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Drivers of Liking and Effects of Corn Hybrics on Quality of Corn Tortilla

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DRIVERS OF LIKING AND EFFECTS OF CORN HYBRIDS ON QUALITY OF CORN TORTILLA

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in
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by
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B.S., Universidad Autónoma Chapingo, 1995
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December 2007

Dedicated to

My parents

Mr. Moisés Herrera Gallegos
Mrs. Rosa Corredor García

&

Brothers and Sister
Carlos, Hugo, Abel, and Alejandra

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ABSTRACT

Corn tortilla, an ancient staple food of Mexico and Central America, is still the base food in those countries and has also become more popular in other countries with high Hispanic population. However, mechanization of corn tortilla production has modified the original sensory attributes to new standards that meet manufacturer's requirements. The first part of this study attempted to determine the sensory attributes that drive consumer's decision on the acceptability and purchase intent of the corn tortilla available in the Mexican market. The findings may help manufacturers to improve the processing of tortilla and develop products with ethnic authenticity. Overall acceptance was influenced by overall liking and chewiness, while purchase intent was influenced by overall liking, taste, chewiness, rollability, and overall appearance. The second part of the study was aimed to determine differences in the drives of acceptance and purchase intent among two consumer segments differing in education/profession (faculty/graduate students vs. field laborers). It was observed, in general, that consumers preferred the same samples and they used the same attributes to differentiate samples. However field laborers were more discriminative and demanding on the tortilla quality when judging a product. In the third part, instrumental analysis was conducted in an attempt to correlate instrumental and chemical characteristics with levels of acceptability of corn tortilla sensory attributes. Moisture, crude fat, and sulphur contents, force to extend a tortilla strip, and work and force to roll a piece of tortilla were related with the acceptability ratings of tortilla attributes. The last part was conducted to determine effects of different varieties of corn with a fixed cooking method on some physical and cooking properties of corn before and after cooking and determine the effect of corn variety on the tortilla sensory attributes. Results showed that physical and chemical characteristics of different corn hybrids influenced their cooking properties as well as the resulting characteristics of tortilla products that may be related to acceptability such as color, texture and flavor.

CHAPTER 1

INTRODUCTION

1.1 Research Background

For centuries, corn tortilla has been a staple food in some Latin American countries. Corn tortilla is produced by a lime cooking (nixtamalization) process. The original process was developed by ancient settlers from a region called Mesoamerica that included part of Mexico and Central America. The original name of the alkaline process was ‘nixtamalli’. The flat bread produced from alkaline-cooked (nixtamalized) corn was then called ‘tlaxcalli’. Later, the Spanish conquerors who arrived in Mexico named it “tortilla” (Lind and Barham 2004). Over the years, this staple product and its process have encountered several changes such as the use of machinery and new technologies to make corn tortilla production easier for people in urban areas. Today, corn tortillas have also crossed frontiers to the United States where its popularity is increasing among non-Hispanic consumers (Baggs, 2007), even when the product offered to them has some variations in sensory characteristics when compared to its original.

The basic use of corn tortillas in Latin American countries is a carrier for holding different types of fillings. Diverse fillings are used depending on the place or country and availability. A tortilla wrapped around a filling is known as ‘taco’. It can be considered as an equivalent to a sandwich in the occidental culture. There are also many other products derived from nixtamalization and tortilla that are consumed in Latin America such as tortilla chips, tostadas, tamales, etc.(McDonough and others, 2002).

During the tortilla preparation at a household level, corn is first cooked in a water-lime solution (nixtamalized), followed by steeping and milling to produce a dough (masa). Tortilla is made by forming a flat disk of masa by hand, and cooking it over a hot griddle made of clay called ‘comal’, and using firewood as a source of heat. The final product is more palatable and easier to digest than the raw corn. The flavor and other sensory properties of the final product are improved (Caballero-Briones and others, 2000). This ancient process is still practiced in certain parts of Latin American countries, especially in rural areas.

In the above mentioned context, making tortillas was an art that was learned across generations. People usually spent about 1 - 4 hours (sometimes more, depending on the amount of corn) preparing tortillas from the alkaline-cooked corn cooked from the previous night. Typically native varieties of corn were used to produce tortillas (Rangel-Meza and others, 2003). The amount of corn used varied from 2 - 5 kg per batch (at approximately 12 % moisture content). Cooking time, amounts of water, and lime concentration were controlled empirically during the nixtamalization. Although the parameter used to verify the correct nixtamalization is the point when the corn hull can be separated from the kernel by rubbing it between the fingers (Martinez-Herrera and Lachance, 1979), may not be always precise because it also depends on other factors such as hardness of the corn kernel. Since the dough (masa) is molded by hand or using a tortilla press to form the flat disk, a correct nixtamalization is required in order to obtain not only the right physical and sensory properties in the final product (tortilla) but also the right consistency in the “masa.” A bad consistency in the masa may cause more time to be spent in preparing the tortillas because of the lack of or excess of stickiness that makes the masa difficult to mold.

In the urban areas of Mexico, women are nowadays being integrated in work force and changing life styles. In general, women from urban areas currently seldom prepare tortillas at home. These new conditions have created an opportunity for the rapid emergence of tortilla stores (tortillerias), small companies that produce tortilla commercially with a mechanized or partially mechanized process. Even when tortillas produced in these stores initially were not well accepted, women have recognized the advantages of lessening their workload from home-made tortilla preparation (Lind and Barham, 2004). Some changes to the original process were made on this commercial production of tortilla sold in tortilla stores. Commercial manufacturers of tortilla have changed the source of heat for cooking and baking from firewood to butane gas, and batches now are made with large amounts of corn. Also, the manual molding of masa to form a flat disk has been changed to a sheeting and cutting equipment based on rolls, while a clay griddle for baking tortilla has been replaced by iron ovens. In addition, the type of corn used has also been changed from native varieties to commercially produced corn hybrids. This way of producing tortilla is still known as “traditional process” although there are some variations made to the original process (McDonough and others, 2002).

However, problems in the process were encountered when handling and storing nixtamalized corn or “masa” because of its perishable nature. The owners of these small tortilla stores looked for new and cheaper ways to improve their profits which resulted in an alternative use of nixtamalized corn flour (NCF) or instant masa flour (IMF). NCFs are an intermediate step for producing corn tortillas and also corn tortilla chips (Gomez and others, 1991). Today, there are specialized companies that produce NCF for the tortilla manufacturers. These companies cook corn in lime (nixtamalization) to get dry flour that is used by tortilla manufacturers for producing masa and then tortillas. There are different types of NCF for different uses such as table tortillas, restaurant style chips, tortilla chips, corn chips, and tamales (Sahai and others, 2001).

The largest manufacturer of NCF in Mexico, installed its first plant around 1949. According to Rangel-Meza and others (2003), due to the demand of tortilla in urban areas, the process to produce tortilla in Mexico changed from traditional to a commercial process which is split in two main steps: the nixtamalized corn flour production and the tortilla production. Some researchers have pointed out that the industrial process to produce nixtamalized corn flour consists of (1) "heating the maize grains in a continuous industrial cooker in 3% $Ca(OH)_2$ solution." (2) "The cooked grains are then washed with hot tap water at 60 ^oC, then soaked for 3.2 hr to assure a better distribution of humidity within the maize grains." (3) "Thereafter, they are ground with an industrial stone mill and the masa obtained is dried with a flash air drier at 186 ^oC." and (4) "The coarse flours is cooled in a spinning tunnel, ground in a hammer mill, and sieved through U.S. 40 and 60 meshes" (Toro-Vazquez and Gomez-Adalpa, 2001).

1.2 Research Justification

The first plant for NCF production in the United States was installed in 1977 when tortilla was almost completely an ethnic product and its consumption was very small. Today the popularity of tortillas has increased due to the increase in Hispanic population and diversification in taste preferences of the non-Hispanic population in the United States. Several companies have entered the market with both flour (wheat) and corn tortilla. According to the Tortilla Industry Association, the total sales of flour and corn tortilla reached $5.2 billion in 2002 with an annual growth of nine percent. The market for tortilla (corn and flour) is expanding not only for Latin American countries and USA but also to Europe and Asia where some companies have started to produce and commercialize tortilla.

Regardless of the advantages of NCFs for tortilla manufacturers and the efforts to improve the nixtamalization and tortilla production process (reducing pollution, increasing yield, increasing shelf life, reducing tortilla staling, etc.) of commercial tortilla, the main drawback of this commercial and mechanized process is that the finished product does not have the same sensory properties observed in the product prepared by the original production process. Hispanic consumers still prefer tortilla made by the original traditional production process (Caballero-Briones and others, 2000). Further research is needed to improve the commercial process to produce corn tortilla with desirable sensory characteristics.

On the other hand, the non-Hispanic consumers in the USA are demanding more ethnic foods than before. Changes in life style and population structure are some of the reasons for this. Diversification in taste preferences of the American population has opened a great opportunity for alkaline cooked products. The consumption of tortilla bread served in Mexican restaurants and tortilla chips for dipping have increased in the last few years (Baggs, 2007).

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CHAPTER 2

REVIEW OF LITERATURE

2.1 Corn Uses, and Nutritional Value

Maize (*Zea mays* L.) also referred to as corn, is an important grain crop produced in many countries around the world. In Mexico and Central-America where domestication of corn first occurred (Mangelsdorf and others, 1964), corn grains were used for several purposes such as vegetable (fresh) and tortilla (when alkaline-cooked). Today, corn is still a major food for the people in Mexico and Central America. Corn is also popular in the Southern United States mainly as a snack. Today, the United States produces about 40% of the world's corn crop (Wisner and Baldwin, 2003). Also, corn is the third largest cereal crop in the world and is a major source of energy, protein, and other nutrients for both human and livestock (FAO, 1992). Corn contains 7–13% proteins; however, the quality of maize proteins is poor, because they are deficient in the essential amino acids lysine and tryptophan (Bressani, 1990; Paredes-Lopez and others, 2000).

Ways in which lysine might benefit human and animal nutrition have been thoroughly studied by numerous researchers including Mert and others (1964); Yau and others (1999). Nutritionists have, in addition, expressed an interest in learning how much of the original protein quality present in maize grains is maintained in typical products such as tortilla, arepas, porridges, etc. that serve as staple foods in many developing countries (Rooney and Suhendro, 2001).

Due to the nutritional importance of maize, significant efforts have been made to improve its protein quality. Mertz and others (1964) showed that the opaque-2 gene of maize significantly increases lysine concentration. Unfortunately, this gene is associated with reduced grain yield, increased susceptibility to ear rot, soft floury endosperm, and poor dry-milling properties. Because of these undesirable properties, the high-lysine maize was never successfully grown in large acreages. However, plant breeders and biochemists at the International Maize and Wheat Improvement Center (CIMMyT) in Mexico have developed nutritionally improved hard-endosperm lines called quality protein maize (QPM) (NRC, 1988). These lines have good agronomic and processing properties with improved lysine and tryptophan content and can be processed into high quality tortilla and tortilla chips (Sproule and others 1988; Bockholt and Rooney, 1992).

In addition, CIMMyT and the National Research Institute for Forestry, Agriculture, and Livestock (INIFAP) have successfully developed 26 new cultivars and hybrids of QPM mainly for tropical and subtropical regions, that are similar in yield and other agronomic properties to normal maize and these are being introduce into commercial production (INIFAP, 1999).

Corn tortillas supply 37% of the calcium requirement for adults (Serna-Saldivar and others, 1991). However, people consuming non-lime cooked grain (Colombia, Venezuela and some countries in Africa) obtain less that 1% of their recommended daily requirements from these foods. Braham and Bressani (1966) reported high bioavailability of calcium in corn tortillas and that L-lysine in the tortillas increases absorption and retention of calcium. Later, Poneros and Erdman (1988) reported the high bioavailability of calcium in rats fed with corn tortilla prepared by the traditional method of nixtamalization. These researchers found more calcium absorption and retention in rats fed with tortillas than in rats fed with raw corn. These reports were further supported by Gómez-Aldalpa and others (1996), in their study on evaluation of the nutritional quality of tortillas made from two samples of instant corn flour prepared with 0.15 and 0.25% calcium hydroxide, processed either by extrusion or by the traditional nixtamalization process. Both raw corn and tortillas made from instant whole corn flours prepared by extrusion had higher Protein Efficiency Ratio (PER) and Net Protein Utilization (NPU) values ($p<0.05$) than tortillas prepared from the traditional nixtamalization process.

Food and industrial uses of maize (Zea mays L.) grain are an important component of United States agriculture, representing approximately 20% of maize production (Anonymous 1994). To date, there are many other uses for corn grains and its derivatives including its use for animal feed, oil extraction, paper, starch extraction, corn flakes, etc (Bebeli and Smith, 2004). Products from maize wet-milling, particularly those derived from starch, comprise the largest single non-feed use.

2.2 Corn Grain and Anatomical Composition

2.2.1 Corn Grain

Major parts of a corn grain include endosperm (hard and soft), germ, pericarp, and tip (Figure 2.1). Corn grains are caryopsis, a peculiar type of botanical structure in which the ovary wall is fused with the seed coat, making it difficult to separate the two (Gengenbach, 1977). Grain quality assessments have traditionally been largely based on kernel soundness, broken kernels, and an absence of extraneous material and mycotoxins, which are important to all end-uses. In addition, processors and breeding programs rely on numerous empirical tests to identify desirable physical and chemical kernel traits that subjectively predict processing characteristics (Shandera and others, 1997). Test weight, a measure of bulk density, is a rapid method widely used in grain handling and processing.

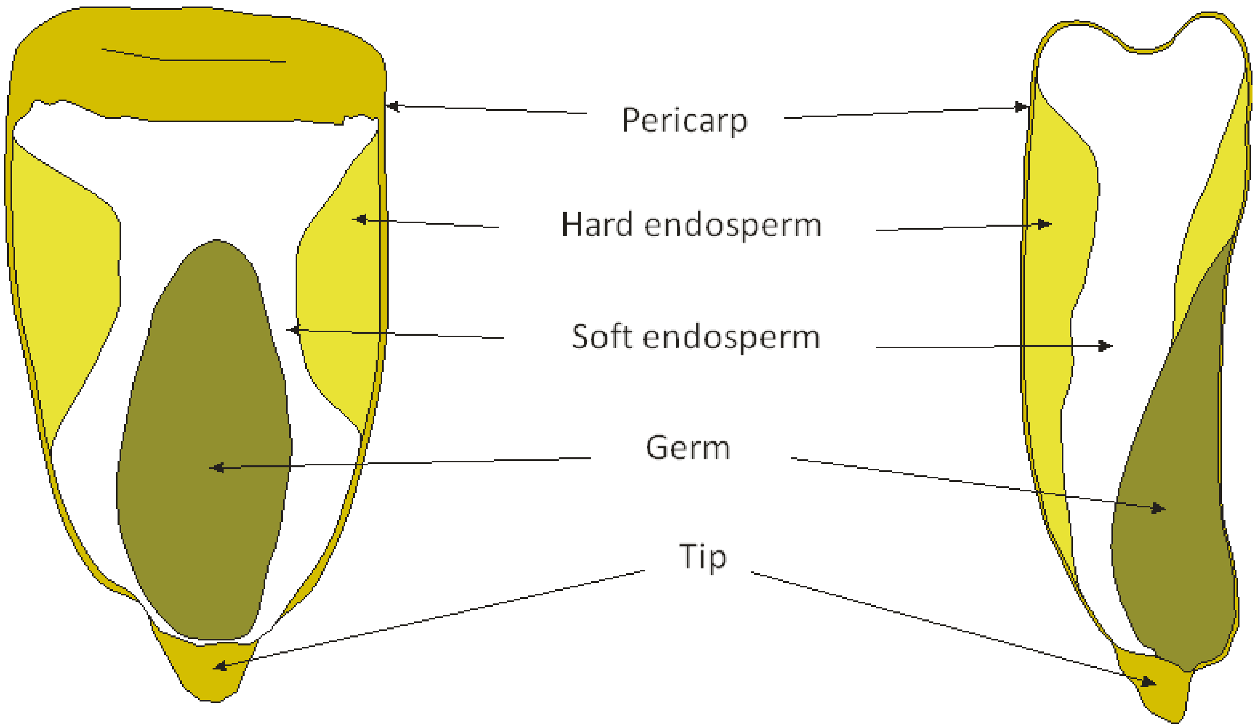

Figure 2.1 - Corn kernel structure. Adapted from Rooney and Suhendro (2001)

2.2.2 Pericarp

The pericarp of corn kernel is a maternal tissue which forms an external layer covering the corn grain. It represents about 5-8% of the dry weight of the grain and its thickness is variable among different corn hybrids and/or varieties (Tracy and Schmidt, 1987). It is mainly composed of ash, fiber and oil (Rooney and Suhendro, 2001). A single layer of cells that is usually considered as part of the pericarp is the aleurone. Aleurone, contains oil, proteins, minerals, ash, vitamins, and enzymes. Pigments of blue and red corn grains are located in this layer. In white and yellow colored grains, this layer does not contribute to the color of the grain

(Ford, 2000). The main functions of the pericarp are to protect the seed from insects or undesirable microorganisms and to serve as a physical barrier in resisting penetration of water to the grain. However, the pericap also provides the grain with semi permeable properties which are very useful in storage and processing of the grain. A broken pericarp is considered as an undesirable grain condition because this allows moisture to be readily absorbed by grain (Wang, 1994). Broken pericarps in corn tortilla processing cause inconsistent quality in the final product and loses in soluble solids resulting in a reduction on the masa yield.

2.2.3 Endosperm

According to Watson (1987), endosperm represents about 82-84% of the dry kernel weight. Starch granules are packed together within a protein matrix of the endosperm elongate cells. Endosperm is classified in two types: hard (horny) and soft (floury). Soft endosperm is opaque due to small air pockets surrounding the starch granules that are a result of protein matrix shrinking during drying (Duvick, 1961) and cause light refraction. Soft endosperm is usually surrounded by hard endosperm although in some kernels part of soft endosperm is very close to the pericarp, particularly in the opposite side to the grain tip wherein the soft endosperm seems to be accumulated more than in the center of the grain. The cells of hard endosperm are smaller than those of the soft endosperm and starch granules are immersed in a thicker protein matrix. Hard endosperm also differs from soft endosperm in the thickness of the subaleurone layer and protein components (Christianson and others, 1969). There are kernels, such as pop corn, whose soft endosperm is minimal and also there are other corn varieties in whose kernels hard endosperm almost does not exist (high-lysine flour corn). The relative amounts of hard and soft endosperm have effects on the density, transparency, cooking characteristics as well as on the potential of particular cultivars for use in different types of corn processing such as wet milling, dry milling, and alkaline-cooking.

2.2.4 Germ

Germ includes embryo and scutellum. It has been observed by Pomeranz and others (1986) that germ makes up about 11% of the kernel weight for most corn kernels independently of their size. The main function of germ is to store nutrients and hormones that are used during the initial stages of germination. Most of the oil content in the corn kernels is contained in the oil bodies or “spherosomes’ of the germ cells. According to Rooney and suhendro (2001) proper nixtamalization of corn does not remove the germ.

2.2.5 Tip (Pedicel)

Pedicel is a maternal tissue with a main function is as bridge to transport photoasimilates and nutrients from the plant for the development the grain (Kladnik and others, 2004) as well as to keep the grain attached to the cob. Part of the pedicel stays attached to the grain after the ear is shelled and becomes a died tissue composed mainly of fiber.

2.3 Corn Varieties

Depending upon the end use (home-made or commercial), parameters for corn variety selection as well as processing conditions may vary resulting in differences in the final product. There are numerous corn varieties available for producing tortilla such as flint, dent, sweet, popcorn, and waxy that exhibit different characteristics of hardness, color, density, etc. (Ford, 2000; Rooney and Suhendro, 2001). Characteristics of kernel such as protein, oil, and starch concentration, and pasting properties have been associated with different genes (Wilson and others, 2004). Maize genotypes have great genetic diversity, consisting of varieties, and single-cross, double-cross, and three-way hybrids. Genotype germplasm sources range from temperate to tropical and from dent to flint kernel characteristics (Duarte and others, 2005).

Traditionally people in rural areas used select corn varieties and adjust alkaline-cooking conditions according to the kernel characteristics in order to get the desired final tortilla product. Parameters that industry uses for corn selection are: easy cooking, hardness, adhesiveness of dough, cooking time, nutritional profile, softness, and shelf life of tortilla (Rangel-Meza and others, 2003). Therefore, commercial varieties of corn improved by breeding may not be suitable for production of home-made tortilla because they may not impart the same characteristics for variety selection used by the people in rural areas (Rangel-Meza and others, 2003). Those commercial varieties are aimed to meet the industry requirements for tortilla production.

Yield is very important to snack food and tortilla manufacturers. Corn not susceptible to overcooking is also important in the case of operator error or equipment failure which may extremely affect the masa quality. Also varieties of corn with low amounts of solids lost in cooking water and readily removable pericarp (Rooney and Suhendro, 2001) are preferred. However, these characteristics can be associated with particular kernel traits (Wilson and others, 2004).

Evaluation of different varieties of corn showed that different kernel characteristics require different cooking times in order to get a good quality masa (Billeb de Sinibaldi and Bressani, 2001). Thus, cooking time depends upon the endosperm hardness and the pericarp thickness. The effect of alkaline cooking on starch properties has been studied in different varieties of corn with different hardness levels: these starches exhibited differences in the viscosity, enthalpy, pH, and solubility (Salinas-Moreno and others, 2003).

White corn is preferred for alkaline-cooked products; however, yellow and blue varieties are also used. As mentioned earlier, the color of yellow corn is given by carotenoids synthesized in the endosperm; color in purple or blue corn is due to anthocyanins synthesized in the aleurone layer (Ford, 2000). The lack of these pigments results in the white color of white corn variety.

2.4 Corn Tortilla

Great amounts of maize tortilla are consumed daily in Mexico, Guatemala, and other Central American countries. The estimated consumption of tortilla by individual Latin American consumers is about 220 pounds per year (McKenzie and others, 2002). In Mexico alone, the daily per capita consumption of tortilla is approximately 325 g (Paredes-Lopez and Saharopulos, 1983). Tortilla supplies 70% of the caloric need and 50% of protein needs daily (Trejo-Gonzalez and others, 1982). However, the deficiency of proteins with sufficient essential amino acids is a major problem in meeting full nutritional needs particularly in some rural areas of Mexico and Central America, primarily where corn is the basic staple food.

According to the Tortilla Industry Association, the market for tortilla has increased in the United States due to an increase in the Hispanic population and the change in the consumption habits of non-Hispanic consumers. Tortilla (wheat and corn) is moving to the mainstream cuisine due to the popularity of Mexican restaurants. Available estimations have shown that Americans consumed about 75 billion tortillas in 1998 (Friedland, 2001). The market reached $5 billion dollars in 2004 (Peabody, 2004) and it is considered the fastest-growing sector in the baking industry.

2.4.1 Corn Tortilla Processing

In the 1990'S, Latin American countries have shown important progress in the industrial production of nixtamalized corn flour primarily used for tortillas, chips, tamales, as well as other typical staple foods. More than 2.7 million tons of dry nixtamalized corn flour are industrially produced in Mexico per year. For Mexicans and other Latin Americans, tortilla is their most important protein source (Waliszewski and others, 2002). However, due to low protein levels and the deficiencies of lysine and tryptophan, some studies for nixtamalized corn flour and tortilla fortification have been conducted (Waliszewski and others, 2002). In these studies, the chemical score of tortilla protein was reported to be increased by adding soybeans (Franze, 1975), cottonseed flour (Mc Pherson and Ou, 1976), cottonseed flour and soy flour (Green and others 1976), and germinated corn (Wang and Fields 1978), or by lime cooking of a whole raw corn-soybean mixture (del Valle and Perez-Villasenor, 1974) or by soybean and sesame addition (Serna-Saldivar and others 1988). Results of these studies have been used very little in practice due to the undesirable changes of sensory properties in enriched tortilla. Probably the best method of tortilla enrichment can be direct lysine and tryptophan fortification up to 83% of these amino acids levels that does not negatively change sensory properties of tortilla (Waliszewski and others 2000).

Up to date, tortilla making techniques vary from one part of the region to another (Katz and others, 1974), but all are based upon a lime-cooking process (Bressani and others, 1958; Bedolla and Rooney, 1982) known as "nixtamalization" that has been used for centuries (Figure

2.2). Alkaline-cooking of corn with lime traditionally called “nixtamalization” is the primary processing step during manufacture of several maize products such as maize chips, tortilla chips, maize tortillas, and taco shells (Milan-Carrillo, and others, 2004). Even with growing popularity of these maize products, little improvement has been made in the ancient maize processing method practiced by the Aztecs; maize for tortillas is cooked in a lime solution at 85–100 ◦C for 10–40 min and steeped for 8–16 hours (Bressani, 1990; Paredes-Lopez, 1983).

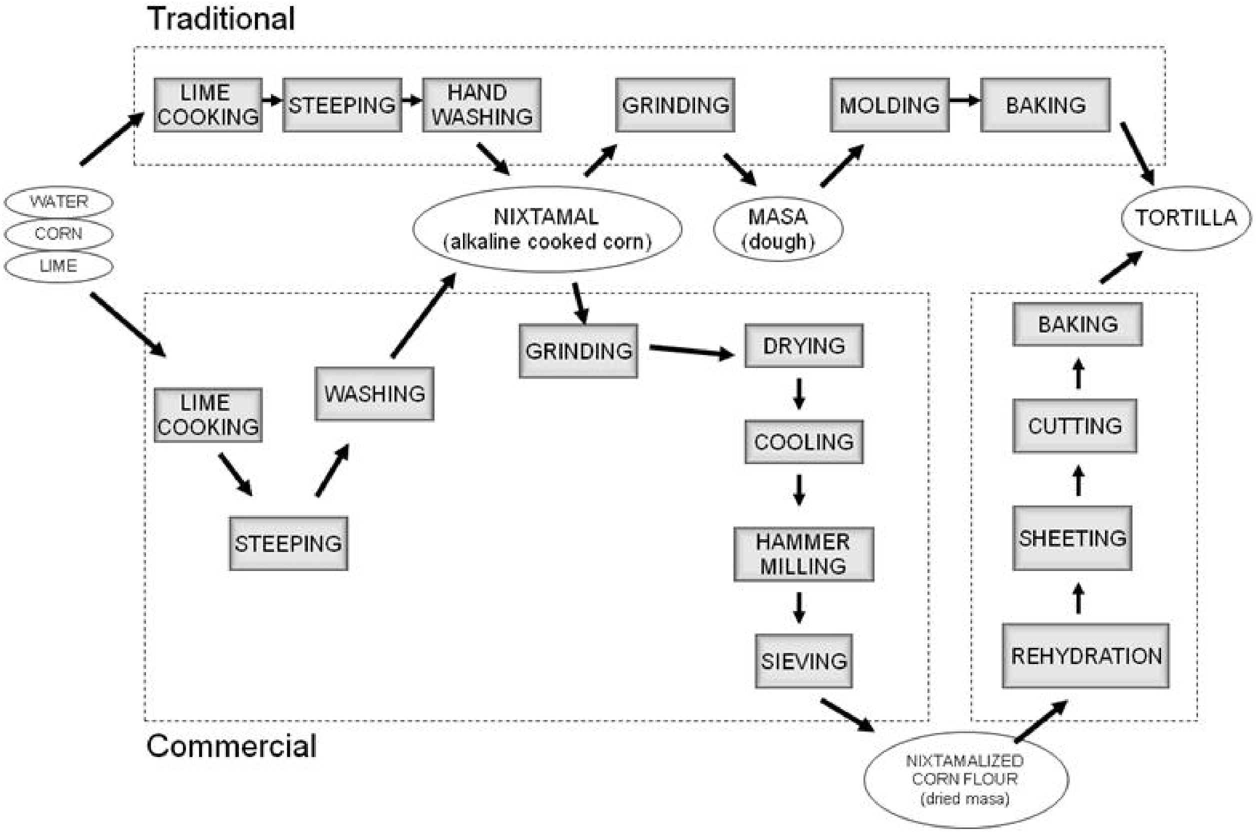

Figure 2.2- Preparation of corn tortilla by traditional vs. commercial processes. Adapted from McDonough and others, (2001).

Processors adjust nixtamalization variables such as cooking temperature, cooking time, steeping time, and lime concentration depending on maize’s physical characteristics to produce acceptable products; relationships among maize kernel characteristics, nixtamalization process conditions, and product variables have largely emerged as general observations based on experience (Serna-Saldivar and others 1993; Sahai and others 2001). Perhaps, the most significant industrial advancement has been the production of nixtamalized corn flours (NCF). The NCF has become popular because it meets standards for certain applications, reduces requirements for labor, energy, floor space, processing time, and equipment, and is convenient and simple to use. A detailed description of different ways of alkaline-cooking of corn is illustrated by McDonough and others (2001).

