0.409	2.012
4	1.261	0.089	0.047	0.070	0.536	1.247
5	1.892	0.160	0.076	0.085	0.477	1.890
6	1.448	0.109	0.064	0.075	0.584	1.422
7	1.731	0.109	0.039	0.063	0.354	1.724
8	1.685	0.127	0.085	0.076	0.670	1.582
9	2.088	0.155	0.063	0.074	0.409	1.720
10	1.736	0.203	0.109	0.117	0.538	0.017
11	1.858	0.127	0.063	0.068	0.496	1.697
12	1.289	0.094	0.046	0.073	0.484	1.141
13	1.855	0.116	0.043	0.062	0.374	1.588
14	2.079	0.194	0.088	0.093	0.454	1.729
15	1.825	0.123	0.064	0.067	0.519	1.825

Appendix B.5
MC2 experiment results at 6.94% MC.

Specimen Number	Hardness kg	Gumminess kg	Chewiness kg-mm	Cohesiveness kg-mm/kg-mm	Springiness mm	Fracturability kg
1	1.809	0.118	0.045	0.065	0.380	1.760
2	1.851	0.111	0.044	0.060	0.398	1.809
3	1.836	0.102	0.040	0.055	0.396	1.805
4	1.659	0.111	0.070	0.067	0.627	1.650
5	1.484	0.098	0.055	0.066	0.560	1.452
6	2.012	0.083	0.033	0.041	0.402	2.007
7	1.865	0.106	0.046	0.057	0.433	1.838
8	2.067	0.106	0.046	0.051	0.433	2.067
9	2.108	0.139	0.066	0.066	0.477	2.108
10	1.694	0.094	0.043	0.056	0.453	1.688
11	2.198	0.103	0.033	0.047	0.320	2.198
12	1.841	0.102	0.040	0.055	0.396	1.840
13	2.014	0.117	0.047	0.058	0.400	2.009
14	1.680	0.089	0.031	0.053	0.350	1.677
15	1.894	0.105	0.039	0.055	0.378	1.887

Appendix B.6
MC2 experiment results at 7.84% MC.

Specimen Number	Hardness kg	Gumminess kg	Chewiness kg-mm	Cohesiveness kg-mm/kg-mm	Springiness mm	Fracturability kg
1	2.209	0.133	0.078	0.060	0.586	2.169
2	1.586	0.085	0.033	0.054	0.383	1.586
3	2.416	0.135	0.072	0.056	0.538	2.385
4	2.055	0.100	0.037	0.049	0.376	2.055
5	2.758	0.251	0.135	0.091	0.541	2.730
6	1.894	0.090	0.039	0.048	0.432	1.887
7	2.046	0.110	0.053	0.054	0.481	2.034
8	2.009	0.071	0.029	0.035	0.405	2.009
9	2.132	0.140	0.084	0.066	0.601	2.122
10	2.129	0.116	0.044	0.055	0.380	2.100
11	2.136	0.126	0.054	0.059	0.430	2.110
12	1.327	0.088	0.039	0.066	0.448	1.316
13	1.697	0.078	0.032	0.046	0.415	1.697
14	1.747	0.064	0.024	0.036	0.385	1.747
15	1.743	0.097	0.037	0.055	0.387	1.741

Appendix B.7
MC2 experiment results at 8.08% MC.

Specimen Number	Hardness kg	Gumminess kg	Chewiness kg-mm	Cohesiveness kg-mm/kg-mm	Springiness mm	Fracturability kg
1	1.835	0.096	0.039	0.052	0.410	1.797
2	1.836	0.073	0.028	0.040	0.387	1.823
3	1.798	0.105	0.048	0.058	0.461	1.795
4	1.891	0.086	0.044	0.045	0.511	1.643
5	1.706	0.079	0.035	0.047	0.436	1.695
6	1.307	0.083	0.057	0.063	0.694	1.291
7	1.876	0.080	0.035	0.043	0.435	1.876
8	2.020	0.101	0.050	0.050	0.489	2.020
9	1.714	0.091	0.053	0.053	0.583	1.714
10	1.613	0.094	0.041	0.059	0.439	1.261
11	1.762	0.084	0.035	0.048	0.409	1.762
12	1.201	0.061	0.036	0.051	0.592	1.199
13	1.159	0.055	0.028	0.047	0.511	1.150
14	1.772	0.082	0.038	0.047	0.461	1.772
15	1.698	0.077	0.033	0.046	0.429	1.679

Appendix C.1
Oil level experiment results at 0.0% oil reduction.

