LEAVENING AND TEMPERATURE EFFECTS ON THE PHYSICAL AND RHEOLOGICAL PROPERTIES OF WHEAT FLOUR TORTILLAS

By

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CHAPTER 1

INTRODUCTION

Tortillas are the second most popular bread type in America, according to results from the 2002 State of the Tortilla Industry Survey. Having cornered 32% of the sales for the U.S. bread market, tortillas trail white bread by only 2%. They have been a dynamically growing part of the food industry for many years now and are becoming popular on many restaurant menus as substitutes for other breads. Challenges in meeting consumer demands for new and low fat tortillas have included negative effects on the machineability and quality of the products. The adjustments of formulation and processing techniques that are necessary can sometimes have a negative effect on the product in areas such as texture, storage stability and consumer acceptance. In this study we produced thirty six treatments as combinations of leavening agent (1.0, 1.2, and 1.4%), cook temperature (191, 232, and 249°C), and storage time (1, 7, 14, and 30 days). The physical and textural properties of the tortillas were analyzed. Texture analyses, puncture, Kramer Shear Cell, and compression were conducted along with subjective analyses, rollability and peelability. Physical properties were recorded such as weight, diameter, thickness, moisture and color. Significant three way interaction between leavening agent, temperature, and storage time was found for five variables (pforce, pdistance, color b*, C*, and thickness). Amongst all twenty five response variables no significant two way interaction was found between leavening agent and temperature. Four variables had significant two way interaction between leavening agent and storage time (puncture distance and gradient, Kramer shear cell distance, and compression area) while five variables had significant interaction between temperature and storage time (compression force, area and gradient, and color scores b* and C*). Percent leavening agent seemed to have the greatest affect on the products, creating tortillas that were whiter, smaller, thicker, heavier, stronger and tougher. Storage time also had significant affects by making the tortillas less stretchable, less chewy and less able to resist shearing and compression.

CHAPTER 2

REVIEW OF LITERATURE

Wheat Flour Tortilla Processing

For the production of wheat flour tortillas there are three main processes: die cut, hand stretch and hot-press. The die cut method is the most efficient because the dough is sheeted and cut into circles all by machine. This method is quick and convenient but it doesn’t result in the highest quality product. Die cut tortillas are more pastry like and lose their flexibility faster than the hot-press tortillas. The hand stretched method tends to produce tortillas that are larger, thinner and stronger than the die cut or hot-press tortillas, but this method slows down production due to the increased amount of labor involved (Dally and Navarro 1999, Waniska 1999). The most commonly used processing method is the hot-press method even though it is not the most efficient. This method produces the highest quality tortillas; tortillas that are strong, have a soft texture and retain more flexibility over a longer storage time. According to Bello et al (1991) hot-pressed tortillas are more distinctly layered, slightly chewy, and resist tearing and cracking. These characteristics are preferred for many food items such as tacos and burritos as well as wraps and snacks. The production efficiency of the hot-press method and overall quality of the product have increased due to improvements in equipment and operating software (Bello et al 1991, Dally and Navarro 1999, Waniska 1999).

Wheat Flour Tortilla Ingredients

A typical flour tortilla recipe contains four ingredients: flour, water, shortening and salt, while a commercial recipe may include ingredients to help prolong shelf life and increase shelf stability such as: leavening agents, emulsifiers, hydrocolloids and antimicrobial agents.

Bleached and enriched wheat flour is the main ingredient of flour tortillas. It is generally 80 to 95% of the dry ingredients weight with a protein content of 9.5 to 12.5% (Casso 2003). The protein content of the flour is important because it can affect properties of the baked tortilla. Flour with a high protein quality produces tortillas with longer shelf life, but if the protein gets too high then the tortillas become more difficult to process (Serna-Saldivar et al 1988, Dally and Navarro 1999, Waniska 1999). When not enough protein is present in the flour, the dough is weak and sticky and has poor handling properties during processing (Adams 2001).

When making a bread product, water is used to create a gluten matrix that forms the structure of the final product. Insufficient water results in stiff dough that has poor machinability and does not relax properly and when there is excess water in the formula the dough is sticky, also resulting in poor machinability because it adheres to surfaces and requires the use of more dusting flour (Bello et al 1991). Compared to bread dough, tortilla formulas contain less water but more shortening in order to create the typical tortilla texture that does not have a fully developed gluten matrix like in bread (Serna-Saldivar et al 1988).

Shortening affects many aspects of the tortilla's quality, processing characteristics and final flavor. In the production of die-cut and hand stretched tortillas a melted shortening or liquid oil is typically used but for the hot-press method most operations use a solid shortening (Serna-Saldivar et al 1988). Shortening helps to decrease the strength of the gluten bonds by binding to some of the hydrophobic proteins. It also reduces stickiness of the dough and prevents retrogradation (staling) which shows in the rollability analysis (Serna-Saldivar et al 1988; Adams 2001).

Salt plays a large role in bread products because of its affect as a flavor enhancer. It is also used to strengthen the gluten network resulting in more machinable dough. It also assists in prolonging the products shelf life due to a lower water activity (Serna-Saldivar et al 1988).

Unlike many bread products that use yeast as their leavening agent, tortillas are produced using a chemical leavening system. There are two components to a chemical leavening system: a base and an acid (Adams and Waniska 2002). Sodium bicarbonate (NBC) is typically used as the base and sodium acid pyrophosphate (SAPP), sodium aluminum phosphate (SALP) or monocalcium phosphate (MCP) as the acid. Leavening agents are used to alter the internal structure of the product which allows for air pockets to be formed within the product. A chemically leavened tortilla has 1.2-2.2 cm/g specific volume, spongy texture and is white in appearance (Adams 2001). With less leavening agent used the tortillas appear to be more translucent than white in color.

Emulsifiers also known as dough conditioners can be used to improve extensibility and dough softness, typically in “low-fat” or “no-fat” tortillas (Waniska 1999). An emulsifier such as sodium stearoyl lactylate (SSL) is used to improve dough mixing by forming strong bonds with the proteins of the gluten matrix (Friend et al 1995). Other emulsifiers such as distilled monoglycerides can slow down the staling process as well as reduce the sticking of tortillas within a package (Serna-Saldivar et al 1988, Waniska 1999, Adams 2001). Morrison (1976) also saw improvements with the use of emulsifiers in gluten-free breads. He concluded the emulsifiers improved the quality by increasing the aggregation of starch granules in the dough.

The reason for using antimicrobial agents is most obviously to prolong the shelf life of the product by preventing microorganisms from growing. Some of these agents are potassium sorbate, sodium or calcium propionate or sorbic acid (Casso 2003). For these to work the tortilla pH must be <6.1 with a target pH of 5.9 – 6.1 so other acids such as acetic acid, citric acid or phosphoric acid are used to reduce the pH (Serna-Saldivar et al 1988). When these acids are added to the dough they have the potential to disturb or interfere with the leavening reaction mostly by causing the reaction to begin too soon which causes the product to lose some of the carbon dioxide gas because it is unable to retain it within the cellular structure. In order to prevent the acids interaction with the leavening agent they are often encapsulated in an edible coating with a high melting point which offers a delayed release until baking (Dally and Navarro 1999). Fumaric acid is commonly used because it is less soluble in the dough which also helps prevent it from interfering with the leavening reaction (Waniska 1999).

Baking Temperature and Time

Tortillas unlike other bakery products are baked, cooled to ambient temperatures and packaged typically in less than 5 minutes (Waniska 1999). During baking the partial gelatinization of starch, denaturation of protein, and the loss of moisture occurs (Gonzalez-Agramon and Serna-Saldivar 1988). It is typical of flour tortillas to lose around 10% moisture during the baking process (Bello et al 1991, Gonzalez-Agramon and Serna-Saldivar 1988).

Tortillas baked a longer time in order to yield browned and large puffed areas lose their freshness characteristics more quickly than do less-baked tortillas (Bello et al 1991, Friend et al 1995). The browned, puffed tortillas are baked until they attain an internal temperature >95 °C in order to volatilize water and puff the tortilla. This practice increases starch modification during baking and a more rigid structure forms during storage (Waniska 1999). This modification is a partial gelatinization of the starch molecules. According to Bello et al (1991) tortillas immediately after baking are approximately 95 °C.

Leavening Agents

Bakery products are leavened by air, steam, thermal expansion, and biological or chemical methods. The use of these methods to create and retain gas bubbles within the product provides increased volume and a light, porous, tender texture (Adams and Waniska 2002). Since many consumers in the U.S. prefer fluffy, thick, opaque tortillas (Waniska, 1999) the use of the right chemical leavening system is vital.

The most common leavening bases used in baked cereal products are sodium bicarbonate (NBC), potassium bicarbonate (KBC) or ammonium bicarbonate (ABC) (Bejosano and Waniska 2004). During the mixing process these bases are joined with the acids that after a certain time cause a reaction to occur that produces carbon dioxide. The acids are determined due to the desired rate of reaction. Monocalcium phosphate is a rapid leavening acid which causes the evolution of carbon dioxide as soon as it is hydrated, generally during mixing (Book et al 2002). Sodium acid pyrophosphate (SAPP) is a time released acid that generally reacts during resting and baking and sodium aluminum phosphate (SALP) is a heat-activated acid which reacts to increased temperatures. Dough containing SAPP-28, a certain type of sodium acid pyrophosphate, tends to have higher (better) ratings for smoothness, softness and toughness when compared with dough's prepared using other leavening acids (Cepeda et al 2000).

Leavening acids can be used singly or in combination in a formula (Book et al 2002). The slower acting and heat activated acids are commonly used in combination with organic acids (citric, fumaric, lactic and tartaric) which are, like monocalcium phosphate, fast-acting acids. The addition of fumaric acid has been seen to substantially improve tortillas containing SAPP-28 by eliminating the strong "pyro" aftertaste and reducing the amount of time the dough needs to rest (Cepeda et al 2000).

According to Adams and Waniska (2002) increasing the amount of leavening agent by 50% can increase the opacity and height of the tortillas but decreases the diameter in most cases. Also the tortillas produced with medium-to-slow dissolving acids are thicker and more opaque but do not retain their flexibility as well as the thinner ones.

The leavening system affects many characteristics of the tortilla such as height, diameter, pH, moisture and strength (Book et al 2002). Since the leavening system can affect the pH and the pH affects the shelf life; the leavening system must work well with the preservatives. The pH should be <6.1 to activate the preservatives (Friend et al 1995) while the target pH is 5.9-6.1 (Cepeda et al 2000). Fumaric acid is added in most occasions to reduce the pH because it is fast-acting and effectively lowers the pH without causing dough machinability problems like other acidulants (Friend et al 1995). It causes less machining problems because it is less soluble in the dough and interferes less with the leavening reaction (Waniska 1999).

The baking powders traditionally used in tortillas were originally developed for bakery products that were mixed at much cooler temperatures than tortillas. Tortilla dough is mixed at an average temperature of 93 °F where other bakery products are mixed 20-50 °F cooler. They were also created for products that were to be baked 10 times longer than tortillas' 30-40 second bake time. Hence, in tortillas more leavening reactions occur during mixing, dough dividing/rounding, resting, and hot pressing and less leavening occurs during baking than in most bakery products (Waniska 1999).

Textural Analysis

The texture of food is not something that is easily measured. There are two ways to perform texture analysis measurements; subjectively or objectively. Subjective analysis takes more time and involves more people but provides the only way to directly measure texture. Some instrumental methods can be used to measure similar characteristics of foods that are observed by sensory panelists (Truong and Daubert 2003). Like many foods, wheat flour tortilla texture can be measured with both methods (Wang and Flores 1999a, b). The subjective method involves sensory evaluation and rollability testing. The objective methods are large deformation, meaning they use a larger area of sample and are destructive to the product, rheological methods such as extensibility and Kramer shear cell using a texture analyzing machine. The objective methods are quantitative, sensitive, fast and repeatable when compared with the subjective methods (Suhendro et al 1999).

Subjective Rollability Analysis

The rollability test is a simple and easy analysis that produces a reliable measurement for the changes in tortilla characteristics that occur during storage. This analysis can be accomplished without the use of sensory panel experts or expensive equipment (Bejosano et al 2005). The subjective rollability methods are commonly used in both flour and corn tortillas to observe textural changes during storage or to see how the addition of an additive has affected the product (Bello et al 1991, Friend et al 1993, Suhendro et al 1993, Yau et al 1994). Since this test is subjective it can have significant variability depending on the training, experience and preferences of the person conducting the tests as well as the time of day, room temperature, humidity, etc. The method is also not known for its sensitivity to changes in the tortilla that occur within the first 24 hours after baking (Yau et al 1994, Suhendro 1998). Waniska in 1976 used this method to evaluate the extent of breakage when rolling a piece of chapatti around a dowel. Bello et al (1991) and Suhendro et al (1993) also used this method during the storage of tortillas to measure the changes in texture over time.

Subjective Sensory Evaluation

For a descriptive analysis a minimum of seven trained panelists is recommended (Larmond 1977). Training methods such as the Spectrum method can be used to train the panelists (Meilgaard et al 1999). Parameters addressed in evaluation are appearance, odor, flavor, and texture. Under texture, panelists comment on things such as hardness, bending, extensibility, rollability, springiness, fracturability, cohesiveness, and moisture absorption (Bejosano et al 2005).

Evaluations can also be done with consumer acceptability panels of greater than thirty untrained volunteer panelists. They score the tortillas on a like-dislike scale of one to ten for acceptability, taste, stretchiness, and staleness (Bejosano et al 2005).

In 2005 Bejosano and others found that the objective rheological parameters showed a rapid decrease in quality the first five days after baking. Over the rest of the storage they saw much slower changes. This behavior created a logarithmic curve. In contrast the results from the sensory analysis, both expert and consumer, showed a linear progression because the panelists did not detect a significant difference between fresh (0 day) and 1-day-old flour tortillas.

Objective Analysis

Large strain methods such as puncture, penetration, bending, tension, shear, and compression analysis are commonly used to evaluate freshness and textural changes of foods with respect to storage conditions (Truong and Daubert 2003). These methods are sensitive, reliable and can register small changes in flexibility and rollability that are due to a difference in formulation or storage time (Bejosano et al 2005). According to Suhendro et al (1998) and Srinivasan et al (2000) the objective texture measurements can characterize the rheology of wheat flour as well as corn tortilla texture. Their subjective rollability scores were significantly correlated with their objective test findings.

Extensibility

The most suitable rheological methods to analyze textural changes in tortillas during storage are the two-dimensional extensibility, puncture and stress relaxation tests. Wang and Flores (1999a, b) measured the extensibility/stretchability of flour tortillas using the TA-XT2 texture analyzer with the tortilla fixture attached. Stretchability measurements are recommended because they are repeatable and are an important textural property of wheat flour tortillas (Mao et al 2002). Parameters of force, modulus, and work of deformation as well as force and distance to rupture can be obtained through extensibility analysis (Bejosano et al 2005). The stress relaxation tests, also known as compression analysis, test the resiliency of the tortillas, their ability to return to their original shape after being stretched to almost maximum stretch.

Kramer Shear Cell

Kramer shear cell measurements are recommended because the analysis measures force combined with compression, shearing and extrusion (Mao et al 2002). The ability of the tortillas to resist compression, shearing and extrusion is expressed as the maximum force (N) (Mao et al 2002). The Kramer shear cell can have 1-5 shearing blades and has been used in studies attached to an Instron Universal Testing Machine (Bedolia et al 1983, Twillman and White 1988) or a TA-XT2 texture analyzer (Arambula et al 1998, Mao and Flores 2001, Mao et al 2002).

Firmness

Wang and Flores (1999b), Mao and Flores (2001), and Mao et al (2002) measured the firmness of flour tortillas using the TA-XT2 texture analyzer with a 0.75 in round-end end probe (TA-108) in the compression force mode, while other studies used the Kramer shear cell, attached to an Instron Universal Testing machine or a TA-XT2 texture analyzer, to express firmness (Bedolia et al 1983, Arambula et al 1998, Twillman and White 1988).

CHAPTER 3

LEAVENING AND TEMPERATURE EFFECTS ON WHEAT FLOUR TORTILLA PROPERTIES

Abstract

Tortillas are the second most popular bread type in the United States and comprise 32% of the bread market sales, trailing white bread by only 2%. Challenges in the tortilla industry include consistency during processing and quality of the products. The effects of leavening agent, process temperature and storage time on the physical properties of tortillas were studied. The design (3x3x4) consisted of thirty six treatments of leavening agent (1.0, 1.2, and 1.4%), temperature (191, 232, and 249°C), and storage time (1, 7, 14, and 30 days). Physical and textural properties of the tortillas were analyzed. Texture analyses, puncture/extensibility, Kramer shear cell, and compression were conducted along with rollability and peelability. Physical properties were recorded such as weight, diameter, thickness, moisture and color. Significant three way interaction between leavening agent, temperature, and storage time was found for five variables (strength/puncture force, stretchability/puncture distance, b*, C*, and thickness). Rollability and peelability showed significant two way interaction between leavening agent and temperature. Four variables had significant two way interaction between leavening agent and storage time (stretchability/puncture distance, Kramer shear cell distance, compression area and peelability) while six variables had significant interaction between temperature and storage time (compression force, area and gradient, peelability and color scores b* and C*). This study suggests that more physical properties are affected by significant interactions of temperature and storage time and leavening agent and storage time compared to temperature and leavening agent. More studies are needed to determine the efficiency of controlling specific parameters and their effects on key tortilla quality factors.

Introduction

Tortilla History

Flat breads made of corn masa originated 10,000 years before Christ as the main food source for the Aztec Indians in Mexico. Wheat flour tortillas were not created until the Spaniards brought wheat to the New World. The name tortilla was derived from the Spanish word “torta” meaning “round cake” (TIA 2002a).

Tortillas as part of the American diet used to be considered an ethnic food and were typically found in the Hispanic and international foods sections of grocery stores. Now, not only are they the most popular ethnic bread in the U.S. being more popular than the bagel, English muffin and pita bread but are also close on the heels of the white bread market. Tortillas trailed white bread sales in 2002 by two percent making them not only the most popular ethnic bread but the second most popular bread type in America, domestic or ethnic (TIA 2002c). They are now a significant part of the mainstream

American diet and no longer considered just an ethnic food. They often serve as substitutes for traditional breads like hot dog buns, sandwiches and pizza (TIA 2002b).

U.S. Tortilla Market

In 2005 tortillas and related by-products comprised a record-breaking $6.1 billion tortilla industry (TIA 2005), an estimated 85 billion flour and corn tortillas, not including their use for chips. Tortillas have experienced some of the fastest growth in the U.S. baking industry according to findings of a market research study conducted by Aspex Research Survey. The tortilla industry continues to experience widespread, dynamic growth in practically every food business segment, recently including the U.S. Department of Agriculture's Women Infants and Children (WIC) Program which provides food assistance to 8 million people per month (TIA 2008). While sales of prepackaged white bread have seen steady decline, sales of tortillas continue to rise, doubling in the past decade (Petrak 2006a). There are more than 300 companies in the United States that produce tortillas. They produce many sizes and varieties of flavors but the basic flour tortilla remains most popular, out selling corn tortillas by a 2-to-1 margin (Petrak 2006a). In food service operations 78% of fine dining restaurants and 74% of casual/family restaurants offer tortillas on their menu (Petrak 2006b). Tortillas are now a common occurrence in establishments such as McDonald's, Arby's, Subway, Applebee's and Chili's (Petrak 2006b). Portability, taste, versatility and perceived healthfulness are all reasons that tortillas have continued in popularity. It is quite a feat, to go from a homemade ethnic bread product centuries ago to a commercialized American staple with Americans consuming some 7 billion pounds of tortillas each year (Petrak 2006a).

Tortilla Characteristics

Wheat flour tortillas produced in the United States undergo a scrutiny of analysis to ensure that the product’s taste, texture, and physical characteristics meet the specifications set forth by the customer. In order to prolong the storage stability (freshness) and the shelf life (microbial), chemical leavening agents, acidulants, preservatives, emulsifiers and reducing agents can be added to the traditional ingredients, flour, water, salt and shortening.

In the U.S., good quality tortillas are expected to be opaque; meaning they are white in color. Consumers also expect them to be flexible, easy to fold or roll, slightly chewy, and they must resist tearing or breaking (Bello et al 1991, Cepeda et al 2000). The leavening agents used in tortillas create the fluffy/spongy, layered product with a whiter/more opaque appearance. These are characteristics that many consumers prefer (Waniska 1999).

The cook temperature of the product affects the appearance like the leavening system affects the opacity. Consumers prefer white tortillas with toasted brown spots. These toasted areas are parts of the tortilla that due to the expansion of air bubbles internally, are pressed onto the cook surface and therefore brown more than the other parts of the tortilla. Cooking tortillas at different temperatures can change the color of the spots from tan to dark brown, but if the temperature is too cool then no brown spots are created and the product is less desirable. At the same time if the temperature is too high, then the spots become exceedingly dark and that also creates an undesirable product. So in order to produce a high quality desirable product, the leavening system and the cooking temperature must be appropriate.

Tortilla Texture

The texture of food is not something that is easily measured. There are two ways to perform texture analysis measurements; subjectively and objectively. Subjective analysis takes more time and involves more people but provides the only way to directly measure texture. Some instrumental methods can be used to measure similar characteristics of foods that are observed by sensory panelists (Truong and Daubert 2003). Like many foods, wheat flour tortilla texture can be measured with both methods (Wang and Flores 1999a). The subjective method involves sensory evaluation and rollability testing. The objective methods are large deformation rheological methods such as extensibility and Kramer shear cell using a texture analyzing machine. The objective methods are quantitative, sensitive, fast and repeatable when compared with the subjective methods (Suhendro et al 1999).

Large strain methods such as puncture, penetration, bending, tension, shear, and compression analysis are commonly used to evaluate freshness and textural changes of foods with respect to storage conditions (Truong and Daubert 2003). These methods are sensitive, reliable and can register small changes in flexibility and rollability that are due to differences in formulation or storage time (Bejosano et al 2005). According to Suhendro et al (1998) the objective texture measurements can characterize the rheology of corn tortilla texture. They reported that subjective rollability scores were significantly correlated with their objective test findings of force and work (r = -0.89 and -0.92) respectively.

Wang and Flores (1999a, b) measured the extensibility/stretchability of flour tortillas using the TA-XT2 texture analyzer with the tortilla fixture attached.

Stretchability measurements are recommended because they are repeatable and are an important textural property of wheat flour tortillas (Mao et al 2002). Parameters of force, modulus, and work of deformation as well as force and distance to rupture can be obtained through extensibility analysis (Bejosano et al 2005).

Kramer shear cell measurements are recommended because they measure the force combined with compression, shearing and extrusion (Mao et al 2002). The ability of the tortillas to resist compression, shearing and extrusion is expressed as the maximum force (N) (Mao et al 2002).

This study was intended to be conducted using commercially produced tortillas but due to scheduling conflicts we were unable to complete the production commercially.

Objective

The objective of this study was to determine the effects of leavening agent, cook temperature, and storage time on the textural characteristics of wheat flour tortillas.

1. Determine how an increased percent of leavening agent affects the thickness, storage stability, and textural characteristics of the tortillas.

2. Determine how an increased cook temperature affects the thickness, storage stability and textural characteristics of the tortillas.

3. Determine how an increased storage time affects the strength and storage stability of the tortillas.

Materials and Methods

Tortilla Processing

Table 1 has a summary of the treatment design consisting of 3x3x4 variables of percent leavening used, cook temperature (°C) and the storage time (days), respectively. The tortilla formula used is described in Table 2. The wheat flour tortillas were made using batches of 500g of flour (bleached and enriched; 13.3% moisture, 0.50% ash, and 11.2% protein, obtained from ADM Arkady, Enid, OK), 30g of shortening (Serapio's Tortilla Factory, Oklahoma City, OK), 7.5g salt (United Salt Corporation, Houston, TX), Tortilla Blend sodium bicarbonate (0.4, 0.6, 0.8%)(Arm & Hammer, Church & Dwight Company, Old Fort, OH), 2.9g sodium acid pyrophosphate (SAPP 28) (ICL Performance Products LP, St. Louis, MO), 2g calcium propionate and 2g potassium sorbate (Serapio's Tortilla Factory, Oklahoma City, OK), 1.25g sodium-2-stearoyl lactylate (Caravan Ingredients, Lenexa, KS), 1.25g fat-encapsulated fumaric acid (Bakeshure FT, Balchem Corporation, Slate Hill, NY), and 282g tap water at 38°C.

A hot-press tortilla-making process was used based on the report of Mao and Flores (2001) with some modifications. The dry ingredients were mixed at slow speed, dial set to 1 (stir), with a paddle (flat beater) in a mixer (KitchenAid, St. Joseph, MI) for 1 minute. The shortening was added and mixed for 3 minutes at the stir position. The attachment was then switched to a dough hook and 262g of warm tap water (38°C) was added and mixed for 1 minute at stir for the hydration of flour particles. Then 20g more warm (38°C) tap water was added to the remaining dry flour particles at the bottom of the mixing bowl and mixed at medium speed, dial set to 2, for 3 minutes for dough development. Dough was allowed to rest for 5 minutes in a Ziploc® storage bag, then divided into 40-g pieces and rounded by hand. The rounder's hands contained a small amount of shortening to prevent the surface of the dough balls from drying out during proofing. The dough balls were then covered with foil and proofed at room temperature for 30 minutes. The dough balls were flattened by hand and placed in an electrically heated tortilla press (~138°C), (Maquinas Tortilladoras Gonzalez, S. A., model TH – 10, Guadalupe, N. L., Mexico) for 2-3 seconds. They were then cooked for 30 seconds on each side in a stove top non-stick skillet set at one of three temperatures, 191, 232, or 249°C. The temperature of each pan was checked, prior to cooking each tortilla, using an infrared thermometer and kept within ±5°. The range of temperature was determined in a preliminary study. After baking, the tortillas were placed on a cooling rack until cool to the touch (~15 minutes). Twelve tortillas were placed into each polyethylene bag obtained from a commercial production facility and stored at room temperature until analysis at day 1, 7, 14, or 30. A summary of the treatment design is recorded in Table 1; three leavening levels (1.0, 1.2, and 1.4%), three cook temperatures (191, 232 and 249°C) and four storage times (1, 7, 14 and 30 days) were studied. A total of three 500g batches were prepared for each treatment.