2.4.2 Changes in Corn during Tortilla Processing

Corn proteins are considered to have low nutritional quality, because zein, the main protein fraction in corn has a low concentration of the essential amino acids lysine and tryptophan (Mertz, 1970). According to Gomez-Adalpa and others (1996), the nixtamalization process produces changes that improve the nutritional quality of tortilla. However, the process also has its disadvantage that, during the soaking and cooking steps, some nutrients such as mineral and vitamins are lost (Martinez-Flores and others, 2002). Both, industrial and traditional processes have been studied to describe the physical and chemical changes in the corn kernels that occur during nixtamalization and tortilla production. Khan and others (1982) evaluated three different methods: traditional, industrial and pressure-cooking. Properties including softness, texture, color and overall acceptability of tortilla, processed by the traditional method under optimum conditions were superior when compared to those of tortilla produced by the commercial (industrial) and pressure-cooking methods under the same conditions.

2.4.3 Effect of Lime on Corn Tortilla Quality

Food grade lime is used for the alkaline-cooking of corn "Nixtamalization". Lime is composed mainly of $Ca(OH)_2$ (hydrated lime) or CaO (quick lime) although it may contain other minerals such as iron, sulfur, phosphorous, manganese and magnesium in very low concentrations. The concentration used for alkaline-cooking depends upon the grain weight. Tortilla manufacturers commonly use a concentration of 1% of the grain weight; however, it may vary from 0.5 to 2.0 %. Most of the lime used during alkaline cooking is lost during washing of nixtamal and only a small amount (0.2%) is retained by the grain (McDonough and others, 2001). Lime is responsible for the main changes in corn kernels and characteristics found in alkaline-cooked corn products such as removal of pericarp, bioavailability of calcium, sensory properties, and increased niacin bioavailability (Bressani and others, 1958).

Chemical changes that occur during the lime treatment of corn (Bressani and Scrimshaw, 1958), and during preparation of tortilla (Bressani and others, 1958) have been reported. More recently, an extensive review of the role of lime in the alkaline treatment of corn for tortilla preparation (Trejo-Gonzalez and others, 1982) as well as a review of tortilla production technology (Paredez-Lopez and Saharopulos, 1983) were published. Bedolla and Rooney (1982) reported a higher degree of starch gelatinization during alkaline cooking of soft endosperm maize that produced a sticky masa not suitable for tortilla making.

The main changes in corn kernels during lime cooking have been described by Gomez and others (1989). These changes include weakening of kernel cell walls to facilitate pericarp removal, degradation or solubilization of endosperm periphery, swelling of the starch granules throughout the kernel, maintenance of the granule integrity within the endosperm, and protein swelling without disruption of its position around the granules.

The effect of lime $Ca(OH)_2$ on corn starch was studied by Bryant and Hamaker, (1997). Their findings showed that starch gelatinization occurs around the kernel periphery where water is more abundant. Partial swelling of starch granules might modify their original shape and birefringence (Toro-Vazquez, and Gomez-Adalpa, 2001). At low lime concentrations (< 0.4% w/v), starch properties such as swelling, digestibility, and solubility were more affected than at lime concentration higher than 0.4 % w/v. The study suggested that binding sites for Ca++/CaOH+ produced by the high pH of the system generate Ca-starch cross links that stabilize the granules. Sahai and Jackson (2001), stated that 75% - 85% of starch granules remain undamaged and ungelatinized after the nixtmalization process and the main changes are produced during steeping. Such changes appear to play an important role in the masa functionality.

Nixtamalization induces some changes in protein composition of corn. Albumins, globulins, zeins, and glutelin-like components become insoluble after interacting with other biochemical entities catalyzed by alkaline pH and heating during tortilla processing (Ortega and others, 1986). Nutritional quality in tortillas is superior to that of raw corn because of an increased availability of niacin (Bressani and others, 1990). Total protein content increases due to loss of soluble carbohydrates during washing of the alkaline-cooked maize. Some amino acids are affected during an alkaline treatment. According to Sandersons and others (1978), losses of arginine and cystine amino acids occur during the tortilla production.

Solubilization of kernel pericarp causes changes in fiber content in corn during the nixtamalization process. Caballero-Briones and others (2000), studied these changes by x-ray diffraction, photoacuostics, and scanning electron and atomic force microscopy. Hemicellulose attack by alkaline pH and hot water during the cooking stage causes changes in crystallinity and thermal diffusivity. Morphological modifications were observed by scanning electron and atomic force microscopy.

Other changes in corn kernel composition are related to minerals due to the addition of lime during the nixtamalization process. According to Bressani and others (1990), ash, magnesium, and calcium contents in tortillas increase while a decrease in sodium and potassium was observed.

2.4.4 Quality and Sensory Properties of Tortilla and Related Products

Consumer preferences are based upon what the consumers can evaluate by using their own senses. The sensory responses to taste, smell, and texture are influenced by physiological, metabolic, and genetic variables. A combination of these factors, with attitudinal, social, and economic variables, determines the food preferences and food choices (Drewnowski, 1997).

Consumers from Mexico and Central American countries have been linked to corn tortilla centuries ago. Before tortilla production became mechanized and industrialized, corn tortillas and their quality depended upon the skills and ability of women to make them. Women acquired the ability to make a good quality tortilla after several trials. However, commercial production of tortillas has caused inconsistent quality among brands, particularly its sensory properties (Arambula-Villa and others, 2004), causing consumers to prefer the home-made style tortilla (Caballero-Briones and others, 2000).

The quality of tortilla has been evaluated from different points of view. In general, two factors are critical for tortilla preservation: microbial growth and texture (Reyes-Vega and others, 1998). Texture of tortilla depends upon several factors: raw materials, processing and handling. Extensibility (Suhendro and others, 1999), rollability (Suhendro and others, 1998b), and bending (Suhendro and others, 1998a) have been successfully used for assessing objectively the texture of tortilla. However, there are some other textural attributes of tortilla that may be evaluated by instrumental analysis such as tearing resistance, cohesiveness, and springiness (Reyes-Vega and others, 1998).

Flavor of tortilla has also been evaluated by several authors. The most used technique to evaluate the flavor of tortillas is GC-MS. This technique measures the level of volatile compounds which are closely related to the flavor of tortilla. Even though many volatile compounds have been identified (Karahadian and Johnson, 1993; Buttery and Ling, 1995), only a few are considered as key odorants (Grosch, and Schieberle, 1997). 2- aminoacetophenone is the volatile compound that has shown the highest Odor Activity Value (OAV) and probably results from tryptophane breakdown during alkaline processing.

The kernel germ has been reported to affect texture and flavor of tortilla (Martinez-Bustos and others, 2001; Vidal-Quintanar and others, 2001). Lack of oil affects adversely the flavor and texture of tortilla. The presence of oil improves tortilla firmness and chewiness.

Color of tortilla is also an important factor for consumer acceptance. In general, a white color is preferred by Latin American consumers. Previous studies have found that kernel color of raw corn can be used to predict color of alkaline-cooked food products (McDonough and others, 2002). In white and yellow kernels β-carotene is in part responsible for the color of tortillas. A yellowish color may also suggest excess of lime during cooking of white corn; however, it is not completely true when tortillas are made from yellow corn. There are also blue colored tortillas made from blue corn. This color in tortillas is often associated with organic corn products. Anthocyanins located in the aleurone layer are responsible for the color of blue tortillas (Salinas-Moreno and others, 2003b). Measurement of corn tortillas color can be objectively done by using reflectance colorimeters evaluating L*, a*, and b* parameters (Waliszewski and others, 2004).

In a study by Sproule and others (1988), the nutritional values of tortilla and chips made from quality protein maize (QPM) were compared with those made from normal maize. QPM tortilla and chips were found to have good acceptability for flavor and color profiles. It was also reported that the protein efficiency ratio and feed efficiency of QPM products were much superior to those products from normal maize.

Another attempt to improve the nutritional quality of tortillas was the development of bean-corn tortilla. This study conducted by Machado and others (2007) showed that a combination of 50% red or white beans and 50% corn masa flour had similar acceptability than corn tortillas. These authors found that the combination of bean-corn is an inexpensive, nutritious, and convenient way to improve nutritional characteristics of corn tortilla that can supply reasonable nutrient requirements for vitamins, minerals and proteins.

2.4.5 Alternative Methodologies to Alkaline-cooking of Corn

San Martin-Martinez and others (2003) proposed a selective nixtamalization process where fractions of corn grain are nixtamalized separately. The nixtamalized and non-nixtamalized fractions were blended to form a masa for producing tortillas. Their findings showed advantages of the selective nixtamalization over the traditional process such as decreased processing time and water required for the process.

Some researchers are developing alternative methods to minimize the pollution caused by the nixtamalization process. The most recent method was developed by Sahai and Jackson (2001); they utilized enzymes to nixtamalize the corn to produce corn masa flour. This experimental method was found to be effective for reducing pollution and energy consumption, but sensory properties of tortilla produced need to be improved.

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CHAPTER 3

IDENTIFYING DRIVERS FOR CONSUMER ACCEPTANCE AND PURCHASE INTENT OF CORN TORTILLA*

***Herrera-Corredor JA**, Saidu J, Khachatryan A, Prinyawiwatkul W, Carballo-Carballo A, and Zepeda-Bautista, R. 2007. Identifying Drivers for Consumer Acceptance and Purchase Intent of Corn Tortilla. Journal of Food Science. Accepted for publication. Reprinted by permission of Journal of Food Science. Appendix 2.

3.1 Introduction

Production and commercialization of food products are closely associated with the keyword “quality.” However, the way this concept is understood by manufacturers and consumers may vary depending upon their particular points of view. A simplistic definition for the quality of a food product, in a utilitarian term, stated by Peri (2005) is “fitness for consumption” which involves a whole set of requirements that sometimes are overlooked by either manufacturers or consumers. These requirements include from “the product as a food” to “the product as an object of trade.” The quality of a food product is basically under the control of the manufacturers because they have the means to determine which raw materials, processing and even package to use and to present the product to consumers. In this context, sensory quality is a means by which products and consumers can interact. Sensory perceptions, along with memory, culture, and emotions, are what consumers associate with food quality and they have a great influence in determining consumer preferences for food products. Particularly, culture plays an important role when defining authenticities of foods that are required by new international markets (Paschel 2007). A better understanding of consumer preferences and acceptability of product attributes will help reduce the gap on the concept of quality between manufacturers and consumers by matching consumer expectations of food products.

Corn tortilla is a staple food in Mexico and Central America that was developed by ancient Mesoamericans (Mckenzie 2002). Its preparation was a woman’s duty at a household level. Corn tortilla is produced by an alkaline cooking of corn, so-called nixtamalization. This alkaline treatment causes chemical and physical changes in the corn kernel, thus improving its nutritional quality, processing characteristics, and sensory properties of the final product (Bressani and others 1958; Caballero-Briones and others 2000; Wacher 2003). The use of modern machinery for commercial corn tortilla production occurred in the 1960s (Lind and Barham, 2004). Consumers can now buy industrially-produced corn tortillas that are prepared from instant masa flour. These tortillas often contain additives for improved product attributes such as texture and shelf life, but their sensory qualities are often compromised. This commercial corn tortilla production to meet supply and demand at an affordable price has different sensory attributes (such as taste and texture) from those usually found in home-made prepared corn tortilla. Such sensory attributes contribute to the overall satisfaction when consumers eat a meal with corn tortilla served as a basic carrier.

Preferences for food products are affected by different factors: learned and unlearned (Drewnowski 1997; Birch 1999). Consumers now are expecting not just simple nutrition or low prices when purchasing foods. Understanding preferences and the traditional preparation and process of the corn tortilla will help improve the commercial production processes to effectively offer acceptable products with authenticity of sensory quality to consumers.

Research to date on corn tortilla and its production process has been primarily focused on improving nutritional properties, understanding physical and chemical changes of processed corn, and decreasing the level of pollution generated during processing (Bressani and others 1990; Gomez-Adalpa and others 1999; Sahai and Jackson 2001) . In view of the above, this study was conducted to evaluate acceptance and purchase intent of corn tortillas available in the Mexican market and to determine sensory drivers of acceptance and purchase intent of the products.

3.2 Materials and Methods

3.2.1 Samples of Corn Tortilla

Ten samples of corn tortilla (Table 3.1 and Figure 3.1) were carefully selected from different places in Texcoco, the State of Mexico, Mexico. Selection criteria were (1) samples representing a wide variety of different types of corn tortilla available in the Mexican market, and (2) samples representing a wide range of desirable and undesirable sensory characteristics of corn tortilla. Eight tortilla samples used in this study belonged to one of the three types of corn tortilla available in the Mexican market (home-made, small commercial-scale, large commercial-scale), and two were lab-scale made (Table 3.1 and Figure 3.1). Since consumers were not given information about the types, sources, or history of the samples, the types or sources of tortilla used in this study should not introduce biases.

For the home-made samples, we arranged to have them prepared by a house-wife who had extensive experience in tortilla-making; they were manually prepared using the original traditional technology and made from scratch, i.e., whole-dried corn kernels. The small commercial-scale samples were obtained from tortilla stores that used a partially mechanized process, and produced using nixtamalized corn kernels (similarly used for the home-made samples), nixtamalized corn flour, or a mixture of both. The large commercial-scale sample packed in plastic bags was obtained from the local supermarket; this sample was produced by a fully mechanized industrial process, made from industrially produced nixtamalized corn flour, and contained food additives used to enhance product texture and shelf life. Experimental tortilla samples were made using our proprietary process by a research group at Colegio de Postgraduados (CP), Texcoco, the State of Mexico, Mexico. Freshly prepared samples of tortilla were obtained and kept cool one day prior to the consumer testing to ensure product freshness.

Table 3.1-Corn tortilla samples used for the consumer test

Sample Code	Sample name	Source	Sample type
H1	San Miguel	Home-made obtained from a town named San Miguel Tocuila	Home-made
H2	San Andres	Home-made obtained from a town named San Andres Rivapalacio	Home-made
H3	Tlaxcala	Home-made produced in the State of Tlaxcala	Home-made
S1	Montecillo	Produced by a tortilla store in Montecillo town	Small-scale
S2	San Bernardino	Produced by a tortilla store in San Bernardino town	Small-scale
S3	Comercial Mexicana Texcoco	Produced by a tortilla store owned by a supermarket	Small-scale
S4	Tortilla Store in Texcoco	Produced by a tortilla store in Texcoco downtown	Small-scale
L1	Milpa Real Brand	From the local supermarket (downtown of Texcoco)	Large-scale
E1	Experimental Variety cl13 x cl1	Prepared at Colegio de Postgraduados, Texcoco	Experimental
E2	Experimental Variety cl22 x cl23	Prepared at Colegio de Postgraduados, Texcoco	Experimental

As this study was focused on identifying sensory attributes driving acceptance and purchase intent of corn tortillas, the instrumental and chemical data for these ten tortillas were not presented to avoid complication of the manuscript.

Figure 3.1- Corn tortilla samples used for the consumer study. Pictures from left to right: H1, H2, and H3 (first row), S1, S2 ,S3, and S4 (second row), and L1, E1, and E2 (last row). See table 3.1 for sample descriptions.

3.2.2 Questionnaire and Consumer Testing

Untrained Mexican consumers (N = 300), who regularly consumed corn tortilla, participated in the study. Most of the participating consumers resided in the State of Mexico and Mexico City, although some of them were originally from different states. Consumer testing was conducted at the Colegio de Postgraduados located in Texcoco, the State of Mexico, Mexico. The test was conducted in a large conference type room illuminated with cool, natural, fluorescent lights. The questionnaire was written in Spanish. Consumers were briefed about the questionnaire, particularly the sensory attributes and their meanings, and sample handling during evaluation.

All samples were re-heated by hot plates immediately prior to serving. Each consumer received a set of three (one whole piece per sample) out of ten samples (Table 3.1) for evaluation, according to the balanced incomplete block design (Plan 11.5: $t=10$, $k=3$, $r=9$, $b=30$, $\lambda=2$, $E=0.74$, type II) (Cochran and Cox 1957). Each sample was evaluated in 90 repetitions. Additional test samples were given to consumers upon request. In order to reduce biases and allow the consumers to focus only on the sensory acceptability of the tortilla, no filling was provided. Water and expectoration cups were provided to consumers to use during the test to minimize any residual effects between samples. Consumers were asked to respond to a three-part questionnaire (Appendix 1). Part I: consumers were asked to provide demographic information including age, gender, country of origin, amounts of tortillas consumed each day, the type of tortilla they consume more frequently, and the most important sensory characteristic that affects acceptability of corn tortilla. These questions were asked before consumers evaluated the samples. Part II: consumers were asked to evaluate acceptability of each attribute of corn tortilla (one whole piece) in the following order: appearance, color, thickness, rollability, resistance-to-tearing, aroma, chewiness, taste and aftertaste, and overall liking. They rated the samples in the order in which they were presented using a 9-point hedonic scale (1= dislike extremely, 5= neither dislike nor like, 9= like extremely) (Peryam and Pilgrim 1957). For thickness, rollability, and resistance-to-tearing attributes, consumers were instructed to manipulate each sample by touching, rolling, and tearing each sample before assigning the scores. In Part III, the binomial (yes/no) scale was used to determine overall acceptance and purchase intent of each sample (Sae-Eaw and others 2007).

3.2.3 Statistical Data Analysis

All data were analyzed at $\alpha=0.05$ using the SAS software version 9.1.3 (SAS Inst. 2003). Frequency tables were constructed from the demographic data. Analysis of Variance (ANOVA) was used to determine significant differences among ten samples by testing if at least one sample was significantly different from other samples in terms of acceptability of each sensory attribute and overall liking. The Tukey's studentized range test was used to locate differences among the ten corn tortilla samples. Multivariate analysis of variance (MANOVA) was used to determine if significant differences existed among ten samples when correlations among all sensory attributes tested simultaneously were taken into account. Descriptive discriminant analysis (DDA) (Huberty 1994) was used to determine sensory attributes responsible for the underlying differences among ten samples. Prediction of acceptance and purchase intent was done using predictive discriminant analysis (PDA) with quadratic models for variances (Huberty 1994), and logistic regression analysis (LRA) (Allison 1999). PDA used a hit rate (%) to determine whether a sample with a specific profile of sensory acceptability ratings is classified as accepted or rejected, as well as purchased or not-purchased. This classification of samples helped to determine which sensory attributes were critical to overall acceptance or purchase intent of corn tortilla. LRA was used to model the probability of acceptance or purchase intent, taking into account all attributes tested simultaneously and their possible correlations. Finally, principal component analysis (PCA) was used to reduce dimensions and construct a product-attribute bi-plot to observe correlation among attributes and ability of attributes for discrimination and grouping.

3.3 Results and Discussion

3.3.1 Demographic and Product Information

The majority (84.95%) of participating consumers were between 25-54 years of age (Figure 3.2). About 9.4% of consumers were 18-24 years of age and 5.7% were 55 years of age or older. Approximately 70.5% were male and 29.5% were female. The majority of participating consumers (59.7%) were originally from the State of Mexico, 10.40% from Mexico City and 3.0% from the State of Veracruz. About 40.7% of the consumers reported that they consumed 1-3 tortillas per day, 25% consumed 4-6 tortillas per day, and 17.7% consumed 7-9 tortillas per day, totaling 83.4% of the participants in the consumer testing (Figure 3.3). The other 16.6% indicated that they consumed corn tortilla either “occasionally” or “more than nine tortillas per day.” Most participants (84.0%) reported that they normally consumed tortillas (the small-scale type) purchased from tortilla stores or tortillerias. About 9.7% prepared and consumed home-made tortillas, and the rest of the consumers purchased tortilla (the large-scale type) from supermarkets. Based on prior experience, consumers (without taste testing the sample) indicated taste (36.77%) and overall appearance (28.87%) as the two most important sensory attributes of corn tortilla that affect overall acceptance.

3.3.2 Differences Among Samples

ANOVA showed that consumers were able to detect significant differences ($P<0.0001$) in sensory acceptability of the ten attributes among ten tortilla samples (Table 3.2). Based on the

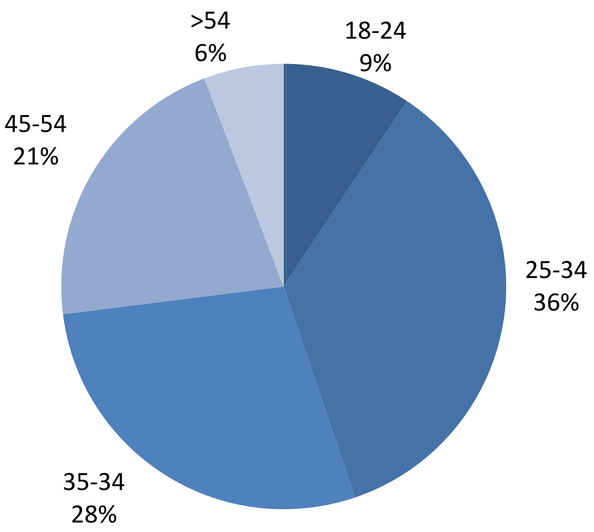

Figure 3.2- Age profile of population surveyed based on 300 consumers.

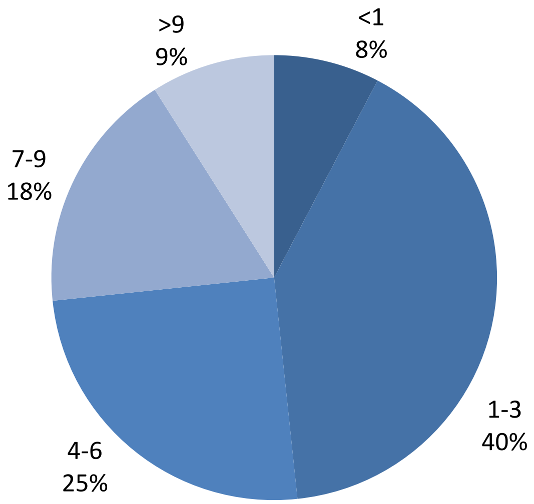

Figure 3.3 - Number of tortillas consumed per day based on 300 consumers.

overall liking scores, there were three samples (S2, H1, and H2) receiving a score higher than 6.5, while three samples (S3, H3, and E1) receiving a score lower than 5.5. The latter group generally had lower scores for rollability, chewiness, and resistance-to-tearing compared with those of the former group. The E1 sample had the lowest overall liking score (5.2), which was attributed to the low scores (<5.0) for rollability, chewiness and resistance-to-tearing. The contribution of these three sensory attributes (rollability, chewiness and resistance-to-tearing) toward overall sensory differences will be further discussed. The large-scale sample (L1) was highly rated on acceptability of rollability, resistance-to-tearing, and chewiness which can be attributed to the presence of additives such as carboxymethyl cellulose and xanthan gum added as stabilizers, and guar gum and carrageenan added as texturizers. Samples H1 and H2 (home-made) and S2 (small-scale) were highly rated for aroma, color, taste, overall liking, appearance and aftertaste.

When differences among samples were tested with all attributes (appearance, color, thickness, rollability, resistance-to-tearing, aroma, chewiness, taste, aftertaste, and overall liking) considered simultaneously and all possible correlations among attributes taken into account, MANOVA results indicated that all ten tortilla samples were significantly different based on the Wilks' Lambda statistic (F-value = 4.46 and *P*<0.0001) (Table 3.3). According to DDA, main attributes (construct) responsible for the underlying differences among ten samples were rollability with a canonical correlation of 0.791, chewiness with a canonical correlation of 0.687, and resistance-to-tearing with a canonical correlation of 0.542, all located in the first dimension (Can1, 49.68% explained variance). These three attributes (the main construct) are related to the textural property of the products, suggesting that consumers differentiated corn

Table 3.2-Mean consumer scores for sensory acceptability of ten corn tortillas[a]

Attributes	Sample[b]									
	S1	S2	S3	S4	H1	H2	H3	E1	E2	L1
Overall appearance	5.7±1.8 bc	6.7±1.7 a	5.5±1.8 bc	5.1±1.9 c	6.6±1.5 a	6.3±1.5 ab	5.4±2.1 c	4.9±2.0 c	5.7±1.7 bc	5.6±1.8 bc
Color	5.7±1.7 bc	6.5±1.6 a	5.8±1.8 abc	5.7±1.9 bc	6.4±1.6 ab	6.3±1.5 abc	6.0±1.7 abc	5.5±1.9 c	5.8±1.5 abc	5.6±1.9 c
Thickness	6.2±1.5 ab	6.8±1.4 a	5.8±1.6 bc	6.1±1.6 ab	6.1±1.8 ab	6.2±1.6 ab	5.4±2.0 bc	5.2±1.9 c	6.1±1.6 ab	6.0±1.6 ab
Rollability	5.9±1.8 abc	6.8±1.4 a	4.4±2.2 e	5.7±2.1 bcd	5.7±2.0 bcd	6.3±1.7 ab	4.9±2.1 de	4.5±2.1 e	5.4±2.0 cd	6.3±1.7 ab
Resistance-to-tearing	6.0±1.8 abc	6.8±1.4 A	5.3±2.1 cd	6.0±1.9 abc	6.2±1.9 abc	6.5±1.6 ab	5.4±2.2 cd	4.8±2.2 d	5.9±1.9 bc	6.2±1.7 abc
Aroma	6.0±1.6 bcd	6.8±1.4 a	6.0±1.7 bcd	5.7±1.9 bcde	6.5±1.6 ab	6.3±1.6 abc	5.7±1.6 cde	5.4±1.7 de	5.8±1.7 bcde	5.2±1.9 e
Chewiness	6.0±1.7 abc	6.7±1.5 a	4.9±2.1 de	5.6±2.1 bcd	6.4±1.7 ab	6.1±1.6 abc	5.0±2.0 de	4.3±2.0 e	5.4±2.0 cd	6.1±1.8 abc
Taste	6.0±1.7 ab	6.6±1.6 a	5.5±1.9 b	5.5±1.8 b	6.5±1.9 a	6.8±1.4 a	5.4±1.8 b	5.3±1.8 b	5.5±1.9 b	5.4±2.1 b
Aftertaste	5.8±1.7 abcd	6.5±1.3 a	5.7±1.6 bcd	5.1±2.0 d	6.0±1.7 abc	6.1±1.6 ab	5.4±1.9 bcd	5.3±1.8 cd	5.6±1.8 bcd	5.4±1.8 bcd
Overall liking	5.9±1.8 bc	6.7±1.6 a	5.4±1.8 c	5.5±1.7 c	6.6±1.5 ab	6.6±1.3 ab	5.4±1.9 c	5.2±1.8 c	5.8±1.7 c	5.6±1.8 c

[a] Mean of 90 replications ± standard deviation based on 300 consumers and a 9-point hedonic scale (1 = dislike extremely, 5 = neither like nor dislike, 9 = like extremely). Means within the same row followed by different letters are significantly different (P<0.05).

[b] See table 3.1 for sample descriptions.

tortillas largely by their texture. For example, the S2 sample with the highest overall liking score had significantly higher scores for these (main construct) attributes than the E1 sample with the lowest overall liking score (Table 3.2). Sunhedro and others (1998) pointed out that textural characteristics such as flexibility and rollability, in addition to flavor and color, play an important role in the quality of tortilla.

Table 3.3-Canonical structure r's describing group differences among ten corn tortilla samples[a]

Attribute	Can1	Can2	Can3
Overall appearance	0.3361	0.7279	0.2488
Color	0.1094	0.4989	0.2091
Thickness	0.3665	0.1674	0.5707
Rollability	0.7915[b]	0.2297	0.1180
Resistance-to-tearing	0.5424[b]	0.2654	0.2690
Aroma	0.1474	0.6464	0.4446
Chewiness	0.6867[b]	0.4411	0.3028
Taste	0.3077	0.6362	-0.0859
Aftertaste	0.1810	0.5231	0.2655
Overall liking	0.3504	0.7074	0.1354
Cumulative Variance Explained	49.68%	75.71%	84.42%
MANOVA Wilks' Lambda statistic	F-value = 4.46	*P*-Value = <0.0001	

[a] Based on the pooled within group variances. Can1, Can2, and Can3 refer to the pooled within canonical structure in the 1st, 2nd and 3rd canonical discriminant functions, respectively.

[b] Indicates sensory attributes that largely accounted for group differences in Can1.

3.3.3 Importance of Sensory Attributes in Predicting Acceptance and Purchase Intent

Corn tortilla exhibits several complex sensory characteristics. Consumers give importance to sensory attributes in different degrees in order to make a sound judgment about a product

(Moskowitz and Krieger 1995). To date, consumer sensory attributes that affect overall acceptance and purchase intent of corn tortilla have not been reported.