Specimen Number	Hardness kg	Gumminess kg	Chewiness kg-mm	Cohesiveness kg-mm/kg-mm	Springiness mm	Fracturability kg
1	1.565	0.140	0.090	0.090	0.642	1.565
2	1.122	0.122	0.103	0.109	0.844	1.101
3	1.207	0.108	0.070	0.089	0.652	1.155
4	1.692	0.207	0.143	0.122	0.691	0.009
5	2.385	0.265	0.172	0.111	0.647	0.009
6	1.247	0.108	0.074	0.087	0.686	1.232
7	1.204	0.111	0.072	0.092	0.652	1.181
8	1.697	0.184	0.124	0.109	0.672	0.007
9	1.254	0.106	0.083	0.084	0.781	1.245
10	1.227	0.128	0.096	0.104	0.753	0.005
11	1.421	0.154	0.119	0.109	0.773	1.265
12	1.266	0.119	0.096	0.094	0.805	1.150
13	1.313	0.132	0.091	0.101	0.690	1.019
14	1.257	0.119	0.100	0.095	0.840	1.086
15	1.605	0.199	0.153	0.124	0.772	0.010

Appendix C.2
Oil level experiment results at 10.35% oil reduction.

Specimen Number	Hardness kg	Gumminess kg	Chewiness kg-mm	Cohesiveness kg-mm/kg-mm	Springiness mm	Fracturability kg
1	1.358	0.177	0.182	0.130	1.033	1.197
2	0.636	0.101	0.130	0.159	1.287	0.529
3	0.809	0.123	0.156	0.152	1.273	0.809
4	1.218	0.190	0.241	0.156	1.270	0.007
5	1.261	0.168	0.175	0.133	1.047	0.000
6	0.890	0.112	0.126	0.125	1.126	0.003
7	0.838	0.127	0.127	0.151	1.004	0.014
8	1.153	0.223	0.307	0.193	1.374	1.124
9	1.483	0.274	0.356	0.185	1.300	0.006
10	1.240	0.175	0.167	0.141	0.958	0.013
11	1.166	0.171	0.175	0.146	1.023	1.005
12	1.333	0.163	0.199	0.123	1.220	1.169
13	1.108	0.124	0.123	0.112	0.990	1.067
14	1.172	0.154	0.145	0.131	0.944	0.987
15	1.043	0.121	0.148	0.116	1.230	1.025

Appendix C.3
Oil level experiment results at 22.07% oil reduction.

Specimen Number	Hardness kg	Gumminess kg	Chewiness kg-mm	Cohesiveness kg-mm/kg-mm	Springiness mm	Fracturability kg
1	0.601	0.096	0.142	0.160	1.476	0.495
2	0.716	0.072	0.081	0.100	1.126	0.709
3	0.703	0.040	0.031	0.057	0.785	0.703
4	0.604	0.101	0.177	0.168	1.745	0.558
5	0.921	0.053	0.035	0.057	0.658	0.546
6	0.965	0.035	0.022	0.036	0.632	0.963
7	1.237	0.099	0.102	0.080	1.032	1.231
8	0.920	0.112	0.145	0.122	1.295	0.005
9	0.521	0.073	0.090	0.140	1.233	0.514
10	0.398	0.025	0.022	0.063	0.875	0.398
11	0.584	0.035	0.029	0.060	0.808	0.571
12	0.677	0.076	0.087	0.113	1.137	0.585
13	0.497	0.060	0.084	0.120	1.412	0.496
14	1.127	0.130	0.124	0.115	0.953	1.099
15	0.754	0.073	0.079	0.096	1.085	0.754

Appendix C.4
Oil level experiment results at 27.37% oil reduction.

Specimen Number	Hardness kg	Gumminess kg	Chewiness kg-mm	Cohesiveness kg-mm/kg-mm	Springiness mm	Fracturability kg
1	0.467	0.015	0.009	0.032	0.616	0.459
2	1.039	0.064	0.060	0.061	0.947	1.039
3	0.675	0.045	0.045	0.067	0.990	0.675
4	0.351	0.067	0.095	0.189	1.427	0.342
5	0.947	0.059	0.049	0.062	0.837	0.934
6	0.568	0.034	0.029	0.059	0.868	0.549
7	0.288	0.016	0.012	0.054	0.763	0.287
8	0.367	0.027	0.029	0.075	1.067	0.367
9	0.403	0.048	0.057	0.118	1.206	0.367
10	0.568	0.017	0.013	0.030	0.738	0.568
11	0.492	0.042	0.041	0.086	0.976	0.379
12	0.400	0.015	0.012	0.037	0.818	0.395
13	0.609	0.042	0.047	0.068	1.122	0.609
14	0.852	0.051	0.044	0.060	0.847	0.849
15	0.887	0.080	0.070	0.090	0.875	0.887

Appendix D
Results from modified atmosphere storage experiment.