Tortilla Physical Characteristics

Tortilla diameter was determined by averaging two perpendicular measurements on each of three tortillas for a total of six observations per treatment. Tortilla weight and thickness were determined from a stack of 12 tortillas with three observations per treatment. The average weight and thickness were divided by 12 to represent the value of a single tortilla. The moisture content was determined on the day of analysis (storage day

1, 7, 14, or 30) using the two-stage Approved Method 44-15A (AACC 2000) and a household coffee grinder (Braun model KSM 2, Braun GmbH, Kronberg, Germany) rather than a Wiley laboratory mill. One tortilla was torn into pieces, weighed and air dried for 24 hours. It was then ground in a coffee grinder and a certain amount weighed into a pre-weighed pan and then dried in a convection oven. After the oven drying the sample was weighed and the moisture content calculated. Means of three tortillas per treatment were reported. Tortilla color was determined for three tortillas with three repetitions each using a Minolta spectrophotometer (model CM-3500d, Minolta, Ramsey, NJ) with a large aperture (30 mm mask) in order to analyze a larger area of sample.

Subjective Analysis – Rollability and Peelability

Subjective rollability scores were recorded for three tortillas per treatment. Each tortilla was evaluated by rolling it around a dowel with a diameter of 1-cm. It was then given a rollability score of 1 – 5, with 1 – unrollable/breaks, 2 – has large tears, 3 – shows many small cracks, 4 – has a few small cracks and 5 – rolls easily without cracking (Cepeda et al 2000).

Subjective peelability scores were given similarly to the rollability scores. As the tortillas were separated from the stack for the rollability analysis, three were given a subjective score for how well they separated. One package of twelve tortillas for each treatment was subjectively given three peelability scores of 1 – 5, 1 – sticks significantly and tears when separated, 2 – sticks and tears a little, 3 – sticks but does not tear, 4 – sticks very little and 5 – no sticking/separates easily from the stack.

Objective Rheological Methods

The extensibility, Kramer shear cell, and compression of flour tortillas were measured using a texture analyzer (model TA – XT2, Texture Technologies Corp., Scarsdale, NY) to estimate the changes in strength, stretchability, stiffness, toughness and firmness.

A TA – 108 tortilla film fixture and a ¾ inch diameter tapered acrylic probe with a flat edge were used for the extensibility/puncture analysis, as suggested by Texture Technologies Corp., Scarsdale, NY. The tortillas were fixed onto the fixture one at a time with the probe attached to the analyzer arm above. The probe traveled downward at 10.0 mm/sec until the tortillas surface was detected at 0.25N force (pre-test). Once the trigger force was reached the graph proceeded to plot the effect of the tortilla under tension as the probe traveled at 2.0 mm/sec to 25 mm, a predetermined distance to stretch the tortilla until it completely ruptured. The exceeding of the elastic limit of the tortilla was observed as the maximum force. The probe was then withdrawn back to the start position at a rate of 15.0 mm/sec. The maximum force (N), distance (mm) the tortilla stretched before rupture, area under the curve or work (N*mm), and slope/gradient (N/mm), which is the ratio of the force to distance, were recorded (Mao et al 2002). The definition of parameters is summarized in Table 3.

Kramer shear test measures the ability of the tortilla to resist compression, shearing and extrusion. It was conducted using a Kramer shear cell with methods reported by Mao and Flores (2001) and Mao et al (2002) using a TA – 91 fixture with five blades attached to a TA –XT2 texture analyzer. The blades were calibrated to a distance of 5 mm from the end of the blades to the product. The tortilla sample was cut

(3.0 x 7.5 cm) and placed over the bottom of the sample cell. The force deformation curve was measured as the blades compressed and sheared the sample. The variables measured were force (N), distance (mm), area under the curve or work (N*mm), and the slope/gradient (N/mm), which is the ratio of the force to distance.

The TA – 108 tortilla film fixture and ¾ inch diameter tapered acrylic probe were also used, like the extensibility/puncture test, to conduct a residual deformation test, or a test of firmness without exceeding the elastic limit of the tortillas, based on the method of Bejosano et al (2005) with modifications. This test was conducted using the "return to start" option, set in compression mode with a trigger force of 0.05N. The probe traveled downward until it reached the tortillas surface. It then stretched the tortilla down 10 mm and returned to the start position. The pre-test, test and post-test speeds were respectively set at 3.0, 1.0, and 10.0 mm/sec. Force (N), distance (mm), area under the compression curve (N*mm), gradient/slope (N/mm), which is the ratio of force to distance, area under the decompression curve (N*mm), and distance of decompression/travel (mm) were recorded.

Statistical Analysis

The experimental design consisted of thirty six combinations of leavening agent, cook temperature, and storage time. Twelve subsamples of tortillas per treatment were used in analysis of textural properties (puncture/extensibility, Kramer shear cell, and compression) and physical properties (weight and thickness). Three subsamples of tortillas were used for textural analysis (rollability and peelability) and physical properties (color score, moisture content, and diameter). The effects of formula and processing conditions on tortilla quality were evaluated using methods for non-replicated data sets described by Milliken and Johnson (1989). This method was used to determine the significance of three way interactions using a multiplicative interaction model. When the multiplicative interaction model did not find significant three way interaction for the response variables, usual analysis of variance (ANOVA) methods were used to evaluate a model with main effects and two-way interactions. The three-way interactions provided the error term and all tests of significance were performed at $p<0.05$. This study did not contain true replication due to differences in batch processing and packaging. True replication would have improved the study and made the statistical analyses simpler and much easier to obtain.

Results and Discussion

Tortilla Physical Properties

The means of the wheat flour tortilla physical properties are shown in Table 4 with the highest and lowest means in bold. The moisture content in food products is among important parameters that determine shelf life stability, textural characteristics and mouth feel. There was a significant effect on moisture due to the cook temperature (Fig. 1) (Table 5). Means across leavening level and storage time revealed higher moisture contents in tortillas cooked at 191°C (33.9%) compared to 232°C (32.3%) and 249°C (32.8%). This was expected due to a lower rate of drying for the 191°C treatment during the cooking process of 30 seconds per side. Treatment 13 (1.2% / 191°C / day 1), had the highest moisture content of 34.8% (Table 4). This treatment had the lowest cook temperature (191°C) and the shortest storage time (1day), therefore being exposed to the least amount of heat and having the least amount of time to lose moisture into the atmosphere. Treatment 8 (1.0% / 232°C / day 30) had the lowest percent moisture of 30.7% (Table 4). It is likely due to the loss of moisture to the atmosphere over the storage time of 30 days.

In any food product, consistency is demanded by both producers and consumers. Therefore physical characteristics need to be measured and studies conducted to ensure consistency and identification of negative effects due to formulation and processing changes. Table 5 has a summary of the variables that significantly affected (P-values) the characteristics of the flour tortillas. The tortilla diameter showed a significant effect by the percent leavening agent in the formula (Table 5). The lower the percent leavening agent, the significantly larger the diameter of the tortillas were (Fig. 2). The largest mean diameter recorded was 16.5cm from the combination 1.0% / 249°C / day 14 (treatment 11), while the smallest (13.87 cm) was obtained from 1.4% / 249°C / day 7, treatment 34 (Table 4). Adams and Waniska (2002) found similar results as they measured a decrease in tortilla diameter when they doubled the leavening acids monocalcium phosphate and citric acid from 0.5 to 1.04 and 0.36 to 0.84 Baker's %, respectively. Friend and coworkers (1995) also found tortillas with smaller diameters with the use of citric acid as an acidifier rather than with fumaric acid. Sidhu and coworkers (1980) reported that the reducing effect of the fumaric acid is due to a free radical mechanism that stabilizes the sulfhydryl groups of protein that creates a dough structure that has fewer disulfide cross-links. This could potentially explain the small diameters observed in this study as we increased the leavening base (sodium bicarbonate) but did not increase the acids (SAPP 28 and fumaric acid).

The weight of the tortillas was significantly affected by temperature and percent leavening (Table 5). The weight of tortillas decreased as the temperature increased (Fig. 3). This is likely due to the increased moisture loss in tortillas cooked at the higher temperature. As the leavening agent increased there was also an increase in weight (Fig. 4). This is expected from the increased retention of moisture. The heaviest tortillas were from the combination of 1.4% / 191°C / day 14 and had an average weight of 37.1 g, which supports the conclusion of moisture retention and increased leavening agent, while the lightest tortillas recorded (34.85 g) were from 1.0% / 232°C / day 1 (Table 4). A significant difference between the mean weight of the 1.0% and the 1.4% tortillas was observed, while the 1.2% tortillas were not significantly different from either group (Fig. 4).

The thickness of tortillas was mainly affected by the leavening system involving an acid and a base as well as the moisture and heat. The thickness, like the weight, was significantly affected by the percent leavening agent and the cook temperature as well as some three way interactions between the leavening agent, temperature and storage time (Table 5). The combinations 249°C / 1.0%, 232°C / 1.2%, and 232°C / 1.4% exhibited similar behavior over time and for 30 days storage showed shorter tortilla stacks when compared to the other treatment combinations (Fig. 5). The increase in thickness due to the percent leavening agent and temperature was expected for the increased carbon dioxide production in the product where the leavening agent was increased as well as an increased size of the individual gas bubbles due to the higher cook temperature. SAPP 28 is a temperature triggered leavening acid that retains nearly all the carbon dioxide during mixing and forming of a product and then releases it quickly when heated (Kichline

1970). In agreement with the report of Adams and Waniska (2002), a significant increase in thickness was observed as the percent leavening acid increased from 0.36-0.84 Baker's % citric acid and 0.5-1.04 monocalcium phosphate. They observed the thickness increase from 2.2-2.4mm and 2.0-2.3mm, respectively. The three leavening levels in this study produced tortillas with significantly different thicknesses with 1.4% making the thickest (4.7mm) and 1.0% the thinnest (3.4mm) (Fig. 6). An increased temperature also caused tortillas with significantly different thicknesses with 191°C being the thinnest at 3.62mm and 249°C being the thickest at 4.54mm (Fig. 7). The thinnest tortillas were from treatment 3 (1.0% / 191°C / day 14) with an average thickness of 2.74mm, as identified in Table 4. It is expected that the lower leavening level and cook temperature were not ideal conditions for the production and expansion of gas during the cooking process. The thickest tortillas were made with the highest leavening level and highest temperature, treatment 35 (1.4% / 249°C / day 14) with an average thickness of 5.42mm (Table 4). This suggests that tortillas cooked at higher temperatures may require less leavening agent to produce an equally thick product.

There was no significant difference between 1.2% and 1.4% leavening agent for the L* analysis of color while the 1.0% treatment had a significantly lower score (Fig. 8). The tortillas with 1.4% leavening agent for day 30 color analysis had molded. So the data were compared twice, once omitting all the day 30 tortillas, therefore analyzing days 1, 7, and 14 with all leavening agents and temperatures then again with the 30 day tortillas included but taking out all of the 1.4% tortillas. For the L* value of whiteness, both analysis methods showed a significant effect due to leavening agent (Table 5). As our leavening system was increased from 1.0 to 1.4% an increase in L* from 76.2 to 78.4

was observed. Figure 8 shows a significantly lower L* value was obtained from 1.0% tortillas over both 1.2% and 1.4% suggesting that the tortillas were more translucent due to less carbon dioxide production or retention. This can be explained by the decreased production of carbon dioxide during processing caused by the decreased amount of leavening agent in the formula. Fewer air bubbles were retained in the tortilla, which yielded tortillas with less whiteness, because the appearance of whiteness is derived from the refraction of light from the air bubbles within the product. Adams and Waniska (2002) reported opacity as a subjective percentage of the whole tortilla. They observed an increase in opacity from 65 to 93% as different leavening acids were increased from 0.36 to 1.04 Baker's percent. Also another study by Bejosano and Waniska (2004) observed an increase in percent opacity from 80 to 91% as the leavening was increased from 6.7 to 20.2 g/kg.

The a* value, which describes the red/green of the product, was significantly affected by leavening agent, temperature, and storage time (Table 5). When the 1.4% data was omitted, a marginal significance for storage time was recorded (data not shown). With both methods we observed an increasing a* value from 0.73 to 0.95 as the leavening agent increased from 1.0 to 1.4%, respectively (Fig. 9); likewise when the temperature increased from 191° to 242°C, an increase from 0.51 to 1.13 was observed (Fig. 10). When the 30 day results were omitted, day 1 tortillas had a significantly lower a* value (Fig. 11) but when the 30 day tortillas were included and the 1.4% data were taken out, day 1 and 30 had significantly lower scores than day 7, while day 14 was not significantly different from either group (data not shown).

Color parameters b* and chroma (C*) were numerically similar and statistically the same for all analysis. C* is a measurement of color intensity while b* represents the degree of yellow/blue. The three way interaction for b* and C* was compared by both temperature and leavening agent to determine which temperatures and percent leavening agents had the most significant effect. There was a significant three way interaction for these parameters ($p < 0.05$) (Table 5). Temperature by day found 191° / day 7, 232° / day 7 and 249° / day 1 as not significantly different from each other. Day 14 / 249° and 232° had significantly higher b* and C* values (Fig. 12 & 13) when compared to all treatments. They were significantly affected by leavening agent and the temperature/day two-way interaction when the day 30 data was omitted (Table 5). C* and b* both increased significantly with 1.4% leavening (18.5 and 18.4, respectively) with the other two levels not being significantly different from each other at 17.4 and 17.5 (Fig. 14). With the 30 day analysis omitted b* and C* had significantly higher scores as the temperatures and storage times increased with the highest b* and C* scores of 19.49 and 19.54 for treatment 35 (1.4% / 249°C / day 14).

For color values L*, a*, b*, and C*, there were similar trends for the high and low means. The highest mean values came from treatments with 1.4% leavening and for a*, b*, and C* were combinations of 1.4% as well as 249°C (Table 4). The lowest scores all came from the 191°C / 1.0% combinations.

Hue angle was inversely affected by percent leavening agent and temperature, when compared to the other color scores, with its highest value of 89.07 coming from the combination 191°C / 1.0%, treatment 3, while its lowest score of 86.1 came from 232°C / 1.2%, treatment 18 (Table 4). This opposite effect could be explained by the definition of hue angle: it describes the color in terms of the human visual perception of red, yellow, blue, green, etc. In the color space L*C*h, hue (h) is the angle of the cylindrical coordinates rather than the rectangular coordinates as in the L*, a*, b* color space. Hue angle ranges from 0° (red, +a*), 90° (yellow, +b*), 180° (green, -a*) to 270° (blue, -b*) (Minolta 1998). The hue angle for both analysis methods was significantly affected by the leavening agent and temperature (Table 5). As the percent leavening agent and the temperature increased, the hue angle significantly decreased from 88 to 87.08 and 88 to 86.6, respectively (Fig. 15 & 16).

Extensibility

The extensibility/stretchability of the flour tortillas is expressed as the maximum force and rupture distance required to completely puncture the tortillas. The greater the distance at the point of rupture the more stretchable the product, and the greater the force at the point of rupture the stronger the product (Texture Technologies 2009). Examples of stretchability tracings from the TA – XT2 texture analyzer are presented in Figure 17. The average puncture force for each treatment is reported in Table 6, with the lowest and highest values in bold. For puncture force, the storage time interacted with temperature/leavening agent combinations ($p < 0.05$) and day 30 tended to have a lower force for some temperature/leavening agent combinations. Temperatures of 191° and 232°C at 1.4% leavening agent and 249°C / 1.0% appear to have lower puncture forces at day 30 than the other temperature/leavening agent combinations at days 1, 7, and 14 (Fig. 18). A lower puncture force value means a weaker tortilla, one that would break more easily when being filled with other ingredients such as meat and vegetables. Puncture force was also significantly affected by temperature and storage time (Table 5). When comparing temperatures, the lowest (191°C) had a significantly smaller puncture force of 6.0 N compared to the highest temperatures (249°C) at 6.66 N (Fig. 19). For storage times, day 1 had a significantly higher puncture force value of 7.24 N and day 14 had the lowest average force value of 6.0 N (Fig. 20). This suggests that tortillas produced at 191°C are weaker than the ones produced at higher temperatures, and also that the fresher the tortillas are the stronger they will be. The other two temperatures and three days were not significantly different from each another. These results fall in line with the tortilla baking tests conducted by Alviola et al (2010) at Texas A & M. They observed an average force of 9.41 N on day 0 that fell to 8.55 N by day 14, a significant decrease in strength over the first 14 days of shelf life.

Puncture distance at the breaking point suggests the degree of stretchability of the product (Texture Technologies 2009). Puncture distance was affected by the 3-way interaction of temperature, leavening agent, and storage time ($p<0.05$). At day 1 of storage, values tended to be higher with 249°C / 1.2% (treatment 21), 191°C / 1.4% (treatment 25), and 249°F / 1.4% (treatment 33) having larger values (Table 6) than other temperature/leavening agent combinations, meaning the tortilla was able to stretch further before rupturing (Fig. 21). Puncture distance was significantly affected by temperature and there was a significant two-way interaction of leavening agent/storage time (Table 5). When looking at the interaction between leavening agent/storage time, a decrease in puncture distance was observed as storage time increased and when comparing leavening agents the puncture distance increased as the leavening agent increased (data not shown). At 191°C the puncture distance of 11mm was significantly shorter than the other two temperatures that were not significantly different from one another both having a distance of 11.61mm (Fig. 22), suggesting that for more extensible tortillas a cook temperature higher than 191°C would be most appropriate.

The area under the curve, which represents the work during the test, was also recorded along with the gradient or slope from the point of initial contact with the tortilla extending to the point of maximum force at the point of rupture, data is recorded in Table 6. The area was significantly affected by leavening agent, temperature, and storage time (Table 5). A degree of toughness can be observed from the total area under the curve (Texture Technologies 2009). The puncture area increased from 28.13 to 37.94 N*mm as the leavening agent increased, with significantly different values for each leavening level, (Fig. 23). Puncture area also increased as the temperature increased with it being significantly smaller than the others at 191°C (30.24 N*mm) (Fig. 24). With each days analysis there was a significant decrease in puncture area from 44.8 N*mm day 1 to 26.84 N*mm day 14, until day 30 where it was not significantly different from day 7 or 14 (Fig. 25). Similar results found by Alviola et al (2010) observed a decrease from day 0 (88.15 N*mm) to day 14 (37.5 N*mm). These results suggest that fresh tortillas made with higher amounts of leavening agent and cooked at higher temperatures would be tougher than ones made with lower leavening and cooked at lower temperatures.

Puncture gradient, which is used to interpret the stiffness of a product (Texture Technologies 2009), was significantly affected by leavening agent and storage time (Table 5). The gradient was inversely related to the percent leavening agent, showing a significantly higher score with the 1.0% leavening level (0.62 N/mm) (Fig. 26). The puncture gradient was directly related to the length of storage. As storage time increased from day 1 to 30 so did the puncture gradient from 0.48 to 0.62 N/mm with a significantly lower value on day 1 (Fig. 27), meaning the tortillas with less leavening and longer storage times were tougher than the other treatments. This can be expected by contributions of retrograded starch and staling expected as the storage time progresses.

The mean values for the puncture test (the analysis of stretchability), are shown in Table 6. The highest force, distance and largest area were from treatment 33 (1.4% / 249°C / day 1), as identified in Table 1, with the largest gradient from treatment 24 (1.2% / 249°C / day 30). The lowest puncture force and puncture area were from treatment 15 (1.2% / 191°C / day 14) while the shortest distance and smallest gradient came from treatments 4 (1.0% / 191°C / day 30) and 25 (1.4% / 191°C / day 1), respectively. Bejosano et al (2005) found that fresh tortillas had a lower puncture force value (day 0 = 1.01 N) and longer extension before rupture (day 0 = 3.81 mm) and over time an increase in puncture force (day 15 = 1.57 N) as the tortillas began to stale. In comparison, our results showed fresh tortillas to have a higher puncture force (day 1 = 7.2 N) and longer extension (day 1 = 14.8 mm) which is a sign of strength and stretchability. I believe Bejosano analysis more represents the stiffness and toughness of the product where this study shows the strength and stretchability. That is why their results began lower and increased over time. As storage time increased puncture force dropped over days 7 (6.3 N) and 14 (6.0 N) but on day 30 (6.3 N) showed a small increase that proved to be insignificant. The day 30 increase can be attributed to staling as the tortillas were harder.

Kramer Shear Cell Measurements

The ability of the tortilla to resist compression, shearing and extrusion is expressed as the maximum force (N) and the work/area under the curve (N*mm) as the energy required to attain failure. Examples of these graphs can be viewed in Figure 28. Kramer shear force was significantly affected by the storage time (Table 5). When comparing storage time, day 1 had a significantly higher Kramer shear force value of 43 N than do the other days that ranged between 33.7 and 35.9 N (Fig. 29). This suggests that fresh tortillas are not as easily torn or cut as older products, while tortillas stored from 7 to 30 days show similar values of Kramer shear force. This suggests that tortillas degrade quickly during the first week after production and then more slowly after 7 days. Mao and Flores (2001) observed similar trends in Kramer shear force over a storage time of four days. The maximum forces ranged from 96.66 to 77.77, 77.53 to 65.65, and 77.36 to 68.00 N for fresh (2 hr), 2-, and 4-day-old tortillas, respectively.

Kramer shear distance was affected by the interaction between leavening agent/storage time. Day 1 had significant effects with all leavening levels, 1.0% / day 1 being significantly shorter than 1.4% / day 1. Tortillas from 1.2% / day 1 were not significantly different from either of the other combinations (Fig. 30).

Kramer shear area was significantly affected by leavening agent and storage time (Table 5). Kramer shear area is significantly larger with 1.4% leavening (data not shown). Day 1 had a significantly larger Kramer shear area (116 N*mm) than the other days that were not significantly different from each other ranging from 83.4 to 79.4 N*mm (Fig. 31), meaning more energy was required to run the tests for day 1 analysis or for 1.4% leavening levels, it was harder work to compress and shear the samples.

Kramer shear gradient was significantly affected by leavening agent and storage time (Table 5). So as the leavening agent increased the gradient decreased, with the 1.0% leavening level having a significantly larger gradient of 8 N/mm while the other two levels were 6.9 and 6.6 N/mm, respectively (Fig. 32). The Kramer gradient for day 1 was significantly smaller than day 30, but day 7 and 14 were not significantly different from either day 1 or 30 (data not shown), meaning that the 1.0% leavening level and the tortillas stored for 30 days were stiffer than the other levels of leavening and storage times.

As with the results from the puncture test, treatment 33 (1.4% / 249°C / day 1) again had the highest force, distance and largest area for the Kramer Shear Cell measurement (Table 6), while treatment 8 (1.0% / 232°C / day 30) had the largest gradient. Treatment 3 (1.0% / 191°C / day 14) had the shortest distance and the smallest area while treatments 28 (1.4% / 191°C / day 30) and 26 (1.4% / 191°C / day 7) had the lowest force and smallest gradient, respectively (Table 6). Treatment 33 having the highest scores for puncture and Kramer Shear Cell makes it stand out. The higher leavening and higher cook temperature creates a fresh tortilla that is very strong as well as stretchable.

Compression Analysis

The compression analysis is a residual deformation test or a test of firmness. The compression/decompression analysis determines the resiliency of the tortillas. As they are compressed strength and stretch are calculated. Then when they are decompressed the amount of recovery can be calculated as recovery distance and area (Fig. 33).

Compression force was significantly affected by leavening agent and a two-way interaction between temperature and day (Table 5). Only day 1 showed a significant effect by temperature where 191°C had a significantly larger compression force value of 3.6 N when compared to 249°C / day 1 (2.5 N), with 232°C / day 1 (2.9 N) falling in between but not significantly different from the other temperatures on day 1 (Fig. 34). As temperature increased the compression force values decreased. The significant effect of leavening agent showed 1.0% with a significantly larger compression force (5 N) than 1.2% (4.3 N) but 1.4% (4.6 N) was not significantly different from either (Fig. 35), meaning that products made with low leavening levels and cooked at low temperatures would have higher compression force values, making them a stronger product that could be less stretchable.

Compression distance was set to 10mm; therefore the highest score was 10mm which was recorded for treatments 1, 5, 9, 13, 14, 17, 18, 21, 25-27, 29-31, and 33-35 (Table 6). These treatments did not rupture when stretched to 10mm. The treatments not listed broke before reaching 10mm, the shortest of which was treatment 4 (1.0% / 191°F / day 30) (Table 6) with a compression distance of 8.6mm suggesting that tortillas containing less leavening agent don’t retain their ability to stretch and recover for as long as those with more leavening agent. This is exemplified in Figure 36 which shows that the treatments with the highest leavening level retained more stretch over the storage time.

Compression area had a temperature/day interaction with marginal temperature effect from 191-249°C but due to Tukey’s correction the p-value was not less than 0.05. Compression area also had two-way interaction between leavening agent/day where day

14 and 30 were interacting with all leavening levels (Table 5). The 1.4% and day 30 combination was the only value to be significantly different. It had a significantly larger compression area when compared to the other day 14 and 30 combinations (data not shown), concluding that the higher leavening level and longer storage time created a product that required more work and energy to compress, likely making a product that is less desirable because of its toughness.

Compression gradient was significantly affected by leavening agent and a two-way interaction between temperature and storage time (Table 5). The interactions showed storage time to be significantly different with an increasing compression gradient as the temperature decreased. The compression gradient for 191°C was significantly larger than that of 249°C, while 232°C was not significantly different from either of the other temperatures (data not shown). The leavening agent effect showed 1.0% to have a significantly larger compression gradient than both 1.2% and 1.4% which were not significantly different from one another, meaning that tortillas cooked at lower temperatures with lower leavening agents have a steeper slope; they reach maximum force in a short distance.

Decompression area/travel time was also obtained from the compression analysis. The decompression is pictured as the second half of the compression tracing, from maximum force to the return to zero force (Fig. 33). The decompression area was affected by all three main effects but with no significant interactions (Table 5). Leavening agent showed a significantly larger decompression area of 11.9 N*mm with 1.0% leavening when compared to 1.4% (9.83 N*mm). In the middle and not significantly different from either 1.0% or 1.4% was the 1.2% leavening (10.92 N*mm).

For temperature, 191°C had a significantly larger decompression area with 249°C being in the middle and 232°C having the smallest decompression area (data not shown). Day effect showed significant change from day 1 to 7 and 14 to 30 but not from 7 to 14 (Fig. 37). Day 1 had the smallest decompression area (5.87 N*mm), and it increased for subsequent day's analyses up to 16.12 N*mm on day 30, meaning the products with smaller decompression areas were likely to have shorter travel distance or smaller maximum force because they were not as strong or as able to recover as well as some of the other treatment groups.

Decompression travel/time was only significantly affected by leavening agent where each leavening level (1.0, 1.2, and 1.4%) had a significantly different decompression travel distance, which increased as leavening agent increased, 5.7, 6.6, and 7.2 mm, respectively (Table 5) (Fig. 38). So the treatments with higher leavening levels were able to recover more than the treatments with lower levels. The product was more resilient to the compression stretching.