From PCA (Figure 3.4), the first two principal components (PC1 and PC2) explained 91.42% of the cumulative variance. From visual observations, three groups of samples were observed: I (S2, H1, H2), II (S1, S4, E2, L1), and III (S3, H3, E1). The attributes with higher ability for discrimination were rollability, chewiness and resistance-to-tearing, similarly identified by DDA in the 1st dimension (Can1) (Table 3.3). Aroma and color were closely correlated, suggesting possible bias caused by the sample color. This is observed when cooking corn, particularly the white variety, with a high concentration of lime that results in a yellowish final product with a bitter taste and flavor. Taste, aftertaste, overall liking, and overall appearance were positively correlated, suggesting a tendency of the consumers to rate those attributes in the same magnitude and direction; this is substantiated by the DDA results in the 2nd dimension (Can2) (Table 3.3).

In this study, the probability of the product to be accepted and purchased was modeled using LRA based on a full model considering all attributes simultaneously. The full model for overall acceptance (Table 3.4) indicates that chewiness (*P*=0.003) and overall liking (*P*<0.0001) were significantly important in determining the product acceptance. Every 1-unit increase of the chewiness score (based on a 9-point hedonic scale) will increase the probability of the product to be accepted by 27.6% (odds ratio = 1.276), and, similarly, by 91.9% for every 1-unit increase of the overall liking score (odds ratio=1.919). Purchase intent was determined mainly by overall appearance (P=0.018), rollability (P=0.043), chewiness (P=0.048), taste (P=0.000), and

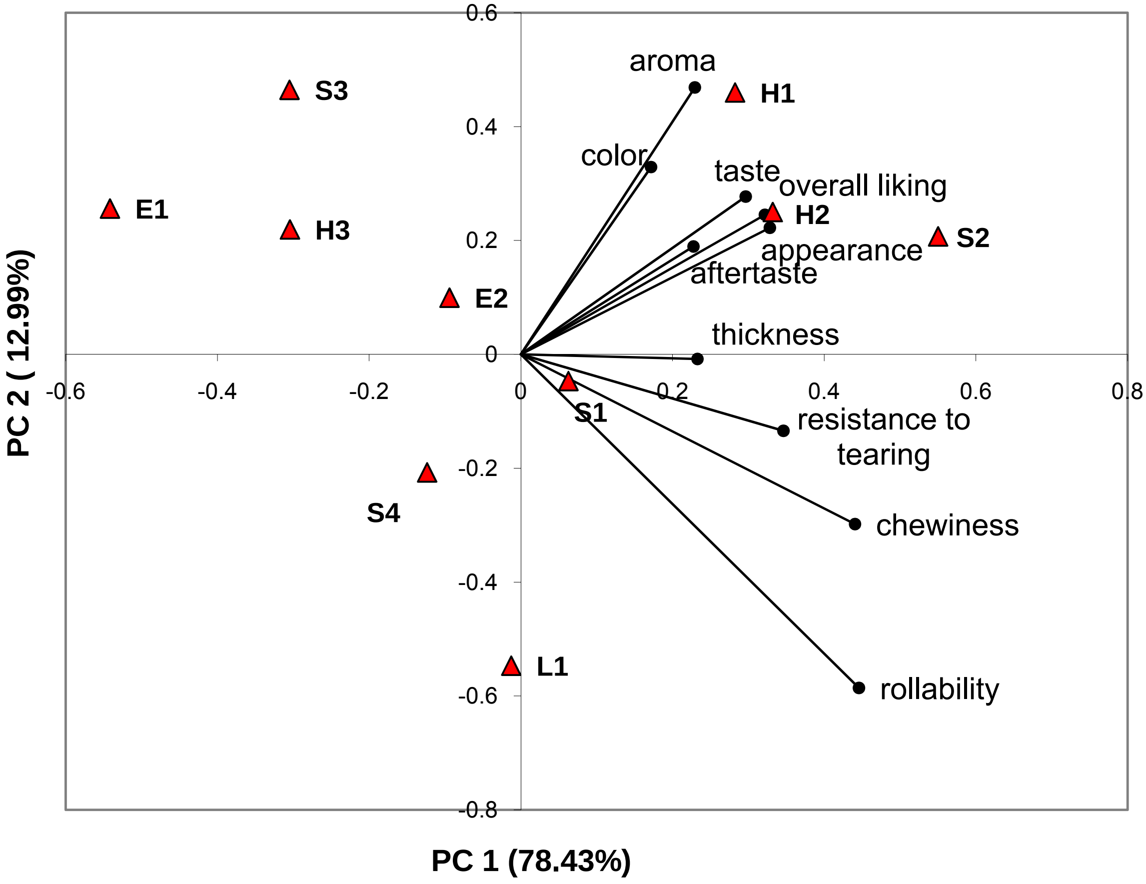

Figure 3.4-The PCA product-attribute biplot involving the principal component (PC) 1 (78.43%) and the principal component 2 (12.99%). See Table 3.1 for sample descriptions.

overall liking (*P*<0.0001). Based on the odds ratio estimates, taste was the second most important attribute determining purchase intent after overall liking. This result confirms the finding from the initial question (Part I questionnaire) about the important attributes determining product acceptance. The odds ratio estimate for taste is 1.465, meaning that every 1-unit increase of the taste acceptability score on a 9-point hedonic scale will likely increase the purchase intent of the product by 46.5%.

Table 3.4-Parameter estimates, probability, and odds ratio estimates for predicting overall acceptance and purchase intent of corn tortilla[a]

	Overall acceptance			Purchase intent		
Parameter	Estimate	Pr>χ^2	Odds Ratio	Estimate	Pr>χ^2	Odds Ratio
Overall Appearance	0.094	0.280	1.099	0.209	0.018	1.232
Color	0.061	0.508	1.062	0.062	0.500	1.064
Thickness	-0.030	0.718	0.971	-0.040	0.635	0.961
Rollability	0.102	0.170	1.108	0.149	0.043	1.160
Resistance-to-tearing	0.129	0.090	1.137	0.021	0.792	1.021
Aroma	0.007	0.940	1.007	0.025	0.789	1.025
Chewiness	0.243	0.003	1.276	0.165	0.048	1.180
Taste	0.182	0.067	1.200	0.382	0.000	1.465
Aftertaste	0.085	0.414	1.089	-0.063	0.562	0.939
Overall Liking	0.652	<.0001	1.919	0.695	<.0001	2.004

[a] Based on the logistic regression analysis (LRA), using a full model with ten sensory attributes. The analysis of maximum likelihood estimates was used to obtain parameter estimates. Parameter estimates were considered significant when probability of the Wald χ^2 value was less than 0.05.

Overall appearance (odds ratio = 1.232) was significantly important to purchase intent, but color was not, even though it is closely related to appearance. This suggests that consumers may have given less importance to color if they liked overall appearance of the product when making a purchase decision. Samples used in this study exhibited complex characteristics of appearance (e.g., black/burned areas, a not perfectly round shape, stripes across the surface caused by processing equipment, different visual texture, and different observable particle size of corn grits); these characteristics contributed to the overall appearance. Rollability (odds ratio= 1.16) and chewiness (odds ratio=1.18) are textural attributes whose ratings, if increased by 1-unit on a 9-point hedonic scale, will likely increase the purchase intent of the product by 16.0% and 18.0%, respectively. Based on LRA results (Table 3.4), we may conclude that overall acceptance of products was conditioned to lesser numbers of attributes (two) than was purchase intent (five), revealing that consumers were more demanding and scrutinizing when deciding on which product they would be willing to buy.

In this study, PDA was performed using both a full model and a single-variable model to predict overall acceptance and purchase intent. Results (Table 3.5) reveal that the full model can correctly predict product acceptance with 79.83% accuracy. Based on a single-variable model, overall liking (81.56%), chewiness (78.43%), and taste (78.22%) were attributes giving the three highest hit rates for product acceptance. Analysis of purchase intent showed a similar pattern (Table 3.5).

Table 3.5-Correct classification (% hit rate) for overall acceptance and purchase intent of corn tortilla[a]

	Hit Rate (%)	
	Overall acceptance	Purchase intent
A full model (10 variables)	79.83	79.83
A single-variable model		
Overall Appearance	73.19	74.23
Color	71.91	71.67
Thickness	72.39	70.74
Rollability	70.80	71.58
Resistance-to-tearing	74.38	71.99
Aroma	74.24	74.03
Chewiness	78.43	76.92
Taste	78.22	79.20
Aftertaste	75.06	75.43
Overall Liking	81.56	81.44

[a] Based on the predictive discriminant analysis (PDA). Hit rate (%) is the correct classification of an unknown unit (product) into a group (either accepted compared with not-accepted and/or purchased compared with not-purchased) based on a specific profile of sensory acceptability ratings.

3.4 Conclusions

This study identified sensory attributes critical to overall acceptance and purchase intent of corn tortilla products. Overall acceptance was influenced by overall liking and chewiness, while purchase intent was influenced by overall liking, taste, chewiness, rollability, and overall appearance. These attributes should be focused when developing commercial corn tortillas in an attempt to offer products with authenticity of sensory quality to the Mexican market or elsewhere.

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CHAPTER 4

IMPACT OF EDUCATION/PROFESSION ON ACCEPTANCE AND PURCHASE INTENT OF CORN TORTILLA

4.1 Introduction

The industrial revolution and globalization have altered the way we work and produce goods. The effect of this alteration can be observed even in consumer preferences for food. People migrating from rural areas to cities are focusing on work and having less time to prepare their own food. This is the particular case with corn tortilla. Corn tortilla is a staple food and is served as a basic carrier in most Mexican and Central American dishes. Preparation of this product was at household level using native varieties of corn (Rangel-Meza, 2004), is time consuming and labor intensive, including cooking corn using firewood, forming a flat disk of masa by hand and baking it on a hot clay griddle to obtain an end product. The emergence of small tortilla producing stores has made acquisition of tortilla more convenient for consumers than making their own tortilla at home. However it faces some challenges for the tortilla store owners such as increasing the product's shelf life and profits. Production of nixtamalized corn flour at large scale for tortilla production in Mexico has facilitated an effort to overcome these challenges (Milan-Carrillo and others, 2004). Today only a minimum (almost none) percentage of tortilla made in Mexico and Central America is home-made and the market of tortilla is mainly shared among tortilla stores that use whole corn, nixtamalized corn flours or a mixture of both, as raw materials to industrially produce tortillas. These new conditions have affected the production, acquisition and consumption of corn tortilla. Lind and Barham (2004) explain tortilla production and its relationship with economics, social, cultural, political and moral concerns.

Differences in diet among populations with different socioeconomic status were studied by Roos (1996) to determine how nutrient intake and food consumption varied according to education and household income in men and women. Their findings indicated differences among the type and amounts of foods consumed. In 2001, the USDA conducted a study focused on income and food expenditures cautioning that a generational effect must be considered in order to accurately depict consumption profiles (Blisard, 2001). Lifestyle is another factor that is closely related to socioeconomic status that has effects on the diet as observed by Divine and Lepisto (2005). A recent study conducted by Sloan (2006) acknowledges the generational effect showing how American tastes and preferences have changed over generations. These experiences in the USA can perhaps be extrapolated to other countries, particularly Latin America where the gap between socioeconomic groups is more evident.

The population of Mexico, among other Latin American countries, has unequal distributions of education and income (Martinez-Rizo 2002). According to the National Institute of Geography, Statistics, and Informatics (2005) (Instituto Nacional de Geografia, Estadistica e Informatica, INEGI), the population of Mexico was estimated at 103.3 million in 2005. The most populated entities were the State of Mexico, Federal District, and the State of Veracruz, concentrating 13.6%, 8.5%, and 6.9% of the total population, respectively. The levels of education vary among age groups. According to the INEGI report, educational levels varied among ages as follows: 94.2% of children from ages 6 to 14 attended school while only 52.9% of the population between ages 15-19 attended school in the same year. This information helps to understand the distribution of education among the Mexican population. The objective of this study was to determine whether education/profession of two Mexican consumer segments affected overall acceptance and purchase intent of different types of tortilla based on their sensory attributes.

4.2 Materials and Methods

4.2.1 Samples of Corn Tortilla

Ten corn tortilla samples were collected in Texcoco, State of Mexico for this study (Table 4.1). Sample selection criteria included: sufficient quantity for the consumer test (at least 90 pieces each, about 4 kg) and samples representing a wide variety of tortillas available on the Mexican market including desirable and undesirable sensory characteristics. Sources where tortilla samples were obtained included: home-made, tortilla stores, supermarkets, and experimentally prepared.

Table 4.1-Corn tortilla samples used for the consumer test

Sample Code	Sample name	Source	Sample type
S1	Montecillo	Produced by a tortilla store in Montecillo town	Small-scale
S2	San Bernardino	Produced by a tortilla store in San Bernardino town	Small-scale
S3	Comercial Mexicana Texcoco	Produced by a tortilla store owned by a supermarket	Small-scale
S4	Tortilla Store in Texcoco	Produced by a tortilla store in Texcoco downtown	Small-scale
H1	San Miguel	Home-made obtained from a town named San Miguel Tocuila	Home-made
H2	San Andres	Home-made obtained from a town named San Andres Rivapalacio	Home-made
H3	Tlaxcala	Home-made produced in the State of Tlaxcala	Home-made
E1	Experimental Variety cl13 x cl1	Prepared at Colegio de Postgraduados, Texcoco	Experimental
E2	Experimental Variety cl22 x cl23	Prepared at Colegio de Postgraduados, Texcoco	Experimental
L1	Milpa Real Brand	From the local supermarket (downtown of Texcoco)	Large-scale

4.2.2 Consumer Segments

Two consumer groups (150 each) were selected for this study, representing two education/profession groups. Criteria for consumer recruitment were: (1) 18 years and older, (2) not allergic to product ingredients such as corn and $Ca(OH)_2$, and (3) availability for the entire survey. The first group (A) consisted of faculty/graduate students with a college degree or higher. This group has more tendencies to eat away from home rather than preparing food at home. The second group (B) consisted primarily of field laborers whose duties include such field activities as cropping and husbandry, and having a salary much lower than the first group. Also, their education is usually at high school or lower. They usually bring to work food prepared at home to avoid spending money at restaurants.

4.2.3 Consumer Testing and Questionnaire

Consumer testing was conducted at the Colegio de Postgraduados located 4 kilometers from Texcoco, State of Mexico, Mexico. Consumers were presented with a Spanish-written questionnaire and briefed about the different sections, particularly the meanings of the sensory attributes they were required to evaluate. To emulate regular serving conditions, samples were reheated and served hot. Following the balanced incomplete block design, (Plan 11.5: $t=10$, $k=3$, $r=9$, $b=30$, $\lambda=2$, $E=0.74$, type II) (Cochran and Cox 1957), each consumer evaluated a set of three (one whole piece per sample) out of ten samples. Each sample was evaluated in 45 repetitions. In order to reduce biases and allow the consumer to focus on the sensory acceptability of the tortilla, no filling was provided. The questionnaire was organized in three parts as follows. Part I: questions that provided demographic information on age and gender. Part II: acceptance questions in which consumers were asked to evaluate the acceptability of corn tortilla (one whole piece) in terms of appearance, color, thickness, rollability, resistance-to-tearing, aroma, chewiness, taste and aftertaste, and overall liking. Samples were rated in the order in which they were presented using a 9-point hedonic scale in which 1= dislike extremely, 5= neither dislike nor like, 9= like extremely (Peryam and Pilgrim 1957). Part III: question based on a binomial (yes/no) scale used to determine overall acceptance and purchase intent of each sample (Sae-Eaw and others 2007). Water and expectoration cups were provided to consumers to use during the test no minimize any residual effects between samples.

4.2.4 Statistical Data Analysis

Data obtained from the surveys were analyzed at α = 0.05 using the SAS software, version 9.1.3, service pack 3 (SAS Inst. 2003). Demographic data were analyzed and presented using frequency tables for each consumer group. Determination of significant differences among samples, groups, and their interaction was done by Analysis of Variance (ANOVA proc mixed) using acceptability ratings of sample attributes individually. Differences among the acceptability of each attribute of the ten samples of tortilla were located by the Tukey's studentized range test. Proc GENMOD was performed to evaluate overall and individual sample differences on acceptance and purchase intent among the two groups. Multivariate analysis of variance (MANOVA) was conducted by education/profession group to test for significant differences among ten samples using all ten attributes simultaneously. Underlying sensory attributes responsible for the overall differences among the ten samples were determined by descriptive discriminant analysis (DDA) (Huberty 1994) on each consumer group. Acceptance and purchase intent for each group were predicted using two different approaches: predictive discriminant analysis (PDA) (Huberty 1994), and logistic regression (LRA) (Tepper 1997, Allison

1999, Meullenet and others 2003). Product-attribute bi-plots for each consumer group were constructed using the principal components (PCA) analysis result to elucidate information on the correlations among attributes, grouping, and discrimination ability.

4.3 Results and Discussion

4.3.1 Demographic Information

The consumer age profile was grouped as:18-24, 25-34, 35-44, 45-54, and >54 years of age. The majority of the consumers (70.47%) in group A (faculty/graduate students) were between the ages 25-34 (78.32%) and 35-44 (22.15%). 65.78% of consumers in group B (field laborers) were between the ages 35-44 (34.22%) and 45-54 (31.56%). The age profile indicates that group A was composed of more younger people than group B. Gender distribution within groups was similar with 68.46% male and 31.54% female in group A; and 72.48 % male and 27.52% female in group B.

The number of pieces of corn tortilla consumed on a regular basis was recorded as <1, 1-3, 4-6, 7-9, and >9 pieces of tortilla per day. 80.01% of consumers in group A reported eating 1-3 (46.67%), 4-6 (20.67%), and 7-9 (12.67%) tortillas per day. Likewise, 86.67% of group B consumers reported a tortilla consumption pattern with 34.67%, 29.33%, and 22.67% respectively. These data indicated that group A consumers had a tendency to eat less numbers of tortillas per day than group B. This was likely due to a diversification of their diet as a result of income that dictated lifestyle and dietary needs. With respect to the type of tortilla consumed on a regular basis, 86.67% of group A consumers, while 81.33% of those in group B reported that they consumed small-scale commercial tortillas from tortilla stores. Only a small number of consumers (7.3% in group A, and 12% in group B) reported eating home-made tortilla, and 2.67% in group A, and 4% in group B reported they ate large-scale commercial tortilla.

4.3.2 Differences in Attribute Ratings among Samples and as Affected by Education/Profession

A list of samples with a brief description is presented in Table 4.1. Also a list of the main effects (groups, samples, and groups*sample interaction) is shown in Table 4.2. According to the ANOVA analysis (Table 4.3), ratings of overall appearance of samples were affected by both samples and groups (P= 0.0173). In group A, sample H2 had the highest mean rating (6.63) and sample S4 had the lowest (5.44). In group B, the highest mean rating (7.11) was for sample H1 and the lowest (4.4) for sample E1. The most accepted sample was different for each group; however, samples receiving the highest score were both home-made (Table 4.3). Ratings of color were only affected by sample differences (P <0.0001) with no effect of groups or groups*sample interaction. Ratings of sample thickness were influenced only by sample differences (P<0.0001) with sample S2 being the most acceptable for both groups (6.97 for group A and 6.71 for group B). Acceptability of sample rollablity was influenced by a combination of samples and groups (P=0.0005). Group A liked rollability of samples S2, S4, H2, and L1, while Group B liked rollability of samples S2, H2 and L1.

Resistance to tearing was also influenced by a combination of samples and groups. Group A most preferred resistance-to-tearing of the home-made sample H2 (6.95) while group B most preferred sample S2 (7.11). However, both groups rated the lowest score for experimental sample E1 (5.46 for group A and 4.2 for group B). For aroma, no interaction effect was observed between samples and groups but there were differences among samples and groups. Both groups preferred the aroma of the same samples (H1, H2, S1, S2, and S3) but in different degree. Overall group A had the tendency to rate aroma of samples higher than group B. Sample L1 had the lowest rating on aroma for both groups, which could be explained by the negative effect of the preservatives added to the product on its aroma. In the case of chewiness, both groups preferred sample S2 the most. Group A also preferred sample H2 while group B also preferred sample H1, both are home-made samples. No significant effect of groups was observed on the ratings of the taste acceptability and it was evident that both groups liked the taste of the home-made samples (H1 and H2) and the small-scale commercial sample S2. However, ratings of aftertaste (of samples H1, H2 and S2 again) were influenced by group preferences in addition to sample differences. The same pattern was observed for overall liking; samples H1, H2 and S2 were the most liked by both groups of consumers. These results (Tables 4.2 and 4.3) confirmed and provided more detail about the preferences for home made tortilla regardless of education/profession of consumers.

Table 4.2- Significance of main effects and their interactions for acceptability of corn tortilla attributes

Attribute	Main effect[a]		
	Education	Sample	Education*Sample
Overall Appearance	0.0455	<.0001	0.0173
Color	0.1399	<.0001	0.2149
Thickness	0.0941	<.0001	0.0662
Rollability	0.0013	<.0001	0.0005
Resistance-to-Tearing	<.0001	<.0001	0.0025
Aroma	0.0135	<.0001	0.239
Chewiness	0.0055	<.0001	0.0068
Taste	0.0831	<.0001	0.3675
Aftertaste	0.0014	<.0001	0.4399
Overall liking	0.0004	<.0001	0.0824

[a] Based on results from proc MIXED.

Table 4.3 – Mean consumer scores for sensory acceptability of ten corn tortillas[a]

		Sample[b]									
	Group[c]	S1	S2	S3	S4	H1	H2	H3	E1	E2	L1
Overall appearance	A	5.68±1.5 ab	6.57±1.9 ab	5.72±1.7 ab	5.44±1.9 b	6.22±1.5 ab	6.63±1.2 a	5.54±2.1 ab	5.53±1.7 ab	6.02±1.4 ab	5.64±1.9 ab
	B	5.71±2.0 bc	6.82±1.4 ab	5.4±1.8 cd	4.91±1.8 cd	7.11±1.2 a	5.97±1.6 abc	5.31±2.1 cd	4.4±2.1 d	5.38±1.8 cd	5.62±1.7 bc
Color	A	5.75±1.6 a	6.57±1.6 a	6.20±1.8 a	5.86±1.8 a	6.02±1.8 a	6.55±1.2 a	6.09±1.8 a	5.77±1.5 a	5.95±1.3 a	5.77±1.8 a
	B	5.66±1.7 bc	6.55±1.6 ab	5.56±1.7 bc	5.59±1.8 bc	6.90±1.2 a	6.08±1.7 abc	5.93±1.7 abc	5.26±2.0 c	5.81±1.6 abc	5.48±1.8 bc
Thickness	A	6.17±1.4 abc	6.97±1.2 a	5.95±1.7 abc	6.37±1.5 abc	5.75±1.9 bc	6.55±1.5 ab	5.93±1.9 abc	5.38±1.8 c	6.33±1.5 abc	5.86±1.8 abc
	B	6.30±1.5 a	6.71±1.5 a	5.65±1.5 ab	6±1.6 ab	6.44±1.5 a	5.97±1.6 ab	5.04±1.9 b	5.13±1.9 b	5.88±1.6 ab	6.28±1.3 a
Rollability	A	5.93±1.4 ab	6.62±1.5 a	5.00±2.2 b	6.6±1.7 a	5.73±2.0 ab	6.35±1.7 a	5.41±2 ab	4.83±2.0 b	5.72±1.8 ab	6.24±1.6 a
	B	6.04±2.0 abc	7.13±1.2 a	3.95±2.1 d	4.82±2.0 cd	5.84±2 abc	6.38±1.5 ab	4.39±2.0 d	4.17±2.0 d	5.16±2.0 bcd	6.48±1.8 a
Resistance to-tearing	A	6.32±1.4 ab	6.64±1.5 ab	5.86±2.0 ab	6.56±1.6 ab	5.93±1.8 ab	6.95±1.3 a	6.04±2.0 ab	5.46±2.0 b	6.24±1.6 ab	6.28±1.7 ab
	B	5.74±2.0 bcd	7.11±1.3 a	4.86±1.9 cde	5.52±1.9 bcd	6.46±1.8 ab	6.2±1.7 ab	4.76±2.2 de	4.2±2.1 e	5.57±2.0 bcd	6.11±1.7 abc
Aroma	A	5.95±1.6 abc	6.77±1.4 ab	6.17±1.8 abc	5.86±1.9 abc	6.33±1.4 abc	6.88±1.2 a	5.86±1.4 abc	5.74±1.5 bc	6.15±1.4 abc	5.35±1.8 c
	B	6.04±1.5 abc	6.88±1.4 a	5.83±1.5 abc	5.64±1.8 bc	6.71±1.7 ab	5.88±1.6 abc	5.54±1.8 c	5.2±1.8 c	5.56±1.8 bc	5.04±1.9 c
Chewiness	A	5.97±1.5 ab	6.66±1.5 a	5.24±2.0 bc	6.29±1.8 ab	6.06±1.7 ab	6.53±1.4 a	5.65±1.8 abc	4.64±1.9 c	5.51±1.9 abc	6.11±1.8 ab
	B	6.06±1.9 ab	6.88±1.3 a	4.66±2.0 cde	5.09±2.1 bcde	6.77±1.7 a	5.82±1.6 abc	4.46±2.0 de	3.97±2.0 e	5.42±2.1 bcd	6.09±1.8 ab
Taste	A	5.91±1.9 b	6.48±1.6 ab	5.84±1.8 b	5.55±1.9 b	6.37±1.7 ab	7.11±1.2 a	5.58±1.7 b	5.64±1.6 b	5.86±1.7 b	5.70±2.1 b
	B	6.24±1.6 abc	6.72±1.5 a	5.22±1.8 c	5.55±1.6 abc	6.66±2.1 a	6.48±1.5 ab	5.40±1.9 bc	5.08±1.9 c	5.29±2.0 bc	5.28±2.0 bc
Aftertaste	A	5.73±1.5 ab	6.70±1.2 a	5.84±1.6 ab	5.26±1.9 b	6.06±1.5 ab	6.60±1.3 a	5.63±1.7 ab	5.72±1.4 ab	5.84±1.5 ab	5.73±1.8 ab
	B	5.95±1.7 ab	6.42±1.3 a	5.56±1.5 ab	5.11±2.0 b	6.11±1.8 ab	5.68±1.6 ab	5.18±1.9 b	4.91±2.0 b	5.46±2.0 ab	5.06±1.8 b
Overall liking	A	5.84±1.5 bc	6.84±1.4 ab	5.88±1.8 bc	5.79±1.5 c	6.40±1.3 abc	6.97±1.0 a	5.68±1.8 c	5.72±1.5 c	6.20±1.3 abc	5.73±1.7 c
	B	6.02±1.9 abcd	6.68±1.7 ab	5.02±1.7 de	5.29±1.8 cde	6.86±1.5 a	6.28±1.4 abc	5.22±1.9 cde	4.77±1.9 e	5.40±1.9 cde	5.48±1.8 bcde

[a] For each group, mean ± standard deviation were based on 150 consumers and a 9-point hedonic scale (1 = dislike extremely, 5 = neither like nor dislike, 9 = like extremely). Means within the same row followed by different letters are significantly different ($P<0.05$).

[b] See Table 4.1 for sample descriptions.

[c] Groups A = Falculty/Graduate Students; B= Field Laborers.

A further analysis conducted by MANOVA using all ten attributes simultaneously (appearance, color, thickness, rollability, resistance-to-tearing, aroma, chewiness, taste, aftertaste, and overall liking) revealed that all ten samples were different in their acceptability of their attributes in both groups based on the Wilks' Lambda statistic (F-value = 2.42 and *P*<0.0001 for group A and F-value = 3.45 and *P*<0.0001 for group B) (Table 4.4). The DDA analysis showed the primary attributes underlying differences in acceptability of samples by consumers were the same in both groups: rollability with canonical correlation=0.5374 in group A and 0.8194 in group B; chewiness with canonical correlation =0.4037 in group A and 0.6696 in group B; and resistance to tearing with canonical correlation 0.3153 on group A and 0.5764 in group B. The magnitude of the canonical correlation for these discriminating attributes is higher in group B suggesting that this group (field laborers) was more discriminating while judging acceptability for samples, particularly texture-related attributes (i.e. rollability, chewiness and resistance-to-tearing). In addition, group B utilized rollability, resistance-to-tearing, and chewiness and their relationships to a greater extent, compared to group A, when differentiating the ten samples (Table 4.4).