Oil level	Oxygen content %	Storage time weeks	Storage bag	Hardness kg	Gumminess kg	Chewiness kg-mm	Cohesiveness kg-mm/kg-mm	Springiness mm	Fracturability kg
full	10	0	a	1.489	0.189	0.220	0.127	1.167	1.266
full	10	0	a	1.500	0.141	0.147	0.094	1.048	1.176
full	10	0	a	1.726	0.223	0.227	0.129	1.017	1.590
full	10	0	a	1.695	0.216	0.203	0.127	0.941	1.553
full	10	0	b	1.351	0.214	0.209	0.158	0.975	0.015
full	10	0	b	1.297	0.162	0.159	0.125	0.981	1.016
full	10	0	b	1.848	0.286	0.309	0.155	1.080	0.008
full	10	0	b	1.311	0.199	0.191	0.152	0.961	1.062
full	10	0	c	1.258	0.145	0.127	0.115	0.876	1.151
full	10	0	c	1.190	0.139	0.133	0.116	0.958	1.177
full	10	0	c	1.505	0.184	0.171	0.122	0.930	0.720
full	10	0	c	1.528	0.197	0.215	0.129	1.091	0.021
full	10	12	a	1.220	0.165	0.207	0.136	1.253	1.196
full	10	12	a	1.525	0.213	0.245	0.140	1.150	1.525
full	10	12	a	1.732	0.241	0.256	0.139	1.063	0.007
full	10	12	a	2.297	0.326	0.318	0.142	0.977	0.010
full	10	12	b	1.717	0.263	0.253	0.153	0.964	0.005
full	10	12	b	1.559	0.222	0.204	0.142	0.920	1.099
full	10	12	b	1.681	0.253	0.277	0.151	1.096	0.009
full	10	12	b	1.262	0.154	0.162	0.122	1.054	1.262
full	10	12	c	1.201	0.136	0.133	0.113	0.980	1.201
full	10	12	c	1.320	0.172	0.177	0.131	1.029	1.258
full	10	12	c	1.545	0.179	0.157	0.116	0.874	1.342
full	10	12	c	1.925	0.277	0.271	0.144	0.979	1.401

Appendix D (continued)

Oil level	Oxygen content %	Storage time weeks	Storage bag	Hardness kg	Gumminess kg	Chewiness kg-mm	Cohesiveness kg-mm/kg-mm	Springiness mm	Fracturability kg
full	2	0	a	1.858	0.253	0.247	0.136	0.973	0.008
full	2	0	a	1.643	0.187	0.181	0.114	0.965	1.421
full	2	0	a	1.550	0.193	0.166	0.124	0.861	1.365
full	2	0	a	1.500	0.208	0.265	0.139	1.276	1.378
full	2	0	b	1.419	0.159	0.135	0.112	0.850	1.025
full	2	0	b	0.875	0.089	0.091	0.102	1.023	0.802
full	2	0	b	1.502	0.215	0.192	0.143	0.895	0.016
full	2	0	b	1.796	0.244	0.241	0.136	0.988	1.390
full	2	0	c	1.934	0.357	0.345	0.185	0.967	0.009
full	2	0	c	1.369	0.238	0.294	0.174	1.235	0.001
full	2	0	c	1.191	0.127	0.117	0.106	0.927	1.189
full	2	0	c	1.303	0.145	0.124	0.111	0.853	1.124
full	2	12	a	1.175	0.179	0.211	0.152	1.181	0.029
full	2	12	a	1.196	0.154	0.173	0.129	1.124	0.866
full	2	12	a	1.674	0.193	0.183	0.116	0.947	1.438
full	2	12	a	1.854	0.259	0.264	0.140	1.019	1.552
full	2	12	b	1.392	0.224	0.237	0.161	1.061	0.044
full	2	12	b	1.292	0.184	0.251	0.143	1.363	1.292
full	2	12	b	2.074	0.373	0.552	0.180	1.480	0.023
full	2	12	b	1.809	0.282	0.257	0.156	0.910	0.068
full	2	12	c	1.489	0.238	0.285	0.160	1.196	1.312
full	2	12	c	1.141	0.128	0.157	0.112	1.223	1.135
full	2	12	c	1.209	0.119	0.108	0.098	0.910	1.195
full	2	12	c	1.387	0.182	0.202	0.131	1.113	1.264