The highest mean values for compression force, compression area, gradient, decompression area, and travel were treatments 8, 36, 4, 16, and 35, respectively (Table 6). The first four of those treatments were stored for 30 days while treatment 35 was stored for 14. The low score for force, compression area, and decompression area was treatment 33 (1.4% / 249°C / day 1) and the low scores for gradient and travel were treatments 21 (1.2% / 249°C / day 1) and 1 (1.0% / 191°C / day 1), respectively. All of the mean values are shown in Table 6.

Rollability

Rollability scores were determined subjectively with whole number scores of 1 – 5. Multiple treatments, as identified in Table 1, had a high rollability score of 5 (1, 5, 9, and 29) as well as many with the lowest score of 1 (19, 27, 28, 32, 35, and 36) (Table 6). Rollability was significantly affected by storage time and an interaction between percent leavening agent and temperature (Table 5). All temperatures with 1.0% leavening agent had significantly higher rollability scores than all of the temperatures with 1.4% leavening as well as the 1.2% at 232° and 249°C. Scores for 1.2% at 191° and 1.2% at 249°C were significantly higher than the scores for 1.4% at 191°C. Each day's rollability analysis was significantly different from the others except days 14 and 30 were not significantly different from each another with average scores of 4.5, 2.6, 1.8, and 1.7 for days 1, 7, 14, and 30, respectively (Fig. 39). Bejosano et al (2005) observed a similar trend of rollability over a 15 day period. They observed averages of 5.0, 4.9, 4.8, and 4.6 for days 0, 1, 8, and 15, respectively, with each day being significantly different from the others except day 8 was not significantly different from either day 1 or 15. This suggests that the tortilla texture changes most quickly in the beginning but then slows down as storage time progresses. Bejosano et al (2005) could differentiate the age of their tortillas by their rollability scores, which could separate day 0 (fresh) tortillas from 1-day-old tortillas. We also observed differences by percent leavening. The higher the percent leavening the thicker the tortillas were which then hindered their rollability. Adams and Waniska (2002) also found reduced shelf stability, as determined by rollability scores in tortillas with high amounts of leavening. They concluded that it was due to the increased thickness of the product.

Peelability

Peelability was scored the same as rollability and also had multiple perfect scores of 5 (14, 17, 26, and 27) and two treatments with the lowest received score of 2 (3 and 25) (Table 6). Peelability was significantly affected by leavening agent/temperature and day/temperature combinations (Table 5). At 1.0 and 1.4% leavening at all temperatures there was no significant difference in mean peelability score (data not shown). However with 1.2% leavening, 232°C had a significantly higher mean score than 249°C with 191°C not significantly different from either. When comparing storage time and temperature interactions, day 14 stood out because the three temperatures had mean peelability scores that are not significantly different from one another (data not shown). Day 1, 191°C is significantly lower than all other points except day 7 and 30 at 249°C. Day 7 / 191°C had the highest mean peelability score. It was significantly higher than all other day/temperature combinations except day 7 and 30 at 232°C.

Conclusions

1. As the percent leavening agent increased the thickness of the tortillas increased which negatively affected the products storage stability as observed by the rollability scores. Increasing the percent leavening agent also showed an increase in strength of the tortillas to resist the compression, shearing and extrusion of the Kramer shear cell. Decreasing the percent leavening agent made tortillas that were more able to retain their ability to recover from stretching. They were more able to return to their original shape after being stretched almost to rupture.

2. Increasing the cook temperature also showed an increase in the thickness of the product which had a negative effect on the rollability scores that represent the products storage stability. The increased cook temperature showed an increased toughness of the product, its ability to resist compression as well as a being less stiff and hard/breakable.

3. As the storage time increased the tortillas became weaker and a significant decrease in strength was observed in the first week after processing. Storage time also decreased the tortillas stability as observed by a significant decrease in rollability scores as the storage time increased.

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TABLE 1

Experiment Design of Wheat Flour Tortilla Treatments[a]

Treatment ID	Total Leavening Agent (%)	Cook Temperature (°C)[b]	Storage Time (days)
1	1.0	191	1
2	1.0	191	7
3	1.0	191	14
4	1.0	191	30
5	1.0	232	1
6	1.0	232	7
7	1.0	232	14
8	1.0	232	30
9	1.0	249	1
10	1.0	249	7
11	1.0	249	14
12	1.0	249	30
13	1.2	191	1
14	1.2	191	7
15	1.2	191	14
16	1.2	191	30
17	1.2	232	1
18	1.2	232	7
19	1.2	232	14
20	1.2	232	30
21	1.2	249	1
22	1.2	249	7
23	1.2	249	14
24	1.2	249	30
25	1.4	191	1
26	1.4	191	7
27	1.4	191	14
28	1.4	191	30
29	1.4	232	1
30	1.4	232	7
31	1.4	232	14
32	1.4	232	30
33	1.4	249	1
34	1.4	249	7
35	1.4	249	14
36	1.4	249	30

[a] Three batches of 500g flour per treatment were used.

[b] 375, 450, 480 °F

TABLE 2

Wheat Flour Tortilla Formulation[a]

Ingredient	Batch Amount (g)	Flour Basis (%)
Flour (13.3% moisture)	500	100
Shortening	30	6
Salt	7.5	1.5
Sodium Bicarbonate[b]	Adjusted	Adjusted
SAPP 28[c]	2.9	0.58
Calcium Propionate	2	0.4
Potassium Sorbate	2	0.4
SSL[d]	1.25	0.25
Fumaric Acid	1.25	0.25
Water (38°C)	282	56.4

[a] Adams and Waniska (2002) and Bejosano et al (2006) with modifications.
[b] Adjusted for each batch to either 2 (0.4%), 3 (0.6%), or 4 (0.8%).
[c] Sodium acid pyrophosphate.
[d] Sodium-2-stearoyl lactylate.

TABLE 3

Abbreviations and Definitions of Parameters Used for Statistical Analysis

Test	Abbr.	Units	Definitions
Puncture	PForce	N	Force required to completely puncture/rupture a tortilla. Measure of stretchability to the point of rupture.
	PDistance	mm	Distance the tortilla stretches to the point of rupture. Measure of stretchability as the length that the tortilla can be stretched to the point of rupture. The greater the length the more stretchable the tortilla is.
	PArea	N*mm	Total work under the puncture curve. Toughness.
	PGradient	N/mm	Gradient/slope of the line from contact with tortilla to maximum force. The higher the slope the stronger the tortilla. Stiffness.
Kramer Shear Cell	KForce	N	Force required to shear the tortilla strip.
	KDistance	mm	Distance the tortilla is stretched before shearing.
	KArea	N*mm	Total work under the Kramer curve.
	KGradient	N/mm	Slope of the line from contact with tortilla to maximum force.
Compression	CForce	N	Amount of resistance to stretching the tortilla 10mm. Measure of the firmness without exceeding the elastic limit of the tortillas.
	CDistance	mm	The distance the probe stretches the tortilla, set at 10mm.
	CArea	N*mm	Total work under the Compression curve (as the tortilla is stretched downward).
	CGradient	N/mm	Slope of the line from contact with tortilla to maximum force.
	DArea	N*mm	Total work under the Decompression curve (as the tortilla pushes against the probe returning up).
	DTravel	mm	Distance the tortilla pushed against the probe moving up.
Rollability	Roll	1 to 5	Subjective score of 1-5 depending on how the tortilla rolled, 5=best 1=worst.
Peelability	Peel	1 to 5	Subjective score of 1-5 depending on how the tortilla peeled away from the stack, 5=peels easily, 1=breaks.
Color Score	L*		Indicates lightness (black 100-white 0).
	a*		Red-green.
	b*		Yellow-blue.
	C*		Chroma.
	h		Hue angle.
Moisture	Moist	%	Moisture content of the cooked tortillas.
Diameter	Dia.	cm	Average to two perpendicular lines.
Weight	Wt.	g	Average from measurement of a stack of 12 tortillas divided by 12.
Thickness	Thick	mm	Average of three measurements of a stack of twelve tortillas divided by 12.

TABLE 4

Moisture, Color, Thickness, Weight and Diameter of Wheat Flour Tortillas

Tortilla	**Moisture**	**Color**					**Thickness**	**Wt.**	**Dia.**[2]
Treatment	**(%)**	**(L*)**	**(a*)**	**(b*)**	**(C*)**	**(h)**	**(mm)**	**(g)**	**(cm)**
1	32.66	**74.76**	0.44	17.74	17.74	88.60	2.75	35.25	16.08
2	33.66	75.62	0.49	16.04	16.04	88.24	3.01	35.87	15.13
3	34.23	74.80	**0.26**	**15.64**	**15.64**	**89.07**	**2.74**	35.88	16.37
4	33.03	75.01	0.30	15.82	15.83	88.95	2.97	36.07	15.15
5	31.01	78.02	0.34	17.52	17.53	88.89	3.56	**34.85**	15.82
6	33.46	77.58	1.11	16.81	16.85	86.23	3.48	35.44	15.90
7	32.47	76.88	1.01	18.98	19.01	87.10	3.73	35.33	15.82
8	**30.71**	76.11	0.74	16.81	16.83	87.56	3.51	35.08	15.88
9	32.93	77.18	0.84	17.45	17.47	87.24	3.81	35.30	14.93
10	32.41	75.58	1.11	18.11	18.19	87.67	3.55	35.10	15.55
11	32.69	75.57	1.01	18.47	18.50	86.90	4.12	34.86	**16.53**
12	32.74	77.45	1.07	17.20	17.23	86.42	3.55	35.72	15.82
13	**34.75**	78.37	0.55	17.68	17.69	88.24	3.73	36.26	14.98
14	34.59	77.87	0.77	16.88	16.89	87.39	3.44	36.35	14.57
15	34.58	78.94	0.48	16.09	16.10	88.29	3.78	36.18	14.58
16	32.12	78.09	0.37	16.72	16.72	88.72	3.86	35.39	15.05
17	31.63	78.46	0.86	17.37	17.39	87.14	4.56	35.85	15.50
18	32.26	78.30	1.17	17.17	17.21	**86.10**	4.06	35.15	15.57
19	32.44	78.61	0.85	18.33	18.35	87.36	4.60	35.53	14.63
20	32.31	78.53	0.85	17.17	17.19	87.17	3.61	35.04	15.55
21	33.35	78.97	1.03	17.14	17.18	86.54	4.71	35.18	15.38
22	34.00	78.86	1.09	17.85	17.88	86.54	4.55	35.72	15.13
23	31.34	77.33	1.18	18.81	18.85	86.39	4.39	35.67	15.83
24	33.47	78.41	1.18	17.74	17.78	86.18	5.03	35.41	14.10
25	34.59	**79.11**	0.46	18.53	18.54	88.59	4.29	36.08	14.47
26	34.07	77.79	0.52	17.83	17.84	88.39	4.07	35.84	15.02
27	34.16	77.25	0.62	19.33	19.34	88.18	4.29	**37.13**	14.28
28	33.80	N/A	N/A	N/A	N/A	N/A	4.57	36.33	14.55
29	33.90	77.70	0.84	17.99	18.01	87.28	4.56	35.29	15.10
30	33.14	78.15	0.97	18.12	18.14	86.93	4.92	36.13	14.47
31	31.85	77.54	1.27	18.83	18.88	86.16	5.27	35.82	15.22
32	N/A	N/A	N/A	N/A	N/A	N/A	4.16	35.48	15.42
33	32.91	77.61	1.12	17.79	17.83	86.39	5.08	35.58	15.40
34	32.81	78.14	**1.39**	18.01	18.09	85.83	5.13	35.60	**13.87**
35	32.61	77.44	1.38	**19.49**	**19.54**	85.93	**5.42**	35.25	14.60
36	N/A	N/A	N/A	N/A	N/A	N/A	5.19	35.74	14.72

N/A Data not available due to molding.

[2] Diameter is the average of two perpendicular lines on each of three tortillas.

TABLE 5

P-Values of Flour Tortilla Variables and Leavening Agent, Temperature and Storage Time[a]

Response Variable[b]	LAgent	Temp	LAgent x Temp	Day	LAgent x Day	Temp x Day	LAgent x Temp x Day
Moisture		*0.0114					
Diameter	**0.0039						
Weight	*0.0356	**0.0018					
Thickness	***<0.0001	***<0.0001					*<0.05
L*	***0.0007						
a*	*0.0352	***<0.0001		*0.0228			
b*	**0.0099					*0.0432	*<0.05[c]
C*	**0.0096					*0.0421	*<0.05
h	*0.0423	***0.0003					
PForce		*0.0177		***0.0005			*0.05
PDistance		*0.0205			*0.0408		*<0.05
PArea	***<0.0001	*0.0105		***<0.0001			
PGradient	**0.0035			***0.0006			
KForce				***0.0002			
KDistance					*0.0264		
KArea	*0.0193			***<0.0001			
KGradient	***<0.0001			*0.0294			
CForce	*0.0110					*0.0211	
CDistance							
CArea					**0.0095	*0.0393	
CGradient	**0.0035					*0.0269	
DArea	*0.0401	*0.0165		***<0.0001			
DTravel	***<0.0001						
Rollability			***0.0010	***<0.0001			
Peelability			***<0.0001		***<0.0001	***<0.0001	

[a] Significant difference *, **, ***, $P < 0.05$, 0.01, and 0.001, respectively.
[b] Variables defined in Table 3.
[c] Significant only when day 30 data was excluded.

TABLE 6

Textural Properties of Wheat Flour Tortillas[a]

	Stretchability (Puncture Test)				Kramer Shear Cell[b]				Firmness (Compression Test)						Rollability	Peelability
ID	**Force (N)**	**Dist. (mm)**	**Area (N*mm)**	**Grad. (N/mm)**	**Force (N)**	**Dist. (mm)**	**Area (N*mm)**	**Grad. (N/mm)**	**Force (N)**	**Dist. (mm)**	**CArea (N*mm)**	**Grad. (N/mm)**	**DArea (N*mm)**	**Travel (mm)**	**Score (1-5)**	**Score (1-5)**
1	7.30	12.80	41.74	0.55	41.10	5.51	102.22	7.29	4.03	**10.00**	13.31	0.40	6.97	**4.95**	**5.0**	3.0
2	5.94	9.48	24.07	0.60	37.77	4.51	78.77	8.15	4.81	9.71	17.21	0.49	12.51	5.30	3.3	4.3
3	5.74	8.47	21.21	0.65	30.55	**3.66**	**55.31**	8.09	5.12	9.39	18.62	0.54	17.15	6.00	2.7	**2.0**
4	6.23	**8.46**	21.72	**0.71**	34.73	3.90	67.08	8.69	5.60	**8.61**	18.82	**0.64**	22.79	6.74	2.3	3.7
5	7.35	12.51	38.30	0.57	40.83	5.44	88.95	7.32	3.08	**10.00**	9.84	0.30	5.30	5.20	**5.0**	4.7
6	6.20	9.47	24.74	0.63	38.50	4.67	80.13	8.02	4.86	9.93	17.78	0.49	10.06	5.60	3.7	2.7
7	5.67	9.65	22.51	0.56	37.00	4.77	75.24	7.56	4.56	9.81	16.65	0.46	11.14	6.08	2.7	2.7
8	7.25	10.12	26.96	0.70	44.30	4.71	90.62	**9.20**	**6.62**	9.96	21.85	0.66	11.92	5.82	2.7	4.0
9	7.75	13.03	41.68	0.57	45.31	5.67	112.48	7.81	3.03	**10.00**	10.09	0.30	5.56	5.57	**5.0**	4.3
10	6.66	10.04	26.34	0.64	38.55	4.67	77.11	8.05	5.41	9.72	16.78	0.55	13.37	5.62	3.3	3.0
11	6.41	9.25	24.67	0.67	35.57	4.45	66.30	7.75	5.59	9.98	18.82	0.55	9.67	5.43	2.7	3.0
12	5.72	10.12	23.63	0.54	36.22	4.78	73.78	7.40	5.57	9.58	21.36	0.57	16.41	6.48	2.3	2.7
13	6.69	14.41	43.08	0.45	38.68	6.33	106.29	5.95	3.39	**10.00**	12.65	0.33	6.87	6.33	4.7	2.3
14	5.59	10.49	27.60	0.51	36.40	5.53	95.92	6.41	4.38	**10.00**	17.90	0.43	8.40	6.42	3.0	**5.0**
15	**5.32**	8.77	**20.76**	0.58	32.07	4.25	71.43	7.31	4.44	9.94	18.32	0.44	9.89	7.36	1.7	4.7
16	5.84	9.74	26.01	0.58	38.32	4.73	91.99	7.91	5.12	9.15	21.45	0.55	**21.42**	6.79	2.0	4.0
17	6.84	13.81	38.89	0.48	44.81	6.24	113.91	7.02	2.53	**10.00**	9.41	0.25	5.18	7.10	4.3	**5.0**
18	6.63	12.49	37.23	0.51	33.19	5.14	81.68	6.27	4.98	**10.00**	21.05	0.49	10.07	7.07	2.0	4.7

[a] Mean of 10 measurements for Stretchability, Kramer, and Firmness and mean of 3 for Rollability and Peelability.

[b] Resistance to compression, shearing and extrusion.

TABLE 6 cont.

Textural Properties of Wheat Flour Tortillas[a]

	Stretchability (Puncture Test)				Kramer Shear Cell[b]				Firmness (Compression Test)						Rollability	Peelability
ID	Force (N)	Dist. (mm)	Area (N*mm)	Grad. (N/mm)	Force (N)	Dist. (mm)	Area (N*mm)	Grad. (N/mm)	Force (N)	Dist. (mm)	CArea (N*mm)	Grad. (N/mm)	DArea (N*mm)	Travel (mm)	Score (1-5)	Score (1-5)
19	5.72	10.63	26.92	0.52	35.28	4.64	77.53	7.39	4.62	9.86	18.61	0.46	10.69	6.28	**1.0**	4.0
20	6.48	10.23	31.46	0.61	32.88	4.48	72.37	7.11	4.88	9.60	18.60	0.50	14.03	6.52	1.3	4.7
21	7.09	16.83	46.73	0.41	42.16	6.08	106.21	6.76	2.41	**10.00**	8.58	**0.24**	4.75	6.18	4.3	4.3
22	6.27	10.13	28.17	0.59	35.04	5.06	83.40	6.71	4.84	9.94	19.26	0.48	10.21	6.57	2.0	2.7
23	5.55	9.68	23.53	0.54	30.43	4.37	70.22	6.72	4.88	9.83	18.99	0.49	11.59	6.03	1.7	3.7
24	6.92	9.43	30.75	**0.71**	37.02	5.08	82.21	7.10	5.39	9.60	23.08	0.56	17.89	6.63	2.0	3.0
25	6.67	16.21	46.96	**0.40**	41.84	6.97	125.89	5.86	3.46	**10.00**	13.31	0.34	7.36	7.03	2.7	**2.0**
26	6.22	11.25	33.95	0.53	32.48	5.47	89.42	**5.76**	4.55	**10.00**	20.50	0.45	9.66	7.73	2.3	**5.0**
27	6.37	9.98	31.25	0.61	31.09	4.97	79.24	6.05	4.75	**10.00**	20.52	0.47	9.28	6.92	**1.0**	**5.0**
28	5.43	9.35	24.47	0.56	**28.32**	3.99	60.05	6.88	5.57	9.92	28.41	0.56	13.20	7.12	**1.0**	4.0
29	7.53	15.66	46.84	0.47	46.12	6.91	131.42	6.54	3.11	**10.00**	11.25	0.31	6.35	6.52	**5.0**	3.7
30	6.50	12.46	37.21	0.50	36.41	5.37	93.71	6.60	4.69	**10.00**	19.74	0.46	9.63	7.41	2.0	4.7
31	7.10	11.79	39.23	0.58	39.91	5.00	97.78	7.80	4.87	**10.00**	21.10	0.48	10.03	7.44	1.7	3.7
32	6.42	10.47	31.57	0.59	30.74	4.50	70.83	6.64	5.76	9.97	26.78	0.57	11.86	7.00	**1.0**	4.0
33	**7.89**	**17.95**	**58.89**	0.43	**49.23**	**7.84**	**157.40**	6.15	**2.05**	**10.00**	**7.99**	0.20	**4.48**	7.36	4.7	4.7
34	6.96	12.48	40.46	0.54	35.10	4.60	70.35	7.39	4.99	**10.00**	20.83	0.49	9.91	7.13	2.0	4.0
35	6.15	10.07	31.53	0.59	32.23	4.47	78.43	6.95	5.17	**10.00**	24.34	0.51	10.78	**7.87**	**1.0**	4.7
36	6.52	10.27	32.98	0.61	38.58	5.43	105.28	6.98	6.17	9.90	**28.81**	0.62	15.47	7.30	**1.0**	4.0

[a] Mean of 10 measurements for Stretchability, Kramer, and Firmness and mean of 3 for Rollability and Peelability.

[b] Resistance to compression, shearing and extrusion.

FIGURE 1

Moisture content of tortillas as a function of cooking temperature.
Means of 34 observations, S.E. = 0.2569718

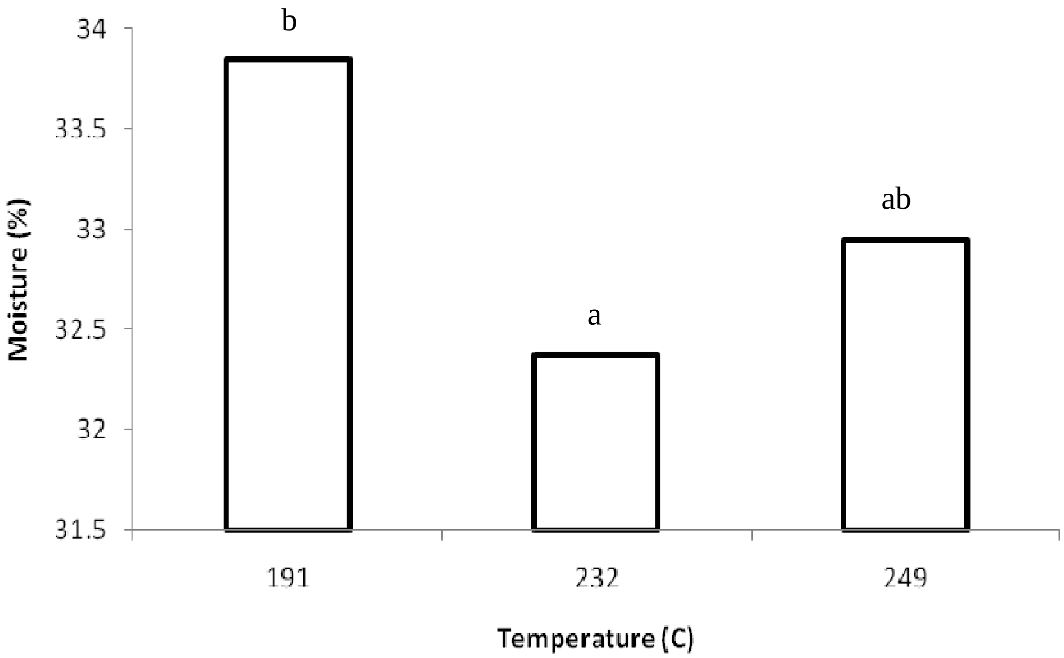


FIGURE 2

Diameter of tortilla as a function of leavening agent.
Means of 36 observations, S.E. = 0.167503

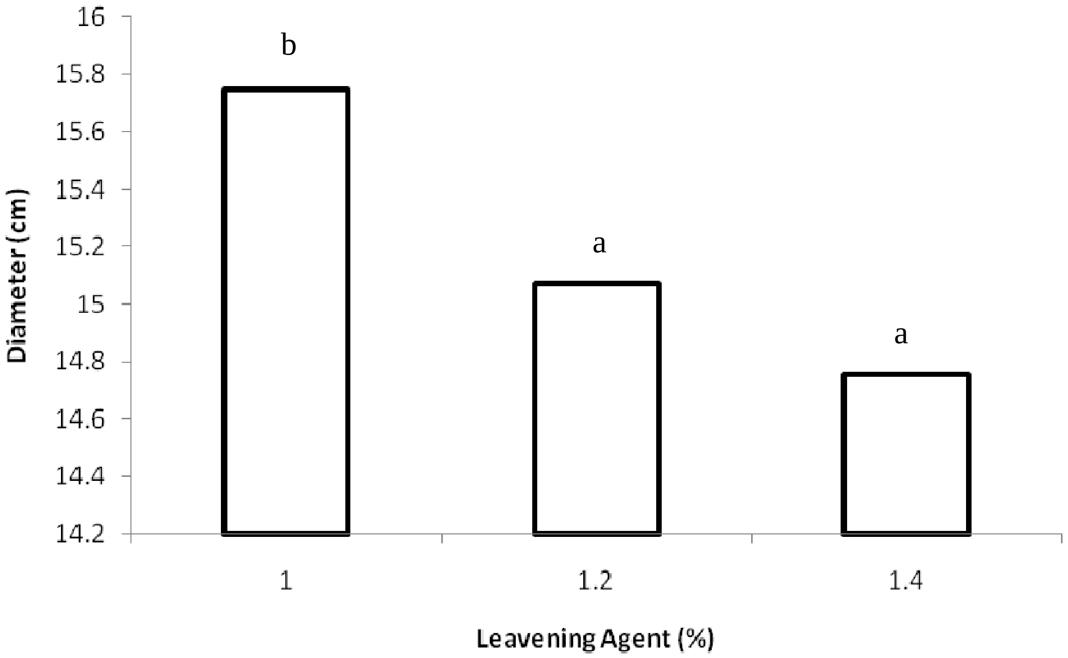


FIGURE 3

Tortilla weight as a function of cooking temperature.
Means of 36 observations, S.E. = 1.312997

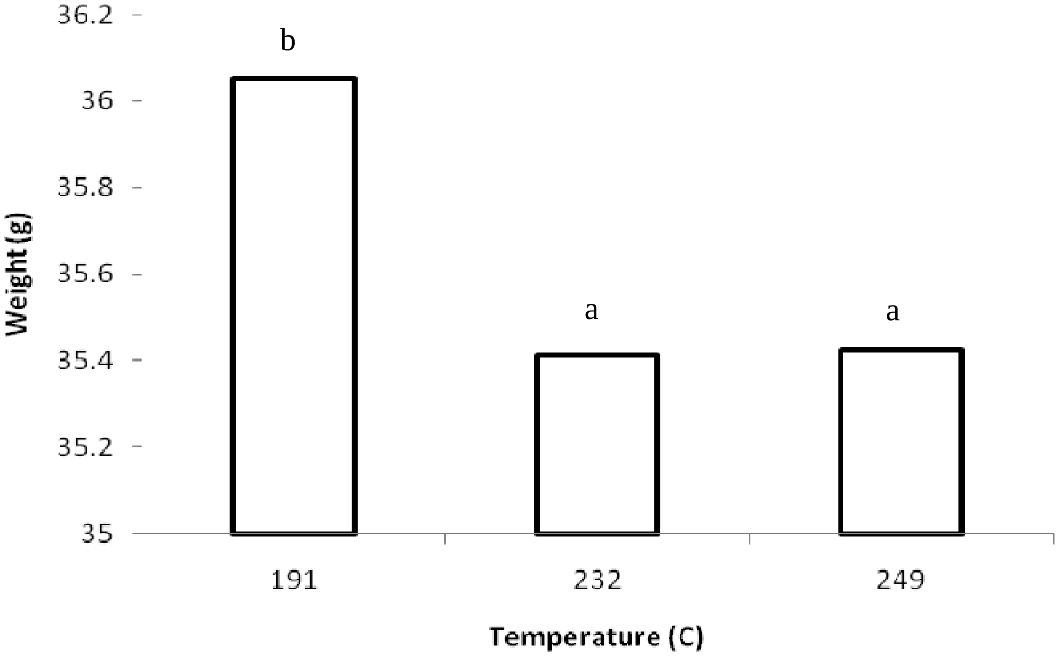


FIGURE 4

Tortilla weight as a function of leavening agent.
Means of 36 observations, S.E. = 1.312997

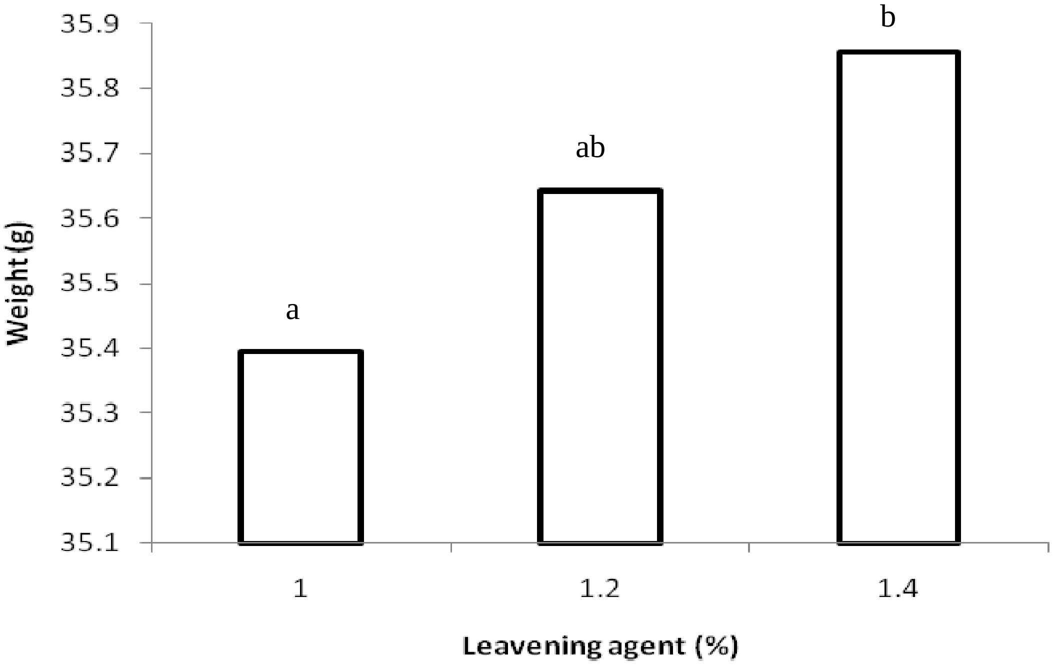


FIGURE 5

Interaction between the thickness and the storage time as combinations of cook temperature (°C) and % leavening agent.