It was previously described that differences were observed on how both groups rated acceptability of samples based on their attributes (Tables 4.3 and 4.4); however, there were also differences in the level of overall acceptance and purchase intent for particular samples between the two groups (Table 4.5). The overall level of positive acceptance (yes) for all samples combined was significantly higher (P=0.0002) in group A (73.83%) than in group B (62.16%). Significant differences in positive acceptance responses for individual samples were found only in samples S3 (group A = 68.18; group B=40.0%), E2 (group A= 80.0%; group

Table 4.4- Canonical structure r's describing group differences among ten corn tortilla samples for each consumer group [a]

	Falculty/Graduate Students			Field Laborers		
Attribute	Can1	Can2	Can3	Can1	Can2	Can3
Overall appearance	-0.0881	0.6426	0.2345	0.4422	0.7698	0.1426
Color	-0.0576	0.3195	0.4262	0.1628	0.6064	0.0205
Thickness	0.1509	0.4164	0.6640	0.3738	0.1465	0.4638
Rollability	0.5374[b]	0.6104	0.2360	0.8194[b]	0.1557	-0.1207
Resistance-to-tearing	0.3153[b]	0.4056	0.2594	0.5764[b]	0.3564	0.1901
Aroma	-0.1918	0.6245	0.4562	0.2061	0.5853	0.1392
Chewiness	0.4037[b]	0.7024	0.1747	0.6696[b]	0.4343	0.2946
Taste	-0.1364	0.7038	0.0306	0.3564	0.4897	-0.1908
Aftertaste	-0.1599	0.5512	0.2030	0.2087	0.3986	0.1324
Overall liking	-0.1175	0.7796	0.2810	0.4065	0.5986	-0.0434
Cumulative Variance Explained	0.4913	0.7061	0.8291	0.5260	0.7380	0.8601
MANOVA Wilks' Lambda statistic	F value =2.42 P-value= <.0001			F value = 3.45 P-value= <.0001		

[a] Based on the pooled within group variances. Can1, Can2, and Can3 refer to the pooled within canonical structure in the 1st, 2nd and 3rd canonical discriminant functions, respectively.
[b] Indicates sensory attributes that largely accounted for group differences in Can1.

B=59.09%), and E1 (group A=60.0%; group B=31.11%). For these samples the level of positive acceptance was always lower in group B (Table 4.5). For the other samples there were no differences in the level of acceptance (P > 0.05) between two groups.

A similar analysis conducted on positive purchase intent showed no overall difference for purchase intent between the two consumer groups. Differences in positive purchase intent for individual samples were found only in samples S3 (group A = 62.79; group B=33.33%), and E1 (group A = 56.82%; group B=31.11%). In both samples, group B (about 70%) would not purchase the products, whereas at least 56% of group A would. The explanation for this may be

Table 4.5 – Positive overall acceptance and purchase intent for all ten samples as affected by education/profession

	Positive overall acceptance (%)			Positive purchase intent (%)		
	Faculty/ Graduate Students	Field Laborers	$^{a}Pr>\chi^{2}$	Faculty/ Graduate Students	Field Laborers	$^{a}Pr>\chi^{2}$
Overall Sample	73.83	62.16	0.0002	64.63	58.45	0.0600
S1	75.56	72.73	0.7607	56.82	68.18	0.2723
S2	91.11	88.89	0.7258	82.22	88.89	0.3722
S3	68.18	40.00	0.0086	62.79	33.33	0.0065
S4	64.44	63.64	0.9367	48.89	52.38	0.7448
H1	86.36	77.78	0.2956	81.40	79.55	0.8278
H2	91.11	84.44	0.3399	88.89	82.22	0.3722
H3	57.78	39.53	0.0888	51.16	34.88	0.1293
E1	60.00	31.11	0.0067	56.82	31.11	0.0158
E2	80.00	59.09	0.0348	60.00	58.14	0.8592
L1	63.64	61.36	0.8257	56.82	54.76	0.8478

[a] Based on SAS proc GENMOD analysis and using $\alpha=0.05$

found in Table 4.3 by comparing differences among ratings for the sample attributes given by each group. For sample S3, differences in the mean score for rollability and resistance-to-tearing was at least 1.0 point on the 9-point hedonic scale. Similarly for sample E1, attributes having a difference superior to 1.0 point in the hedonic scale were overall-appearance and resistance-to-tearing.

According to the principal component analysis in the first and second dimensions, PC1 and PC2 accounted for 86.36% of the total variance in group A (Figure 4.1) and 91.93% in group B (Figure 4.2). The PCA sample-attributes bi-plots for each group showed three sets of samples with different characteristics. Group A: I (H2, S2, and H1), II (E1, S3, E2, and H3) and III (S4, L1, and S1); group B: I (H1, S2, H2, and S1), II (S3, H3, E1, S4, and E2), and III (L1). These findings show that consumers in both groups (A and B) classified samples differently, particularly group B that clearly separated sample L1 from the others. Attributes that presented high ability to discriminate among samples were rollability, chewiness, and aroma for both groups. The first two attributes identified by PCA results (rollability and chewiness) are also supported by those identified by DDA in the first dimension (Can 1- Table 4.4). Based on the angles between attributes in the bi-plot of group A; color, overall appearance, overall liking, taste, aftertaste, and aroma showed very high correlation among the attributes in contrast to the same attributes in group B. This provides another evidence that both groups perceived samples differently.

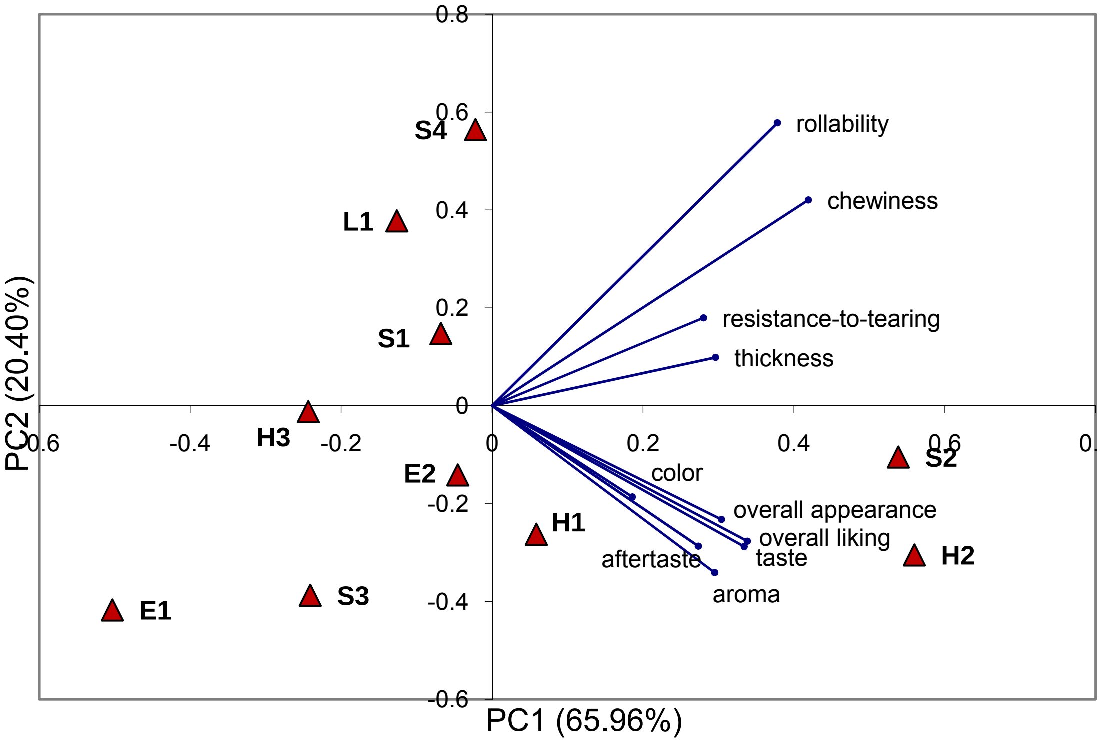

Figure 4.1- The PCA product-attribute biplot for group A (Faculty/Graduate students) involving the principal component 1 (PC1) and the principal component 2 (PC2). See Table 4.1 for sample descriptions.

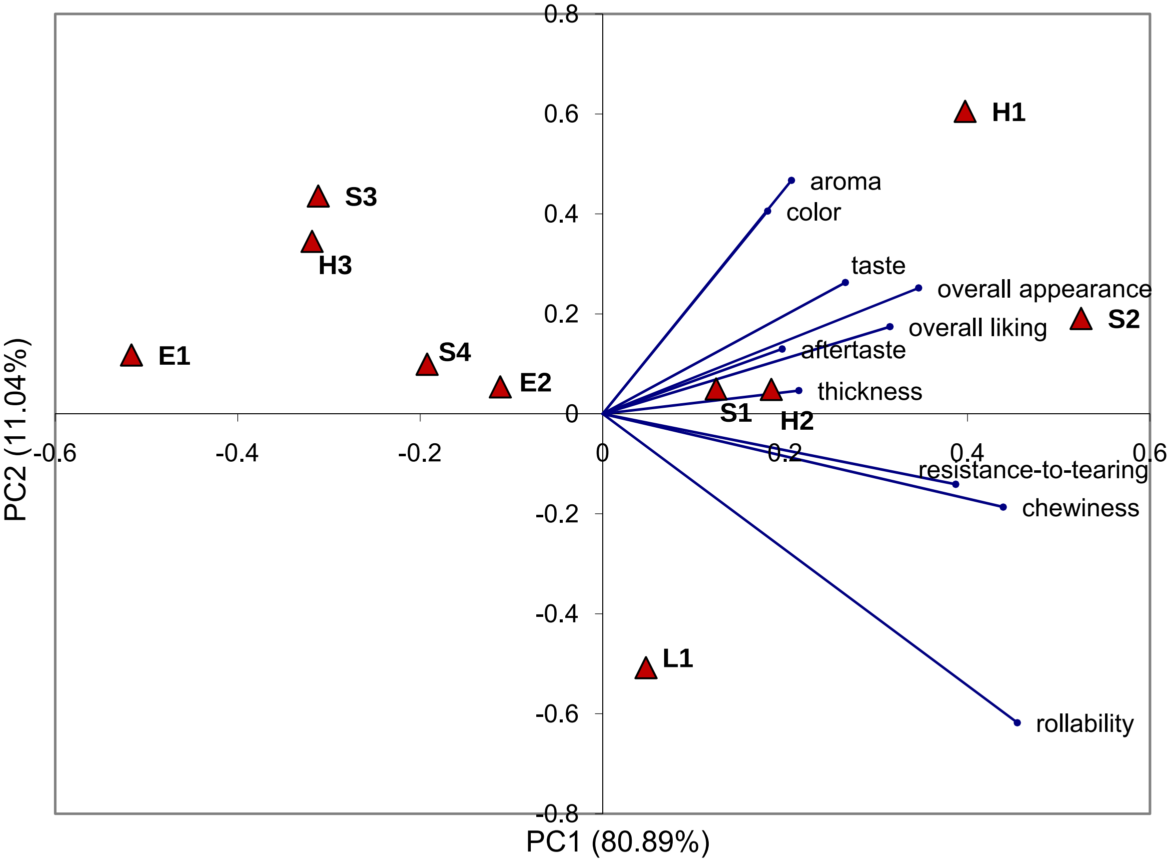

Figure 4.2-The PCA product-attribute biplot for group B (field laborers) involving the principal component 1 (PC1) and the principal component 2 (PC2). See Table 4.1 for sample descriptions.

4.3.3 Prediction of Acceptance and Purchase Intent of Tortillas as Affected by Education/Profession

Logistic regression was performed with all ten attributes simultaneously using a full model to determine probabilities of overall acceptance (Table 4.6) and purchase intent (Table 4.7). For group A consumers, overall acceptance was primarily based on overall liking (P=0.0002) of the tortilla. For group B consumers overall liking ($P < 0.0001$) and chewiness

(P=0.0108), and to a lesser extent, taste (P=0.05) influenced overall acceptance. Based on the odds ratio estimates overall acceptance is likely to increase by 120.3 % (odd ratio=2.203) in group A for every 1-point increase of the overall liking score on the hedonic scale. For group B, every one-point increase of the mean acceptability score for chewiness would increase the probability of a tortilla product being accepted by 33.8 % (odds ratio = 1.338). Acceptability will also likely increase by 27.9% (odds ratio= 1.279) for every 1-point increase in the mean taste score on the hedonic scale and by 84.9% (odds ratio= 1.849) for every 1-point increase in the overall liking score.

With respect to purchase intent, more attributes were taken into account in deciding to purchase a tortilla product. Color (P=0.0532), taste (P=0.0503), and overall liking (P=0.0002) are critical for purchase intent in group A, while overall appearance (P=0.0285), chewiness (P=0.0219), taste (P=0.0019), and overall liking (P=<.0001) were critical to group B consumers. Based on tables 4.6 and 4.7, it is obvious that group B consumers utilized more attributes than group A consumers when deciding overall acceptance and purchase intent of tortilla products. Odd ratios for group A suggest that a 1-point increase in the score of color, taste, and overall liking will likely increase the purchase intent probability by 31.1% (odds ratio=1.311), 42.0% (odds ratio=1.420) and 127.8% (odds ratio=2.278) respectively. For group B, every 1-point increase in color, chewiness, taste, and overall liking will likely increase the probability of purchase intent by 30.7% (odds ratio=1.307), 31.3% (odds ratio=1.313), 54.2% (odds ratio=1.542), and 97.2% (odds ratio=1.972), respectively.

Another approach used in this study to predict overall acceptance and purchase intent was PDA, which was performed on each consumer group. The approach was intended to

Table 4.6-Parameter estimates, probability, and odds ratio estimates for predicting overall acceptance of corn tortilla[a]

	Faculty / Graduate Students			Field Laborers		
Attribute	Estimate	$Pr>\chi^2$	Odds Ratio	Estimate	$Pr>\chi^2$	Odds Ratio
Overall Appearance	0.0283	0.8403	1.029	0.1375	0.2379	1.147
Color	0.2426	0.0852	1.275	-0.1174	0.3606	0.889
Thickness	-0.1175	0.3251	0.889	0.128	0.3042	1.137
Rollability	0.0919	0.414	1.096	0.0721	0.4914	1.075
Resistance-to-tearing	0.1774	0.1221	1.194	0.0701	0.5054	1.073
Aroma	0.1401	0.3325	1.15	-0.1075	0.3746	0.898
Chewiness	0.1993	0.1195	1.221	0.2915	0.0108	1.338
Taste	0.1133	0.5414	1.12	0.2461	0.0538	1.279
Aftertaste	0.0515	0.785	1.053	0.094	0.4678	1.099
Overall Liking	0.7899	0.0002	2.203	0.6145	<.0001	1.849

[a] Based on the logistic regression analysis (LRA), using a full model with ten sensory attributes. The analysis of maximum likelihood estimates was used to obtain parameter estimates. Parameter estimates were considered significant when probability of the Wald χ^2 value was less than 0.05.

classify each consumer's responses toward samples input into accepting/rejecting and purchasing/not purchasing. In this regard, a full model using all ten attributes simultaneously and single-variable models for each attribute were used. The rate of correct classification (% hit rate) was used to determine the attributes with higher ability for prediction (Table 4.8). The full model was able to correctly predict overall acceptance at 80.19% for group A and 77.75% for group B. Single variable models for overall liking, taste, and chewiness yielded the three highest hit rates for both groups (82.35%, 78.15%, and 76.98%, respectively, for group A and 80.77%, 78.28%, and 79.91% respectively for group B). Also, the ability of the full model to correctly predict purchase intent was 79.23% for group A and 78.96 for group B (Table 4.8).

The single-variable model for group A accurately predicted purchase intent which was driven by overall liking(81.24%), taste(79.50%), and aftertaste (76.54%), while in group B, by overall liking (81.65%), chewiness(79.68%), and taste (78.90%). These results support previous results from LRA, particularly for group B consumers, in which overall liking, chewiness and taste played critical roles for both overall acceptance and purchase intent. According to Inman (2001) flavor (taste and odor) is a sensory attribute related to the consumer's preferences that drives them to switch from one product to another. The implication of this difference in perceptions between these two groups is that group A was more likely to compromise the sensory quality for the convenience aspect of corn tortilla.

Table 4.7- Parameter estimates, probability, and odds ratio estimates for predicting purchase intent of corn tortilla[a]

	Faculty/Graduate Students			Field Laborers		
Attribute	Estimate	Pr>χ^2	Odds Ratio	Estimate	Pr>χ^2	Odds Ratio
Overall Appearance	0.1343	0.3187	1.144	0.2678	0.0285	1.307
Color	0.2706	0.0532	1.311	-0.1798	0.184	0.835
Thickness	-0.1864	0.115	0.83	0.1752	0.18	1.191
Rollability	0.1959	0.0633	1.216	0.0702	0.5107	1.073
Resistance-to-tearing	0.0935	0.4277	1.098	-0.0105	0.9233	0.99
Aroma	0.1365	0.3527	1.146	-0.0941	0.4448	0.91
Chewiness	0.0242	0.8487	1.024	0.2725	0.0219	1.313
Taste	0.3505	0.0503	1.42	0.4332	0.0019	1.542
Aftertaste	-0.0052	0.9771	0.995	-0.0882	0.5309	0.916
Overall Liking	0.8235	0.0002	2.278	0.679	<.0001	1.972

[a] Based on the logistic regression analysis (LRA), using a full model with ten sensory attributes. The analysis of maximum likelihood estimates was used to obtain parameter estimates. Parameter estimates were considered significant when probability of the Wald χ^2 value was less than 0.05.

Table 4.8 - Correct classification (% hit rate) for overall acceptance and purchase intent of corn tortilla samples by group [a]

	Hit Rate (%)			
	Overall Acceptance		Purchase intent	
Attribute	A[b]	B[b]	A[b]	B[b]
A full model (10 variables)	80.19	77.75	79.22	78.96
A single variable model				
Overall Appearance	74.94	71.42	75.79	72.64
Color	74.54	69.24	74.25	69.05
Thickness	72.52	72.24	70.54	70.93
Rollability	69.38	72.20	70.18	72.97
Resistance-to-tearing	75.62	73.12	71.91	72.05
Aroma	75.39	73.07	74.65	73.39
Chewiness	76.97	79.90	74.20	79.67
Taste	78.15	78.28	79.49	78.89
Aftertaste	75.45	74.66	76.53	74.31
Overall Liking	82.35	80.76	81.23	81.65

[a] Based on the predictive discriminant analysis (PDA). Hit rate (%) is the correct classification of an unknown unit (product) into a group (either accepted compared with not-accepted and/or purchased compared with not-purchased) based on a specific profile of sensory acceptability ratings.

[b] Groups A = Falculty/Graduate Students; B= Field Laborers.

4.4 Conclusions

In this study education/profession of consumers affected acceptance and purchase intent for a set of corn tortillas available in the Mexican market. In general, consumers preferred the same samples (H1, H2, and S2), and they used the same attributes to differentiate samples (rollability, resistance to tearing, and chewiness). However, field laborers (group B) were more discriminative and demanding as observed on the bi-plot charts (correlation among attributes and ability to discriminate) and logistic regression results (the number of attributes they took into account to judge product acceptance and purchase intent).

The group of Faculty/Graduate Students were less discriminative and demanding even though their tendency to accept and purchase products was similar to the field laborers group in terms of the attributes they focused on. According to this study, understanding how each consumer segment differently perceives about the tortilla product will give a better direction for developing value-added tortilla products that provide ethnic authenticity and expected sensory qualities.

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CHAPTER 5

CHEMICAL AND PHYSICAL CHARACTERISTICS OF CORN TORTILLAS RELATED TO ACCEPTABILITY OF SENSORY ATTRIBUTES

5.1 Introduction

As quality control plays an essential role in the food industry to keep food products in the market, assessment of food and acceptability by consumers still centers on what they can perceive about the product using their own senses (sight, hearing, taste, smell, and touch) and how they interpret those perceptions based on several social and economical factors (Kress-Rogers, 2001) and prior experiences. Today most foods are supplied offering comparable safety and nutritional value but their sensory attributes play an important role for product differentiation that has led food companies to take into account consumer's needs and preferences (Hugi and Voirol, 2001). However, due to high variability of measuring conditions and the complexity of sensations in which foods are assessed by consumers (Wright, 2006), the food industry often uses instrumental measurements related to sensory perceptions to overcome the limitations of using humans for assessment of product's characteristics. The quality expectations of consumers and its translation to quantitative quality attribute has been considered a high-priority scientific research need (Heldman, 2004). A list of chemical and physical properties of food products measured by instrumentation that can be correlated to sensory properties is presented by Williams (1994). Relating sensory preferences to instrumental measurements for specific food products such as corn tortilla will help narrow the number of attributes and measurements the food industry needs to focus on to maintain consistency of food product characteristics and meet consumer expectations.

Instrumental techniques have been applied to determine characteristics of corn tortilla, particularly texture. Techniques using instruments such as the Texture Analyzer and Instron Universal Testing machine have helped to correlate sensory data obtained from trained panelists with instrumental measurements (Suhendro and others, 1998a; Suhendro and others, 1998b; Suhendro and others, 1999; Reyes-Vega and others, 1998). The effect of oil content on the textural and flavor properties of tortilla was evaluated by Vidal-Quintanar and others (2001); they reported that a low oil content may negatively affect the tortilla flavor. Karahadian and Johnson (1993) used gas chromatography to determine volatile compounds present in the head space of corn tortillas. Buttery and Ling (1994) conducted a similar study and reported that 2-aminoacetophenone largely contributed to the aroma of tortillas (Buttery and Ling, 1995). Also color of tortillas has been correlated with instrumental measurements. Martinez-Flores and others (2006) observed that L and b parameters increased as the concentration of lime increased.

Traditionally the quality of tortillas is evaluated according to technical and economical points of view such as water absorption capacity, weight loss, and masa and tortilla yield (Mauricio-Sanchez and others, 2004). A specific determination of the quality of tortilla using consumers is, however, required when production of tortilla is aimed to supply an authentic product to international markets. The objectives of this study were to determine physical and chemical characteristics of tortillas and to correlate these characteristics to sensory acceptability of attributes of table corn tortillas rated by consumers.

5.2 Materials and Methods

5.2.1 Corn Tortilla Samples

Ten corn tortilla samples were collected in Texcoco, State of Mexico, Mexico for this study (Table 5.1). The sample selection criterion was that samples representing a wide spectrum of tortillas available in the Mexican market including desirable and undesirable sensory characteristics of tortilla. Sources/types of where tortilla samples included: prepared-at-home, tortilla stores, supermarkets, and experimentally prepared. Samples were kept frozen and vacuum packaged to preserve their sensory properties prior to instrumental analysis.

Table 5.1-Corn tortilla samples used for the consumer test

Sample Code	Sample name	Source	Sample type
H1	San Miguel	Home-made obtained from a town named San Miguel Tocuila	Home-made
H2	San Andres	Home-made obtained from a town named San Andres Rivapalacio	Home-made
H3	Tlaxcala	Home-made produced in the State of Tlaxcala	Home-made
S1	Montecillo	Produced by a tortilla store in Montecillo town	Small-scale
S2	San Bernardino	Produced by a tortilla store in San Bernardino town	Small-scale
S3	Comercial Mexicana Texcoco	Produced by a tortilla store owned by a supermarket	Small-scale
S4	Tortilla Store in Texcoco	Produced by a tortilla store in Texcoco downtown	Small-scale
L1	Milpa Real Brand	From the local supermarket (downtown of Texcoco)	Large-scale
E1	Experimental Variety cl13 x cl1	Prepared at Colegio de Postgraduados, Texcoco	Experimental
E2	Experimental Variety cl22 x cl23	Prepared at Colegio de Postgraduados, Texcoco	Experimental

5.2.2 Sensory Acceptability of Tortillas

A consumer test was conducted at the Colegio de Postgraduados located 4 kilometers from Texcoco, State of Mexico, Mexico. Consumers (N=300) were presented with a Spanish-written questionnaire and briefed about the different sections, particularly the meanings of the sensory attributes they were required to evaluate. To conduct the test as close as possible to the regular tortilla consumption, samples were reheated and served hot. Following the balanced incomplete block design, (Plan 11.5: t=10, k=3, r=9, b=30, λ=2, E=0.74, type II) (Cochran and Cox 1957), each consumer evaluated a set of three (one piece per sample) out of ten tortilla samples. According to this design, each sample was evaluated 90 times (replications). Water was provided to consumers to use during the test to minimize any residual effects between samples. Consumers were asked to evaluate acceptability of corn tortilla (one whole piece) in terms of appearance, color, thickness, rollability, resistance-to-tearing, aroma, chewiness, taste and aftertaste, and overall liking. They rated the samples in the order in which they were presented using a 9-point hedonic scale (1= dislike extremely, 5= neither dislike nor like, 9= like extremely) (Peryam and Pilgrim 1957).

5.2.3 Physical Characteristics

5.2.3.1 Weight

Weight of one whole piece of tortilla was determined using an Ohaus Precision Standard scale, model TS400S with a maximum capacity of 400 g and readability of 0.01g. (Ohaus Corporation, Flurham Park, N.J.. USA). Values were reported as a mean and standard deviation of 5 different tortillas.

5.2.3.2 Diameter

Diameter of one piece of tortilla was measured to the nearest 0.1 cm across the tortilla's center using a ruler. Data were reported as a mean and standard deviation of 5 replications.

5.2.3.3 Thickness of Tortilla

Thickness of one whole piece of tortilla was measured to the nearest 0.001 mm using a micrometer (Model 293-766; Mitutoyo, Tokyo, Japan). Five different random tortillas were measured at room temperature ($24^{o}C$) and expressed as a mean and standard deviation.

5.2.4 Proximate and Mineral Analysis

Moisture content of tortillas was measured gravimetrically in duplicate by grinding and then drying samples at $100^{o}C$ for 48 hours. Protein was analyzed by the standard method EPA 351.2 for Total Kjjeldahl Nitrogen (EPA, 1983) and using 6.25 as a factor to convert the nitrogen content to protein. Crude fat was determined by AOAC Official Method 920.39 (AOAC, 1990). Crude fiber was determined by AOAC Official Method 962.09 (AOAC, 1990). Minerals calcium, copper, iron, magnesium, manganese, phosphorous, potassium, sodium, and sulphur were determined by the method of EPA 200.7 (EPA, 2001). All analysis were done in duplicate.

5.2.5 Differential Thermal Analysis

Differential Thermal Analysis of tortilla was conducted using a DSC Q100 Calorimeter (TA Instruments Inc, New Castle, DE). DSC Pans were obtained from TA Instruments (Part no. 900825.902, T21230). Fresh tortilla was finely ground using a manual grinder equipped with iron disks, frozen to $-80^{o}C$ for 24 hr and then freeze-dried using a VirTis freeze drier (Model - Genesis 35XL, Virtis an SP Industries Company, Gardiner, NY,USA) to reduce to minimum any thermal damage of samples during drying (Sahai and Others, 1999). Dried samples were then ground using a laboratory grinder (Udy Corporation, Fort Collins Colorado, USA) to pass through a 0.5mm screen. Ten mg of ground sample were weighed using an analytical balance (Denver

Instrument, M-220D), transferred to the aluminum DSC pan, and then 20 mg of water was added. Pans were sealed using a press (TA Instruments, New Castle, Delaware). A pan with 20 mg of water was used as a reference. Pans were stored at room temperature (24 ^{o}C) for 30 min prior to the DSC analysis. The analysis was conducted by heating the pans from 30 to 120 ^{o}C at a 10^{o}C/min increment rate. Endotherms obtained were analyzed and temperatures of gelatinization at the beginning, peak, and ending were recorded. Also the transition enthalpy was calculated. Results were reported as the mean and standard deviation of three replicates.

5.2.6 Color of Tortilla

Color of tortilla was determined using a portable spectrophotometer (Model CM-508d, Minolta Camera Co. Ltd., Osaka Japan) with a 2^{o} standard observer and D_{65} illuminant. The spectrophotometer was calibrated using a Minolta certified CM-A70 white calibration cap. The sensor of the spectrophotometer was placed over an even area of each fresh tortilla, avoiding burned areas or irregular surfaces. The spectrophotometer reported the mean of five readings for each color attribute (L*, a*, and b*) every time a color measurement was taken. L* describes lightness (ranging from black to white), a* and b* describe the chromatic coordinates (ranging from –a: greenness, –b: blueness, +a: redness, +b: yellowness). Results were expressed in the CIE scale and values for the parameters L*, a*, and b* were reported as a mean and standard deviation of 5 different tortillas per sample.

5.2.7 Extensibility

Extensibility was determined by the method described by Suhendro and others (1999) using a texture analyser model TA.XT-plus (StableMicro Systems, Haslemere, UK, and Texture

Technologies Corp., Scarsdale, NY). The texture analyser was equipped with a TA-96 Tensile Test Fixture that consisted of two grips, upper and lower, attached to the moving arm and the platform respectively. The grips were checked for vertical alignment and the distance between the upper and lower grips was set to 2.0mm at the beginning of the test using a ruler as suggested by the instrument manufacturer. Each tortilla strip used for the extensibility test was obtained from one tortilla which was cut to a constant specific rectangular size of 2.5 x 4 cm^2. The strip was obtained from a uniform area of the tortilla. For the commercial samples, the strip was cut from between the lines present on the tortilla's surface caused by the oven's conveyor. The test type settings were "return to start" in a mode of tension, a test speed at 1.0 mm/s, a post-test speed at 10 mm/s, and traveling distance of 15 mm. The test was conducted at room temperature (24 ^oC).Graphs obtained were analyzed using the Texture Exponent 32, ver 2.0.01 by calculating the modulus of deformation, force required to extend the strip by 1 mm, force and work to rupture, and extension distance. Results of each parameter were expressed as a mean and standard deviation of 5 replications.