Appendix D (continued)

Oil level	Oxygen content %	Storage time weeks	Storage bag	Hardness kg	Gumminess kg	Chewiness kg-mm	Cohesiveness kg-mm/kg-mm	Springiness mm	Fracturability kg
full	21	0	a	1.432	0.182	0.157	0.127	0.861	1.256
full	21	0	a	1.576	0.170	0.169	0.108	0.989	1.425
full	21	0	a	1.430	0.195	0.208	0.136	1.068	0.056
full	21	0	a	1.645	0.260	0.287	0.158	1.100	0.002
full	21	0	b	1.437	0.162	0.185	0.113	1.142	1.318
full	21	0	b	1.250	0.172	0.202	0.138	1.171	1.245
full	21	0	b	1.666	0.208	0.212	0.125	1.016	1.649
full	21	0	b	1.197	0.195	0.254	0.163	1.304	0.000
full	21	0	c	1.338	0.180	0.178	0.135	0.986	-0.001
full	21	0	c	1.407	0.156	0.182	0.111	1.172	1.397
full	21	0	c	1.736	0.264	0.261	0.152	0.990	-0.001
full	21	0	c	1.260	0.135	0.136	0.107	1.008	1.233
full	21	12	a	1.219	0.155	0.166	0.127	1.069	1.217
full	21	12	a	1.476	0.190	0.231	0.129	1.216	1.408
full	21	12	a	1.277	0.174	0.202	0.136	1.160	0.017
full	21	12	a	1.642	0.196	0.207	0.119	1.054	1.432
full	21	12	b	1.173	0.165	0.163	0.141	0.988	0.955
full	21	12	b	1.406	0.146	0.133	0.104	0.911	1.372
full	21	12	b	1.271	0.130	0.107	0.102	0.827	0.979
full	21	12	b	1.204	0.124	0.126	0.103	1.016	1.198
full	21	12	c	1.500	0.208	0.224	0.139	1.077	1.451
full	21	12	c	1.051	0.147	0.142	0.140	0.966	0.888
full	21	12	c	1.272	0.157	0.159	0.123	1.016	1.087
full	21	12	c	1.594	0.225	0.254	0.141	1.127	1.594

Appendix D (continued)

Oil level	Oxygen content %	Storage time weeks	Storage bag	Hardness kg	Gumminess kg	Chewiness kg-mm	Cohesiveness kg-mm/kg-mm	Springiness mm	Fracturability kg
reduced	10	0	a	0.953	0.126	0.144	0.132	1.142	0.659
reduced	10	0	a	1.030	0.097	0.103	0.094	1.060	1.003
reduced	10	0	a	1.308	0.166	0.181	0.127	1.089	0.979
reduced	10	0	a	1.210	0.267	0.369	0.221	1.381	0.017
reduced	10	0	b	1.051	0.143	0.161	0.136	1.121	0.064
reduced	10	0	b	0.587	0.114	0.170	0.195	1.488	0.027
reduced	10	0	b	1.242	0.205	0.208	0.165	1.016	0.031
reduced	10	0	b	0.993	0.134	0.135	0.135	1.003	0.929
reduced	10	0	c	1.413	0.216	0.238	0.153	1.104	0.024
reduced	10	0	c	1.299	0.234	0.281	0.180	1.200	0.005
reduced	10	0	c	1.191	0.172	0.195	0.144	1.139	0.001
reduced	10	0	c	1.335	0.181	0.182	0.135	1.008	0.076
reduced	10	12	a	1.445	0.154	0.149	0.106	0.969	1.230
reduced	10	12	a	1.040	0.183	0.246	0.176	1.344	0.005
reduced	10	12	a	0.893	0.099	0.091	0.111	0.913	0.813
reduced	10	12	a	1.367	0.195	0.209	0.142	1.073	0.004
reduced	10	12	b	1.306	0.194	0.219	0.148	1.132	1.272
reduced	10	12	b	1.196	0.154	0.199	0.129	1.294	0.034
reduced	10	12	b	1.304	0.188	0.260	0.144	1.385	1.147
reduced	10	12	b	1.463	0.190	0.220	0.130	1.158	1.270
reduced	10	12	c	1.649	0.196	0.212	0.119	1.077	1.463
reduced	10	12	c	1.242	0.195	0.236	0.157	1.208	1.132
reduced	10	12	c	0.962	0.116	0.133	0.121	1.141	0.884
reduced	10	12	c	0.981	0.128	0.139	0.130	1.086	0.934