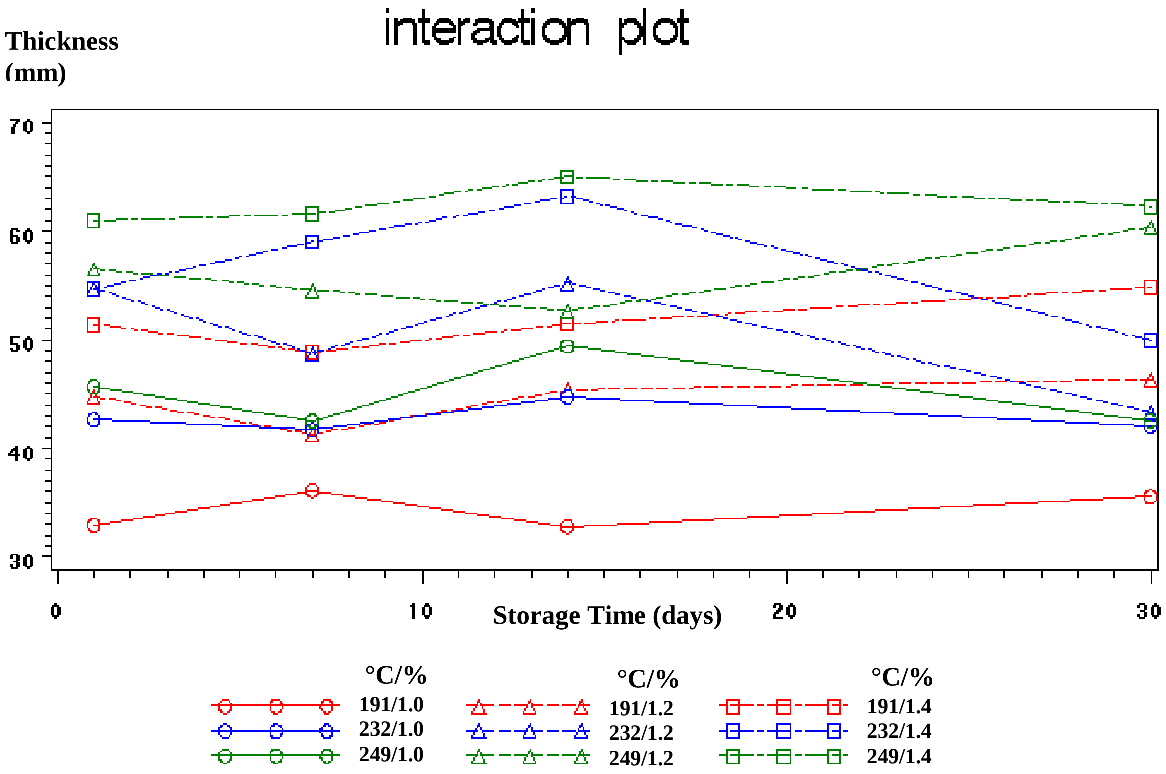


FIGURE 6

Tortilla thickness as a function of leavening agent.
Means of 36 observations, S.E. = 0.920539

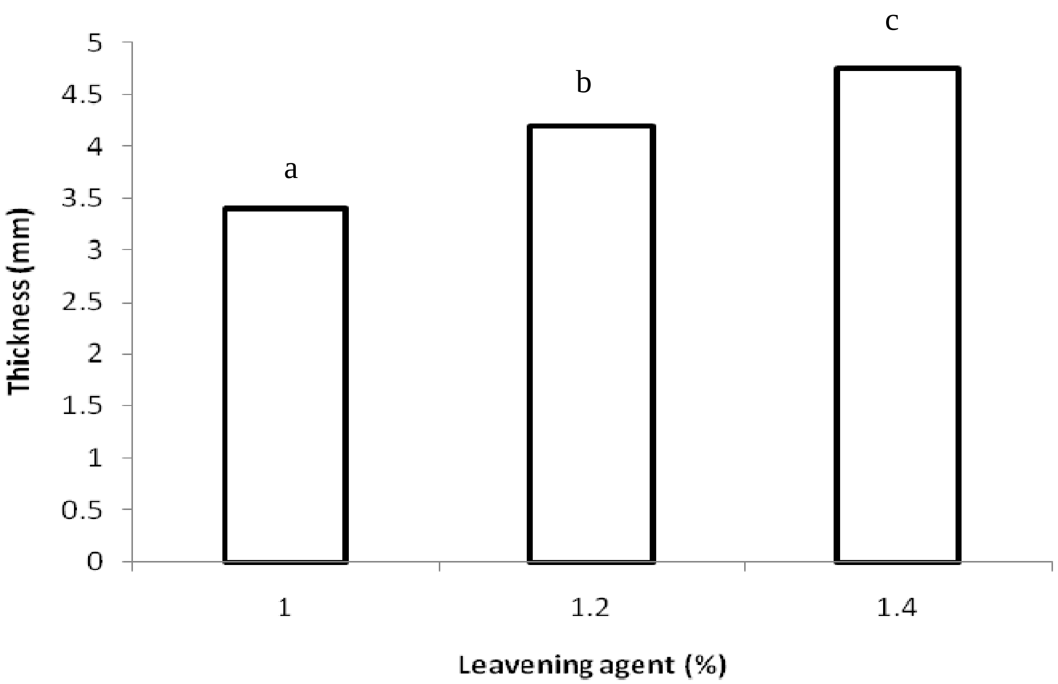


FIGURE 7

Tortilla thickness as a function of cooking temperature.
Means of 36 observations, S.E. = 0.920539

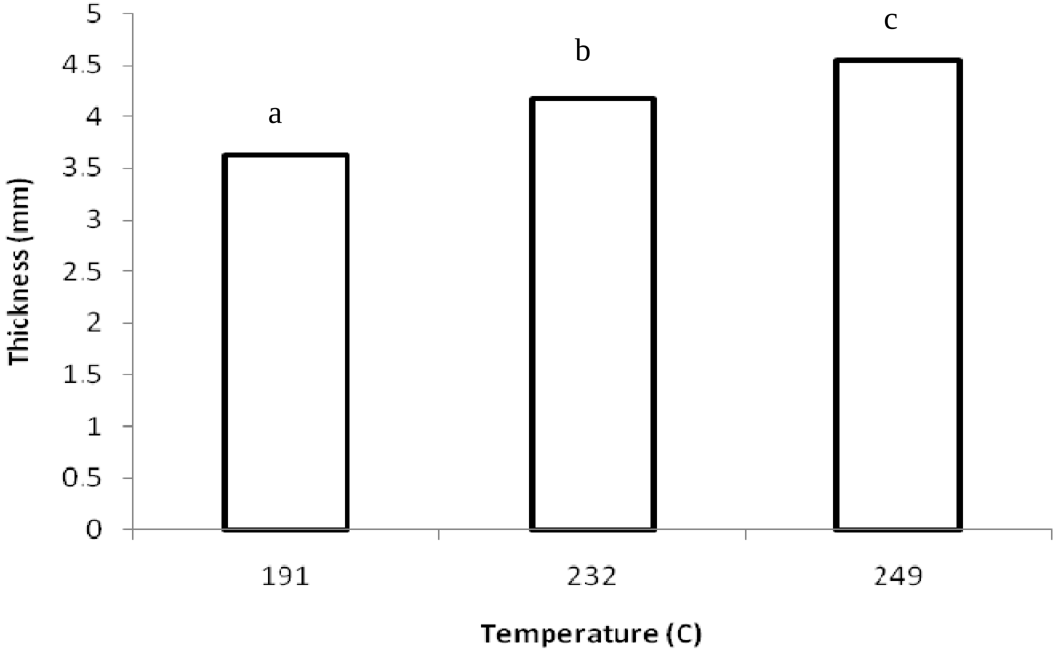


FIGURE 8

Color score L* as a function of leavening agent when day 30 tortillas are omitted. Means of 27 observations, S.E. = 0.2492419

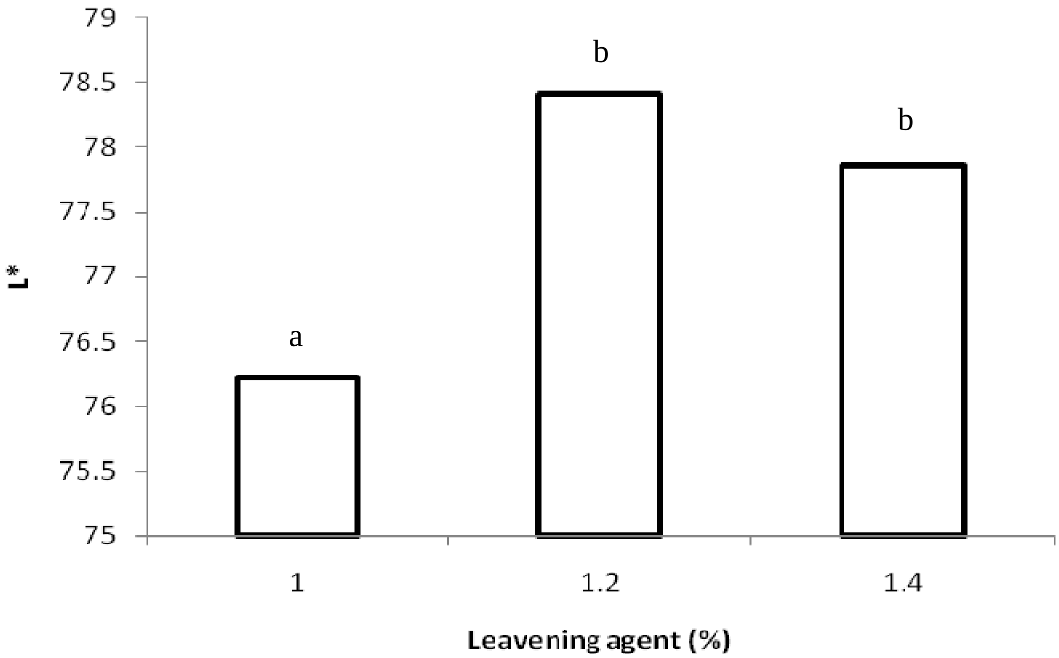


FIGURE 9

Color score a* as a function of leavening agent when day 30 tortillas are omitted. Means of 27 observations, S.E. = 0.04889298

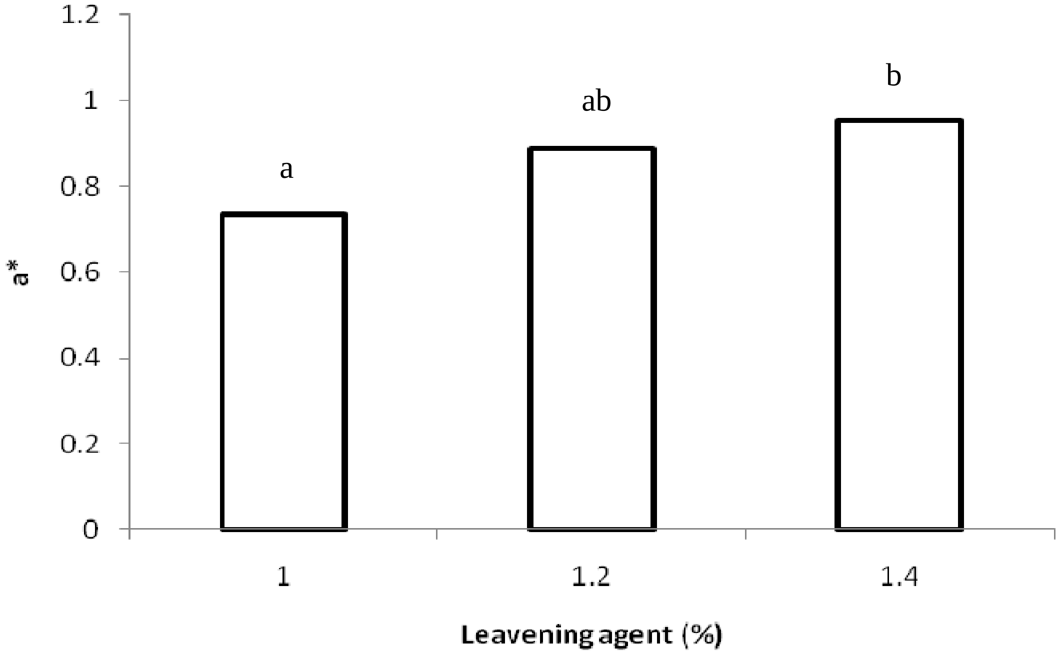


FIGURE 10

Color score a* as a function of cooking temperature when day 30 tortilla are omitted. Means of 27 observations, S.E. = 0.04889298

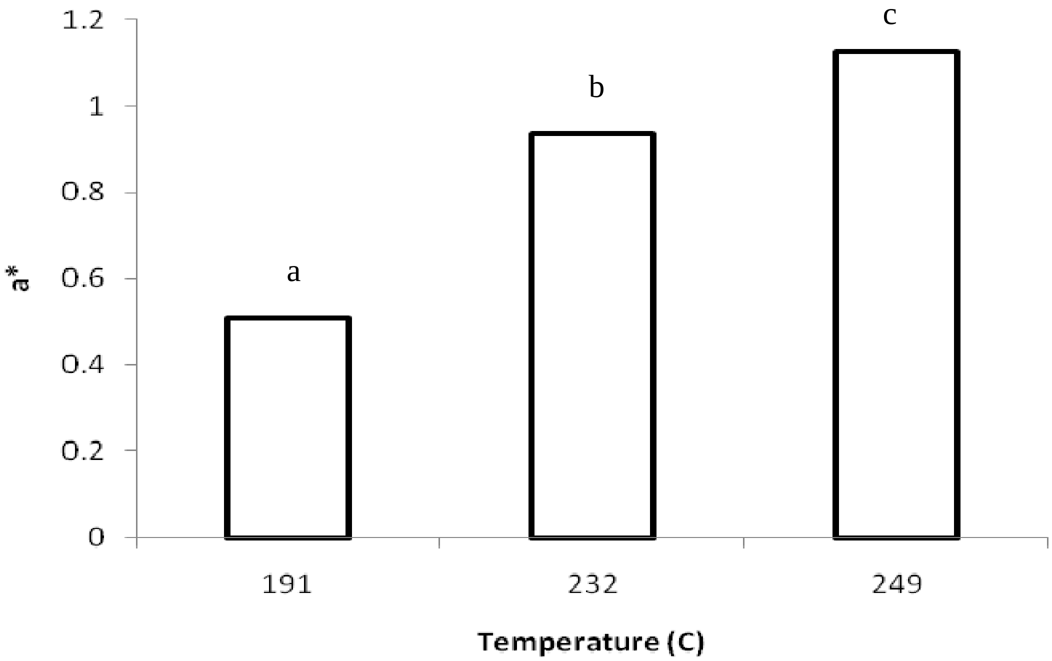


FIGURE 11

Color score a* as a function of storage time when day 30 tortillas are omitted.
Means of 27 observations, S.E. = 0.04889298

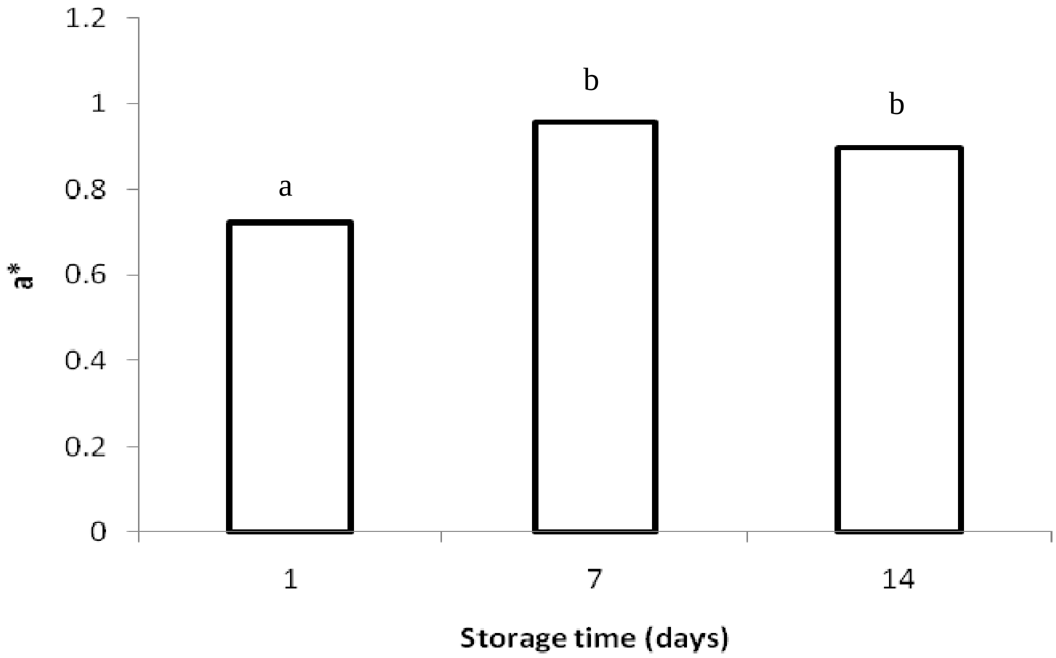


FIGURE 12

Interaction between color score b* and the % leavening agent as combinations of cook temperature (°C) and storage time days 1, 7, and 14.

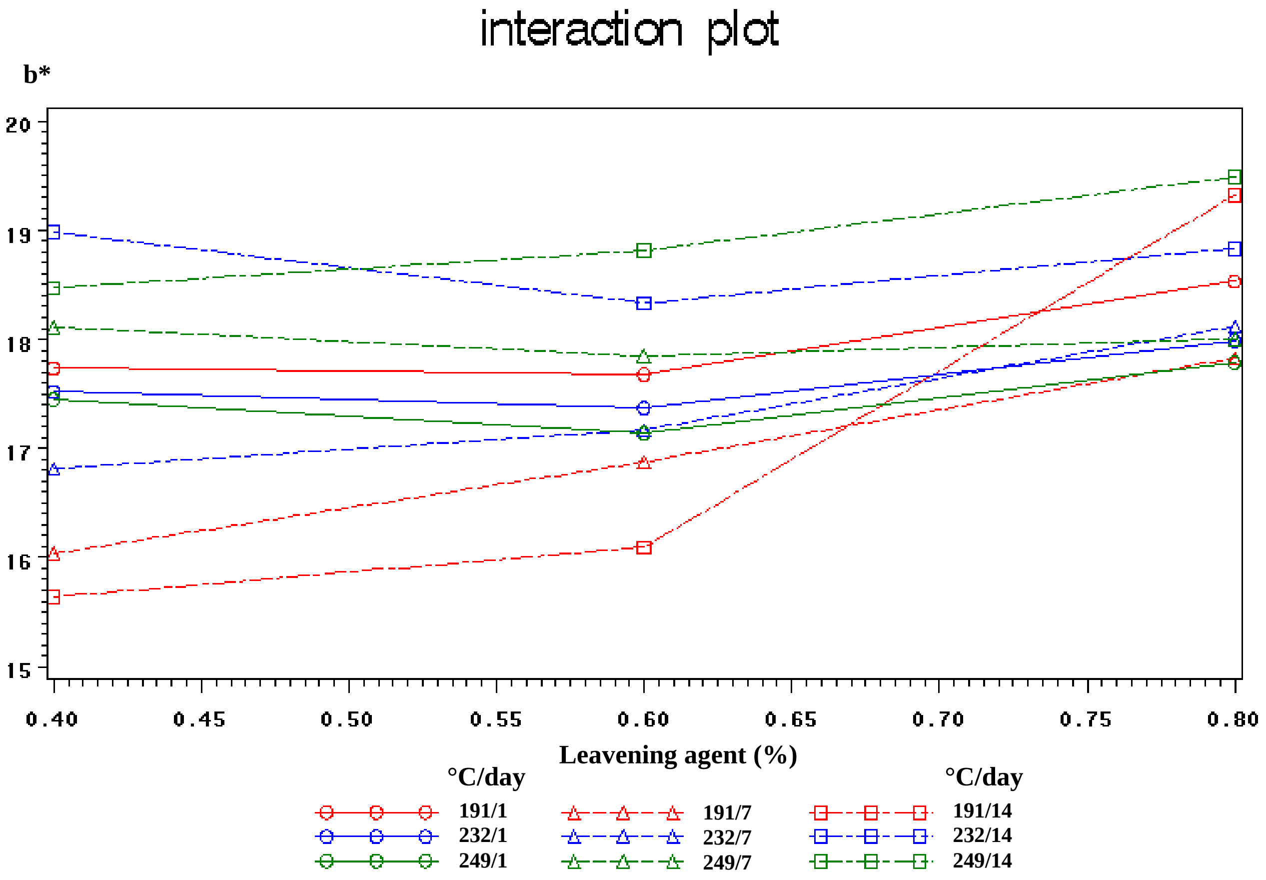


FIGURE 13

Interaction between color score C* and the % leavening agent as combinations of cook temperature (°C) and storage time days 1, 7, and 14.