5.2.8 Rollability

Rollability was determined by the method described by Suhendro and others (1998) using a texture analyser model TA.XT-plus (StableMicro Systems, Haslemere, UK, and Texture Technologies Corp., Scarsdale, NY). The rollability fixture was custom-designed by Texture Technologies Corp. and consisted of an acrylic cylinder (dowel) (20 mm diameter) attached to an acrylic base. A piece of thread rolled to one end of the cylinder and the texture analyser arm pulled the cylinder tangentially causing the cylinder to roll. Tortillas for the test were allowed to stabilize at room temperature (24 ^oC) for 20 min and then attached to the cylinder by an edge.

The force to roll a tortilla was recorded in a tension mode and settings used for this test were: “return to start” option, a trigger force of 0.05N (5 g), a pre-test speed at 10.0 mm/s, a test speed at 3.0 mm/s, a post-test speed at 10.00 mm/s, and a distance of 50mm. Graphs obtained were analyzed using the Texture Exponent 32, ver 2.0.01 by calculating the peak force and the work to roll the tortilla (area under the curve). Results were expressed as a mean and standard deviation of 5 replications.

5.2.9 Statistical Analysis

All data were analyzed at $\alpha=0.05$ using the SAS software version 9.1.3 (SAS Inst. 2003). Analysis of Variance (ANOVA) was used to determine significant differences among ten samples by testing if at least one sample was significantly different from other samples in terms of acceptability of each sensory attribute and physical and chemical characteristics. The Tukey’s studentized range test was used to locate differences among the ten corn tortilla samples. Linear correlations among all the measurements were calculated using the Pearson correlation coefficient (SAS proc corr). Each particular sensory attribute was also analyzed for correlation with the instrumental values. The results were used to construct scatter plots to describe the correlations.

5.3 Results and Discussion

5.3.1 Differences among Sample Attributes

ANOVA showed that consumers were able to detect significant differences ($P<0.0001$) in sensory acceptability of the ten attributes among ten tortilla samples (Table 5.2). Based on the overall liking scores, there were three samples (S2, H1, and H2) receiving a score higher than

6.5, while three samples (S3, H3, and E1) receiving a score lower than 5.5. The latter group generally had lower scores for rollability, chewiness, and resistance-to-tearing compared with those of the former group. The E1 sample had the lowest overall liking score (5.25), which was attributed to the low scores (<5.0) for rollability, chewiness and resistance-to-tearing. The contribution of these three sensory attributes (rollability, chewiness and resistance-to-tearing) toward overall sensory differences will be further discussed. The large-scale sample (L1) was rated with a mean score above 6.0 on the 9-point hedonic scale for rollability, resistance-to-tearing, and chewiness which can be attributed to the presence of additives (such as carboxy-methyl-cellulose) added to improve textural properties of corn tortilla. Two home-made samples (H1 and H2) and one small-scale (S2) were highly rated for aroma, color, taste, overall liking, appearance, and aftertaste.

5.3.2 Selected Physical Properties of Tortilla

All ten tortilla samples generally showed differences among their physical properties. Weight of tortillas approximately ranged from 17 to 40 g per piece (Table 5.3). These values were similar to those reported by Suhendro and others (1998) (15.9-30.0 g) in commercial tortillas from Texas. However, in our study the home-made samples H1 and H2 had the largest weights an obvious dissimilarity from those samples from Texas. Also standard deviations were particularly low in samples L1 (0.83) and S2 (0.78) indicating was more consistency in weight due to the use of commercial machines to make tortillas.

Diameter of tortillas was between 13.0 and 17.0 cm (Table 5.3). The largest three values were found in samples S2, H1, and H2, showing the similarity in diameter of sample S2 to

Table 5.2- Mean consumer scores for sensory acceptability of ten corn tortillas[a]

Attributes	Sample[b]									
	S1	S2	S3	S4	H1	H2	H3	E1	E2	L1
Overall appearance	5.7±1.8 bc	6.7±1.7 a	5.5±1.8 bc	5.1±1.9 c	6.6±1.5 a	6.3±1.5 ab	5.4±2.1 c	4.9±2.0 c	5.7±1.7 bc	5.6±1.8 bc
Color	5.7±1.7 bc	6.5±1.6 a	5.8±1.8 abc	5.7±1.9 bc	6.4±1.6 ab	6.3±1.5 abc	6.0±1.7 abc	5.5±1.9 c	5.8±1.5 abc	5.6±1.9 c
Thickness	6.2±1.5 ab	6.8±1.4 a	5.8±1.6 bc	6.1±1.6 ab	6.1±1.8 ab	6.2±1.6 ab	5.4±2.0 bc	5.2±1.9 c	6.1±1.6 ab	6.0±1.6 ab
Rollability	5.9±1.8 abc	6.8±1.4 a	4.4±2.2 e	5.7±2.1 bcd	5.7±2.0 bcd	6.3±1.7 ab	4.9±2.1 de	4.5±2.1 e	5.4±2.0 cd	6.3±1.7 ab
Resistance-to-tearing	6.0±1.8 abc	6.8±1.4 A	5.3±2.1 cd	6.0±1.9 abc	6.2±1.9 abc	6.5±1.6 ab	5.4±2.2 cd	4.8±2.2 d	5.9±1.9 bc	6.2±1.7 abc
Aroma	6.0±1.6 bcd	6.8±1.4 a	6.0±1.7 bcd	5.7±1.9 bcde	6.5±1.6 ab	6.3±1.6 abc	5.7±1.6 cde	5.4±1.7 de	5.8±1.7 bcde	5.2±1.9 e
Chewiness	6.0±1.7 abc	6.7±1.5 a	4.9±2.1 de	5.6±2.1 bcd	6.4±1.7 ab	6.1±1.6 abc	5.0±2.0 de	4.3±2.0 e	5.4±2.0 cd	6.1±1.8 abc
Taste	6.0±1.7 ab	6.6±1.6 a	5.5±1.9 b	5.5±1.8 b	6.5±1.9 a	6.8±1.4 a	5.4±1.8 b	5.3±1.8 b	5.5±1.9 b	5.4±2.1 b
Aftertaste	5.8±1.7 abcd	6.5±1.3 a	5.7±1.6 bcd	5.1±2.0 d	6.0±1.7 abc	6.1±1.6 ab	5.4±1.9 bcd	5.3±1.8 cd	5.6±1.8 bcd	5.4±1.8 bcd
Overall liking	5.9±1.8 bc	6.7±1.6 a	5.4±1.8 c	5.5±1.7 c	6.6±1.5 ab	6.6±1.3 ab	5.4±1.9 c	5.2±1.8 c	5.8±1.7 c	5.6±1.8 c

[a] Mean of 90 replications ± standard deviation based on 300 consumers and a 9-point hedonic scale (1 = dislike extremely, 5 = neither like nor dislike, 9 = like extremely). Means within the same row followed by different letters are significantly different (P<0.05).

[b] See table 3.1 for sample descriptions.

home-made (H1 and H2) tortillas. Diameter was linear-positively correlated with weight of samples (Pearson correlation coefficient = 0.8444) as illustrated in Figure 5.1. The reason why sample S2 did not follow the same trend was due to its diameter (16.18 cm) which is relatively high (Table 5.3).

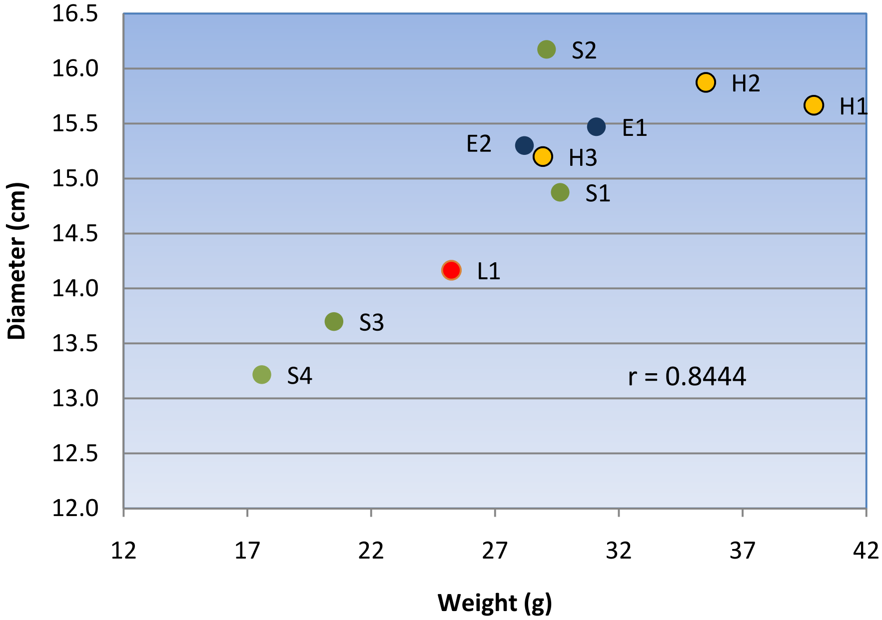

Figure 5.1 – Pearson correlation between weight and diameter of corn tortillas. Values plotted are the means of weight and diameter for each sample. Based on 5 replications.

Thickness of tortilla samples was approximately between 1.2 and 2.3 mm (Table 5.3). The highest values of thickness (2.23 mm) were found in the two home-made samples H1 and H3. Similar values of tortilla thickness were reported by Suhendro and others (1999), and Suhendro and others (1998): 1.09 – 1.85 mm and 1.22-2.15 mm, respectively. A scatter plot involving thickness and weight (Figure 5.2) shows a linear relation between thickness and weight parameters. Only sample H3 departed from the trend due to its highest thickness.

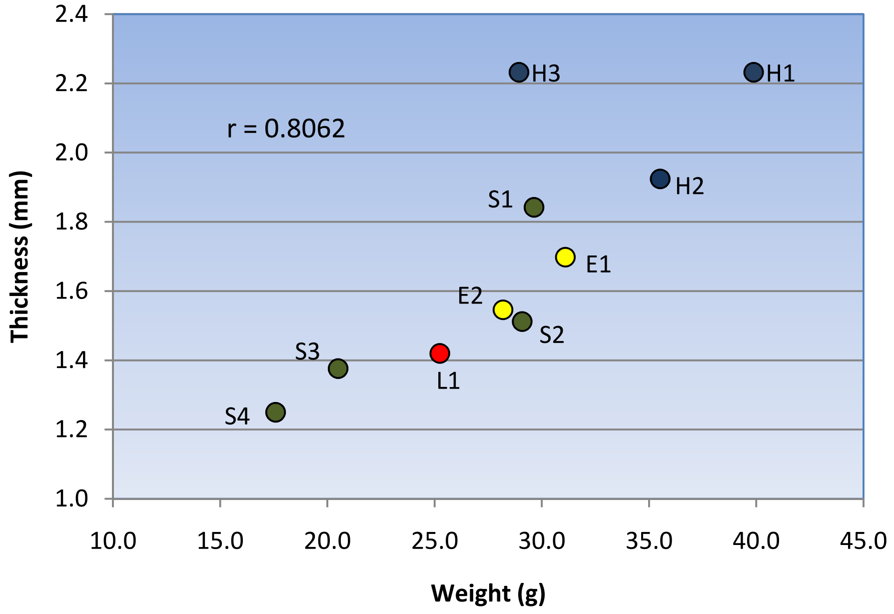

Figure 5.2 – Pearson correlation between weight and thickness of corn tortillas. Values plotted are the means of weight and diameter for each sample. Based on 5 replications.

The more accepted thickness, with a rating of at least 6.2 on the hedonic rating (Table 5.2), were observed for samples S1, H2, and S2, having an actual value of thickness between 1.5 and 1.92 mm. Correlation between these sensory acceptability of thickness and instrumental values is described in Figure 5.3, which indicates that the relation is not linear but most likely polynomial of a second order. Very thin tortilla will lose moisture and get dried faster, it thus may not be suitable to adequately hold fillings. On the other hand, a very thick tortilla would be hard to roll. Interestingly, even though experimental samples E2 and E1 had a thickness (1.55 – 1.7 mm) in this range (1.5-1.92 mm), acceptability ratings were lower than 6.2.

The thickness acceptability values may be influenced and biased by other sensory attributes such as rollability and resistance-to-tearing that were evaluated by the consumer at about the same time they evaluated the thickness of tortilla. Both H1 and H3 samples had the same thickness (2.23 mm); however, the H3 sample received much lower acceptability score for thickness (5.4) than that (6.1) of the H1 sample. This may have been influences by acceptability scores for rollability (5.7 for H1 and 4.9 for H3) and resistance-to-tearing (6.2 for H1 and 5.4 for H3). Another case is the S1 and E1 samples, both having similar thickness (1.7-1.84 mm); however, E1 was much less acceptable (6.2 vs. 5.2). This may have been influenced by rollability and resistance-to-tearing acceptabilities (Table 5.2). The descriptive discriminant analysis (data not shown) indicated that rollability and resistance-to-tearing are closely correlated.

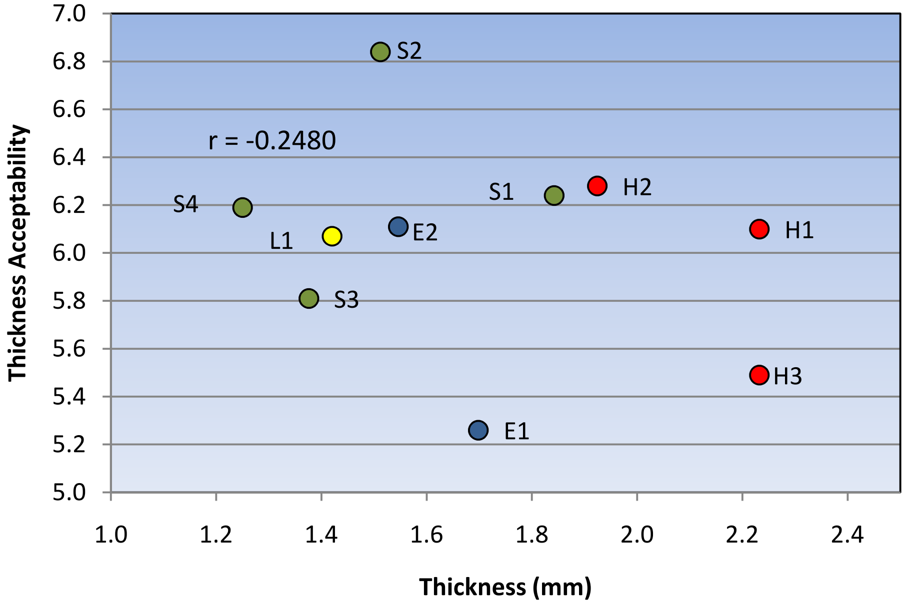

Figure 5.3 – A scatter plot involving instrumental and sensory thickness of corn tortillas. Values plotted are mean values of thickness acceptability (Table 5.2) and actual thickness (Table 5.3) in their respective scales.

In general, consumers had the tendency to like large-sized tortillas. Sample S2 with the largest mean diameter (16.18 mm) had the highest overall appearance score (6.7 in the hedonic scale) (Table 5.2). Also samples H1 and H2 with a weight of 39.89 g and 35.51 g, respectively, and a diameter of 15.67 cm and 15.88 cm respectively, both had mean overall appearance scores of 6.3 - 6.6. All three samples (S2, H1, and H2) had the overall liking score of 6.6 – 6.7; this may also imply that consumers preferred large sized tortilla. These findings are similar to those by Krause and others (1992) who reported differences in size between tortillas prepared for sale and tortillas prepared for home consumption.

Table 5.3- Selected physical properties of ten tortilla Samples [a]

Sample [b]	Weight (g)	Diameter (cm)	Thickness (mm)
S1	29.63±0.97 c	14.88±0.15 dc	1.84±0.08 b
S2	29.08±0.78 c	16.18±0.28 a	1.51±0.04 cde
S3	20.50±1.89 e	13.70±0.38ef	1.38±0.08 de
S4	17.58±1.51 e	13.22±0.43 f	1.25±0.04 e
H1	39.87±1.53 a	15.67±0.70 abc	2.23±0.25 a
H2	35.51±1.52 b	15.88±0.38 ab	1.92±0.15 b
H3	28.93±1.84 c	15.20±0.25 bc	2.23±0.25 a
E1	31.09±2.24 c	15.47±0.42 abc	1.70±0.12 bc
E2	28.19±1.54 cd	15.30±0.49 bc	1.55±0.06 dc
L1	25.24±0.83 d	14.17±0.21 de	1.42±0.02 cde

[a] Numbers with the same letters in each column are not significantly different at α=0.05.

[b] See table 5.1 for sample descriptions

5.3.3 Proximate Analysis of Corn tortilla

Moisture of samples ranged between 35.0 and 47.0% with sample H3 being the one with the lowest moisture content (35.6 %) and samples L1 and H1 being the ones with the two highest (46.97 and 46.45 % respectively) (Table 5.4). These values are consistent with the values (38.2-47.1 %) compiled and reported by McDonough and others (2001) for samples from different sources. The effect of moisture can be observed primarily on the textural properties of tortilla, particularly in the modulus of deformation measured in the extensibility test. This will be further discussed in detail. The correlation between moisture and modulus of deformation was negative (Pearson correlation coefficient = -0.8214), meaning that as the moisture increased, the modulus of deformation decreased and vice versa. This suggests that higher water contents may allow the tortilla to stretch to a longer distance without breaking.

All ten tortillas had the protein content between 6.45 and 9.50 % (Table 5.4). However, there were no statistical differences among samples. These values were lower than those reported by McDonough and others (2001) in the literature (9.5-11.2 %). Also the crude fibre content of samples was found between 1.00 and 2.07% (Table 5.4) showing no statistical differences but being similar to those (1.1 – 2.4 %) also reported by McDonough and others (2001).

Table 5.4 – Proximate analysis (%) of ten tortilla samples (dry weight basis)[a]

Sample [b]	Protein	Crude Fat	Crude Fibre	Moisture
S1	8.60±1.13 a	3.14±0.16 a	1.59±0.37 a	40.67±0.07 e
S2	6.45±1.63 a	2.74±0.10 abc	1.72±0.04 a	37.13±0.04 h
S3	7.20±1.70 a	2.45±0.03 abc	1.03±0.20 a	39.49±0.15 f
S4	8.15±0.78 a	2.13±0.27 c	1.18±0.33 a	45.46±0.02 c
H1	7.15±0.49 a	2.68±0.28 abc	1.24±0.54 a	46.45±0.12 b
H2	9.50±0.28 a	2.98±0.29 ab	2.07±0.39 a	43.07±0.11 d
H3	8.45±1.63 a	2.72±0.04 abc	1.42±0.08 a	35.60±0.20 i
E1	7.85±1.06 a	2.69±0.17 abc	1.28±0.20 a	38.98±0.11 g
E2	8.70±1.41 a	2.47±0.38 abc	1.90±0.49 a	39.75±0.05 f
L1	7.45±1.06 a	2.20±0.06 bc	1.00±0.36 a	46.97±0.07 a

[a] Numbers with the same letters in each column are not significantly different at α=0.05.
[b] See Table 5.1 for sample description.

Crude fat content varied from 2.13 to 3.14% which are in the range compiled and reported by McDonough and others (2001) for ether extract (1.5 – 4.4 %). The effect of the fat content on flavor of tortilla has been reported by Vidal-Quintanar and others (2001). They also reported the effect of oil content on firmness and chewiness but not on rollability of tortilla. Also the flavor of tortilla was reported to be negatively affected by a low fat content. In this study we found no correlation of the crude fat content with the sensory acceptability of chewiness or rollability of tortilla (data not shown). However, there was a slight tendency of taste acceptability to be increased as the crude fat content increased (Figure 5.4). Samples H1, S2, and H2, having the three highest taste acceptability mean scores, also had a high crude fat content. In contrast, samples S4, L1, S3, and E2 with the low acceptability mean scores had low crude fat content. Only sample S1 did not follow this trend suggesting the taste acceptability cannot be explained by only crude fat content but by a combination with other factors such as aroma.

5.3.4 Mineral Content in Tortilla Samples

According to ANOVA, samples were generally different in mineral ($P<0.05$) content (Table 5.5). Only copper did not show differences among samples ($P=0.914$). All mineral contents in this study were compared to values reported for tortilla by McDonough and others (2001). Calcium content varied in a range of 910 to 7080 ppm (0.091 – 0.708 %). The lowest value of this range observed for sample L1 and S3 was comparable to the value (928 ppm) reported previously by McDonough and others (2001). The calcium content in the majority of the samples was 3 to 5 times higher and the highest value (sample S4) was about seven times higher than the (928 ppm) reported value of McDonough and Others (2001). Sahai and others (2001) suggested that calcium content in tortillas depends upon cooking time, steeping time, and kernel hardness. They also mentioned that large manufacturers of nixtamalized corn flours

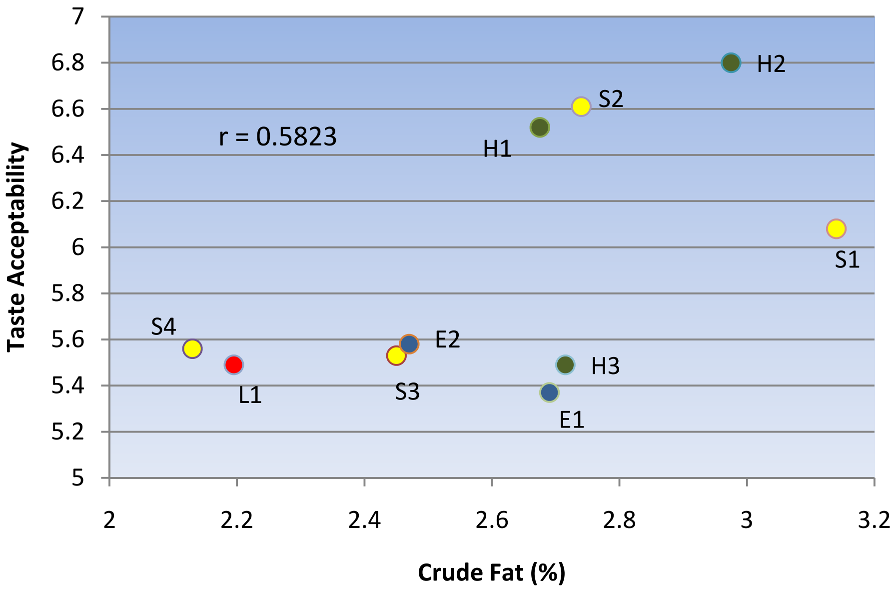

Figure 5.4 – A scatter plot involving crude fat content and taste acceptability of tortillas. Values plotted are mean values of taste acceptability (Table 5.2) and crude fat content (Table 5.4).

use shorter cooking and steeping times than small tortilla manufacturers. These differences in processing conditions may explain the differences in calcium content found among the ten tortilla samples.

Iron content varied from 29 (sample H2) to 80.85 ppm (sample S3). These values were superior to the 25 ppm reported by McDonough and others (2001). There was no specific correlation pattern observed between iron content and the type of tortilla. Magnesium varied from 1060 (sample S3) to 1405 ppm(sample E2). These values were found to be higher to the value (697 ppm) reported by McDonough and others (2001). Manganese content among samples varied from 5.23 (sample S2) to 7.29 (sample H2). Phosphorous content in samples varied from 2630 ppm (sample S3) to 3505 ppm (sample H2). These values are also higher to those (1130 to 1330 ppm) reported by Bresanni and others (1958) and to that (1626 ppm)

Table 5.5 - Mineral content in ten tortilla samples [a]

Sample[b]	Calcium %	Copper ppm	Iron ppm	Magnessium %	Manganesse ppm	Phosphorous %	Potassium %	Sodium %	Sulphur %
S1	0.36±0.01 c	20.35±9.97 a	56.70±30.12 ab	0.13±0 ab	5.83±0.39 dc	0.34±0.01 ab	0.30±0.01 dbc	0.017±0.00 bc	0.13± ab
S2	0.31±0.001 cde	11.74±2.78 a	35.70±0 ab	0.11±0 ced	5.23±0.14 d	0.27±0 ed	0.27±0 de	0.017±0.00 bc	0.09± f
S3	0.10±0.001 f	31.90±30.55 a	80.85±11.53 a	0.11±0 e	5.99±0.05 dbc	0.26±0 e	0.30±0.01 dbce	0.033±0.00 b	0.11± dec
S4	0.71±0.05 a	13.96±10.24 a	64.60±2.55 ab	0.11±0.01 ed	6.09±0.26 dbc	0.26±0.02 e	0.29±0.02 dce	0.032±0.00 b	0.11± de
H1	0.50±0.03 b	22.35±14.64 a	39.50±2.26 ab	0.12±0 ced	6.55±0.35 abc	0.30±0.01 cd	0.26±0.01 e	0.018±0.01 bc	0.10± e
H2	0.33±0.001 cd	29.66±30.18 a	29.00±1.7 b	0.12±0 cbd	7.29±0.4 a	0.36±0 a	0.34±0 ab	0.011±0.00 c	0.11± dc
H3	0.44±0.01 b	26.95±23.12 a	35.65±3.89 ab	0.13±0 cb	6.96±0.15 ab	0.32±0.01 cb	0.28±0.01 dce	0.020±0.00 bc	0.12± dbc
E1	0.28±0.001 de	10.45±0.07 a	41.80±14.85 ab	0.13±0 cb	6.36±0.18 abc	0.34±0 ab	0.31±0 abc	0.015±0.01 c	0.11± dec
E2	0.24±0.001 e	14.22±10.01 a	47.65±4.88 ab	0.14±0 a	6.19±0.04 dbc	0.33±0 b	0.30±0 dbce	0.014±0.01 c	0.12± abc
L1	0.09±0.001 f	18.05±8.41 a	42.40±0.99 ab	0.11±0 ed	6.11±0.32 dbc	0.27±0.01 ed	0.34±0.01 a	0.263±0.00 a	0.13± a

[a] Based on ANOVA analysis at α=0.05. Numbers with same letter in the same column are not significantly different.

[b] See Table 5.1 for sample descriptions.

reported by McDonough and others (2001). Samples had potassium contents between 2620 and 3440 ppm, which are higher than that (2053 ppm) reported by McDonough and others (2001).

Sodium contents in samples in nine tortilla samples (110 – 330 ppm) were very similar to that (133 ppm) reported by McDonough and others (2001); however, only sample L1 presented a sodium content of 2630 ppm. By looking at the ingredients listed on the package of sample L1 the high sodium content was due to the addition of salt (NaCl) and sodium metabisulfite ($Na_2S_2O_5$) used as an antioxidant/preservative during the manufacturing of tortillas at a large scale. Sulphur content ranged between 900 to 1320 ppm. As observed in Figure 5.5, there was a slight negative correlation between sulfur concentration and sensory acceptability of aroma. As the sulfur concentration increased, the aroma acceptability decreased. Particularly, samples S2 and H1 with a lower sulfur concentration had the two highest acceptability ratings for aroma whereas sample L1 with a high sulfur concentration had the lowest aroma rating. A similar but less noticeable behavior was found when plotting sulfur concentration and taste acceptability (data not shown). This tendency of sulfur concentration to affect aroma and taste acceptability may be related to development of off-aromas and off-tastes during processing that are formed via lipid oxidation and hydrolysis, photoxidation, proteolysis, and nonenzymatic browning reactions (Sucan, 2004).

5.3.5 Differential Thermal Analysis

Thermal analysis conducted by DSC showed endothermic curves (see Appendix 2) with significant differences in onset temperature, peak temperature, end temperature, and enthalpy

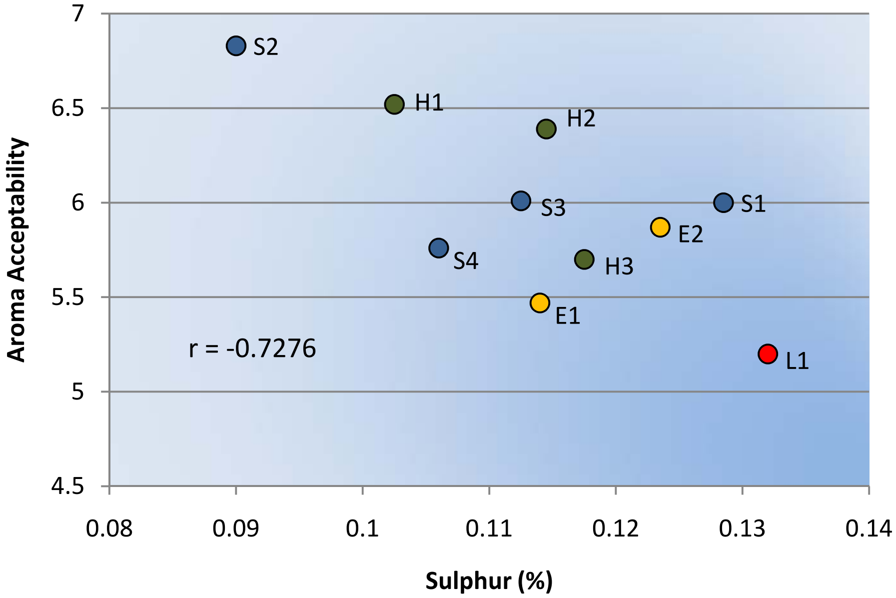

Figure 5.5 – A scatter plot showing sulphur content and aroma acceptability ratings of ten tortilla samples.

of samples (Table 5.6). Mean onset temperatures varied among samples from 41.75 ^{o}C (sample E1) to 49.5 ^{o}C (sample L1). As observed in Table 5.5, only sample L1 had an onset temperature significantly higher (approximately 5-8 ^{o}C) than those exhibited by the other samples. According to Davis (1994) an onset temperature is very helpful to compare physical changes among samples because this temperature is not influenced by a scan rate or sample size. The onset temperature of sample L1 could be affected by other ingredients such as additives (texture enhancers and preservatives) that were present only in this sample. The rest of the samples did not contain preservatives as they were commercialized as a fresh product.