Appendix D (continued)

Oil level	Oxygen content %	Storage time weeks	Storage bag	Hardness kg	Gumminess kg	Chewiness kg-mm	Cohesiveness kg-mm/kg-mm	Springiness mm	Fracturability kg
reduced	2	0	a	1.429	0.233	0.290	0.163	1.245	1.027
reduced	2	0	a	1.158	0.166	0.191	0.144	1.149	1.088
reduced	2	0	a	1.100	0.123	0.128	0.112	1.040	0.782
reduced	2	0	a	0.805	0.125	0.147	0.155	1.180	0.041
reduced	2	0	b	1.111	0.131	0.145	0.118	1.108	0.939
reduced	2	0	b	1.372	0.177	0.222	0.129	1.258	1.367
reduced	2	0	b	1.021	0.141	0.144	0.138	1.025	0.021
reduced	2	0	b	1.158	0.176	0.218	0.152	1.243	0.090
reduced	2	0	c	0.870	0.229	0.336	0.264	1.466	0.011
reduced	2	0	c	1.737	0.354	0.418	0.204	1.181	0.022
reduced	2	0	c	1.399	0.292	0.352	0.209	1.204	1.033
reduced	2	0	c	1.063	0.185	0.233	0.174	1.260	0.908
reduced	2	12	a	1.674	0.215	0.217	0.129	1.008	1.476
reduced	2	12	a	1.009	0.190	0.266	0.188	1.399	0.011
reduced	2	12	a	1.218	0.163	0.171	0.134	1.051	1.092
reduced	2	12	a	1.603	0.253	0.278	0.158	1.099	0.010
reduced	2	12	b	1.210	0.174	0.182	0.144	1.047	0.000
reduced	2	12	b	1.555	0.318	0.385	0.205	1.209	0.023
reduced	2	12	b	1.905	0.304	0.349	0.160	1.148	1.479
reduced	2	12	b	1.453	0.117	0.120	0.081	1.028	1.431
reduced	2	12	c	1.298	0.236	0.262	0.182	1.109	0.056
reduced	2	12	c	0.751	0.111	0.122	0.148	1.099	0.747
reduced	2	12	c	1.192	0.147	0.162	0.123	1.102	1.112
reduced	2	12	c	1.371	0.172	0.180	0.125	1.050	1.282

Appendix D (continued)

Oil level	Oxygen content %	Storage time weeks	Storage bag	Hardness kg	Gumminess kg	Chewiness kg-mm	Cohesiveness kg-mm/kg-mm	Springiness mm	Fracturability kg
reduced	21	0	a	1.064	0.163	0.199	0.153	1.224	0.001
reduced	21	0	a	1.066	0.221	0.312	0.207	1.413	0.004
reduced	21	0	a	2.132	0.137	0.150	0.065	1.089	0.015
reduced	21	0	a	2.000	0.243	0.222	0.122	0.912	1.477
reduced	21	0	b	1.203	0.163	0.175	0.136	1.071	0.025
reduced	21	0	b	0.986	0.145	0.195	0.147	1.347	0.968
reduced	21	0	b	1.291	0.155	0.166	0.120	1.072	1.098
reduced	21	0	b	1.494	0.248	0.319	0.166	1.288	1.226
reduced	21	0	c	0.864	0.081	0.072	0.094	0.896	0.859
reduced	21	0	c	0.918	0.179	0.262	0.195	1.464	0.004
reduced	21	0	c	0.888	0.108	0.133	0.121	1.238	0.869
reduced	21	0	c	1.096	0.164	0.199	0.149	1.217	-0.001
reduced	21	12	a	1.453	0.259	0.278	0.178	1.074	0.023
reduced	21	12	a	1.266	0.231	0.303	0.182	1.311	0.001
reduced	21	12	a	0.868	0.178	0.278	0.205	1.560	0.849
reduced	21	12	a	0.957	0.096	0.108	0.100	1.128	0.878
reduced	21	12	b	0.846	0.096	0.118	0.113	1.228	0.737
reduced	21	12	b	1.236	0.185	0.196	0.150	1.060	0.969
reduced	21	12	b	1.316	0.171	0.182	0.130	1.062	0.019
reduced	21	12	b	1.341	0.219	0.244	0.163	1.111	0.050
reduced	21	12	c	1.585	0.201	0.251	0.127	1.250	0.002
reduced	21	12	c	0.658	0.057	0.062	0.087	1.093	0.658
reduced	21	12	c	1.113	0.191	0.253	0.172	1.321	0.024
reduced	21	12	c	1.336	0.185	0.201	0.139	1.087	1.219