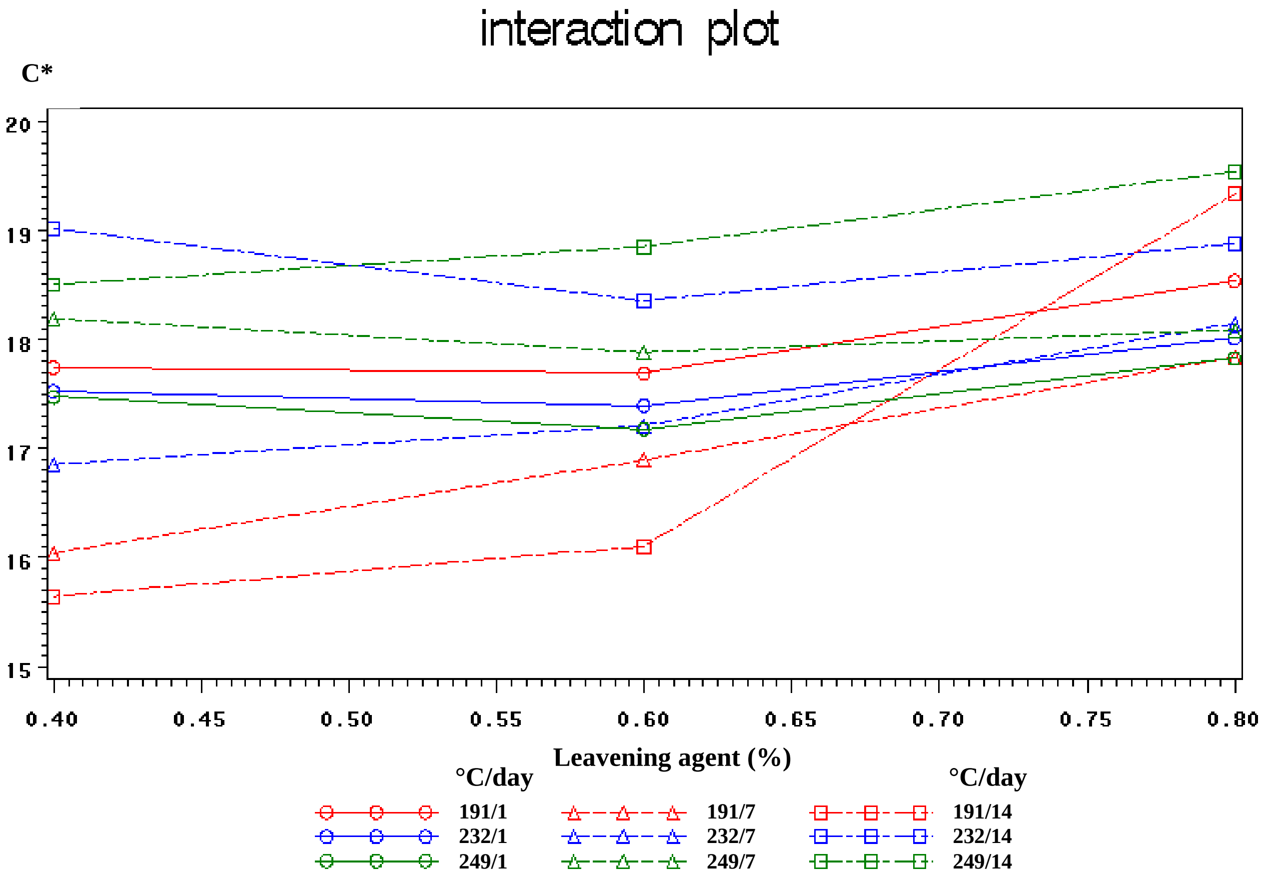


FIGURE 14

Color scores for b* and C* as a function of leavening agent when day 30 tortillas are omitted.
Means of 27 observations, S.E. b*= 0.1933445, C*=0.1935005

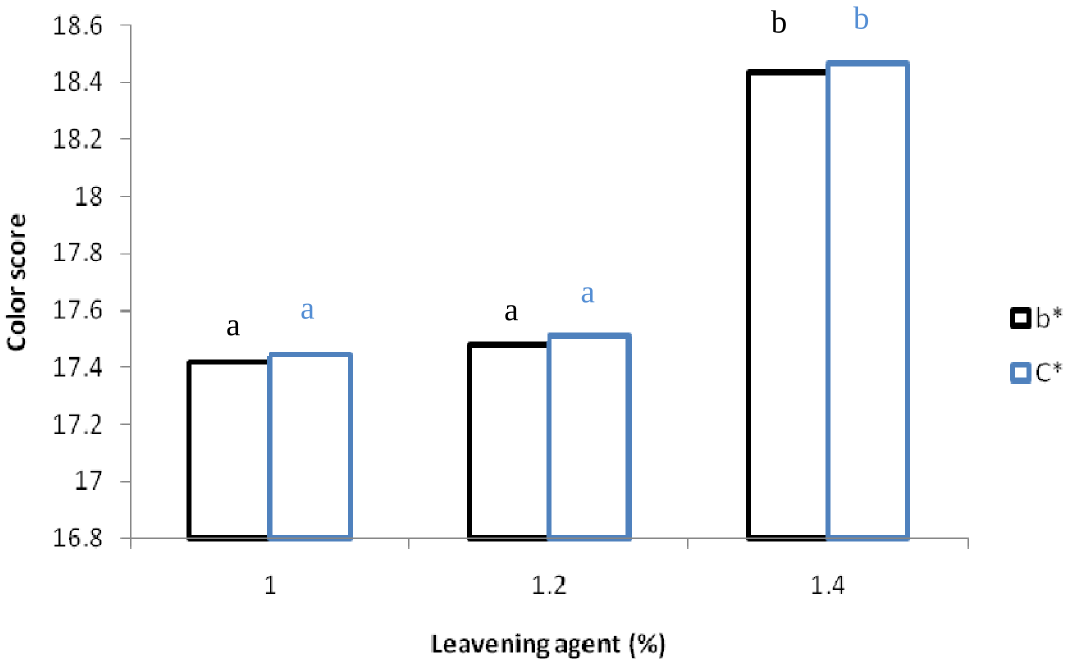


FIGURE 15

Hue angle as a function of leavening agent.
Means of 27 observations, S.E. = 0.1785719

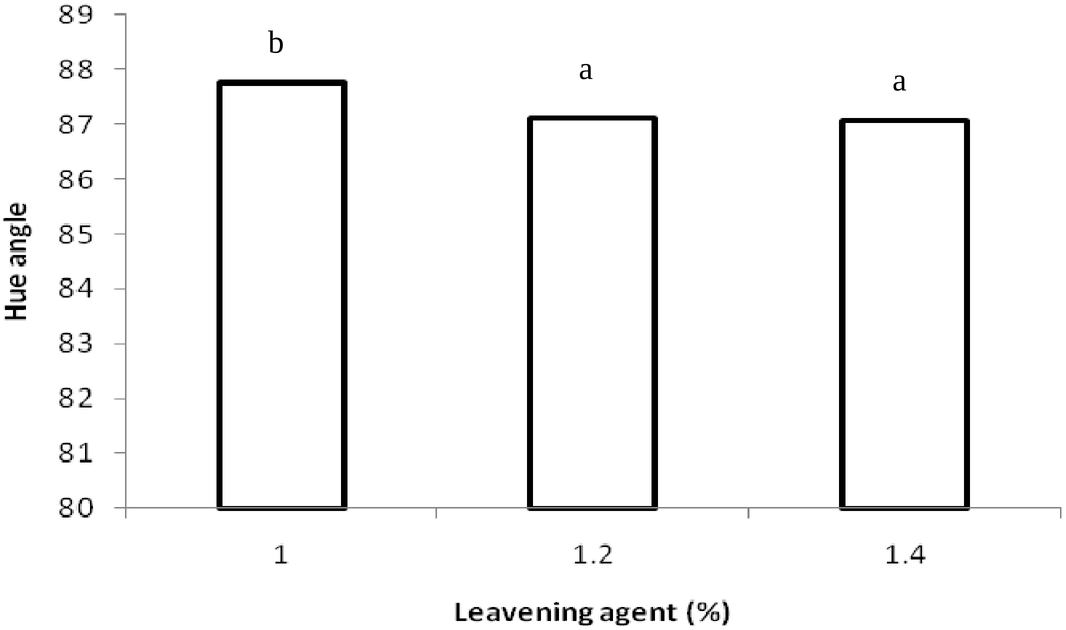


FIGURE 16

Hue angle as a function of cooking temperature.
Means of 27 observations, S.E. = 0.1785719

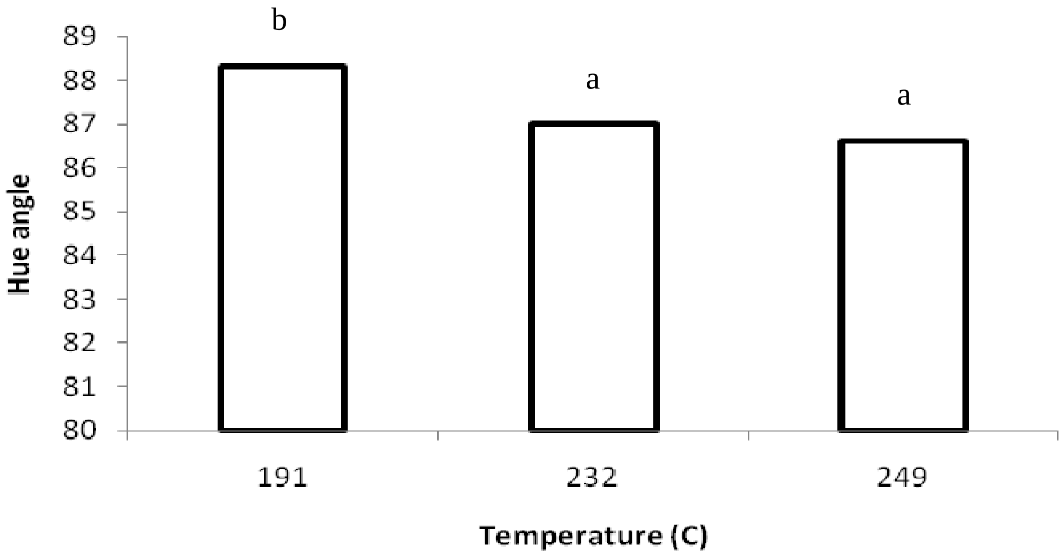


FIGURE 17

Examples of tortilla extensibility analysis determined by cook temperature (°C) averaged across all leavening levels and storage times.

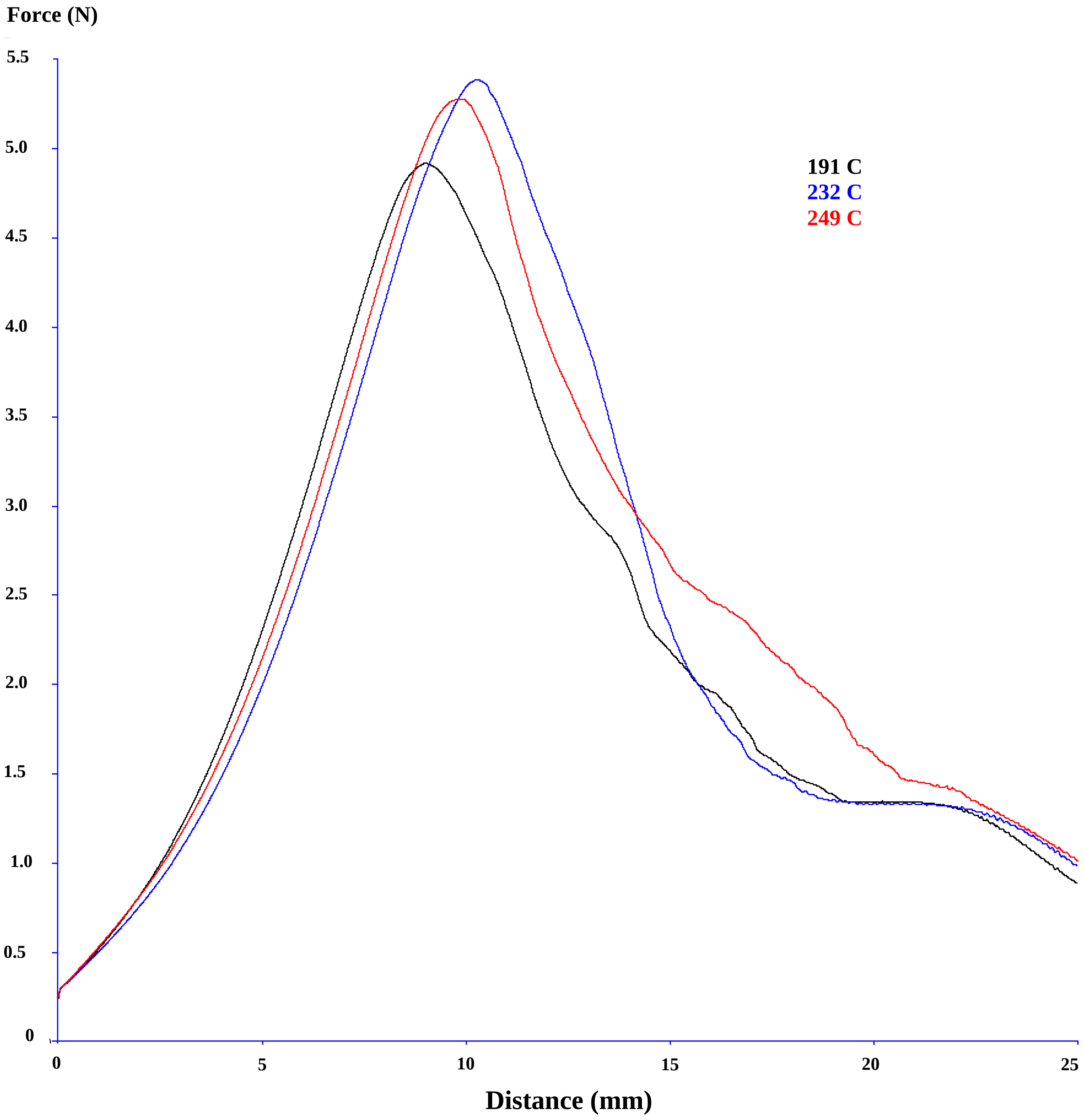


FIGURE 18

Interaction between puncture force and the storage time in days as combinations of cook temperature (°C) and % leavening agent.

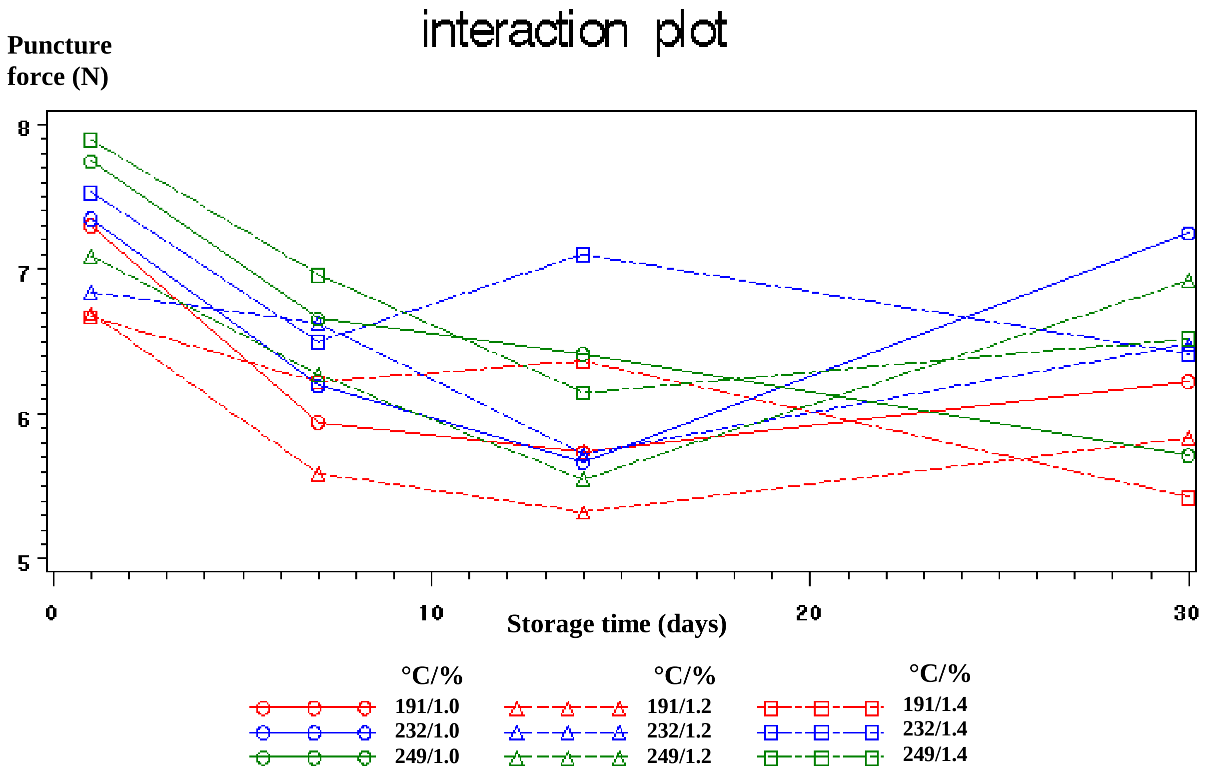


FIGURE 19

Puncture force as a function of cooking temperature.
Means of 36 observations, S.E. = 0.12943766

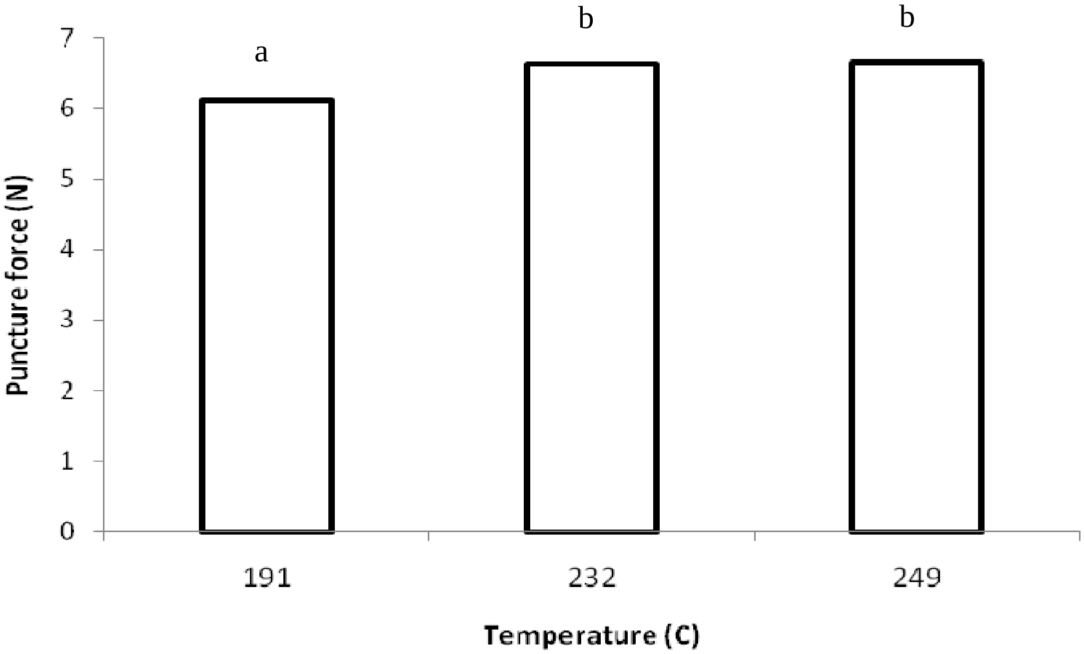


FIGURE 20

Puncture force as a function of storage time.
Means of 36 observations, S.E. = 0.14946173

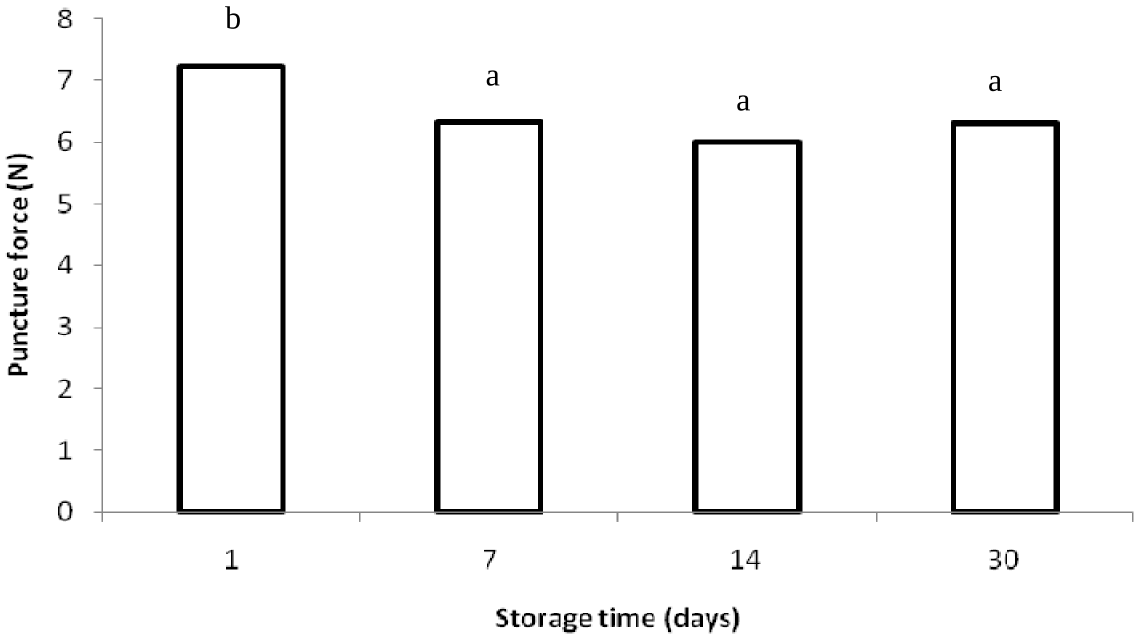


FIGURE 21

Interaction between puncture distance and the storage time in days as combinations of cook temperature (°C) and % leavening agent.

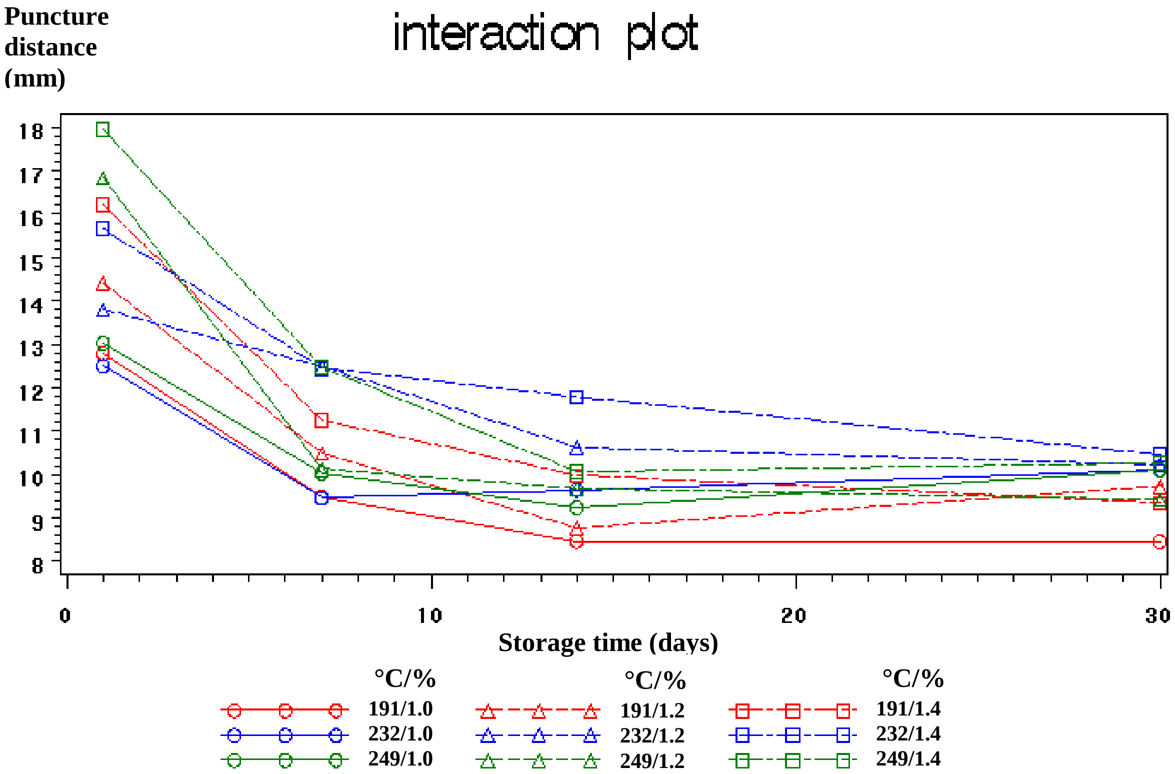


FIGURE 22

Puncture distance as a function of cooking temperature.
Means of 36 observations, S.E. = 0.2026142

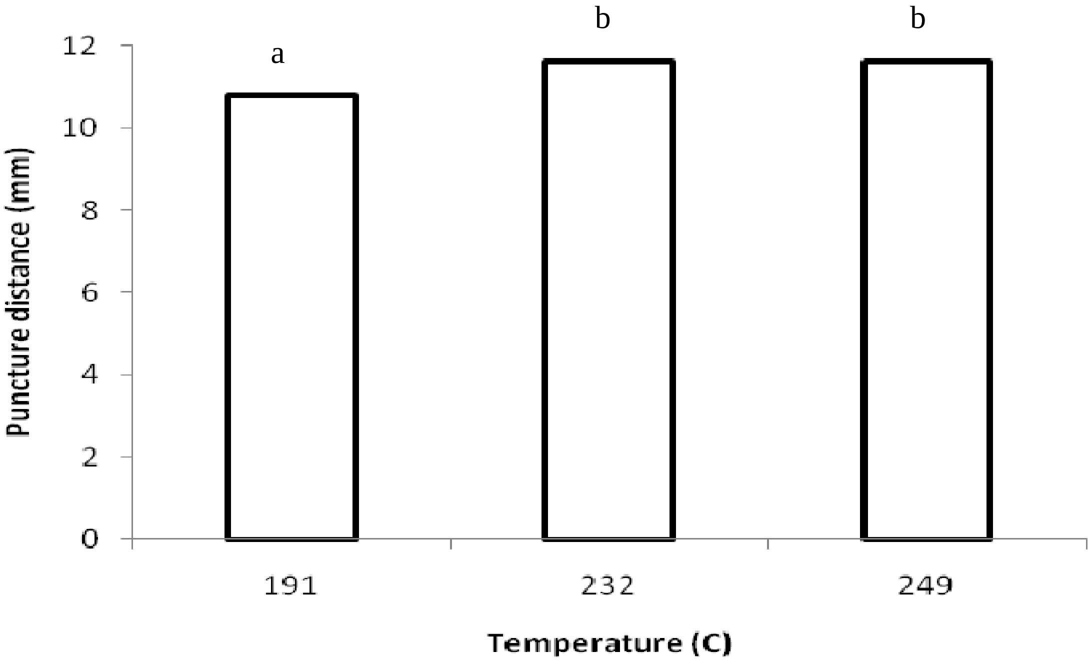


FIGURE 23

Puncture area as a function of leavening agent.
Means of 36 observations, S.E. = 0.7966152

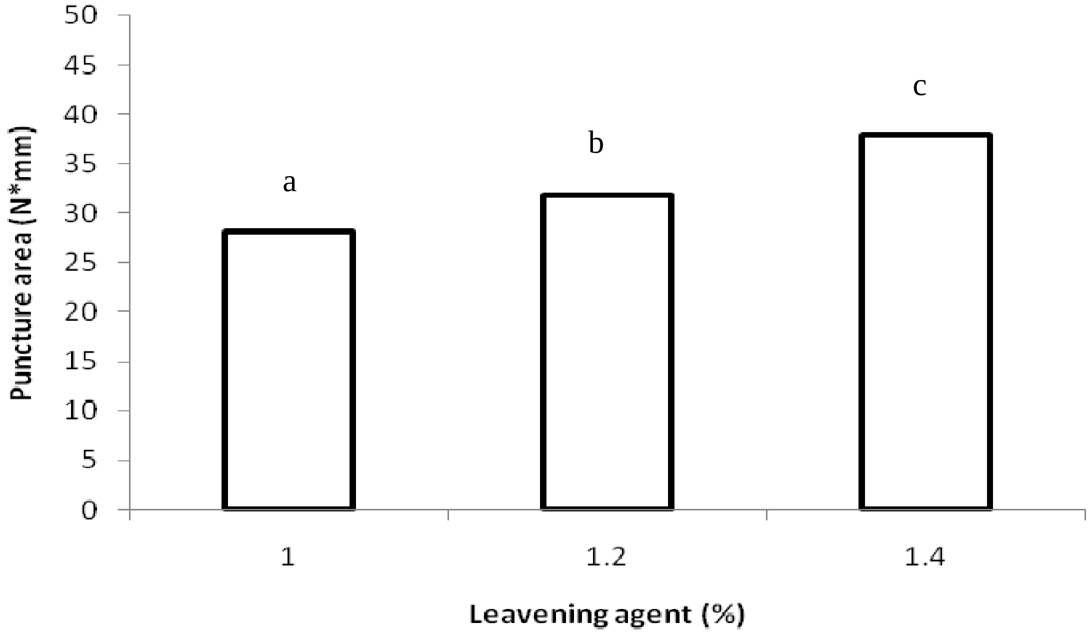


FIGURE 24

Puncture area as a function of cooking temperature.
Means of 36 observations, S.E. = 0.7966152