Mean peak temperatures varied from 50.1^{o}C (sample E1) to 57.5 ^{o}C (sample L1). Sample L1 exhibited the highest peak temperature that may be a result of the highest onset temperature. Other samples showed some differences in the peak temperatures. Variations in the end temperature of the peaks were small among samples; only 4.15 °C between the lowest value (63.6 °C in sample S2) and the highest (67.8°C in sample H2). Interestingly only sample L1 had the smaller peak that was confirmed by the area under the curve or enthalpy. Nine samples had an enthalpy between 2.1 and 3.0 J/g but only sample L1 presented an enthalpy of 1.5 J/g.

Table 5.6 - Thermal analysis of ten corn tortilla samples [a]

Sample [b]	Initial (°C)	Onset (°C)	Peak (°C)	Final (°C)	Enthalpy (J/g)
S1	42.62±0.14 b	42.72±0.04 b	51.10±0.67 bcd	63.87±0.00 bc	2.41±0.11 ab
S2	43.64±0.81 b	44.27±0.69 b	50.82±0.75 cd	63.62±0.13 c	2.52±0.10 ab
S3	43.64±0.68 b	44.22±0.34 b	51.61±0.70 bcd	63.94±0.28 bc	2.53±0.01 ab
S4	42.81±0.14 b	44.46±0.33 b	54.08±0.01 b	67.62±0.45 ab	2.51±0.04 ab
H1	44.41±0.15 b	44.41±1.20 b	53.95±0.37 bc	65.79±0.54 abc	2.07±0.30 ab
H2	43.38±0.54 b	44.12±0.36 b	53.56±0.05 bc	67.77±0.95 a	2.26±0.13 ab
H3	42.30±0.13 b	42.71±0.21 b	51.14±0.30 bcd	64.58±0.54 abc	2.46±0.00 ab
E1	41.47±0.13 b	41.75±0.51 b	50.10±0.32 d	64.70±1.09 abc	3.03±0.40 a
E2	42.49±0.00 b	42.79±0.23 b	51.53±0.98 bcd	65.53±1.36 abc	2.85±0.19 a
L1	49.45±0.54 a	49.48±0.57 a	57.53±0.23 a	65.73±1.62 abc	1.48±0.07 b

[a] Numbers with the same letters in the same column are not significantly different at α=0.05. Based on three replications

[b] See table 5.1 for sample description.

A proper gelatinization is required to assure rheological and textural attributes in several cereal based food products (Biliaderis and others, 1980). Gelatinization of starch requires energy and it is responsible for the endothermic peaks in the thermograms. It has been reported that starch is a major component in the corn kernel and it is partially gelatinized during alkaline processing of corn (Campas-Baypoli and others, 2002). The degree of gelatinized starch depends on the processing conditions such as temperature, time and water availability. Large manufacturers of nixtamalized corn flours normally use conditions to cook and process corn that are different than those used by small tortilla manufacturers and housewives (Bello-Perez and others, 2002). Normally a treatment for producing nixtamalized corn flour is severe causing more starch to gelatinize; this explains, in this study, the small endothermic peak found in sample L1. The condition of starch, in combination with proteins and lipids, in a tortilla product affects textural attributes and water retention capacity (Bueso and others, 2006). However in this study, there was no clear effect of the onset temperature or enthalpy on the acceptability of textural attributes such as rollability, chewiness or resistance-to-tearing for all samples. This can be explained by the use of additives such as carboximethyl cellulose and xanthan gum as stabilizers, and guar gum and carrageenan as texturizers (listed in the package of sample L1) . These additives improved the texture of large-scale tortilla and prevented us from observing differences in texture between sample L1 and the others.

5.3.6 Color Characteristics of Tortilla Samples

Color of tortilla is commonly considered as an important attribute that can determine acceptability of tortilla among Mexican and Latin American consumers. Samples in this study varied in color from white to yellow (Table 5.6). The mean values of lightness (black - white), described by L*, varied from 64.4 (sample S4, darkest) to 74.85 (sample S3, lightest). The lowest mean a* value (redness) was onserved in sample E2 (0.586) and the highest in sample S4 (3.656). The lowest mean b* value (yellowness) was observed in sample L1 (18.48) and the highest in sample S4 (31.24). As shown by the L*, a*, and b*values, color of tortillas is a combination of light yellow and light red tones, mainly resulted from the concentration of carotenes contained in the corn kernel and the effect of calcium hydroxide used during alkaline cooking of corn. In this study there was no apparent correlation between calcium content, L*, a*, or b* and color acceptability of ten samples (data not shown). For instance, samples having the three highest mean scores of color acceptability (H1, H2, and S2) had calcium content and

L*, a*, and b* values similar to those of sample (E1) receiving the lowest score in color acceptability. With this information we may conclude that color acceptability may be influenced by other sensory attributes related to other observable attributes of the samples such as visual appearance and surface characteristics (Herrera-Corredor and others, 2007).

Table 5.7 - Color values of ten tortilla samples [a]

Sample [b]	L*	a*	b*
S1	68.17±1.92 cd	1.93±0.20 b	22.95±0.65 dc
S2	72.62±0.75 ab	1.82±0.22 bc	24.16±1.10 dc
S3	74.85±1.35 a	0.99±0.20 cd	18.78±0.89 e
S4	64.41±2.30 e	3.66±0.62 a	31.24±0.75 a
H1	64.45±1.28 e	3.17±0.51 a	28.15±1.51 b
H2	70.44±0.86 cb	1.23±0.33 bcd	23.39±1.01 dc
H3	66.87±0.53 ed	2.03±0.41 b	25.70±1.28 bc
E1	69.47±2.18 cd	1.34±0.73 bcd	25.17±2.70 c
E2	70.82±1.43 cb	0.59±0.43 d	21.81±1.30 d
L1	74.03±0.32 a	0.92±0.14 d	18.49±0.67 e

[a] Means with the same letter in the same column are not significantly different at α =0.05. L* values determining the level of lightness, a*= redness, and b*=yellowness.
[b] See Table 5.1 fro sample descriptions.

5.3.7 Rollability and Extensibility

Textural characteristics of tortilla are considered among the most important attributes that determine the quality of a tortilla product. In this study texture was assessed by rollability and extensibility (Table 5.8). Rollability, evaluated as the work and force required to roll a tortilla, was significantly different among the ten tortilla samples. The lowest values (10.50 N.mm and 0.2238 N for work and force respectively) were observed in sample S4 while the highest values (33.39 N.mm and 0.92 N for work and force respectively)were observed in sample E1. These ranges of values are comparable to those reported by Suhendro and others (1998a) in lab-made and commercial corn tortillas collected from the Texas market. Work and force values were closely correlated (Pearson correlation coefficient = 0.9926), implying that as force required to roll increased, it also increased the amount of work required to roll the sample. So when plotting work or force to roll obtained with the texture analyzer against acceptability ratings for rollability given by consumers, the results basically were similar (Figure 5.6 and 5.7). This means we can use either work or force to roll in order to make a comparison between both instrumental and sensory techniques.

In terms of rollability acceptability, samples L1, S2 and H2 received the three highest scores above 6.0 on the hedonic scale. The range of work to roll those samples was between 14.24 and 21.45 N.mm and the force to roll them was observed between 0.3192 and 0.5167 N. Interestingly, samples S3 and E2 were located in the same ranges of work and force to roll but did not received as high as scores for the acceptability of rollability (Table 5.2). This shows sensory acceptability for rollability is not a sole function of two parameters (work and force to roll) but perhaps a combination with others such as the ability of the tortilla to roll without breaking that cannot be easily assessed by instrumentation but was taken into account by consumers when making an acceptability judgment. Reyes-Vega and Others (1998) also pointed out the importance of the structure (particle size) and sensory moisture when correlating sensory to instrumental measurements in corn tortilla.

Extensibility of tortilla, determined by the force required to extend a tortilla strip by 1mm, force and work to rupture, modulus of deformation and distance of extensibility, varied in the following ranges: 4.62-11.89 N, 5.96-15.98 N, 7.81-34.98 N.mm, 3.61-8.81 N/mm,

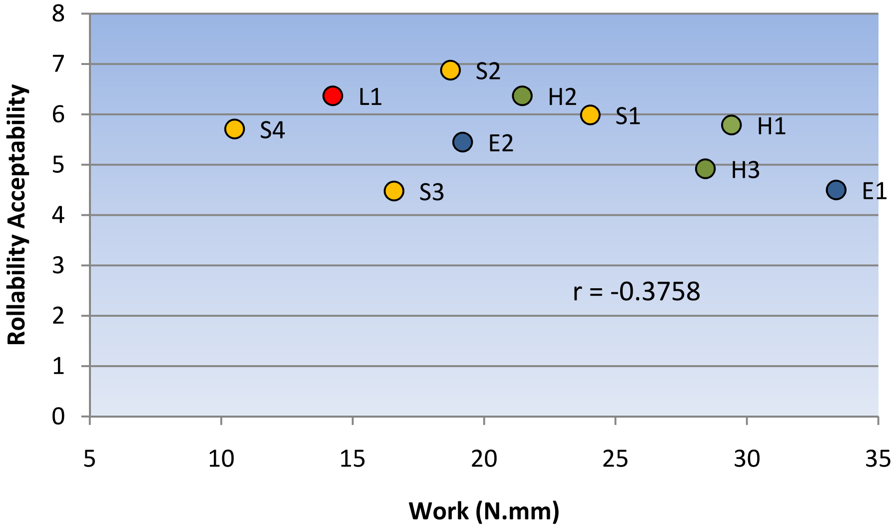

Figure 5.6 – A scatter plot showing relation between work required to roll a tortilla and rollability acceptability ratings of ten tortilla samples.

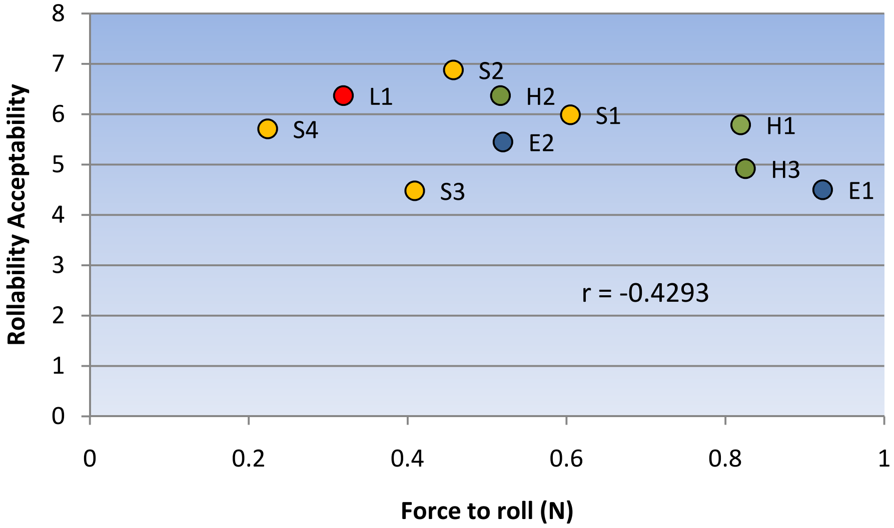

Figure 5.7 – A scatter plot showing relation between force required to roll a tortilla and rollability acceptability ratings of ten tortilla samples.

and 1.27-1.96 mm respectively. ANOVA showed significant differences among ten tortilla samples in all these five parameters (Table 5.8). These parameters also showed correlation among themselves. Force required to extend a tortilla strip by 1mm was closely correlated with modulus of deformation and force to rupture (Pearson correlation coefficient of 0.971 and 0.960, respectively). Force to rupture and work to rupture were also highly correlated (Pearson correlation coefficient=0.953). Samples with higher values in most of these five parameters were tortillas H3 and H1. The lowest values were observed in tortillas L1 and S1.

This instrumental technique using the Texture Analyzer to measure extensibility has been successfully correlated with subjective measurements of rollability and flexibility by Suhendro and others (1999). They reported that this instrumental technique offered better reproducibility than the subjective evaluations. A similar study was conducted using an Instron Universal Testing Machine by Reyes-Vega and others (1998). This study was focused on correlating values from subjective measurements with objective values from the instrument. This study is different from the previous ones because it is aimed to determine levels of acceptability correlated with instrumental measurements.

Relationship between the acceptability of resistance-to-tearing and the force to extend 1mm or the force to rupture is shown in Figures 5.8 and 5.9. Both figures have similar trends: a slight decrease in the acceptability for resistance-to-tearing occurred when force to extend 1mm or force to rupture increased. Only tortillas S2 and H2 seemed not to follow this trend. Their acceptability ratings were the highest for resistance-to-tearing (6.88 and 6.58 on the hedonic scale) but their values observed for force to extend 1mm and force to rupture were in between the overall range for tortilla samples.

Table 5.8 - Extensibility and rollability characteristics of ten tortilla samples [a]

	Extensibility					Rollability	
Sample	Force at 1mm (N)	Force to rupture (N)	Work to rupture (N.mm)	Modulus of Deformation (N/mm)	Distance of Extensibility (mm)	Peak Force (N)	Work to roll N.mm
S1	6.93±0.44 dbc	7.53±0.57 dc	8.69±1.54 c	5.92±0.40 cb	1.28±0.11 c	0.60±0.07 cb	24.04±3.88 dbc
S2	8.77±0.54 bc	10.10±1.08 dbc	16.74±3.62 cb	7.44±0.37 ab	1.36±0.13 bc	0.46±0.05 cd	18.72±1.72 de
S3	7.72±0.59 bc	8.68±0.90 dbc	10.93±2.31 cb	6.59±0.19 cb	1.32±0.11 c	0.41±0.12 cde	16.57±4.64 def
S4	6.29±2.83 dc	7.53±3.43 dc	11.79±9.01 cb	5.09±2.04 cd	1.46±0.15 bc	0.22±0.04 e	10.51±1.37 f
H1	8.94±0.85 abc	12.88±2.11 ab	21.94±8.38 ab	6.58±0.54 cb	1.97±0.34 a	0.82±0.13 ab	29.41±4.17 ab
H2	6.54±1.37 dc	8.52±1.89 dbc	14.04±6.85 cb	5.21±0.99 cd	1.64±0.21 abc	0.52±0.09 cd	21.45±3.73 dec
H3	11.89±2.47 a	15.99±3.81 a	34.98±10.91 a	8.81±1.10 a	1.80±0.26 ab	0.83±0.19 ab	28.42±6.60 abc
E1	9.64±1.03 ab	12.08±1.22 abc	17.06±2.96 cb	7.53±0.74 ab	1.61±0.11 abc	0.92±0.09 a	33.39±2.21 a
E2	8.13±1.33 bc	10.38±2.77 dbc	15.70±6.09 cb	6.18±0.41 cb	1.67±0.37 abc	0.52±0.13 cd	19.18±3.97 de
L1	4.63±0.51 d	5.96±0.90 d	7.81±2.04 c	3.62±0.19 d	1.64±0.16 abc	0.32±0.01 de	14.24±0.70 ef

[a] Numbers in each column with the same letter are not significantly different at α=0.05

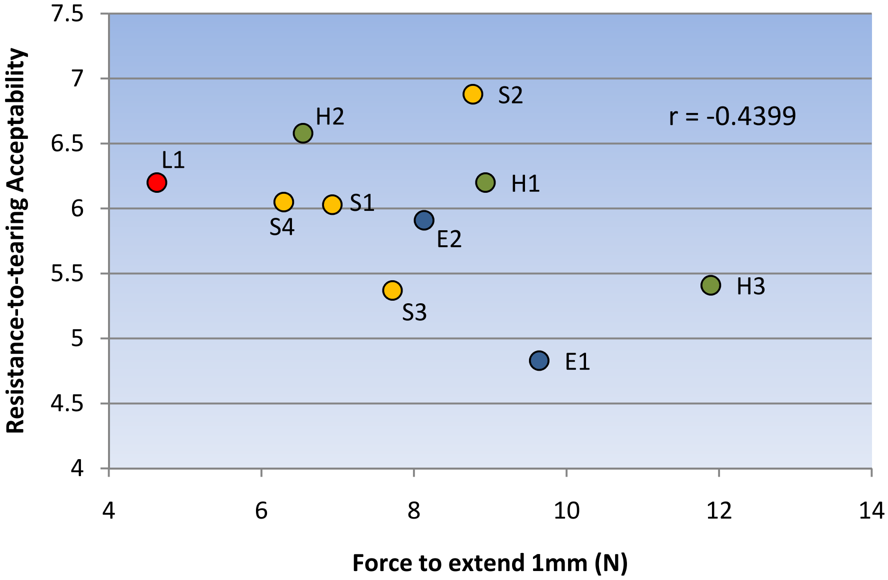

Figure 5.8 – A scatter plot showing relation between force required to extend a tortilla strip and resistance-to-tearing acceptability ratings of ten tortilla samples.

5.4 Conclusions

Instrumental evaluations conducted on ten corn tortilla samples obtained from the Mexican market offered objective and repeatable information about corn tortilla characteristics. Instrumental values of moisture, crude fat, and sulphur contents, force to extend a tortilla strip, and work and force to roll a piece of tortilla were the measurements that exhibited better relationship with acceptability ratings in tortilla attributes. However, this information should be used carefully when trying to predict the acceptance of a tortilla product using instrumental readings since information consumers use when determining liking of particular tortilla attributes is complex. Further studies should be conducted on this matter in order to determine with precision the correlations among degrees of liking among tortilla attributes and instrumentation.

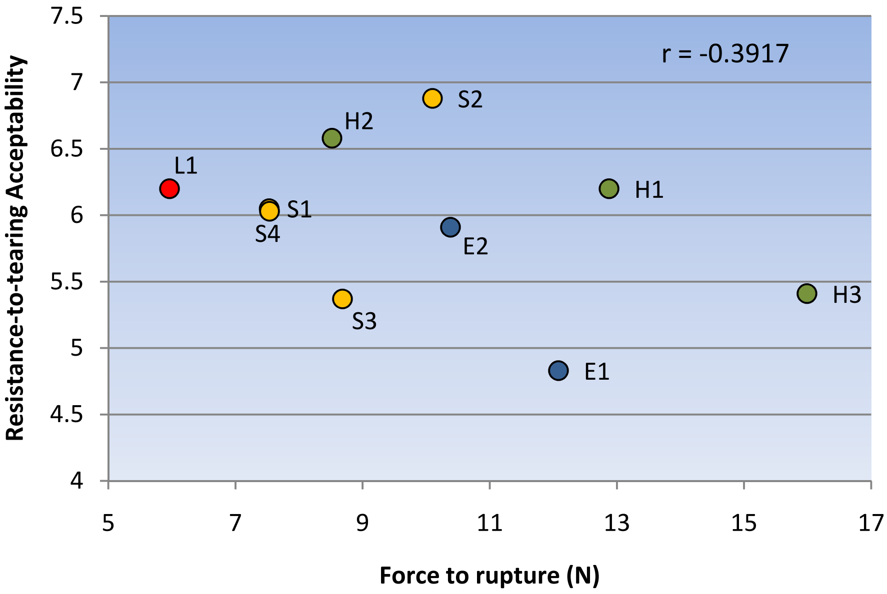

Figure 5.9 – A scatter plot showing relation between force to rupture a tortilla strip and resistance-to-tearing acceptability ratings of ten tortilla samples.

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CHAPTER 6

EFFECT OF HYBRID CHARACTERISTICS ON CHEMICAL AND PHYSICAL CHARACTERISTICS OF CORN TORTILLA RELATED TO SENSORY ACCEPTABILITY

6.1 Introduction

Characteristics of tortilla prepared with the alkaline-cooked corn are affected by many factors, including characteristics of raw materials and process conditions. Variations among corn hybrids are generally recognized as a product of interaction of genotype and environment (Kang and Gorman, 1989; Giauffret and others, 2000). Effects of this interaction are observed in the whole plant but are more pronounced in the corn kernel which can exhibit physical (color, size, density, etc.) and chemical (protein, fat, fiber, volatile compounds, etc.) variations (McKeag and Hougen, 1977; Clark and others, 2006). Each specific set of characteristics in the kernel makes it suitable for a specific use that can vary from animal feed and biomass for fuels to a wide variety of foods for human consumption. Varieties of corn suitable for tortilla production are discussed in this chapter.

Selection of proper corn variety is vital for alkaline-cooking and production of acceptable corn tortilla. According to Rangel-Meza and others (2004), in Mexico and Central America, variety selection for the tortilla production was first practiced by farmers who selected corns to obtain tortilla with specific characteristics such as flavor and texture. This type of selection is still practiced in rural areas in Mexico and Central America. In the past, commercial production of tortilla required large amounts of corn with particular characteristics that small farmers were unable to produce. Now, breeding programs are developing new corn varieties and hybrids for commercial production of corn which is supplied to the corn tortilla industry.

The relevance of corn grain characteristics has been studied in order to predict corn tortilla characteristics. Depending on grain characteristics, manufacturers can adjust process conditions in order to meet tortilla production standards (Sahai and others, 2001). However, characteristics such as yield, water retention, color, and others used for selection of corn variety must be acceptable. The present study is an attempt to include consumer acceptance of tortilla for corn hybrid selection for corn tortilla production. This study evaluated five hybrids of corn processed into tortilla, conducting instrumental analyses, and comparing final tortilla products to those previously identified as acceptable by consumers (Chapter 5).

6.2 Materials and Methods

6.2.1 Raw Materials

Five corn hybrids (Table 6.1) were used in this study: two yellow hybrids (Dekalb DKC 69-70 (AF2) and HyPerformer 9773) supplied by the Department of Agronomy and one white commercial hybrid (RX818W) supplied by Monsanto were cultivated at Louisiana State University's Ben Hur experimental field in 2005. Criteria for hybrid selection included: hybrids had to be suitable for tortilla making, available during the time the study was conducted, and represented wide variations in terms of color and other physical properties. Kernels were field dried, shelled and cleaned prior to storage. Also two white commercial hybrids (33V62 and 32V10) provided by Pioneer produced in the same year (2005) were used for the study. Samples were stored under freezing conditions at -18^{o}C. Food grade lime (VitaCal O ^{TM}) was obtained from Mississippi Lime Co. (Alton, IL). Tap water was used for cooking, washing and masa conditioning.

Table 6.1 – The 2005 Corn hybrids types and codings used for this study

Hybrid	Coding	Type	Provider
1	Dekalb DKC 69-70 (AF2)	Yellow	LSU Agronomy Dept.
2	RX818W	White	Monsanto
3	HyPerformer 9773	Yellow	LSU Agronomy Dept.
4	33V62	White	Pioneer
5	32V10	White	Pioneer

6.2.2 Characterization of Corn Hybrids

6.2.2.1 Thousand-kernel Weight

Thousand-kernel weight (g) was determined in five replications using the technique described by Sahai and others (2001) by weighing 100 clean kernels from each corn variety and multiplying the result by 10.

6.2.2.2 Test Weight (Bulk Density)

Test weight, a measurement of the bulk density of kernels, was conducted by filling up a quart container with clean kernels and recording the weight. This measurement was done in triplicate and results were reported in g/l.

6.2.2.3 Grain Size

Grain size was determined by measuring length (mm), width (mm) and thickness (mm) of kernels to the nearest 0.001 mm using a micrometer (Model 293-766; Mitutoyo, Tokyo, Japan). All measurements were expressed as an average and standard deviation of ten grains.

6.2.2.4 Pericarp Thickness

In order to measure pericarp thickness, grains were cracked to a coarse particle size using an small electric grinder equipped with iron disks. This grinding allowed pieces of pericarp to separate from the grain. Thickness of Individual pericarp pieces were measured using a micrometer (Empire Level MFG corp; Mukwonago, WI, USA). All measurements were expressed as an average and standard deviation of ten pieces of pericarp.

6.2.2.5 Water Absorption

Water absorption capability of each corn hybrid was determined at 20, 40 and 60 min. Ten clean grains with a known moisture content were weighed and then put in a container with 50 ml of water for a determined period of time (20, 40, and 60 min) at room temperature (24 ^{o}C). Subsequently, the excess water was removed and moisture content was determined on those grains and the result was reported as % moisture content.

6.2.3 Alkaline-Cooking of Corn

Corn varieties were alkaline cooked using the following methodology: ingredients (500 g of corn, 5 g of lime, and 1000 ml of water) were put in a glass container and cooked for 45 min at pH 11. A hot plate Cimarec® (Barnstead/Thermolyne, Dubuque, Iowa, USA). The ingredients were cooked by gradually increasing the temperature according to the profile shown in Figure 6.1. The cooking temperature was increased from 25^{o}C to 97 ^{o}C for the first 45 min and then decreased back to room temperature during steeping. Cooking and steeping temperature profile was recorded using a portable handheld data logger model OM-DAQPRO 5300 (Omega Engineering, INC., Stamford, Connecticut, USA). Alkaline-cooked nixtamal was referred to as corn steeped for about 14 hours in a plastic container with lid.

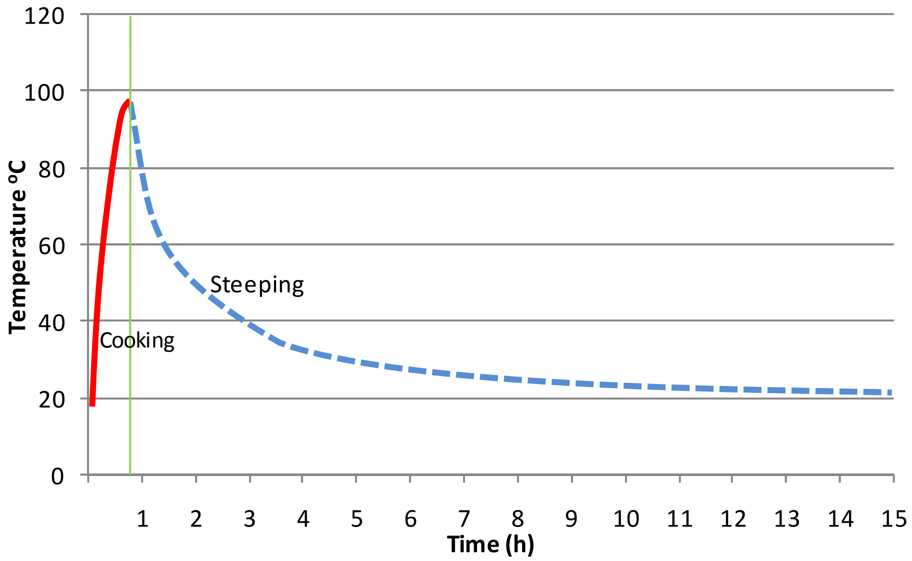

Figure 6.1 - Temperature profile used for the alkaline-cooking and steeping of corn hybrids.

6.2.4 Tortilla Making

Alkaline-cooked corn or nixtamal was washed twice using 1000 ml of tap water each time. Then nixtamal was ground using a manual grinder 'Victoria' (Mecánicos Unidos, Itagüí, Medellín, Colombia) equipped with iron disks. In order to condition ground nixtamal for making tortillas, 200 ml of tap water was added to the ground nixtamal. The resulting dough was divided into 40g balls. Each ball was molded into a flat disk using a manual tortilla press and baked for 4 min (2 min on each side) using a hot plate (Villaware: www.villaware.com) at 200 ^{o}C ± 7^{o}C. Tortillas of approximately 28.11 g, 14 cm diameter and 2.1 mm were prepared, cooled down, and stored under refrigeration prior to analysis.