Appendix D (continued)

Oil level	Oxygen content %	Storage time weeks	Storage bag	Hardness kg	Gumminess kg	Chewiness kg-mm	Cohesiveness kg-mm/kg-mm	Springiness mm	Fracturability kg
full	10	25	a	1.811	0.215	0.209	0.119	0.973	1.727
full	10	25	a	1.166	0.106	0.089	0.091	0.843	1.038
full	10	25	a	1.219	0.152	0.158	0.125	1.039	1.217
full	10	25	a	1.451	0.175	0.169	0.120	0.966	1.233
full	10	25	b	1.221	0.159	0.149	0.130	0.938	1.215
full	10	25	b	1.602	0.157	0.149	0.098	0.945	1.577
full	10	25	b	1.393	0.162	0.174	0.116	1.075	1.233
full	10	25	b	1.703	0.201	0.202	0.118	1.004	1.411
full	10	25	c	1.384	0.189	0.187	0.136	0.991	1.314
full	10	25	c	1.329	0.136	0.119	0.102	0.874	1.039
full	10	25	c	1.374	0.160	0.139	0.117	0.868	1.161
full	10	25	c	1.370	0.177	0.187	0.129	1.059	1.241
full	2	25	a	1.449	0.145	0.133	0.100	0.921	1.435
full	2	25	a	1.720	0.189	0.187	0.110	0.990	1.432
full	2	25	a	1.429	0.154	0.146	0.108	0.948	1.391
full	2	25	a	1.859	0.318	0.345	0.171	1.083	0.014
full	2	25	b	1.812	0.221	0.233	0.122	1.056	1.375
full	2	25	b	1.778	0.203	0.217	0.114	1.066	1.272
full	2	25	b	1.573	0.239	0.264	0.152	1.104	0.579
full	2	25	b	1.619	0.093	0.087	0.057	0.935	1.619
full	2	25	c	1.877	0.202	0.197	0.108	0.971	1.671
full	2	25	c	0.953	0.096	0.098	0.101	1.020	0.953
full	2	25	c	1.603	0.232	0.232	0.145	0.998	0.048
full	2	25	c	1.977	0.203	0.205	0.102	1.013	1.977

Appendix D (continued)

Oil level	Oxygen content %	Storage time weeks	Storage bag	Hardness kg	Gumminess kg	Chewiness kg-mm	Cohesiveness kg-mm/kg-mm	Springiness mm	Fracturability kg
full	21	25	a	1.321	0.115	0.104	0.087	0.904	1.051
full	21	25	a	1.318	0.140	0.144	0.107	1.024	1.210
full	21	25	a	2.087	0.290	0.286	0.139	0.985	1.580
full	21	25	a	1.482	0.177	0.183	0.119	1.035	1.435
full	21	25	b	1.789	0.159	0.150	0.089	0.946	1.712
full	21	25	b	1.411	0.167	0.160	0.118	0.956	1.411
full	21	25	b	1.581	0.131	0.092	0.083	0.701	1.581
full	21	25	b	1.538	0.164	0.158	0.107	0.966	1.530
full	21	25	c	1.347	0.173	0.167	0.128	0.969	0.002
full	21	25	c	1.610	0.230	0.208	0.143	0.903	1.485
full	21	25	c	1.250	0.126	0.103	0.101	0.820	1.250
full	21	25	c	1.727	0.242	0.276	0.140	1.141	1.260
reduced	10	25	a	1.341	0.162	0.147	0.121	0.910	1.018
reduced	10	25	a	1.332	0.173	0.178	0.130	1.031	1.079
reduced	10	25	a	2.096	0.246	0.247	0.117	1.004	1.738
reduced	10	25	a	1.604	0.233	0.264	0.145	1.134	1.329
reduced	10	25	b	1.445	0.233	0.301	0.161	1.293	1.214
reduced	10	25	b	1.107	0.092	0.097	0.083	1.048	1.083
reduced	10	25	b	1.201	0.181	0.219	0.151	1.211	1.131
reduced	10	25	b	1.204	0.207	0.259	0.172	1.251	0.929
reduced	10	25	c	1.571	0.184	0.182	0.117	0.991	1.405
reduced	10	25	c	1.860	0.152	0.174	0.082	1.145	1.835
reduced	10	25	c	1.161	0.159	0.202	0.137	1.270	0.918
reduced	10	25	c	1.038	0.149	0.172	0.143	1.155	0.893

Appendix D (continued)