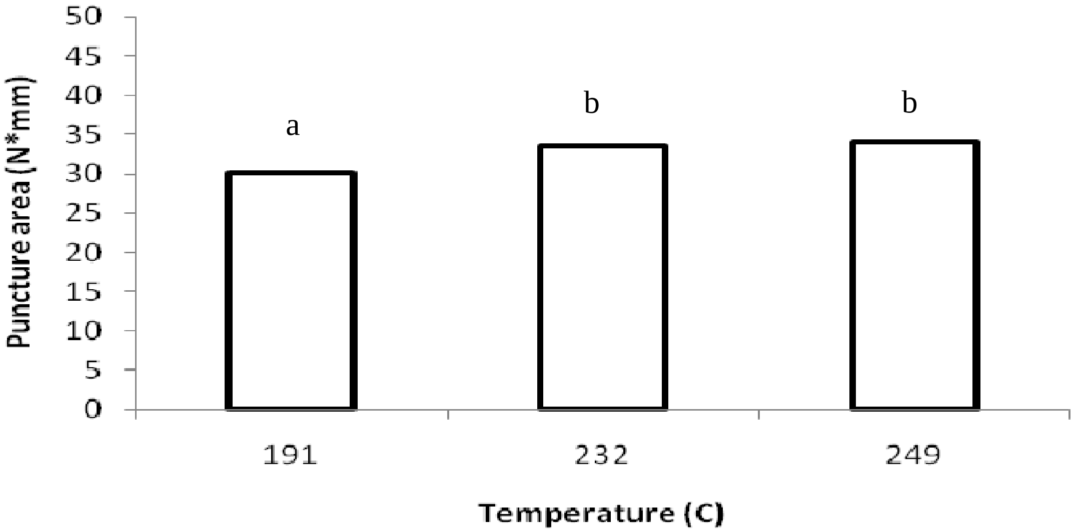


FIGURE 25

Puncture area as a function of storage time.
Means of 36 observations, S.E. = 0.919852

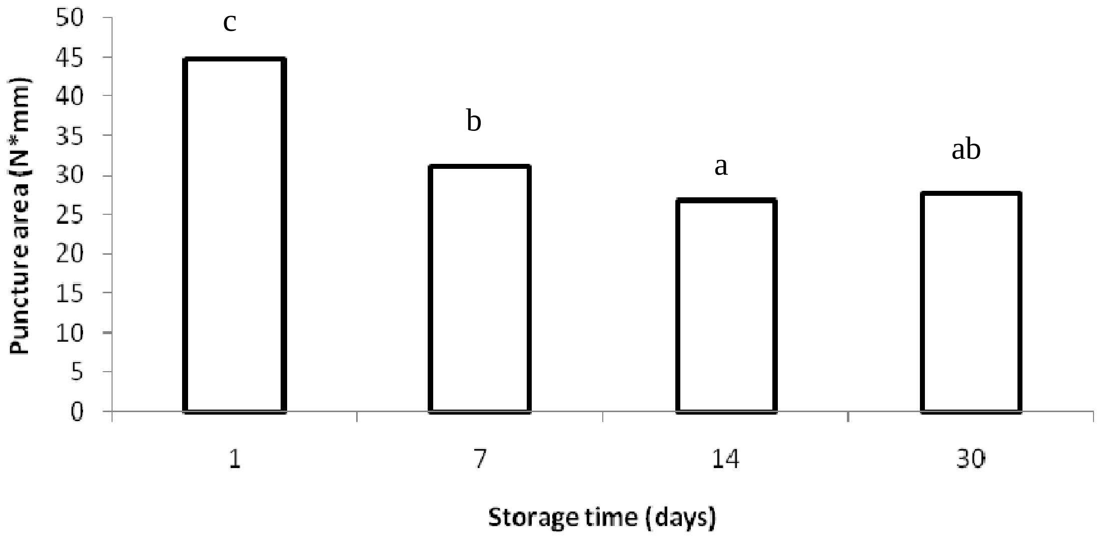


FIGURE 26

Puncture gradient as a function of leavening agent.
Means of 36 observations, S.E. = 0.01492189

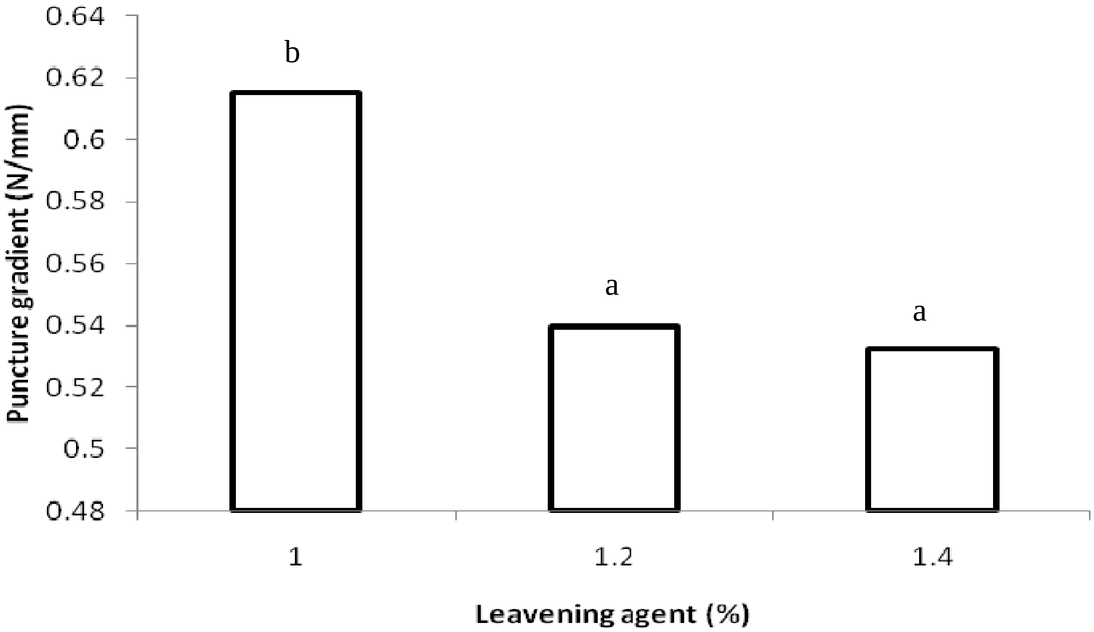


FIGURE 27

Puncture gradient as a function of storage time.
Means of 36 observations, S.E. = 0.01723031

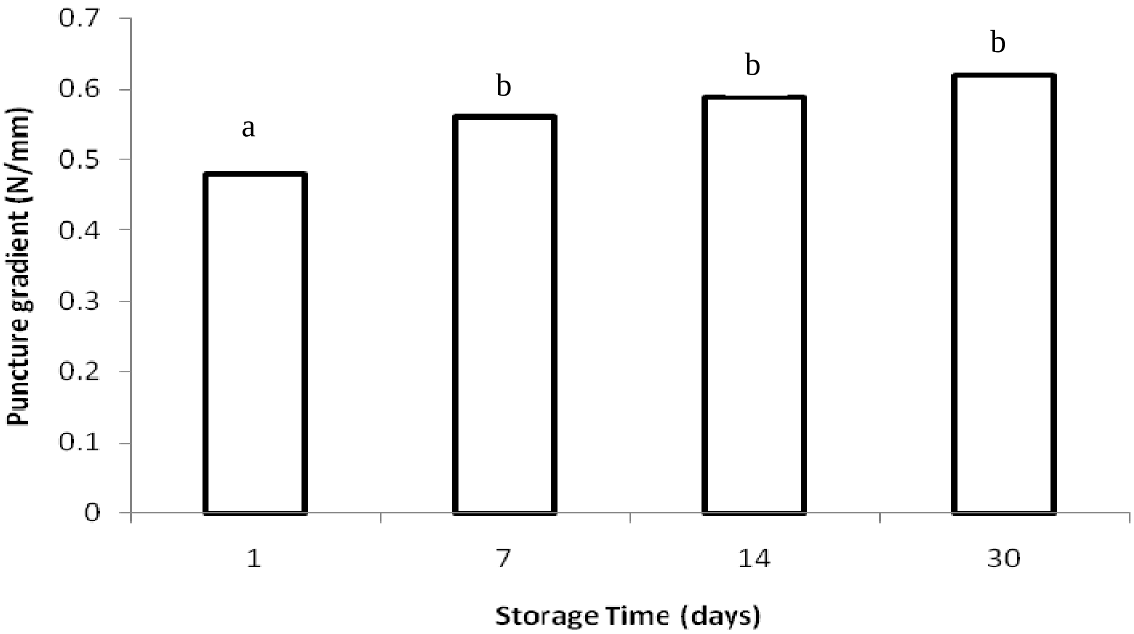


FIGURE 28

Examples of Kramer shear cell analysis of tortillas determined by cook temperature (°C) averaged across all leavening levels and storage times.

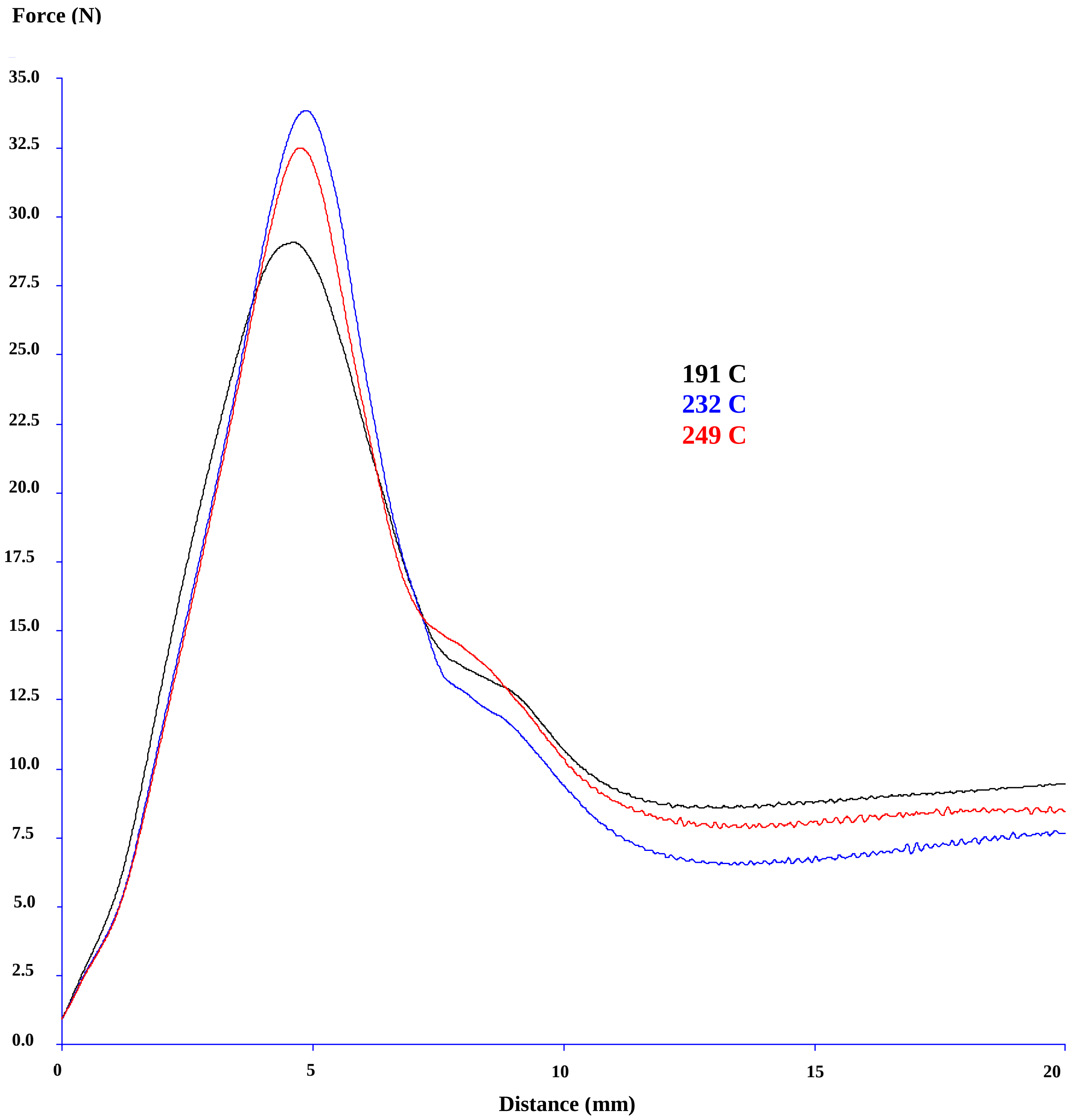


FIGURE 29

Kramer shear force as a function of storage time.
Means of 36 observations, S.E. = 1.0551599

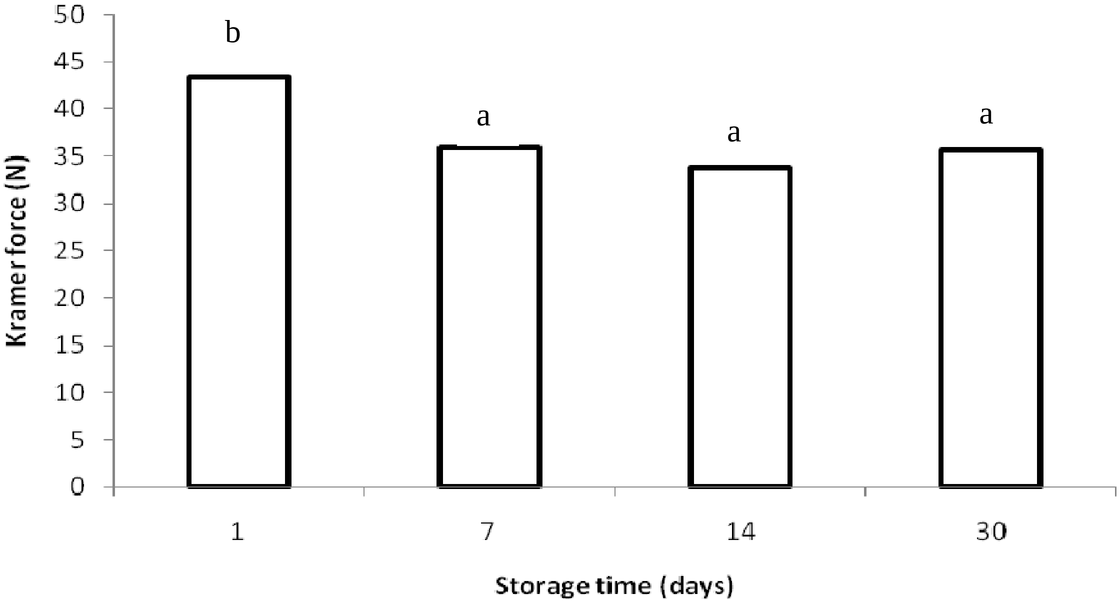


FIGURE 30

Kramer shear distance as a function of leavening agent on storage day 1.
Means of 36 observations, S.E. = 0.1912025

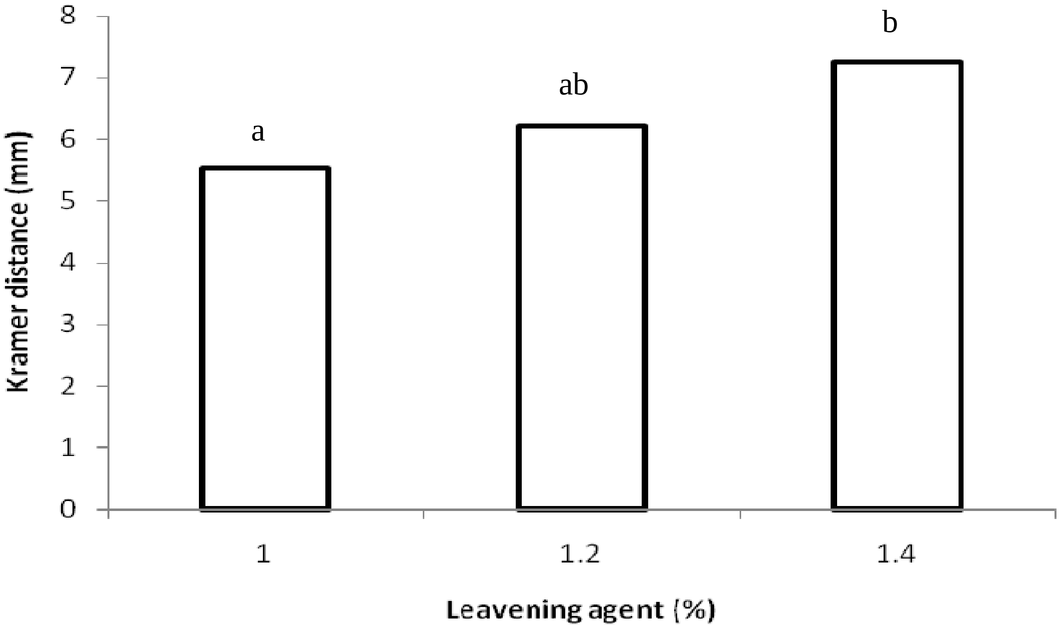


FIGURE 31

Kramer shear area as a function of storage time.
Means of 36 observations, S.E. = 3.913101

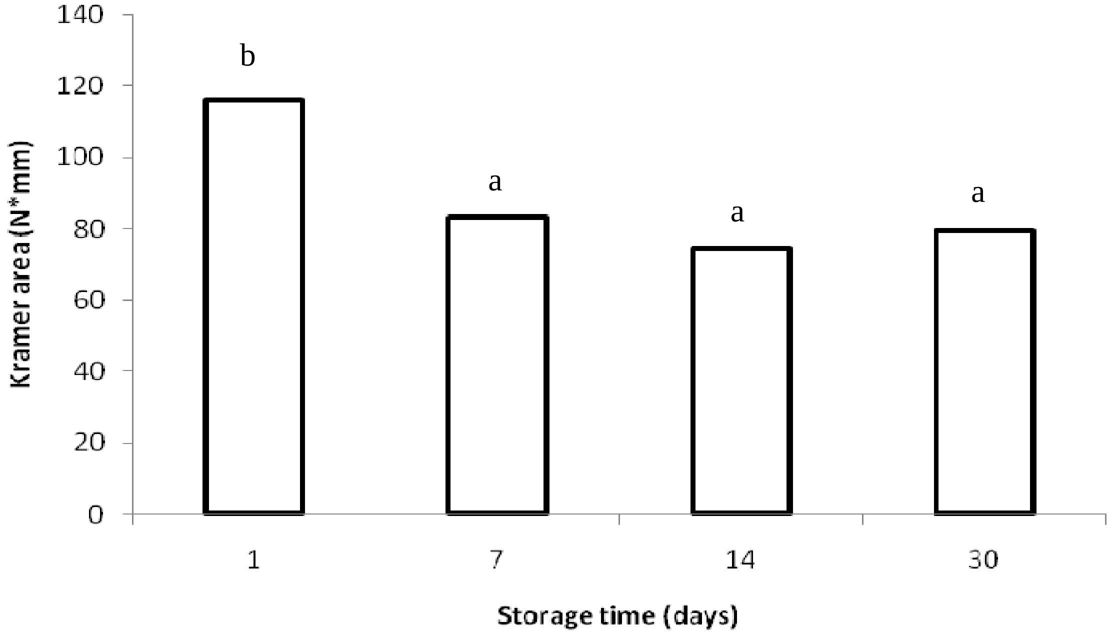


FIGURE 32

Kramer shear gradient as a function of leavening agent.
Means of 36 observations, S.E. = 0.14404009

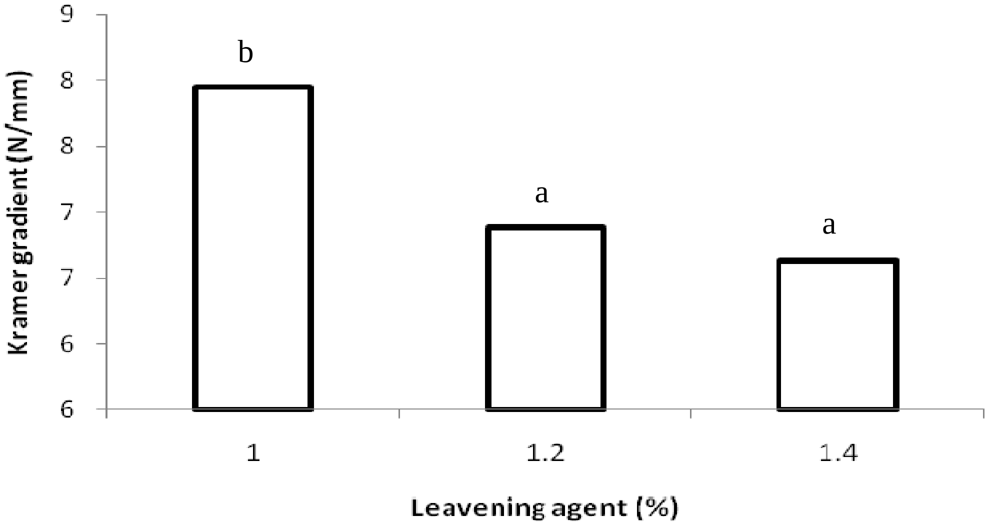


FIGURE 33

Examples of compression analysis of tortillas determined by cook temperature (°C) averaged across all leavening levels and storage times.

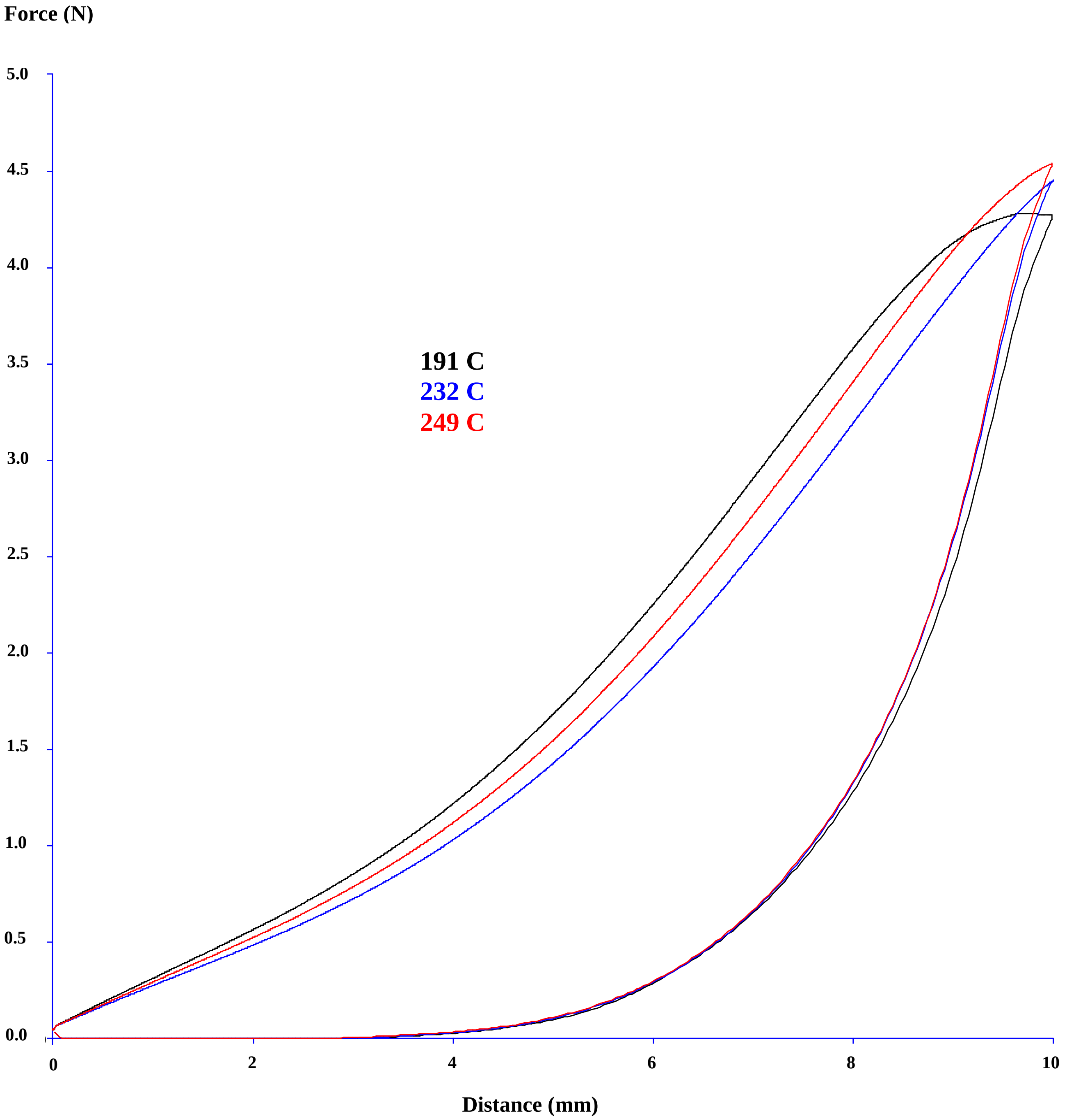


FIGURE 34

Compression force as a function of cook temperature on storage day 1.
Means of 36 observations, S.E. = 0.20596919

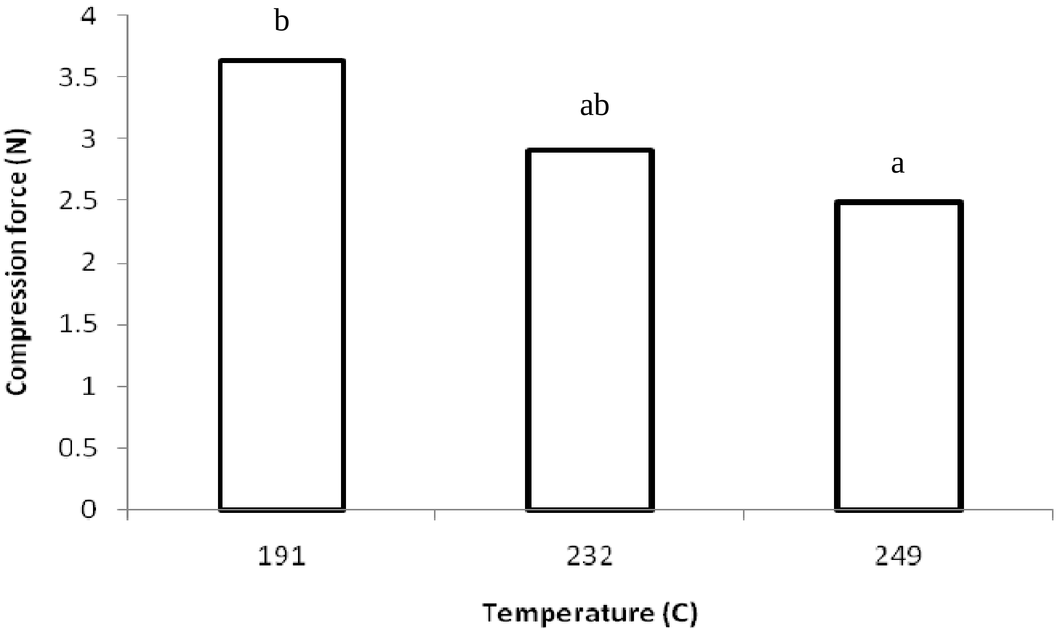


FIGURE 35

Compression force as a function of leavening agent.
Means of 36 observations, S.E. = 0.10298459

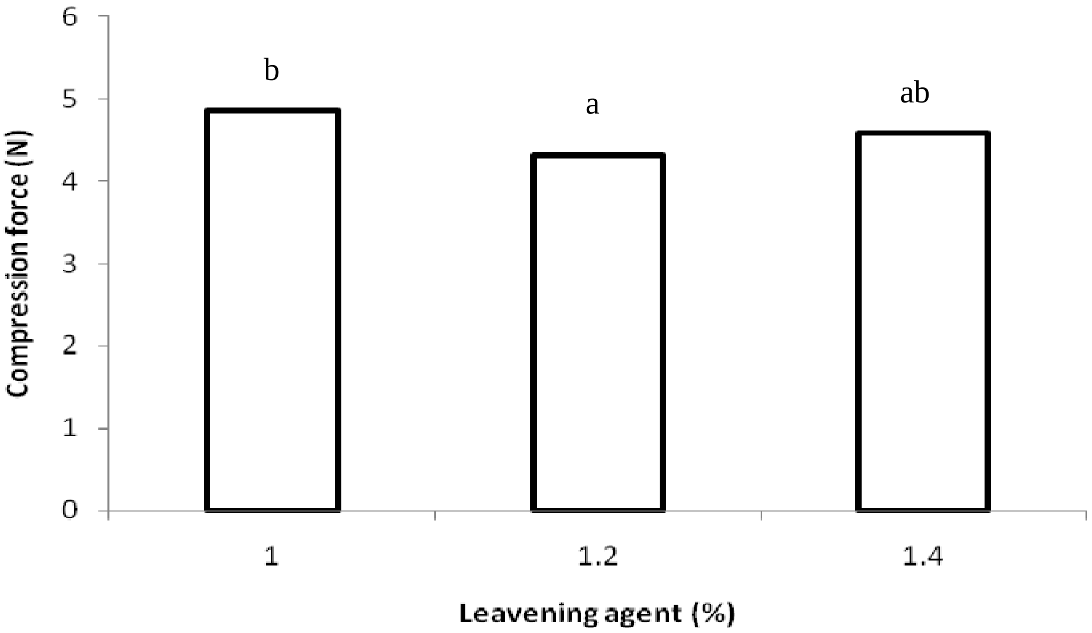


FIGURE 36

Interaction between puncture distance and the storage time in days as combinations of cook temperature (°C) and % leavening agent.