6.2.5 Proximate Analysis

Proximate analysis was conducted on raw kernels, alkaline-cooked corn (nixtamal) and tortilla samples. Moisture content was measured gravimetrically in duplicate by grinding and then drying samples at 100°C for 48 hours. Protein was analyzed by the standard method EPA 351.2 for Total Kjjeldahl Nitrogen (EPA, 1983) and using 6.25 as a factor to convert the nitrogen content to protein. Crude fat was determined by AOAC Official Method 920.39 (AOAC, 1990). Crude fiber was determined by AOAC Official Method 962.09 (AOAC, 1990). Minerals calcium, copper, iron, magnesium, manganese, phosphorous, potassium, sodium, and sulphur were determined by the method of EPA 200.7 (EPA, 2001). All samples were performed in duplicate.

6.2.6 Differential Thermal Analysis

Differential thermal analysis of raw kernels, alkaline-cooked corn (nixtamal) and tortilla was conducted using a DSC Q100 Calorimeter (TA Instruments Inc, New Castle, DE). DSC Pans were obtained from TA Instruments (Part no. 900825.902, T21230). The sample was finely ground using a manual grinder equipped with iron disks, frozen to -80°C for 24 hr and then freeze-dried using a VirTis freeze drier (Model - Genesis 35XL, Virtis an SP Industries Company, Gardiner, NY,USA) to reduce to minimum any thermal damage of samples during drying (Sahai and Others, 1999). Dried samples were then ground using a laboratory grinder (Udy Corporation, Fort Collins Colorado, USA) to pass through a 0.5mm screen. Ten mg of each ground sample was weighed using an analytical balance (Denver Instrument, M-220D, Denver, Colorado), transferred to the aluminum DSC pan, and then 20 mg of water were added. Pans were sealed using a press specifically designed for this purpose (TA Instruments, New Castle, Delaware). A pan with 20 mg of water was used as a reference. Pans were stored at room temperature (24 °C) for only 30 min to avoid further changes of the sample. The analysis was conducted by heating the pans from 30 to 120 °C at a 10°C/min increment rate. Endotherms obtained were analyzed and temperatures of gelatinization at the beginning, peak, and ending were recorded. Also the enthalpy (area under the curve) was calculated. Results were reported as a mean and standard deviation of two replicates.

6.2.7 Pasting Properties

Pasting properties of raw kernels, alkaline-cooked corn (nixtamal), and tortilla were analyzed using a Rapid Visco Analyzer 3D (Newport Scientific, Warriewood, Australia). Samples of each specimen were air-dried at 40^{o}C using a convection oven and then ground using a laboratory grinder (Udy Corporation, Fort Collins Colorado, USA) equipped with a 0.5mm screen. The test samples were prepared at a ratio of 3.36g dry basis sample/ 24.64 g distilled water for a total of 28 g (12% w/v sample). Moisture of samples was pre-determined using a moisture analyzer prior to the RVA analysis in order to take into account the water already present in the sample when preparing the test samples (12% w/v). The sample and water were manually stirred to ensure proper mixing of water and the test sample. The RVA was programmed as follows: hold at 50^{o}C and 960 rpm for 1.0 min; ramp up from 50^{o}C to 95^{o}C in 6.5 min at 160 rpm; hold 5 min at 95^{o}C and 160rpm; ramp down from 95^{o}C to 50^{o}C in 6.5 min at 160rpm; finally hold at 50^{o}C and 160 rpm for 3.0 min making a total of 22 min. This program is similar to that used by Almeida-Dominguez and others (1997). The RVA program is presented in Table 6.2.

Table 6.2 – The RVA settings for analysis

Cumulative Time	Type	Value
0:00:00	Time	50 ^{o}C
0:00:00	Speed	960 rpm
0:01:00	Speed	160 rpm
0:01:00	Time	50 ^{o}C
0:07:30	Time	95 ^{o}C
0:12:30	Time	95 ^{o}C
0:19:00	Time	50 ^{o}C

Data obtained from RVA analysis were peak viscosity (PV), minimum viscosity (MV), final viscosity (FV), time to peak (Ptime), and pasting temperature (PT). Calculation of total setback (TSB) and breakdown (BD) was done automatically by the instrument's software using the formulas: TBS=FV-MV and BD=PV-MV, respectively. Duplicate measurements were taken for each test sample.

6.2.8 Color

Color was determined in raw kernels, wet dough (masa), nixtamalized corn flour (NFC), and fresh tortillas using a portable spectrophotometer (Model CM-508d, Minolta Camera Co. Ltd., Osaka Japan) with a 2^o standard observer and D_{65} illuminant. The spectrophotometer was calibrated using a Minolta certified CM-A70 white calibration cap. The sensor of spectrophotometer was placed over an even area of each test sample. The spectrophotometer reported the mean of five readings for each color attribute (L*, a*, and b*) every time a color measurement was taken. L* described lightness (ranging from black to white), a* and b* described the chromatic coordinates (ranging from –a: greenness, –b: blueness, +a: redness, +b: yellowness). Results were expressed in the CIE scale and values for the parameters L*, a*, and b* were reported as a mean and standard deviation of 5 different specimens per sample.

6.2.9 Extensibility and Rollability of Tortilla

Extensibility was determined by the method described by Suhendro and others (1999) using a texture analyser model TA.XT-plus (StableMicro Systems, Haslemere, UK, and Texture Technologies Corp., Scarsdale, NY). The texture analyser was equipped with a TA-96 Tensile Test Fixture that consisted of two grips, upper and lower, attached to the moving arm and the platform respectively. The grips were checked for vertical alignment and the distance between the upper and lower grips was set to 2.0mm at the beginning of the test using a ruler as suggested by the instrument manufacturer. Each tortilla strip used for the extensibility test was obtained from one tortilla which was cut to a constant specific rectangular size of 2.5 x 4 cm. The strip was obtained from a uniform area of the tortilla. For the commercial samples, the strip was cut from between the lines present on the tortilla's surface caused by the oven's conveyor. The test type settings were "return to start" in a mode of tension, a test speed at 1.0 mm/s, a post-test speed at 10 mm/s, and traveling distance of 15 mm. The test was conducted at room temperature (24 ^{o}C).Graphs obtained were analyzed using the Texture Exponent 32, ver 2.0.01 by calculating the modulus of deformation, force required to extend the strip by 1 mm, force and work to rupture, and extension distance. Results of each parameter were expressed as a mean and standard deviation of 5 replications.

Rollability was determined by the method described by Suhendro and others (1998) using a texture analyser model TA.XT-plus (StableMicro Systems, Haslemere, UK, and Texture Technologies Corp., Scarsdale, NY). The rollability fixture was custom-designed by Texture Technologies Corp. and consisted of an acrylic cylindrical dowel (20 mm diameter) attached to an acrylic base. A piece of thread rolled to one end of the cylinder and to the texture analyser arm pulled the cylinder tangentially causing the cylinder to roll. Tortillas for the test were allowed to stabilize at room temperature (24 ^{o}C) for 20 min and then attached to the cylinder by an edge. The force to roll a tortilla for 50 mm was recorded in a tension mode and settings used for this test were: "return to start" option, a trigger force of 0.05N (5 g), a pre-test speed at 10.0 mm/s, a test speed at 3.0 mm/s, a post-test speed at 10.00 mm/s, and a distance of

50mm. Graphs obtained were analyzed using the Texture Exponent 32, ver 2.0.01 by calculating the peak force and the work to roll the tortilla (area under the curve). Results were expressed as a mean and standard deviation of 5 replications.

6.2.10 Statistical Analysis

All data were analyzed at $\alpha=0.05$ using the SAS software version 9.1.3 (SAS Inst. 2003). A complete randomized experimental design was used for analyzing results for grain characterization, and extensibility and rollability of tortillas. Analysis of Variance (ANOVA) was used to determine significant differences among samples by testing if at least one sample was significantly different from other samples. The Tukey’s studentized range test was used to locate differences among samples. A factorial experimental design was used for water uptake, chemical composition, color, moisture, DSC, and RVA. Determination of significant differences among samples, groups, and their interaction was done by ANOVA and SAS proc mixed.

6.3 Results and Discussion

6.3.1 Physical Characterization of Corn Hybrids

Physical characteristics of grains are usually the first criteria for quality indices and selection of corn hybrids for specific usage purposes. Moisture of five corn hybrids used for this study varied in a regular range of 10-11 % (Table 6.3). There were no significant differences in moisture contents among the three white hybrids; however, moisture contents of the two yellow hybrids were significantly different locating them in the extreme positions among the five hybrids used for this study. Hybrid 3 (yellow) had the highest (10.90%) while hybrid 1 (yellow) the lowest (10.19 %) moisture content. Thousand-weight and test weight values for hybrids (Table 6.3) were similar to those reported by Sahai and others (2001). Particularly hybrid 2 (white) exhibited lowest thousand-weight (196.58 g) and test weight (719.37 g/l) values, as well as grain size determined by length (10.22 mm) and width (8.04mm). This hybrid was relatively small in size when compared to other hybrids. In terms of shape, hybrid 3 was thin (thickness = 3.96 mm) while hybrid 1 was round (thickness = 5.25 mm). Both yellow hybrids (1 and 3) showed significantly higher pericarp thickness (0.07 mm) when compared to the three white hybrids (0.06 mm).

Table 6.3 – Selected physical characteristics of corn hybrids [a]

Hybrid [b]	Thousand-Weight (g)	Test Weight (g/l)	Length (mm)	Width (mm)	Thickness (mm)	Pericarp Thickness (mm)	Moisture (%)
1	336.94 ± 4.76b	748.67 ± 3.85b	11.44 ± 0.53c	9.18 ± 0.53a	5.25 ± 0.36a	0.07 ± 0.01a	10.19 ± 0.08c
2	196.58 ± 4.17d	719.40 ± 11.46c	10.22 ± 0.65d	8.04 ± 0.64b	4.56 ± 0.47b	0.06 ± 0.01b	10.62 ± 0.07b
3	284.03 ± 3.75c	756.77 ± 6.11b	12.19 ± 0.48b	8.91 ± 0.58a	3.96 ± 0.18c	0.07 ± 0.01a	10.90 ± 0.06a
4	331.85 ± 9.63b	789.37 ± 4.74a	12.49 ± 0.45ab	8.77 ± 0.44a	4.55 ± 0.40b	0.06 ± 0.01b	10.62 ± 0.06b
5	354.63 ± 7.04a	786.77 ± 5.83a	13.03 ± 0.62a	9.36 ± 0.60a	4.34 ± 0.38bc	0.06 ± 0.01b	10.79 ± 0.12ab

[a] Numbers with the same letter in the same column are not significantly different at α=0.05.

[b] See Table 6.1 for hybrid description.

6.3.2 Water Uptake of Raw Hybrids

Water uptake is a kernel characteristic that has considerable effect on cooking properties and highly depends on the structural composition of the kernel (Laria and others, 2004). Statistical analysis of water absorption showed significant differences among hybrids (P<0.0001), soaking time (P<0.0001), and absorption speed (interaction of hybrid*time, P<0.0001) (Table 6.11). As observed in Figure 6.2, hybrids 3, 4, and 5 showed similar patterns of water absorption. Hybrid 2 presented the highest water absorption speed and exhibited higher water absorption than other hybrids after 20 min soaking. The maximum (22.39 %) water absorption of hybrid 2 was observed after about 40 min soaking. The other extreme was hybrid 1, having the lowest amount of water absorbed at all times. These differences can be explained according to Laria and Others (2004) who pointed out that the endosperm type and pericarp thickness are the main factors affecting water diffusion to the kernel. Indirect measurements of endosperm type (test weight and thousand-kernel weight) and pericarp thickness (Table 6.3) in hybrid 1 were higher than those of hybrid 2, confirming the effect of structural composition of the kernels on water absorption. Also, another factor that may influence water absorption is the kernel size provided that small-size grains (such as hybrid 2) expose more surface area for water diffusion (Almeida-Dominguez and others, 1997).

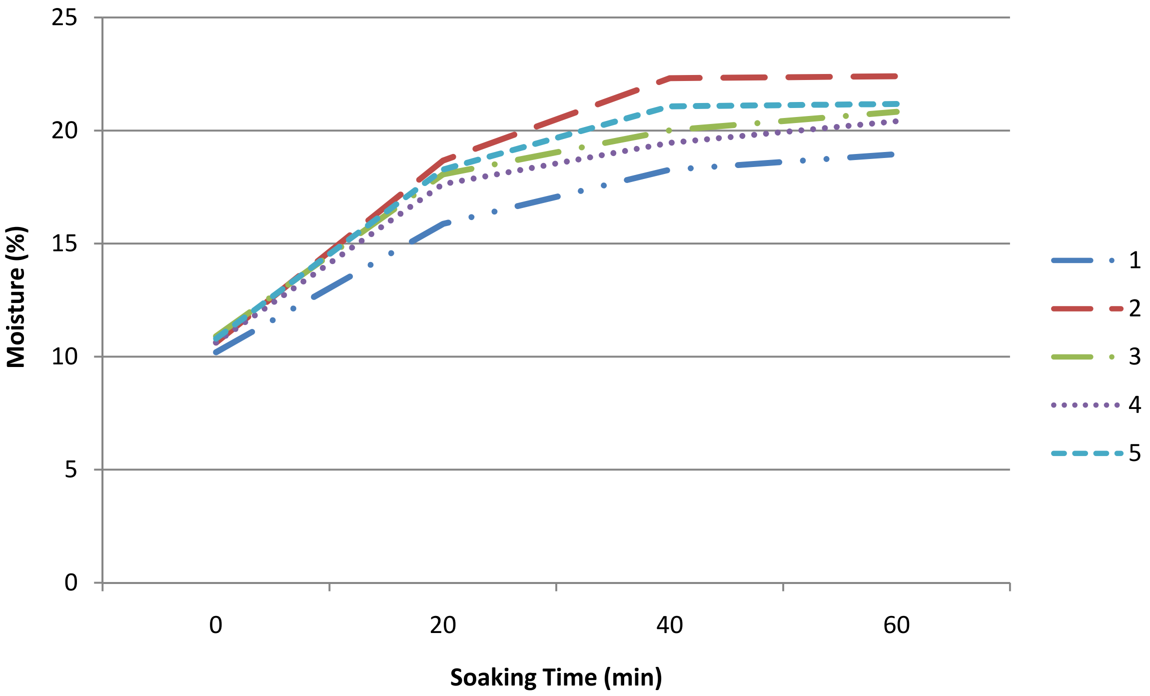

Figure 6.2 - Water absorption of five corn hybrids at room temperature (24 °C). See Table 6.1 for hybrid descriptions.

6.3.4 Effect of Hybrids and Processing on Protein Content of Raw and Cooked Corn and Tortillas

Protein content and quality of corn tortilla have been a concern for food scientists mainly from a nutritional point of view (Ortega and others, 1986). However, the effect of protein on changes in sensory properties has not been studied extensively, although Grosch and Schieberle (1997) suggested that one of the potent odorants present in corn tortilla (2 – aminoacetophenone) may result from a breakdown of tryptophan. Protein contents (Table 6.4) in five corn hybrids used in this study were different among each hybrid and ranged between 7.10 % (hybrid 4) to 10.10 % (hybrid 2). All hybrids showed similar patterns in changes in the protein content at different stages of processing from raw to cooked tortilla (no interaction between hybrid*stage; Table 6.11). There was an average increase of 0.25% of the protein content from raw corn to cooked corn in all hybrids. These changes were attributed to loss of pericarp during washing of corn after alkaline-cooking (Ortega and others, 1986). Protein contents of lab-prepared tortillas were also similar to those found in commercial samples obtained from the Mexican market (Table 5.4) and varied in the range (6.5 – 9.5 %) similarly observed in Table 6.4.

Crude fat is mainly allocated in the germen's kernel and it is usually a quality trait that has been studied by corn breeders when developing hybrids for specific usage purposes (Zuber and Darrah, 1987). Corn hybrids used in this study presented differences ($P<0.0001$; Table 6.11) in the initial crude fat content with variations between 2.62 to 2.9. The yellow hybrids (1 and 3) had higher values compared to the white hybrids (2 and 5; Table 6.4). Only hybrid 4 presented a crude fat content similar to that of the yellow hybrids. Increases in crude fat content were observed in all hybrids after cooking; however, these increases were different among hybrids (P = 0.0044; Table 6.11) particularly hybrid 2 which presented a higher difference (0.525% increase) than the others. These increases in crude fat can also be attributed to degradation of pericarp during cooking.

Table 6.4 – Proximate analysis of raw and alkaline cooked corn and tortillas prepared from five corn hybrids [a]

Composition [b]	Hybrid[c]	Raw	Cooked[d]	Tortilla
Protein (%)	1	8.95±0.21	9.35±0.35	8.70±0.14
	2	10.10±0.28	10.45±0.21	9.50±0.00
	3	7.60±0.42	7.95±0.07	7.80±0.14
	4	7.10±0.28	7.40±0.14	6.90±0.14
	5	7.25±0.07	7.10±0.14	6.60±0.14
Crude fat (%)	1	2.90±0.07	3.31±0.01	2.66±0.07
	2	2.62±0.07	3.15±0.02	2.80±0.00
	3	2.81±0.14	3.19±0.07	2.68±0.00
	4	2.77±0.06	3.04±0.06	2.64±0.04
	5	2.66±0.01	2.91±0.07	2.42±0.06
Crude fibre (%)	1	2.25±0.14	1.70±0.01	1.61±0.05
	2	3.03±0.29	2.04±0.07	1.45±0.38
	3	2.77±0.12	1.97±0.02	1.44±0.07
	4	2.42±0.16	1.69±0.08	1.42±0.00
	5	2.55±0.23	1.58±0.03	1.17±0.28

[a] See Table 6.11 for significance of main effects and their interaction.
[b] Based on duplicate measurements and dry basis.
[c] See table 6.1 for hybrid descriptions.
[d] Alkaline-cooked or nixtamalized corn.

6.3.5 Effect of Hybrids and Processing on Crude Fat Content of Raw and Cooked Corn and Tortillas

Tortillas prepared from these 5 hybrids exhibited similar crude fat content (2.42 – 2.80%) to those obtained from the Mexican market (Table 5.4 and 6.4). Tortilla from hybrid 2 stood out from those made from other hybrids with a 2.8 % crude fat content, suggesting that tortilla prepared from this hybrid may be more acceptable to consumers than those made from the other hybrids, given an apparent relation between fat content and flavor (Vidal-Quintanar and others, 2001).

6.3.6 Effect of Hybrids and Processing on Crude Fiber Content of Raw and Cooked Corn and Tortillas

Crude fiber corn is mainly in the pericarp (Rooney and Suhendro, 2001). A portion of pericarp degraded during cooking is usually removed during washing prior to nixtamal grinding and preparation of masa. Studies conducted by Caballero-Briones and others (2000) using x-ray diffraction, photoacoustics, and scanning electron and atomic force microscopies showed how morphological and chemical changes occur in pericarp at different times during alkaline-cooking. These authors proposed that alkaline-cooking of corn can be viewed as a series of physicochemical phenomena that involve hemicellulose dissolution, swelling, alkaline cellulose formation and phase transition between native and degraded cellulose.

Studied corn hybrids had crude fiber contents between 2.25% (hybrid 1) and 3.03% (hybrid 2) (Table 6.4). These results may look contrasting when compared with the results from pericarp thickness (Table 6.3) indicating a thinner pericarp thickness was observed in hybrid 2 and a thicker pericarp in hybrid 1. However, grain size seemed to be influencing the proportion of crude fiber in the sample as the proportion of pericarp surface per g of sample was higher in sample 2. Changes resulted from alkaline-cooking showed a reduction in crude fiber for all samples (no interaction, Table 6.11). Tortillas prepared from these five hybrids showed crude fiber contents (1.17 – 1.61 %) which were very similar to those of tortillas obtained from Mexican market (0.995- 2.06 %; Table 5.4, Chapter 5).

6.3.7 Effect of Hybrids and Processing on Calcium Content of Raw and Cooked Corn and Tortillas

The use of lime for alkaline-cooking of corn is the main characteristic differentiating corn tortilla production from other industrial processes of corn such as wet milling and dry milling. Lime is mainly composed of calcium oxide or calcium hydroxide (when combined with water). It may also contain other minerals in a very low concentration (such as iron, sulfur, phosphorous, manganese and magnesium). The effect of calcium caused by lime on corn kernels during alkaline-cooking has been extensively studied by several authors (Zazueta and others, 2004). Since the internal composition of the kernel is not homogeneous, diffusion of calcium into the kernels may vary with different structural characteristics. Fernandez-Muñoz and others (2004) pointed out that diffusion of calcium occurs at different rates during alkaline cooking, being most intense in the pericarp during the first 0-5 hrs of cooking and steeping and then in the endosperm and germ.

Raw corn hybrids used for this study did not show significant differences among initial calcium contents (Table 6.5). Further changes in calcium content after cooking and steeping resulted in a significant average increase of 0.2511% for all hybrids ($P<0.0001$; Table 6.11). Calcium contents in final products (0.18-0.25%) were in the range observed in commercial tortillas (0.09-0.71%) obtained from the Mexican market (Table 5.5; Chapter 5).

6.3.8 Effect of Hybrids and Processing on Other Minerals Content of Raw and Cooked Corn and Tortillas

Contents of other minerals in raw and cooked corn and tortillas are presented in Table 6.5. A significant average increase ($P=0.0356$; Table 6.11) of 31.33 ppm in iron content was observed after cooking and steeping. This change may be attributed to iron from the lime used for cooking. Manganese content varied among raw hybrids (P=0.0155; Table 6.11); particularly yellow hybrids had greater manganese contents than that of the white counterparts. However the manganese content was not affected by processing. Potassium contents were also different among raw hybrids (P=0.0003; Table 6.11). Only hybrid 2 showed a potassium content (0.47 %) that was significantly greater than other samples. A significant decrease (P=0.0005; Table 6.11) in potassium content (0.0646 % average) was observed after cooking and steeping for all samples. Potassium may be lost during washing. Hybrids and processing did not affect magnesium, phosphorous, sulphur and zinc contents (Table 6.11). In general, mineral contents in lab-made tortillas from all hybrids showed similar values (Table 6.5) to those found in tortillas from the Mexican market (Table 5.5, Chapter 5).

Table 6.5 - Mineral contents of raw and cooked corn and tortillas prepared from five corn hybrids [a]

	Hybrid[b]	Raw	Cooked[c]	Tortilla
Calcium (%)	1	0.07±0.08	0.23±0.03	0.18±0.001
	2	0.01±0.001	0.26±0.02	0.25±0.001
	3	0.02±0.01	0.26±0.01	0.24±0.01
	4	0.01±0.001	0.22±0.04	0.20±0.001
	5	0.02±0.01	0.41±0.21	0.22±0.001
Copper (ppm)	1	n/a[d]	n/a	16.50±0.42
	2	n/a	n/a	9.82±0.82
	3	n/a	n/a	9.05±0.13
	4	n/a	n/a	6.23±2.28
	5	n/a	n/a	10.75±6.44
Iron (ppm)	1	34.70±0.57	61.10±21.07	60.25±2.33
	2	32.50±0.42	41.40±19.09	57.40±11.31
	3	31.05±0.49	56.55±15.91	60.10±5.23
	4	28.50±10.18	90.30±77.36	41.30±1.98
	5	26.80±3.54	60.89±42.30	40.30±3.54

Table cont'd

Magnessium (%)	1	0.11±0.01	0.10±0.00	0.11±0.001
	2	0.12±0.01	0.11±0.01	0.12±0.001
	3	0.10±0.001	0.10±0.01	0.11±0.001
	4	0.09±0.01	0.10±0.00	0.11±0.001
	5	0.10±0.001	0.16±0.08	0.11±0.001
Manganese (ppm)	1	8.56±0.60	8.78±0.68	8.63±0.32
	2	10.17±3.30	6.06±2.09	6.89±0.03
	3	10.17±0.33	9.28±0.38	9.37±0.06
	4	5.54±0.21	6.73±2.55	4.64±0.11
	5	6.24±0.40	8.62±5.20	5.32±0.30
Phosphorus (%)	1	0.35±0.01	0.31±0.03	0.33±0.001
	2	0.38±0.01	0.31±0.07	0.34±0.001
	3	0.29±0.01	0.28±0.03	0.29±0.01
	4	0.23±0.03	0.29±0.06	0.25±0.01
	5	0.26±0.01	0.45±0.27	0.26±0.01
Potassium (%)	1	0.37±0.01	0.32±0.01	0.33±0.00
	2	0.47±0.01	0.36±0.10	0.37±0.01
	3	0.36±0.00	0.31±0.03	0.31±0.01
	4	0.34±0.02	0.31±0.03	0.28±0.001
	5	0.33±0.00	0.25±0.04	0.27±0.001
Sodium (%)	1	n/a	0.02±0.01	0.03±0.001
	2	n/a	0.02±0.001	0.02±0.001
	3	n/a	0.02±0.01	0.02±0.001
	4	n/a	0.01±0.001	0.03±0.01
	5	n/a	0.03±0.001	0.02±0.001
Sulphur (%)	1	0.13±0.001	0.14±0.01	0.15±0.01
	2	0.16±0.01	0.13±0.03	0.15±0.001
	3	0.12±0.001	0.13±0.01	0.13±0.01
	4	0.10±0.001	0.13±0.02	0.11±0.001
	5	0.10±0.001	0.22±0.16	0.12±0.01
Zinc (ppm)	1	28.90±10.89	54.70±76.79	35.05±5.73
	2	41.60±0.57	47.90±15.13	32.25±0.35
	3	48.40±5.09	41.95±1.20	49.10±28.14
	4	26.60±8.34	31.50±3.39	23.20±1.13
	5	28.65±7.99	45.65±22.98	21.75±1.06

[a] See table 6.11 for significance of main effects and their interaction.

[b] See Table 6.1 for hybrid descriptions.

[c] Alkaline-cooked or nixtamalized corn.

[d] n/a stands for non detectable.

6.3.9 Effect of Processing on Color of Corn Hybrids

Color of tortilla has been used by tortilla manufacturers as a characteristic of quality for market promotion of this product in Mexico and Central America. Accordingly, a whiter tortilla implies quality of a product made from the traditional white varieties and hybrids used for production of corn tortilla. Color is an important attribute in terms of appearance (Herrera-Corredor and others, 2007). Even corn breeders and companies have focused efforts on developing white hybrids specifically for corn tortilla production; availability and low prices have made it possible for the use of yellow hybrids for corn tortilla production. Tortilla manufacturers, either small or large scale, can now offer consumers tortillas varying in color from white to yellow. Color of each particular corn hybrid affects the color of the final tortilla product, but another factor affecting tortilla color is the interaction of corn constituents with lime resulting in yellowness developing especially when the concentration of lime is excessive. In this study, changes in color of yellow and white corn hybrids were evaluated among the different stages of corn tortilla preparation, under the same conditions, in order to determine the effects of the color of raw materials on the final product.

Kernels of yellow hybrids (1 and 3) showed lower values of L* (Table 6.6) than white hybrids (2,4 and 5). This color difference was expected since L* is a measure of lightness. This same behavior was observed at various processing stages of hybrids (masa, nixtamalized corn flour and tortilla). L* value significantly increased (P=0.0001; Table 6.11) from raw grains to masa, continued to increase from masa to NCF but then decreased from NFC to tortilla for all hybrids (Table 6.6). The range in which L* of kernels varied among hybrids was 15.87 points (from 54.86 to 70.73), a variation was from the hybrid differences and to some extent, the color measurement variation made on the surface of the whole grains. However, the range of color lightness variation in masas was smaller (6.11 points), even much smaller in NCF (only 3.98 points), but then slightly increased in final tortilla products (8.36 points) (P=0.0001; Table 6.11). L* values of final tortilla products generally showed no significant differences, except when comparing between tortillas from hybrids 2 (L*=63.46) and 3 (L*=55.1). In general, lightness values (L*) of lab–made tortillas were lower (55.1-63.46) than those (64.41 -74.85) observed in commercial tortillas (Table 5.7), this may be possibly due to coarser particle size of lab-made tortillas causing less light to be reflected.

Values of +a* representing redness and –a* for greenness were evidently different among raw white and yellow corn hybrids. Higher values of a* were found in grains of yellow hybrids (1 and 3) compared to white hybrids (2, 4, and 5; Table 6.6). Overall values of a* were significantly lower in masas and NCFs compared to grains (P<0.0001, Table 6.11). The a* values of tortillas were higher than those of masas and NCFs, but lower than raw grains. Still, the differences in a* of wet masas, NCFs, or tortillas made from white and yellow hybrids were obvious. The a* values (2.78-3.48) in lab-prepared tortillas made from white hybrids were in the range (0.59-3.66) found in commercial tortillas from (Table 5.7) while that (6.95 - 8.27) of yellow hybrids surpassed that range.

Perhaps the most useful value for color as an indication for changes during tortilla processing stages is the b* value, the positive value represents the yellowness. The b* values observed in corn kernels followed the same tendency as those observed for L* and a* values in which yellow hybrids, particularly hybrid 3, clearly differentiated from white hybrids during tortilla processing stages. However, the only significant difference was observed between tortillas from hybrids 2 and 3 where the extreme values of b* were observed (Table 6.6). These results may suggest that even when both a* and b* help differentiate color of hybrids among processing stages, a* values may be a better indicator for color differences among tortillas (final products). Overall, b* values (22.08 – 29.23) observed in lab-made tortillas were in the range (18.49-31.24) observed in commercial tortillas obtained from the Mexican market.