Oil level	Oxygen content %	Storage time weeks	Storage bag	Hardness kg	Gumminess kg	Chewiness kg-mm	Cohesiveness kg-mm/kg-mm	Springiness mm	Fracturability kg
reduced	2	25	a	1.495	0.271	0.352	0.182	1.298	0.013
reduced	2	25	a	1.467	0.183	0.210	0.125	1.145	1.393
reduced	2	25	a	1.070	0.198	0.278	0.185	1.405	0.805
reduced	2	25	a	1.640	0.206	0.235	0.126	1.136	1.368
reduced	2	25	b	1.511	0.185	0.189	0.123	1.021	1.511
reduced	2	25	b	1.973	0.229	0.216	0.116	0.945	1.695
reduced	2	25	b	1.282	0.157	0.162	0.122	1.035	0.860
reduced	2	25	b	1.214	0.179	0.194	0.147	1.084	1.202
reduced	2	25	c	1.401	0.279	0.355	0.199	1.274	0.001
reduced	2	25	c	1.484	0.200	0.214	0.135	1.068	1.315
reduced	2	25	c	0.864	0.120	0.141	0.139	1.181	0.018
reduced	2	25	c	1.034	0.179	0.210	0.173	1.173	1.014
reduced	21	25	a	1.417	0.168	0.176	0.119	1.048	1.362
reduced	21	25	a	0.795	0.115	0.131	0.145	1.135	0.640
reduced	21	25	a	1.742	0.289	0.329	0.166	1.139	1.396
reduced	21	25	a	0.827	0.091	0.088	0.110	0.975	0.800
reduced	21	25	b	1.391	0.134	0.156	0.096	1.166	1.125
reduced	21	25	b	1.421	0.132	0.125	0.093	0.946	1.403
reduced	21	25	b	0.930	0.129	0.144	0.139	1.114	0.868
reduced	21	25	b	1.437	0.184	0.195	0.128	1.063	1.366
reduced	21	25	c	1.429	0.200	0.234	0.140	1.166	1.429
reduced	21	25	c	1.164	0.099	0.087	0.085	0.879	0.982
reduced	21	25	c	1.171	0.231	0.255	0.197	1.104	0.031
reduced	21	25	c	1.079	0.150	0.212	0.139	1.416	0.979

Appendix D (continued)

Oil level	Oxygen content %	Storage time weeks	Storage bag	Hardness kg	Gumminess kg	Chewiness kg-mm	Cohesiveness kg-mm/kg-mm	Springiness mm	Fracturability kg
full	2	36	a	1.417	0.159	0.147	0.112	0.927	1.152
full	2	36	a	1.585	0.201	0.160	0.127	0.797	0.023
full	2	36	a	1.975	0.291	0.389	0.147	1.336	0.036
full	2	36	a	1.494	0.135	0.090	0.090	0.667	1.315
full	2	36	b	2.019	0.268	0.216	0.133	0.807	0.008
full	2	36	b	2.268	0.365	0.329	0.161	0.900	1.598
full	2	36	b	1.773	0.244	0.217	0.137	0.890	0.035
full	2	36	b	1.568	0.201	0.187	0.128	0.927	1.372
full	2	36	c	1.527	0.231	0.247	0.151	1.068	0.012
full	2	36	c	1.048	0.130	0.126	0.124	0.970	0.980
full	2	36	c	2.151	0.251	0.204	0.117	0.812	0.013
full	2	36	c	1.772	0.209	0.157	0.118	0.751	1.450
full	10	36	a	0.948	0.092	0.071	0.097	0.777	0.796
full	10	36	a	1.558	0.182	0.164	0.117	0.906	1.466
full	10	36	a	2.279	0.371	0.312	0.163	0.842	1.500
full	10	36	a	1.860	0.239	0.188	0.129	0.785	1.503
full	10	36	b	1.885	0.268	0.245	0.142	0.914	0.033
full	10	36	b	1.482	0.200	0.149	0.135	0.746	1.277
full	10	36	b	1.443	0.165	0.148	0.115	0.895	1.417
full	10	36	b	1.844	0.235	0.191	0.127	0.813	0.036
full	10	36	c	1.872	0.230	0.176	0.123	0.764	1.555
full	10	36	c	1.400	0.183	0.166	0.130	0.910	1.136
full	10	36	c	1.706	0.191	0.145	0.112	0.761	1.445
full	10	36	c	1.750	0.204	0.175	0.116	0.858	1.744

Appendix D (continued)