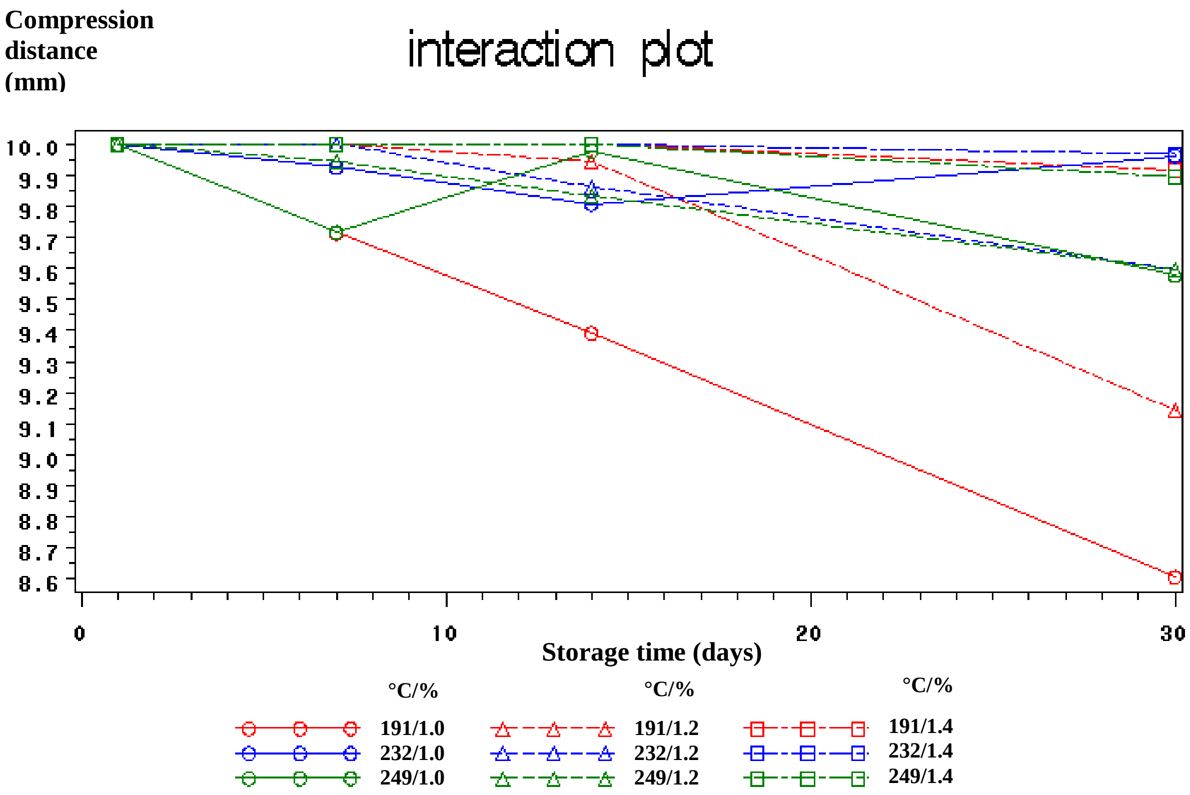


FIGURE 37

Decompression area as a function of storage time.
Means of 36 observations, S.E. = 0.5797071

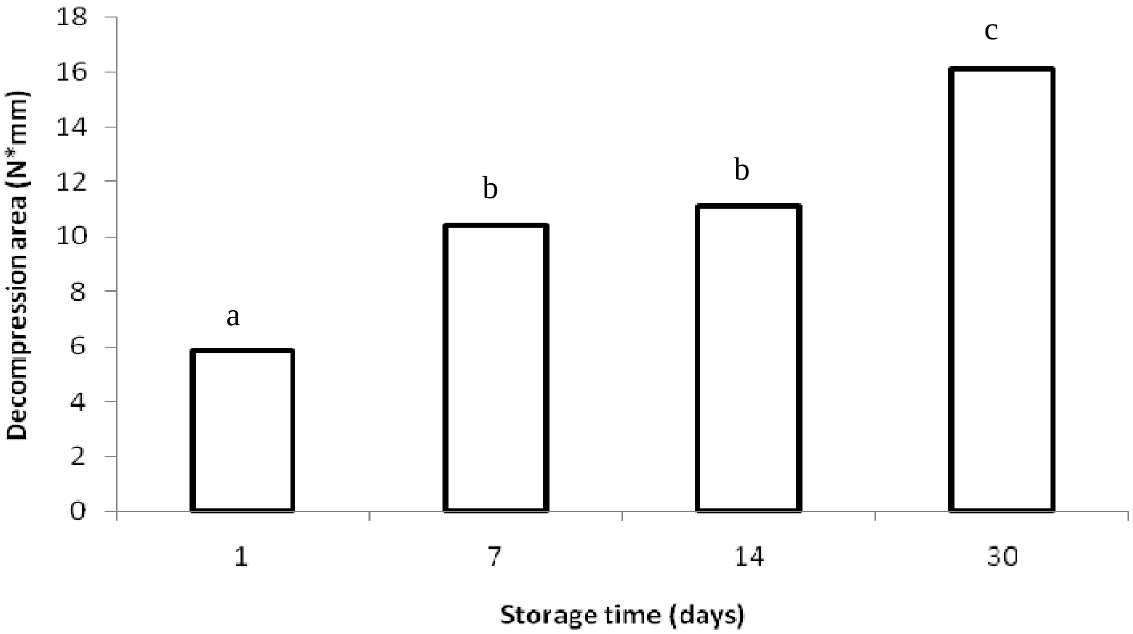


FIGURE 38

Decompression distance as a function of leavening agent.
Means of 36 observations, S.E. = 0.13027059

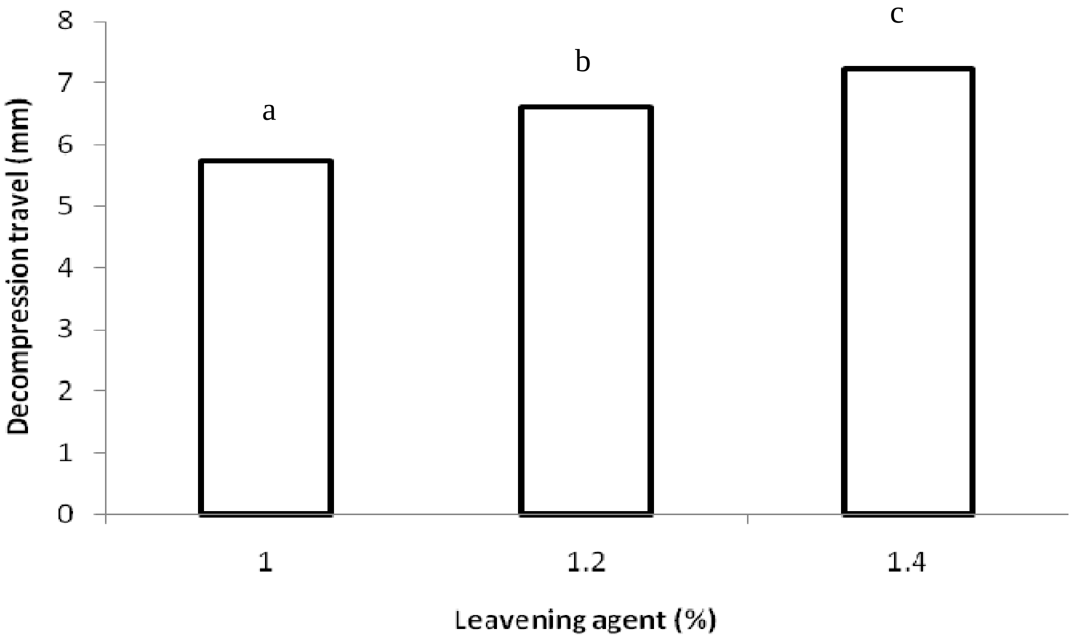
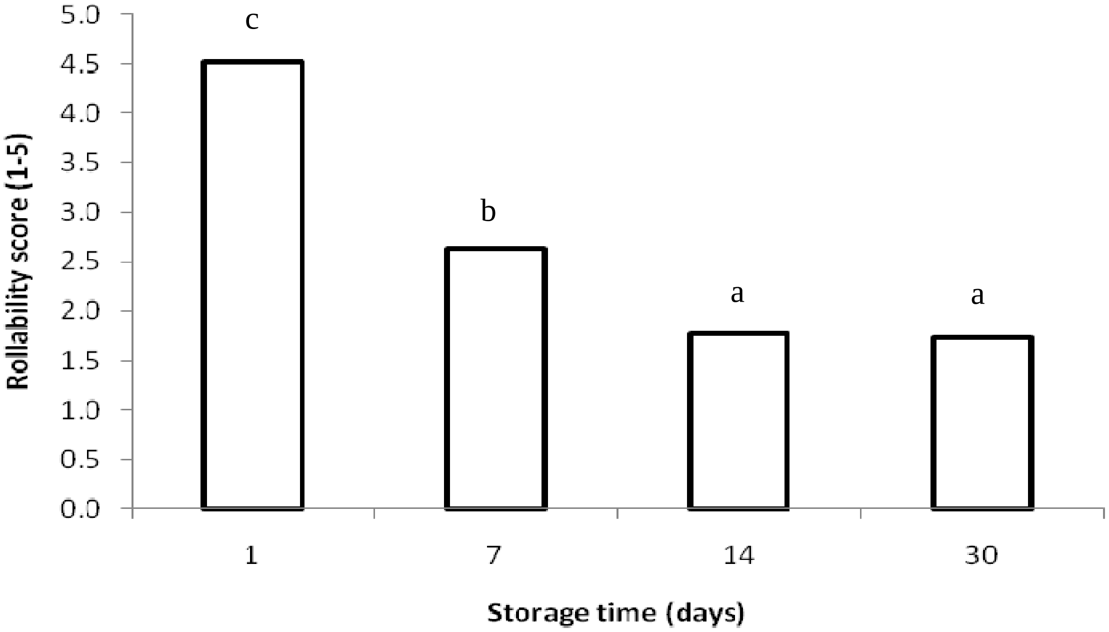


FIGURE 39

Average rollability score for each day of storage.
Means of 72 observations, S.E. = 0.1005



CHAPTER 4

LEAVENING EFFECTS ON OVEN BAKED WHEAT FLOUR TORTILLA EXTENSIBILITY AND COMPARED TO STOVE TOP COOKED TORTILLAS

Abstract

Tortillas are the second most popular bread type in the United States and comprise 32% of the bread market sales, trailing white bread by only 2%. Challenges in the tortilla industry include consistency during processing and quality of the products. The effect of leavening agent and processing methods on the moisture content and stretchability of wheat flour tortillas were studied. The design consisted of three treatments of leavening agent (1.0, 1.2, and 1.4%) baked in an impingement oven at 249°C and then stored for 30 days at room temperature. Textural properties of puncture along with the moisture content were analyzed on day 30 of storage. The data was compared to the results of the previous study and determined that the stovetop cook method produced tortillas with significantly higher moisture contents than the oven baked method. Also that the stove top cook method produced tortillas that were less tough than the oven baked. The increases of leavening agent seemed to increase the strength and the toughness of the tortillas as well as decrease the moisture content. This study suggests that physical and textural properties are significantly affected by the % leavening used

and the cook method. More studies should be conducted to determine the efficiency of controlling specific parameters and their effects on key tortilla quality factors.

Introduction

Tortilla History

Tortillas as part of the American diet used to be considered an ethnic food and were typically found in the Hispanic and international foods sections of grocery stores. Now, not only are they the most popular ethnic bread in the U.S. beating out the bagel, English muffin and pita bread but are also close on the heels of the white bread market. They often serve as substitutes for traditional breads like hot dog buns, sandwiches and pizza (TIA 2002).

U.S. Tortilla Market

In 2005 tortillas and related by-products comprised a record-breaking $6.1 billion tortilla industry (TIA 2005), an estimated 85 billion flour and corn tortillas were produced, not including the tortillas used to make chips. Many sizes and varieties of flavors are produced but the basic flour tortilla remains most popular, out selling corn tortillas by a 2-to-1 margin (Petrak 2006a). Tortillas are now a common occurrence in establishments such as McDonald’s, Arby’s, Subway, Applebee’s and Chili’s (Petrak 2006b). Their portability, taste, versatility and perceived healthfulness are all reasons why tortillas have seen such continued growth and popularity.

Tortilla Characteristics

Consumers expect tortillas to be flexible, easy to fold or roll, slightly chewy, and must resist tearing or breaking (Bello et al 1991, Cepeda et al 2000). The leavening agents used in tortillas create the fluffy/spongy, layered product with a whiter/more opaque appearance, which many consumers also prefer.

Typical flour tortillas are not just white but have toasted brown spots as well. These toasted areas are parts of the tortilla that are exposed to more heat due to the expansion of the air bubbles internally pressing areas of the tortilla onto the heated cooking surface. Using different cooking methods or different temperatures can change the color and the appearance of the spots. They can range from tan to dark brown and large to small, but if the temperature is too cool, no brown spots are created, at the same time if the temperature is too high, the spots become exceedingly dark thus creating an undesirable product with somewhat of a burnt flavor. So in order to produce a high quality and desirable product the leavening system, cooking method, and cooking temperature must be appropriate for the product being produced.

Tortilla Texture

Tortilla products can be analyzed using large deformation rheological methods such as extensibility using a texture analyzing machine. This objective method is quantitative, sensitive, fast and repeatable when compared with subjective methods such as sensory evaluation and rollability (Suhendro et al 1999).

Large strain methods such as puncture (extensibility/stretchability), penetration, bending, tension, shear, and compression analysis are commonly used to evaluate freshness and textural changes of foods with respect to storage conditions (Truong and Daubert 2003). These methods are sensitive, reliable and can register small changes in flexibility and rollability that are due to a difference in formulation or storage time (Bejosano et al 2005). According to Suhendro et al (1998) and Srinivasan et al (2000) the objective texture measurements can characterize the rheology of wheat flour as well as corn tortilla texture. Their subjective rollability scores were significantly correlated with their objective test findings.

Wang and Flores (1999a, b) measured the extensibility/stretchability of flour tortillas using the TA-XT2 texture analyzer with the tortilla fixture attached. Stretchability measurements are recommended because they are repeatable and are an important textural property of wheat flour tortillas (Mao et al 2002). Parameters of force and work of deformation as well as force and distance to rupture can be obtained through extensibility analysis (Bejosano et al 2005).

Objective

The objective of this study was to determine the effect of different amounts of leavening agent and cook methods on the stretchability and moisture content of wheat flour tortillas baked in an impingement oven.

1. Determine how an increased percent of leavening agent affects the moisture, and textural characteristics of the tortillas.

2. Determine how the impingement oven cook method affects the moisture content of the tortillas compared to the stove top cook method.

3. Determine how the impingement oven cook method affects the strength of the wheat flour tortillas compared to the stove top cook method.

Materials and Methods

Tortilla Processing

Table 7 contains a summary of the treatment design by the percent leavening agent used, cook temperature (°C) and the storage time in days. The tortilla formula used is described in Table 8. The wheat flour tortillas were made using batches of 500g of flour (bleached and enriched with 13.3% moisture, 0.50% ash, and 11.2% protein [ADM Arkady, Enid, OK]), 30g of shortening (Serapio's Tortilla Factory, Oklahoma City, OK), 7.5g salt (United Salt Corporation, Houston, TX), Tortilla Blend sodium bicarbonate (0.4, 0.6, and 0.8%) (Arm & Hammer, Church & Dwight Company, Old Fort, OH), 2.9g sodium acid pyrophosphate, SAPP 28 (ICL Performance Products LP, St. Louis, MO), 2g calcium propionate and 2g potassium sorbate (Serapio's Tortilla Factory, Oklahoma City, OK), 1.25g sodium-2-stearoyl lactylate (Caravan Ingredients, Lenexa, KS), 1.25g fat-encapsulated fumaric acid (Bakeshure FT, Balchem Corporation, Slate Hill, NY), and 282g tap water at 38°C.

A hot-press tortilla-making procedure reported by Mao and Flores (2001) was used with some modifications. The dry ingredients were mixed at low speed, dial set to 1 (stir), with a paddle (flat beater) in a mixer (KitchenAid, St. Joseph, MI) for 1 minute.

The shortening was added and mixed for 3 minutes at stir. The attachment was then switched to a dough hook and 262g of warm tap water (38°C) was added and mixed for 1 minute at stir for the hydration of flour particles. Then 20g more warm (38°C) tap water was added to the remaining dry flour particles at the bottom of the mixer bowl and mixed at medium speed, dial set to 2, for 3 minutes for dough development. Dough was allowed to rest for 5 minutes in a Ziploc storage bag, divided into 40-g pieces and rounded by hand. The rounder's hands contained a small amount of shortening to prevent the dough balls from drying out during proofing. The dough balls were then covered with foil and proofed at room temperature for 30 minutes. The dough balls were flattened by hand and placed in an electrically heated tortilla press (~138°C), (Maquinas Tortilladoras Gonzalez, S. A., model TH – 10, Guadelupe, N. L., Mexico) for 2-3 seconds. They were then baked for 45 seconds at 249°C in an impingement oven (XLT Ovens, Bofi Inc., model 3240TS2, Wichita, KS). After baking the tortillas were set to rest on a cooling rack until cool to the touch (~15 minutes). While cooling the tortillas were gently pressed down by hand in order to release the trapped air inside. Twelve tortillas were placed into each polyethylene bag obtained from a commercial production facility and stored at room temperature until analysis on day 30. The treatment design described in Table 7 consists of 3 leavening percentages (1.0, 1.2, & 1.4%), the cook temperature of 249°C, and the storage time of 30 days. A total of three 500g batches were prepared and analyzed for each treatment.

Tortilla Physical Characteristics

The moisture content was determined on the day of analysis (storage day 30) using the two-stage Approved Method 44-15A (AACC 2000) using a household coffee grinder (BrAun model KSM 2) rather than a Wiley laboratory mill. The mean of three tortillas per treatment was reported.

Objective Rheological Methods

The extensibility of flour tortillas was measured using a texture analyzer (model TA XT2, Texture Technologies Corp., Scarsdale, NY).

A TA – 108 tortilla film fixture and a ¾ inch diameter tapered acrylic probe with a flat edge was used for the stretchability/puncture analysis, as suggested by Texture Technologies Corp., Scarsdale, NY. The tortillas were fixed onto the fixture one at a time with the probe attached to the analyzer arm above. The probe traveled downward at 10.0 mm/sec until the tortillas surface was detected at 0.25N force (pre-test). Once the trigger force was reached the graph proceeded to plot the effect of the tortilla under tension as the probe traveled at 2.0 mm/sec for 25 mm, a predetermined distance to stretch the tortilla until it completely ruptured. The exceeding of the elastic limit of the tortilla was observed as the maximum force. The probe was then withdrawn back to the start position at a rate of 15.0 mm/sec. The maximum force (N), distance (mm) the tortilla stretched before rupture, area under the curve or work (N*mm), and the slope/gradient (N/mm), which is the ratio of the force to distance, were recorded (Mao et al 2002). The definition of parameters is summarized in Table 9.

Statistical Analysis

The design consisted of three treatments, all cooked at 249°C and stored for 30 days at room temperature with three different amounts of leavening agent. Three subsamples of tortillas were used for the physical analysis of moisture. Twelve subsamples of tortillas per treatment were used in the textural stretchability analysis. The data was analyzed with data from the previous chapter/study to determine the significant differences between the stove top and impingement oven cook methods. All tests of significance were performed at $p<0.05$.

Results and Discussion

Tortilla Physical Properties

The averages of the wheat flour tortilla physical properties are recorded in Table 10. Moisture was calculated and found to be significantly affected by the leavening agent and cook method (Table 11). The moisture for treatments decreased as the percent leavening level increased from treatment 1 (29.3%) to treatment 3 (25.9%) (Fig. 40). The stove top tortillas from previous data with 1.4% leavening had molded so moisture analysis data was not able to be collected. When comparing the rest of the data, expressed in Figure 41, the stove top tortillas for 1.0 and 1.2% leavening agent have significantly higher moisture contents of 32.7 and 33.5%, respectively, than the oven baked tortillas with moisture contents of 29.3 and 29.1%, respectively. For both methods from 1.0 to 1.2% leavening agent there was not a significant difference in moisture but for the oven method a significant decrease in moisture was seen for treatment 3 with

1.4% leavening. This study suggests that the higher percentage of leavening agent produces a tortilla with lower moisture.

Extensibility

The stretchability of the flour tortillas is expressed as the maximum force and rupture distance required to completely puncture the tortillas. The greater the distance at the point of rupture, the more stretchable the product is and the greater the force at the point of rupture, the stronger the product is (Texture Technologies 2009). Examples of stretchability tracings from the TA – XT2 texture analyzer are presented in Figure 42. The means collected for the impingement oven tortillas are reported in Table 10. Puncture force was affected by percent leavening agent observing an increase with each leavening level, from treatment 1 (6.63 N) to treatment 3 (6.82 N) (Fig. 43). When comparing the oven tortillas which were baked at 249°C with the tortillas prepared by the stove top method at 249°C, no significant differences for puncture force were observed (Table 11).

Puncture distance at the breaking point suggests the degree of extensibility of the product (Texture Technologies 2009). The puncture distance or measurement of extensibility was significantly affected by the percent leavening agent (Table 11) with treatments 1 (1.0%) and 3 (1.4%) having distances of 11.03mm and 11.01mm, respectively, having higher mean puncture distances than treatment 2 (1.2%) (9.58mm) (Fig. 44), suggesting that tortillas are more stretchable with above or below 1.2% leavening. More studies need to be conducted to determine the trend of percent leavening and puncture distance.

The area under the curve, which represents the work during the test, was also recorded along with the gradient or slope from the point of initial contact with the tortilla extending to the point of maximum force at the point of rupture, data is recorded in Table 10. A degree of toughness can be observed from the total area under the curve (Texture Technologies 2009). This study suggests that the puncture area/toughness increases as the percent leavening increases, 25.0, 26.1, and 26.3 N*mm, respectively (Fig. 45). Also, greater than 1.0% leavening creates an equally tough product. Puncture area showed a significant difference when comparing the two cook methods with 1.2 and 1.4% leavening (Fig. 46). Their was not a significant difference with 1.0% leavening (Fig. 46). The stove top methods had significantly higher puncture area at 1.2 and 1.4% leavening than the oven baked tortillas (Fig. 46).

Puncture gradient/initial slope of the puncture curve, which is used to interpret the stiffness of a product (Texture Technologies 2009), was significantly affected by percent leavening agent (Table 11). Each leavening level produced tortillas with different gradients, 1.2% being the highest (0.68 N/mm) and 1.0% the lowest (0.60 N/mm) (Fig. 47). With treatment 2 being the stiffest and 1 and 3 having similar values, more studies should be conducted to better determine how the leavening agent affects the puncture gradient/stiffness of the product.