Oil level	Oxygen content %	Storage time weeks	Storage bag	Hardness kg	Gumminess kg	Chewiness kg-mm	Cohesiveness kg-mm/kg-mm	Springiness mm	Fracturability kg
full	21	36	a	1.798	0.214	0.178	0.119	0.831	1.184
full	21	36	a	0.914	0.100	0.092	0.109	0.918	0.912
full	21	36	a	1.910	0.248	0.231	0.130	0.931	1.275
full	21	36	a	1.644	0.184	0.150	0.112	0.812	1.166
full	21	36	b	1.157	0.125	0.112	0.108	0.891	1.128
full	21	36	b	1.141	0.130	0.124	0.114	0.958	0.779
full	21	36	b	1.331	0.137	0.123	0.103	0.900	0.677
full	21	36	b	2.264	0.320	0.292	0.141	0.914	0.020
full	21	36	c	1.169	0.130	0.119	0.112	0.913	1.086
full	21	36	c	1.571	0.208	0.225	0.133	1.078	1.302
full	21	36	c	2.290	0.298	0.247	0.130	0.831	0.034
full	21	36	c	1.679	0.215	0.189	0.128	0.878	0.011
reduced	10	36	a	1.737	0.261	0.254	0.150	0.971	1.384
reduced	10	36	a	1.537	0.202	0.197	0.131	0.976	1.270
reduced	10	36	a	1.850	0.291	0.314	0.157	1.078	0.017
reduced	10	36	a	1.152	0.165	0.186	0.143	1.127	0.935
reduced	10	36	b	1.199	0.361	0.560	0.301	1.553	0.016
reduced	10	36	b	1.728	0.447	0.623	0.259	1.394	0.021
reduced	10	36	b	1.852	0.316	0.329	0.171	1.042	0.020
reduced	10	36	b	1.506	0.198	0.199	0.131	1.007	1.133
reduced	10	36	c	1.568	0.243	0.308	0.155	1.266	0.010
reduced	10	36	c	1.271	0.302	0.420	0.237	1.392	0.021
reduced	10	36	c	2.126	0.312	0.307	0.147	0.985	0.008
reduced	10	36	c	0.959	0.115	0.111	0.120	0.959	0.053

Appendix D (continued)

Oil level	Oxygen content %	Storage time weeks	Storage bag	Hardness kg	Gumminess kg	Chewiness kg-mm	Cohesiveness kg-mm/kg-mm	Springiness mm	Fracturability kg
reduced	2	36	a	1.122	0.143	0.157	0.128	1.098	0.838
reduced	2	36	a	1.636	0.241	0.286	0.147	1.187	0.025
reduced	2	36	a	1.582	0.247	0.277	0.156	1.125	0.008
reduced	2	36	a	1.442	0.204	0.235	0.141	1.153	0.017
reduced	2	36	b	1.351	0.224	0.278	0.166	1.241	0.017
reduced	2	36	b	1.519	0.302	0.391	0.199	1.294	0.018
reduced	2	36	b	0.864	0.295	0.577	0.342	1.955	0.018
reduced	2	36	b	1.288	0.164	0.157	0.127	0.958	1.159
reduced	2	36	c	1.995	0.430	0.652	0.216	1.514	0.021
reduced	2	36	c	1.869	0.338	0.443	0.181	1.309	0.015
reduced	2	36	c	1.044	0.228	0.309	0.218	1.358	0.029
reduced	2	36	c	1.826	0.247	0.261	0.135	1.057	0.048
reduced	21	36	a	1.447	0.200	0.246	0.138	1.227	1.231
reduced	21	36	a	0.845	0.075	0.076	0.088	1.015	0.836
reduced	21	36	a	1.451	0.227	0.278	0.156	1.226	1.318
reduced	21	36	a	1.892	0.432	0.628	0.228	1.454	0.022
reduced	21	36	b	1.471	0.288	0.461	0.196	1.598	0.028
reduced	21	36	b	1.334	0.193	0.205	0.144	1.063	1.035
reduced	21	36	b	1.365	0.204	0.196	0.150	0.962	0.027
reduced	21	36	b	1.221	0.202	0.262	0.165	1.300	0.038
reduced	21	36	c	1.726	0.314	0.378	0.182	1.202	0.028
reduced	21	36	c	2.282	0.378	0.384	0.166	1.016	0.027
reduced	21	36	c	2.052	0.302	0.315	0.147	1.040	0.058
reduced	21	36	c	1.700	0.388	0.597	0.228	1.538	0.005

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VITA

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Master of Science

Thesis: APPLICATION OF AN ANALYTICAL METHOD TO MEASURE TEXTURE OF PECANS

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