Conclusion

1. With a high percent of leavening agent (1.4%) a decrease in moisture content was observed. Also as the percent leavening agent increased the

tortillas were stronger but also became tougher as the percent leavening agent continued to increase.

2. The oven baked tortillas had significantly lower moisture contents as expected from a method where the product is cooked on both sides at the same time. The use of an oven creates heat above and below the product producing an environment of hot and dry air in the middle surrounding the product. The dry air draws the moisture out of the product more quickly than the cool air over the tortillas in the stovetop cook method.

3. The strength of the tortillas was observed to be stronger and tougher when cooked using the stove top method. The impingement oven method created tortillas that were more stiff and hard making them less strong. The extensibility and stiffness were not as affected by the percent leavening and had varying results, generally with two treatments showing one trend and the third treatment showing the opposite. More studies would need to be conducted to determine the true effects of percent leavening agent on the extensibility and stiffness of wheat flour tortillas.

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TABLE 7

Experiment Design of Oven Baked Wheat Flour Tortillas[a]

Treatment ID	Total Leavening Agent (%)	Cook Temperature (°C)[b]	Storage Time (days)
1	1	249	30
2	1.2	249	30
3	1.4	249	30

[a] Three batches of 500g flour per treatment were used.

[b] 480°F

TABLE 8

Oven Baked Wheat Flour Tortilla Formulation[a]

Ingredient	Batch Amount (g)	Flour Basis (%)
Flour (13.3% moisture)	500	100
Shortening	30	6
Salt	7.5	1.5
Sodium Bicarbonate[b]	Adjusted	Adjusted
SAPP 28[c]	2.9	0.58
Calcium Propionate	2	0.4
Potassium Sorbate	2	0.4
SSL[d]	1.25	0.25
Fumaric Acid	1.25	0.25
Water (38°C)	282	56.4

[a] Adams and Waniska (2002) and Bejosano et al (2006) with modifications.

[b] Adjusted for each batch to either 2g (0.4%), 3g (0.6%), or 4g (0.8%).

[c] Sodium acid pyrophosphate.

[d] Sodium-2-stearoyl lactylate.

TABLE 9

Abbreviations and Definitions of Parameters Used for Oven Baked Tortilla Statistical Analysis

Test	Abbr.	Units	Definitions
Puncture	PForce	N	Force required to completely puncture/rupture a tortilla. Measure of stretchability to the point of rupture. Representative of strength.
	PDistance	mm	Measure of stretchability as the length that the tortilla can be stretched to the point of rupture. The greater the length the more stretchable the tortilla is.
	PArea	N*mm	Total work under the puncture curve. Toughness.
	PGradient	N/mm	Slope of the line from contact with tortilla to maximum force. The higher the slope the stronger the tortilla. Stiffness.
Moisture	Moist	%	Moisture content of the cooked tortillas.

TABLE 10

Textural Properties and Moisture of Oven Baked Wheat Flour Tortillas[a]

Tortilla	**Stretchability (Puncture Test)**				**Moisture**
Treatment	**Force (N)**	**Dist. (mm)**	**Area (N*mm)**	**Grad. (N/mm)**	**(%)**
1	6.63	11.03	25.0	0.60	29.3
2	6.65	9.58	26.1	0.68	29.1
3	6.82	11.01	26.3	0.61	25.9

[a] Mean of 10 measurements for Stretchability and mean of 3 for Moisture.

TABLE 11

P-Values of Oven Baked Flour Tortilla Variables Compared to Stove Top Cooked Tortillas[a]

Response Variable[b]	LAgent	Cook Method	LAgent x Cook Method
Moisture			***<0.0001
PDistance	**0.0057		
PArea			*0.0249
PGradient	**0.0013		

[a] Significant difference *, **, ***, $p<0.05$, 0.01, and 0.001, respectively.
[b] Variables defined in Table 9.

FIGURE 40

Moisture content of oven baked tortillas as a function of leavening agent.

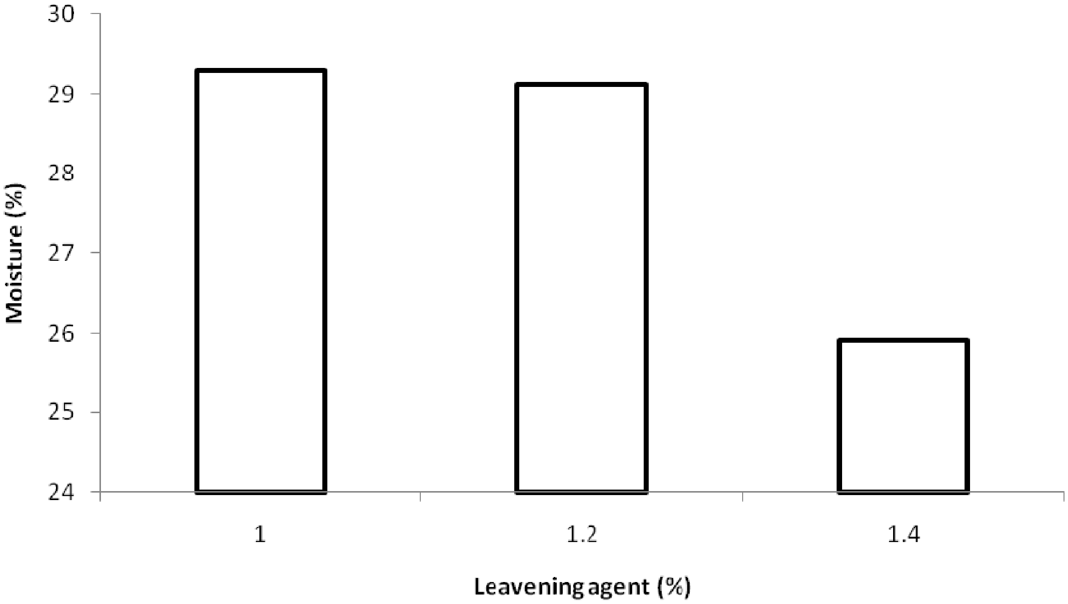


FIGURE 41

Comparing moisture content of oven baked and stove top tortillas as a function of leavening agent.

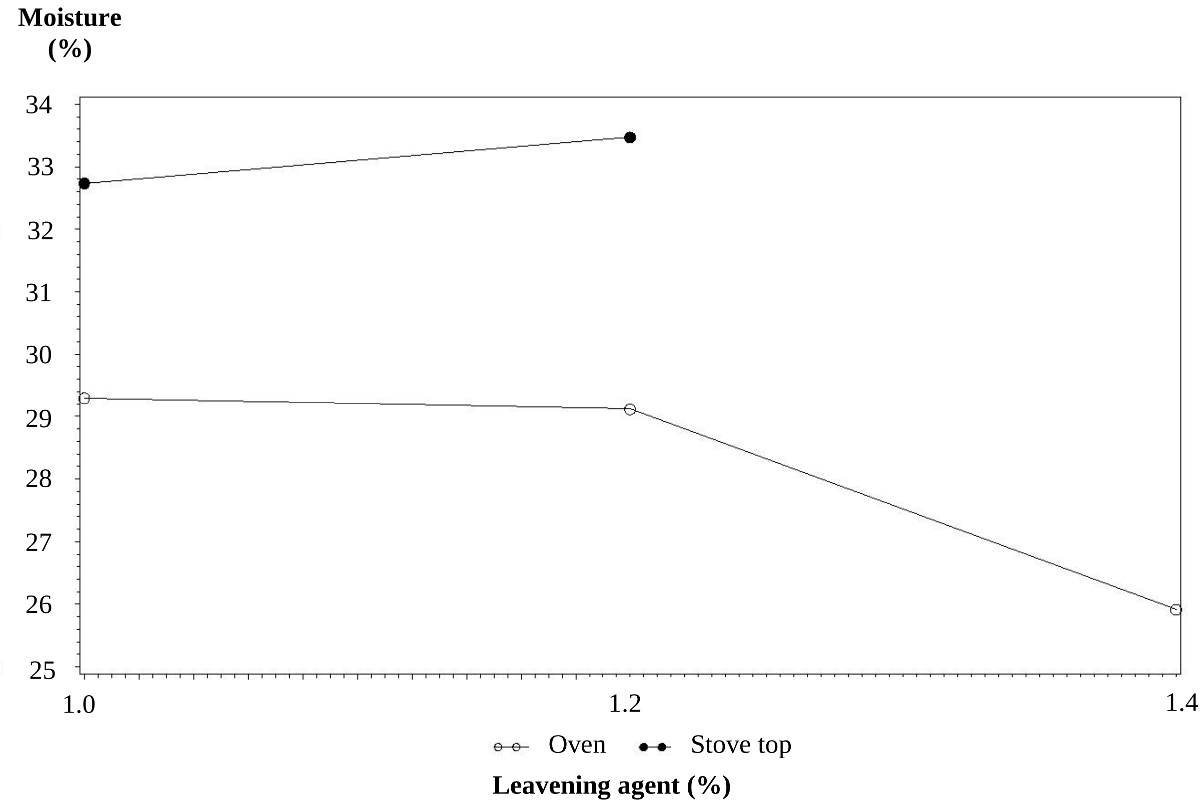


FIGURE 42

Examples of oven baked tortilla extensibility analysis determined by cook temperature of 249°C and a storage time of 30 days.

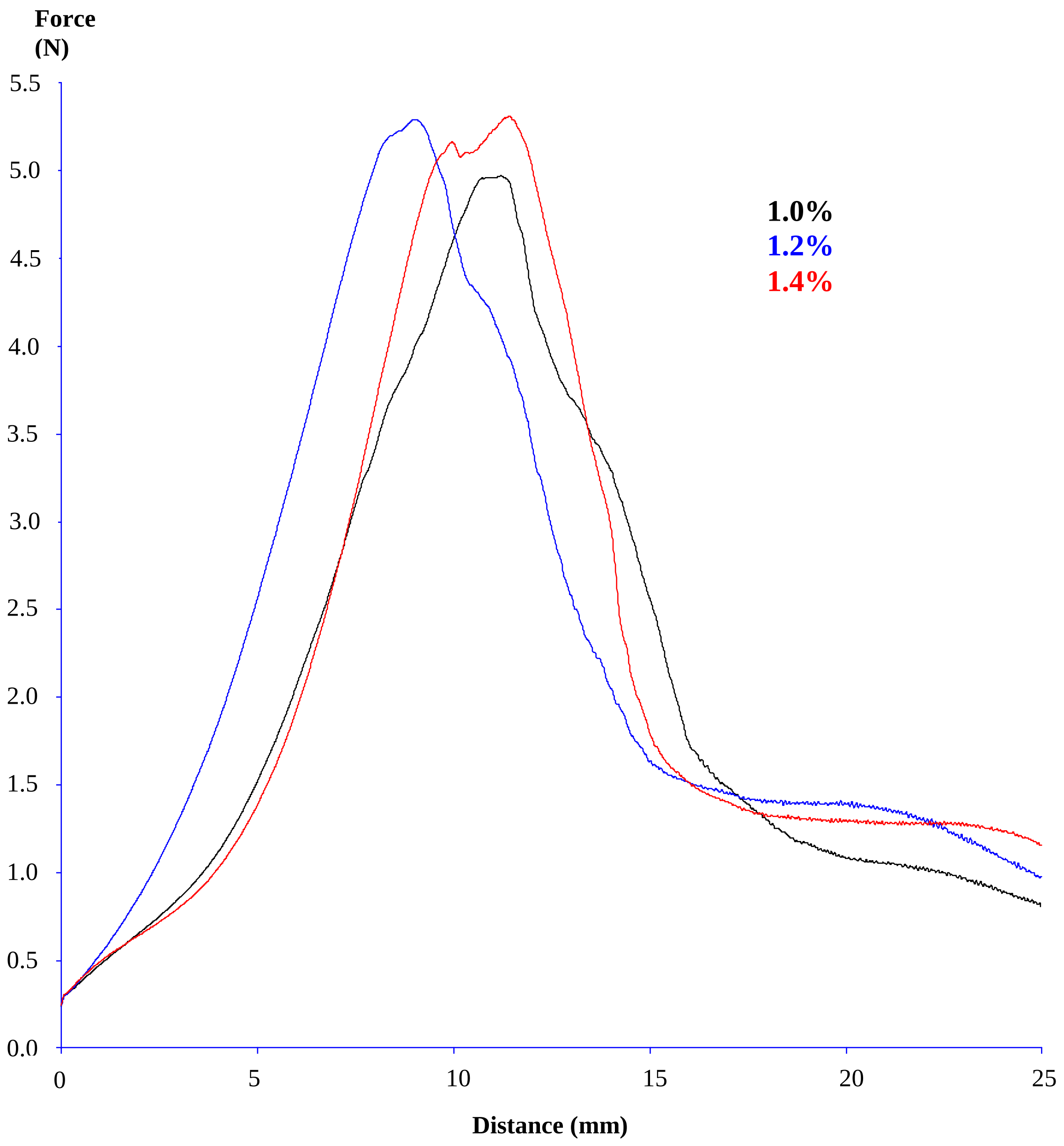


FIGURE 43

Puncture force of oven baked tortillas as a function of leavening agent.

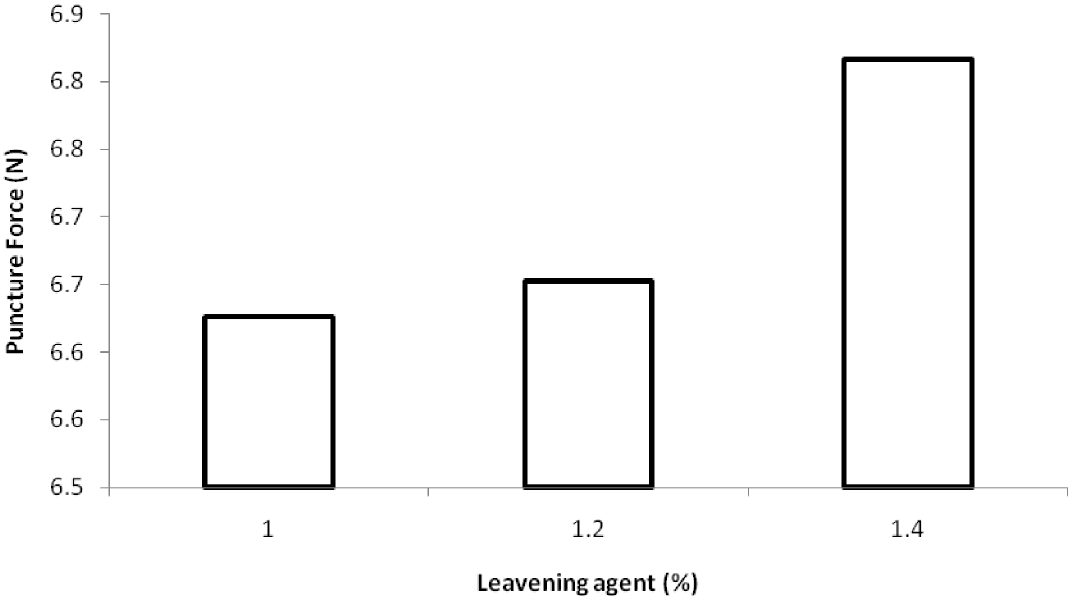


FIGURE 44

Puncture distance of oven baked tortillas as a function of leavening agent.

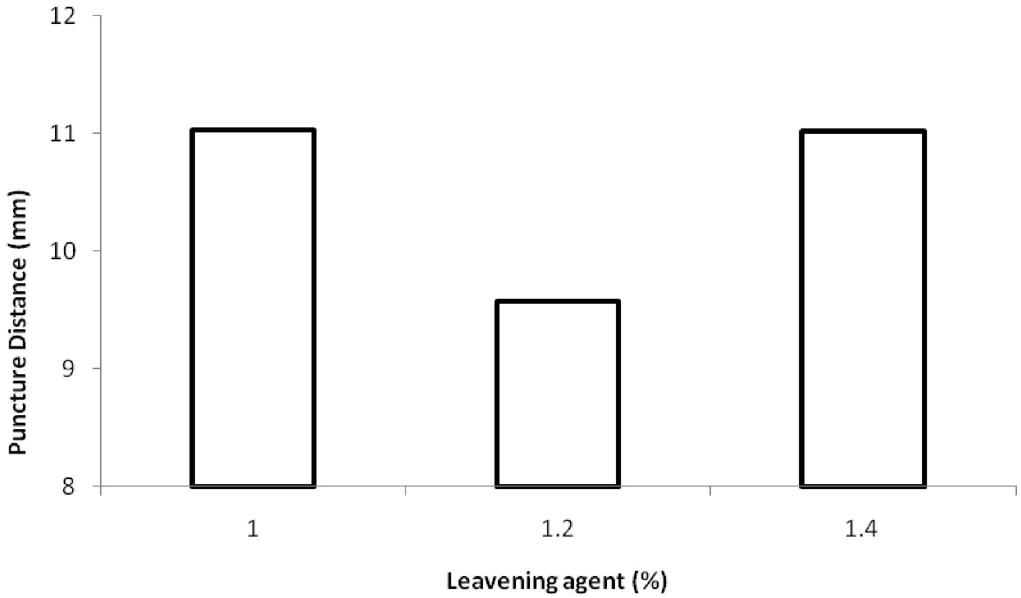


FIGURE 45

Puncture area of oven baked tortillas as a function of leavening agent.

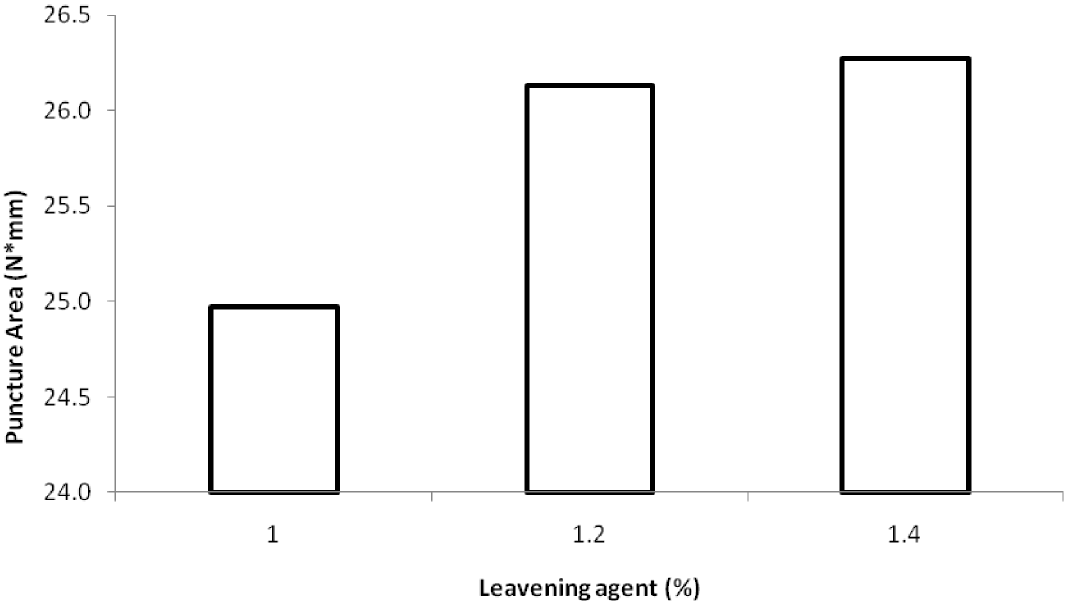


FIGURE 46

Comparing the puncture area of oven baked and stove top tortillas as a function of leavening agent.

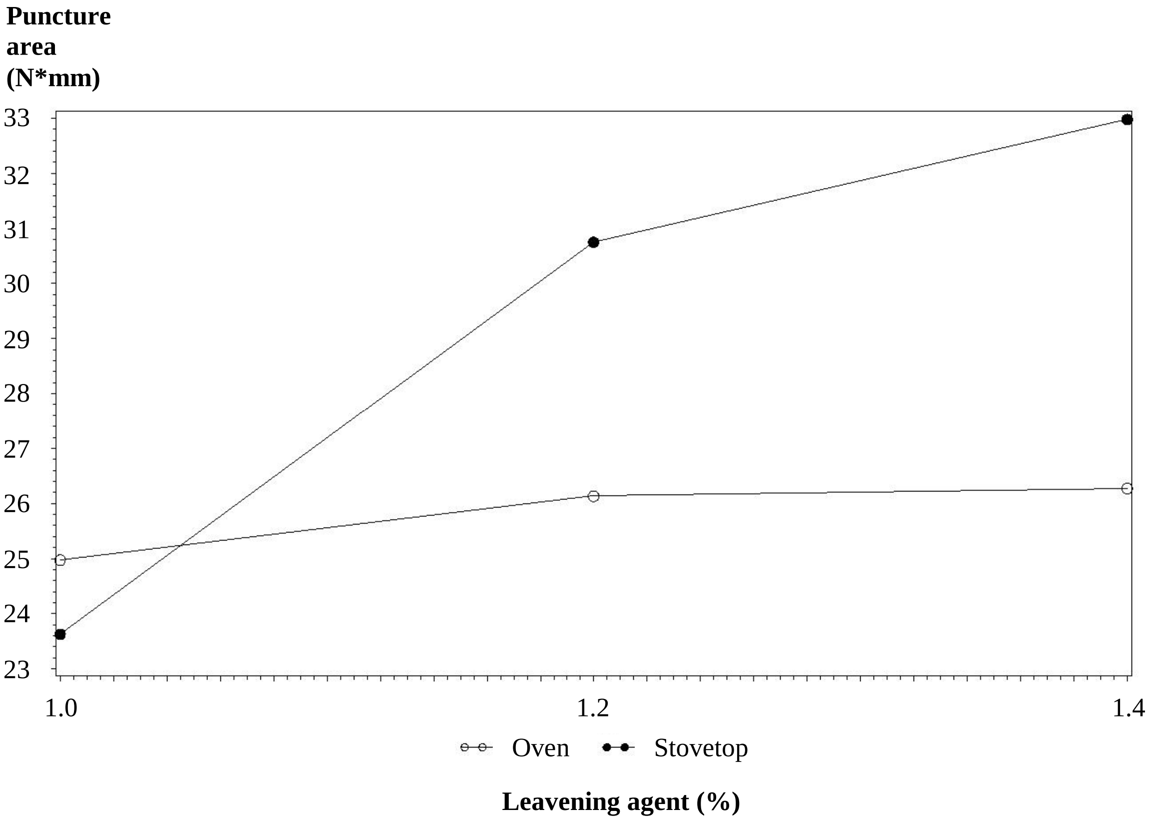
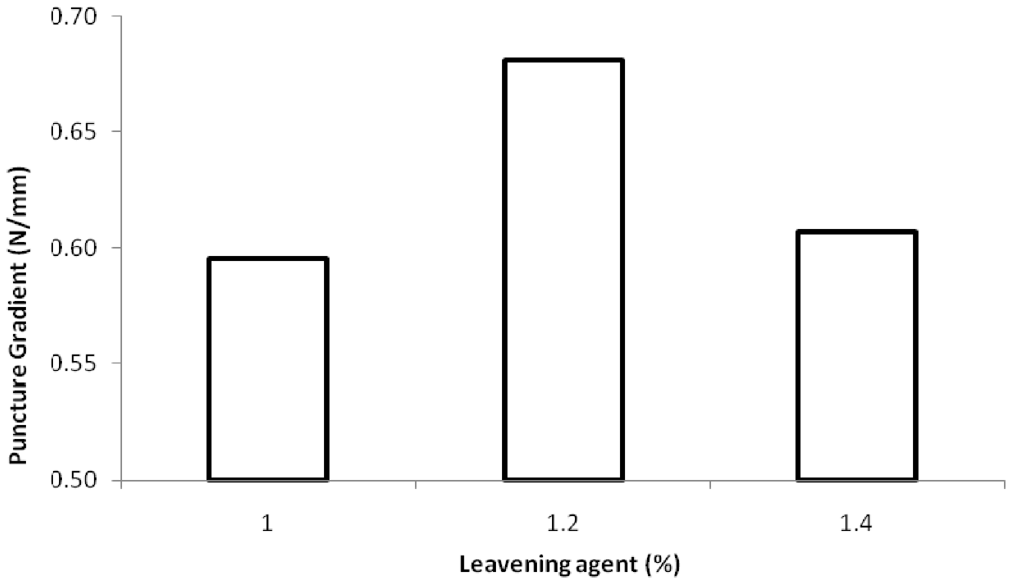


FIGURE 47

Puncture gradient of oven baked tortillas as a function of leavening agent.



CHAPTER 5

FUTURE RESEARCH

- Since in this study's tortillas had to be made by hand, in future studies they could be produced commercially to reduce variability due to human differences.
- More studies should be done to evaluate the effects of cook temperature on the final quality and texture of the product. Ideally using an electric heating source with a temperature gauge.
- Combinations of other leavening acids and bases will produce tortillas with different characteristics. Studies should be conducted to determine the effects of other combinations.
- More studies should be done producing tortilla products with an impingement oven in order to evaluate ingredient variations and market availability for a pita pocket like tortilla product.
- Further studies should be conducted to determine the effect of leavening interactions with other ingredients and how that affects the textural properties of wheat flour tortillas.
- More studies dealing with why and how increased leavening agent reduces the storage stability and which leavening systems have the least negative effect on quality characteristics over time should be conducted.

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VITA

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Scope and Method of Study: Texture analysis of wheat flour tortillas

Findings and Conclusions:

Tortillas are the second most popular bread type in the United States and comprise 32% of the bread market sales, trailing white bread by only 2%. Challenges in the tortilla industry include consistency during processing and quality of the products. The effect of leavening agent, process temperature and storage time on the physical properties of tortillas were studied. The design (3x3x4) consisted of thirty six treatments of leavening agent (1.0, 1.2, and 1.4%), temperature (191, 232, and 249°C), and storage time (1, 7, 14, and 30 days). Physical and textural properties of the tortillas were analyzed. Texture analyses, puncture/extensibility, Kramer shear cell, and compression were conducted along with rollability and peelability. Physical properties such as weight, diameter, thickness, moisture and color were recorded. Significant three way interaction between leavening agent, temperature, and storage time was found for five variables (strength/puncture force, stretchability/puncture distance, b*, C*, and thickness). Rollability and peelability showed significant two way interaction between leavening agent and temperature. Four variables had significant two way interaction between leavening agent and storage time (stretchability/puncture distance, Kramer shear cell distance, compression area and peelability) while six variables had significant interaction between temperature and storage time (compression force, area and gradient, peelability and color scores b* and C*). This study suggests that more physical properties are affected by significant interactions of temperature and storage time and leavening agent and storage time compared to temperature and leavening agent. More studies are needed to determine the efficiency of controlling specific parameters and their effects on key tortilla quality factors.

ADVISER'S APPROVAL: Dr. Patricia Rayas-Duarte