Overall, color parameters (only L*and b*) observed in lab-made tortillas from the five corn hybrids were comparable to those observed in commercial tortillas (Table 5.7); however, only tortillas from white hybrids (2,4, and 5) presented values similar to those(L*=68.17-74.85, a*=0.92-1.93, and b*=1.8.94-24.16) found in the commercial Mexican tortillas (Table 5.7) with high ratings in color acceptability (Table 5.2).

Table 6.6 - Color characteristics of raw materials and tortilla during preparation stages from five corn hybrids [a]

	Hybrid[b]	Raw corn	Wet Masa	NCF[c]	Tortilla
L*	1	54.86±4.44	74.27±0.43	81.97±0.47	58.08±0.77
	2	70.73±5.66	77.26±0.38	85.45±0.30	63.46±1.98
	3	59.97±4.48	71.15±0.75	82.03±1.21	55.10±3.03
	4	65.25±2.92	77.01±0.21	85.74±0.40	59.78±1.40
	5	71.39±3.50	77.06±0.50	85.95±0.35	60.87±1.18
a*	1	17.34±3.10	4.56±0.13	4.03±0.37	8.27±1.06
	2	2.82±1.54	0.06±0.17	0.87±0.08	2.78±0.95
	3	18.24±1.77	3.30±0.24	3.17±0.42	6.95±0.90
	4	2.43±1.06	-0.43±0.08	-0.04±0.17	3.48±0.58
	5	1.07±1.07	-0.65±0.09	-0.08±0.09	3.20±0.64
b*	1	42.48±4.27	27.81±0.76	25.70±0.96	27.51±1.15
	2	27.53±2.65	18.24±0.49	16.85±0.33	22.08±1.89
	3	40.43±9.04	31.12±0.64	27.30±1.09	29.23±1.75
	4	24.53±4.11	20.33±0.43	18.20±0.47	23.58±0.34
	5	22.71±3.71	22.22±0.91	18.17±0.43	25.26±1.30

[a] See Table 6.11 for significance of main effects and their interaction. L*=color lightness, a*=redness, and b*=yellowness.
[b] See Table 6.1 for hybrid descriptions.
[c] Nixtamalized corn flour

6.3.10 Moisture Variations among Alkaline-Cooking Process Stages of Corn Hybrids

Moisture content of five raw hybrids, intermediate products and tortillas was evaluated at each preparation stage showing significant variations in water content among hybrids. Initial moisture contents among all hybrids were similar. After the cooking-steeping stage, moisture significantly increased to an average of 48.62% (P=0.0001; Table 6.11). At this stage, significant differences were observed among hybrids, particularly in hybrid 1 which showed a lower moisture content (45.24%) compared with other hybrids. Increases in moisture of masas were due to addition of water for conditioning ground nixtamal for tortilla making; for this reason, the increases in moisture in all masas were similar. The moisture content in tortillas decreased during baking on an average of 16.04% for all hybrids. These results suggest that under the same processing conditions, the final water content in tortilla will be affected mainly by the water absorbed during cooking-steeping which is influenced by the water uptake capacity of each particular hybrid (Figure 6.2). Differences in water uptakes (Figure 6.2) affect the rate of water diffusion into the kernel during cooking, which, in turn, affects gelatinization of starch on the periphery, making each particular hybrid more or less susceptible to overcooking. The range of moisture content found in lab-made tortillas (39.66 – 44.02%) was in the range found in tortillas from the Mexican market (35.6 – 46.97%; Table 5.4).

6.3.11 Effect of Hybrids and Processing on Thermal Properties of Raw and Cooked Corn and Tortillas

Differential scanning calorimetry (differential thermal analysis) is a helpful technique for evaluating the condition of starch and degree of cooking in different stages of tortilla processing (Sahai and others, 1999). In this study, temperatures associated with the

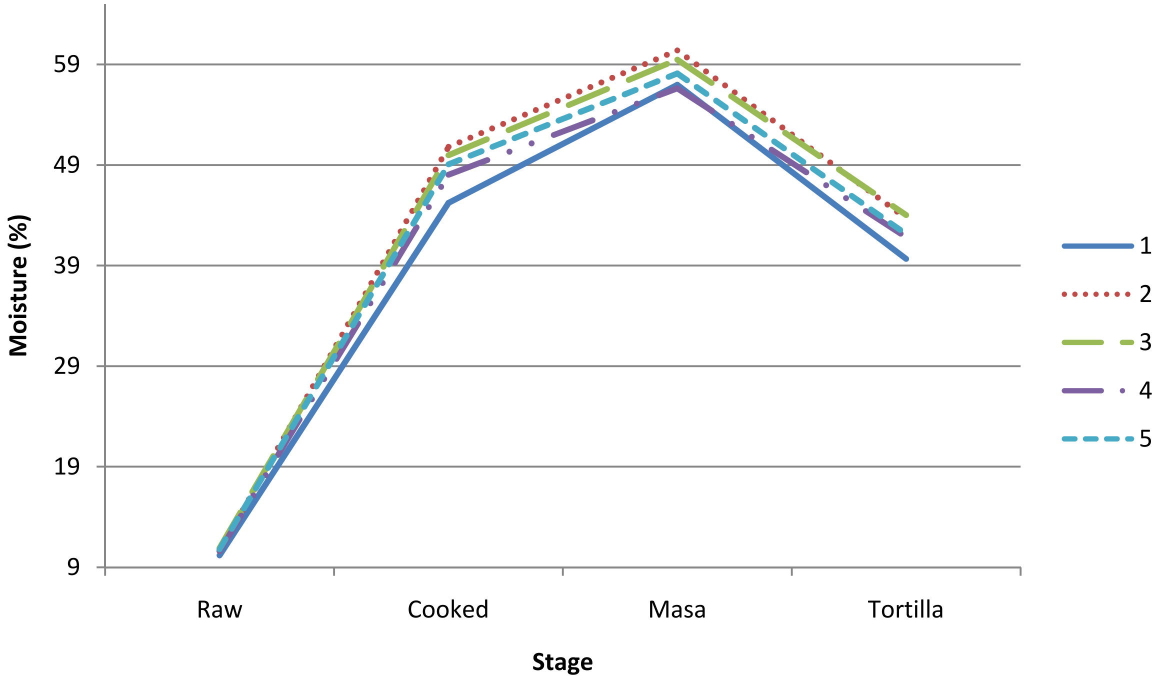

Figure 6.3 - Variations in moisture content of five corn hybrids, intermediate products, and tortillas. See table 6.1 for hybrid descriptions.

endothermic peaks (such as initial, onset, peak, and final) were affected by both tortilla processing stages and hybrid (See Table 6.11 for significance of these main effects). When comparing temperatures (initial, onset, peak, and final) among hybrids, there was a slight tendency of hybrid 2 and 3 to be higher than 1, 4 and 5 when they were in a raw stage (Table 6.7). This tendency was observed for alkaline-cooked kernels, but not in tortillas. Comparing raw and alkaline-cooked corns, there were no significant differences observed in initial, onset, and peak temperatures, but the final peak temperature had a significant average increase of 2.63 ^{o}C. Tortillas from all hybrids showed significant average decreases in initial, onset, peak and final temperatures of 19.08 ^{o}C, 19.77 ^{o}C, 21.98 ^{o}C, and 25.25 ^{o}C, respectively, compared to alkaline-cooked kernels.

Table 6.7 - Thermal analysis of five hybrids during tortilla preparation stages [a]

	Hybrid[b]	Raw	Cooked	Tortilla
Initial (°C)	1	68.20±2.47	67.62±0.35	48.26±1.05
	2	68.09±1.22	67.10±1.22	46.99±1.16
	3	68.18±0.04	67.34±1.05	47.66±0.64
	4	64.70±1.10	65.95±0.25	46.85±0.32
	5	66.04±0.88	65.71±0.26	48.03±1.16
Onset (°C)	1	70.62±1.05	70.35±0.16	51.08±1.81
	2	71.53±1.84	71.49±0.08	51.63±3.83
	3	70.54±1.29	71.92±1.32	49.73±0.58
	4	67.01±3.60	69.23±0.01	48.96±1.10
	5	68.99±2.23	68.21±1.36	50.91±0.06
Peak (°C)	1	74.16±0.17	74.24±0.86	51.32±1.85
	2	75.79±0.76	76.23±1.08	54.31±0.49
	3	74.86±0.49	76.52±2.19	51.70±0.28
	4	72.30±0.33	72.83±0.51	52.45±0.38
	5	71.91±0.69	71.92±0.49	52.02±0.95
Final (°C)	1	83.05±0.66	84.72±0.29	60.04±1.27
	2	85.31±1.81	88.76±2.40	61.46±0.32
	3	83.13±0.66	88.61±3.45	60.49±0.21
	4	83.90±0.67	83.97±1.24	60.26±0.95
	5	80.16±0.11	82.64±2.35	60.19±0.42
Enthalpy (J/g)	1	3.81±1.21	5.14±0.49	0.88±0.12
	2	3.59±0.60	5.93±0.89	1.42±0.30
	3	3.84±0.26	5.03±0.72	1.43±0.15
	4	4.72±0.38	4.97±0.30	1.31±0.30
	5	3.33±0.17	4.63±1.07	1.17±0.23

[a] See Table 6.11 for significance of main effects and their interaction.
[b] See Table 6.1 for hybrid description.

An important measurement in DSC is entalphy because it represents the amount of energy used for gelatinization of starch resulting in loss of crystalline order, and the degree of cooking. Initial enthalpy in raw hybrids varied from 3.3 J/g (hybrid 5) to 4.72 (hybrid 4)(P=0.3507; Table 6.11). Interestingly, enthalpy increased after the alkaline-cooking stage, i.e., the amount of energy required to gelatinize starch in cooked samples was higher than in raw samples. However, there were no significant differences in the enthalpy among alkaline-cooked corn hybrids. This increase in enthalpy after alkaline cooking was previously observed by Sahai and others (1999), and was attributed to starch annealing that occured during steeping. Annealing is associated with partial gelatinization and represents a physical reorganization of starch granules (Tester and Debon, 2000), increasing the energy requirements to gelatinize. Enthalpy values found in tortilla were lower than those found in alkaline-cooked kernels suggesting a complete gelatinization of starch granules caused by both alkaline cooking of kernels and baking of tortillas. Significant changes in enthalpy during tortilla processing stages were not influenced by hybrids (no interaction for hybrid*stage, P=0.4594; Table 6.1) The values found (0.88 – 1.43 J/g) in lab-made tortillas were lower than those found in commercial tortillas (1.48-3.03J/g; Table 5.6) suggesting higher heating conditions when baking lab-made tortillas.

6.3.12 Effect of Hybrids and Processing on Pasting Properties of Raw and Cooked Corn and Tortillas

Raw and processed hybrids (nixtamal and tortillas) showed significant differences in pasting characteristics that were easily observed during RVA analysis (Table 6.8 and 6.11; Figures 6.4-6.6). Previous studies conducted by Almeida-Dominguez and others (1997) reported that viscosity peak is among the best predictors for cooking performance of corn kernels in terms of simmering hydration rates and steeping hydration rates. Comparing pasting properties of raw hybrids, pasting temperatures were observed in a range of 71.55-76.03 ^{o}C and peak times between 6.37 and 6.97 min. Raw hybrids 4 and 5 showed the two highest values for PV, MV, BD, FV and TBS (Table 6.8) and exhibited very similar viscosity profiles

Table 6.8 - Pasting properties of five hybrids during tortilla preparation stages [a]

	Hybrid[b]	Raw	Cooked	Tortilla
Peak Viscosity (cP)	1	144.50±1.30	277.67±0.59	113.71±3.71
	2	86.59±1.29	258.96±0.41	104.71±2.53
	3	96.34±1.18	231.21±5.48	116.09±1.53
	4	223.17±4.48	246.38±0.06	155.38±1.35
	5	228.09±2.24	288.08±1.06	175.63±2.54
Minimum Viscosity (cP)	1	85.08±1.06	140.96±2.30	78.71±2.30
	2	63.25±1.30	175.79±0.65	65.25±2.23
	3	56.58±3.89	153.00±2.83	73.54±0.30
	4	92.17±2.24	156.83±0.35	64.59±1.89
	5	93.63±1.00	149.96±2.18	65.50±1.41
Breakdown (cP)	1	59.42±0.23	136.71±1.71	35.00±1.41
	2	23.34±2.60	83.17±1.06	39.46±0.30
	3	39.75±2.72	78.21±2.65	42.55±1.24
	4	131.00±2.23	89.54±0.41	90.80±0.53
	5	134.46±3.24	138.13±1.12	110.13±1.12
Final Viscosity (cP)	1	224.84±4.01	326.33±5.66	194.63±3.95
	2	153.17±3.77	434.00±1.17	161.00±1.77
	3	154.67±7.78	372.67±5.30	181.88±1.12
	4	244.75±1.88	381.05±0.88	187.67±4.01
	5	243.96±0.30	347.80±0.18	191.17±4.12
Total Setback (cP)	1	139.75±2.94	185.38±3.36	115.92±1.65
	2	89.92±2.47	258.21±1.82	95.75±0.47
	3	98.08±3.89	219.67±2.47	108.34±0.83
	4	152.58±0.35	224.21±1.24	123.08±2.12
	5	150.34±1.29	197.84±2.35	125.67±2.71
Peak Time (min)	1	6.70±0.04	6.80±0.00	6.07±0.00
	2	6.97±0.14	7.40±0.00	3.50±0.04
	3	6.37±0.14	7.44±0.05	3.20±0.10
	4	6.44±0.05	6.97±0.05	3.24±0.05
	5	6.44±0.05	6.80±0.00	3.24±0.05
Pasting Temperature (^{o}C)	1	74.43±0.04	74.82±0.04	50.10±0.00
	2	76.03±0.18	74.63±0.25	50.18±0.04
	3	74.33±0.11	77.20±0.07	50.25±0.14
	4	71.60±0.00	75.32±0.04	50.18±0.04
	5	71.55±0.07	73.75±0.21	50.15±0.07

[a] See Table 6.11 for significance of main effects and their interaction.

[b] See table 6.1 for hybrid descriptions.

(Figure 6.4). According to Rooney and Suhendro (2001), pasting properties are very closely correlated to grain hardness: “the harder the corn, the slower development of viscosity and the lower the viscosity.” However, hybrid 2 seemed not to follow this trend. According to test weight and thousand-weight (Table 6.3), hybrid 2 may be classified as soft endosperm corn but the viscosity development was very low compared to other hybrids. A possible explanation for this is the chemical composition of this hybrid (2) which showed the highest protein content (Table 6.4) compared to the others. Compared with the raw kernels, all alkaline-cooked corns had higher PV, MV, BD, FV, and TBS, except BD for hybrid 4. Increases in peak viscosity in nixtamalized hybrids were due to annealing of starch during nixtamalization of hybrids. The highest increase was observed in hybrid 2 (from 86.59 to 258.9) suggesting annealing occurred in a higher degree in this hybrid.

Pasting characteristics of tortilla (Figure 6.5 vs. 6.6) indicated that heat treatments from both alkaline-cooking and baking during tortilla preparation caused a higher gelatinization of starch than alkaline-cooking alone. Tortillas had significantly lower PV, MV, BD, FV and TBS (Table 6.8 and Figure 6.6), compared to those of nixtamalized corn. These RVA findings along with DSC results suggested that baking is critical for gelatinization of starch in ground nixtamal (masa) during tortilla preparation.

6.3.13 Extensibility and Rollability of Tortillas

Textural properties are critical for the quality, acceptance and purchase intent of tortilla products as they are mainly used as carriers (Herrera-Corredor and others, 2007). The use of instrumentation for evaluation of extensibility of tortillas from five hybrids helped to determine if differences existed among parameters such as force at 1mm, rupture force, work to rupture,

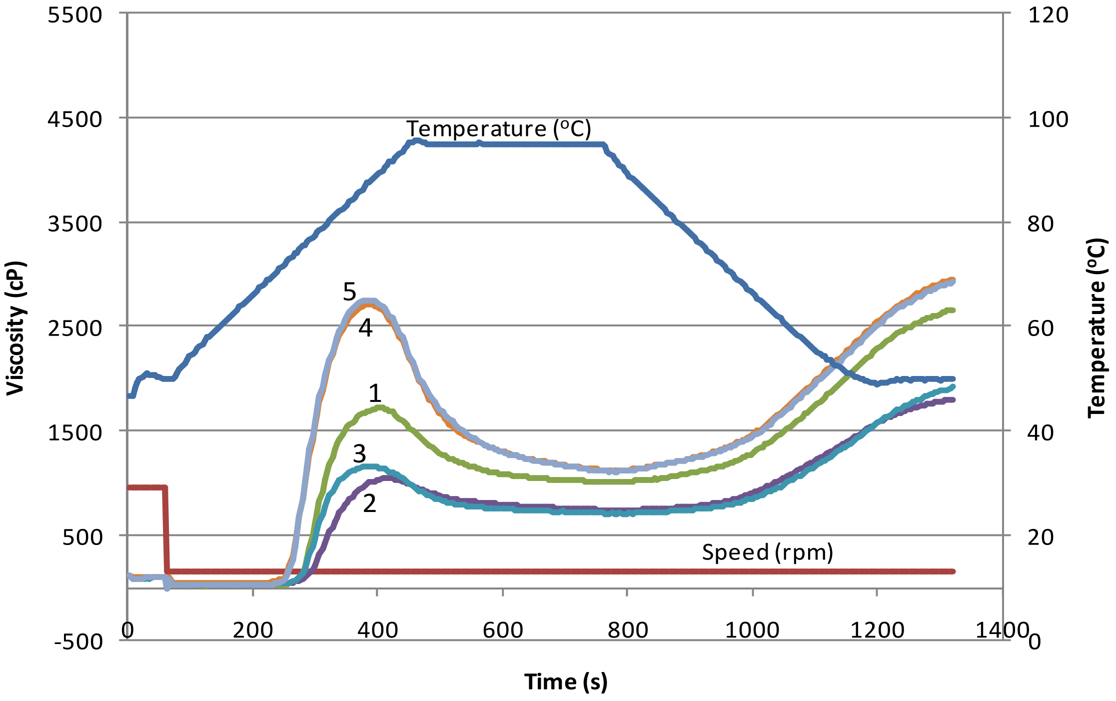

Figure 6.4 – The pasting property profiles of five raw corn hybrids. Numbers (1-5) referred to hybrids (Table 6.1).

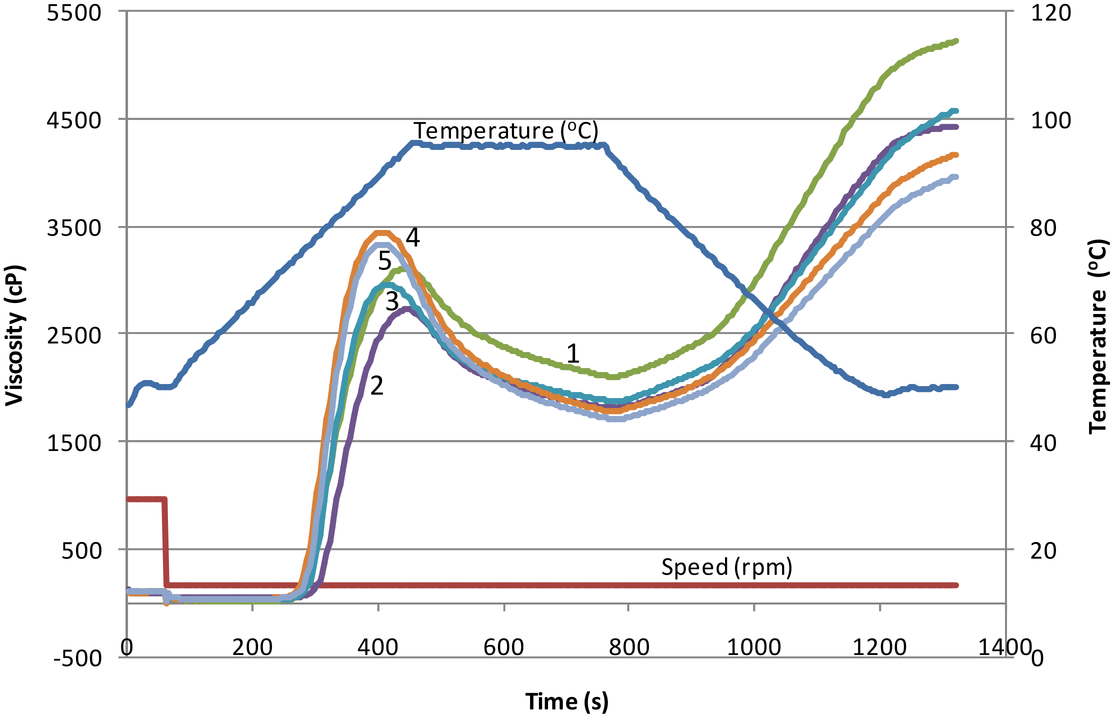

Figure 6.5 – The pasting property profiles of five alkaline cooked corn hybrids. Numbers (1-5) referred to hybrids (Table 6.1).

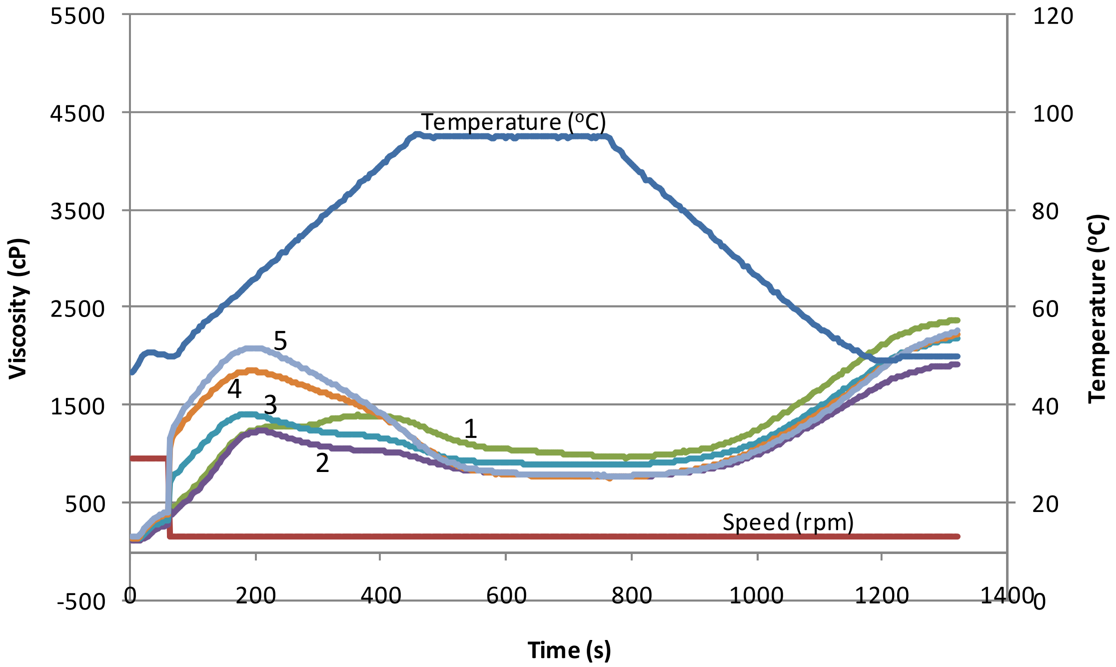

Figure 6.6 – The pasting property profiles of five tortilla samples. Numbers (1-5) referred to hybrids (Table 6.1).

modulus of deformation, distance of extensibility, and total work (Table 6.9). The highest significant force required to extend a tortilla strip by 1mm (16.29 N) was observed in tortillas from yellow hybrid 1 which was significantly higher than in tortillas from hybrids 4 and 5 (14.41 N average), and 2 and 3 (13.05 N average). When comparing force to rupture, tortillas from hybrid 1 (with the higher value: 26.89 N) and 2 (with the lower value: 21.41 N) showed significant differences, while same values for tortillas of hybrids 3,4, and 5 were similar and located in between the values for hybrids 1 and 2. Also similar relative differences were observed for work to rupture. Modulus of deformation was higher in tortillas from hybrid 5 (10.18 N/m) indicating a higher tension when extending the tortilla strip and a lower elasticity than hybrid 3 with the lowest value (8.81 N/m). No significant differences were found in distance of extensibility in all tortillas. Values describing extensibility observed in lab-made tortillas were higher than those found in tortillas from the Mexican market (Table 5.8).

Table 6.9 - Extensibility characteristics of tortillas from five hybrids [a]

Hybrid[b]	Force at 1mm (N)	Rupture Force (N)	Work Rupture (N.mm)	Modulus Deformation (N/mm)	Distance Extensib. (mm)	Total Work (Nm)
1	16.29 ± 0.46a	26.89 ± 1.13a	52.10 ± 10.43a	9.50 ± 1.04ab	2.86 ± 0.38a	68.20 ± 14.50a
2	12.96 ± 0.52d	21.41 ± 1.68b	31.95 ± 6.44b	9.03 ± 0.37ab	2.38 ± 0.26a	43.31 ± 11.71b
3	13.07 ± 0.79cd	23.58 ± 2.26ab	39.71 ± 7.29ab	8.81 ± 0.41b	2.67 ± 0.23a	52.01 ± 9.10ab
4	14.27 ± 0.59bc	24.97 ± 1.54ab	40.54 ± 4.67ab	9.68 ± 0.62ab	2.59 ± 0.19a	53.43 ± 3.65ab
5	14.55 ± 0.80b	24.95 ± 3.10ab	38.73 ± 11.58ab	10.18 ± 0.56a	2.46 ± 0.40a	50.89 ± 9.41ab

[a] Means with the same letters in the same column are not significantly different at α=0.05.
[b] See Table 6.1 fro hybrid descriptions.

Rollability data, determined by the force required to roll the tortilla and the work applied when rolling a sample for 50 mm, were similar among tortillas from all hybrids (Table 6.10). The lack of differences in rollability among tortillas from different hybrids used in this study suggests that hybrid differences, at least under the conditions used in this study, had no effect on rollability. In general, mean force to roll (1.195 N) and mean work to roll (44.717) of lab-made tortillas were higher than values found in commercial tortillas (Table 5.7), values of 0.22-0.92 N for force to roll and 10.51-33.39 N for work to roll.

Table 6.10 - Rollability characteristics of tortillas from five hybrids[a]

Hybrid[b]	Force (N)	Work (Nm)
1	1.26 ± 0.20a	46.39 ± 5.83a
2	1.05 ± 0.20a	37.82 ± 6.17a
3	1.28 ± 0.15a	48.52 ± 6.76a
4	1.08 ± 0.18a	42.01 ± 6.70a
5	1.31 ± 0.13a	48.85 ± 6.49a

[a] Numbers with the same letter in the same column are not significantly different at α=0.05.
[b] See Table 6.1 for hybrid descriptions.

Table 6.11 – P-Values for the main effects and their interaction for different analysis of corn and tortilla making process [a]

	Effect		
	Hybrid	Time	Hybrid*Time
Water uptake	<.0001	<.0001	<.0001
	Hybrid	Stage[b]	Hybrid x Stage
Proximal Analysis			
Protein	<0.0001	0.0009	0.1445
Crude fat	<0.0001	<0.0001	0.0044
Crude fibre	0.0049	<0.0001	0.0746
Moisture	<0.0001	<0.0001	<0.0001
Calcium	0.3432	<0.0001	0.2212
Cooper	0.1304	n/a	n/a
Iron	0.9182	0.0356	0.7728
Magnesium	0.374	0.5096	0.4134
Manganese	0.0155	0.348	0.4387
Phosphorus	0.2915	0.5219	0.3302
Potassium	0.0003	0.0005	0.6454
Sodium	0.2333	0.0187	0.0778
Sulphur	0.5935	0.382	0.435
Zinc	0.6218	0.4759	0.9823
Color			
L*	<0.0001	<0.0001	<0.0001
a*	<0.0001	<0.0001	<0.0001
b*	<0.0001	<0.0001	<0.0001
DSC			
Initial	0.0161	<0.0001	0.3843
Peak	<0.0001	<0.0001	0.0557
Final	0.0021	<0.0001	0.1335
Onset	0.0534	<0.0001	0.726
Entalphy	0.3507	<0.0001	0.4594
RVA			
Peak	<.0001	<.0001	<.0001
Trough1	<.0001	<.0001	<.0001
Breakdown	<.0001	<.0001	<.0001
Final Viscosity	<.0001	<.0001	<.0001
Setback	<.0001	<.0001	<.0001
Peak Time	<.0001	<.0001	<.0001
Pasting Temperature	<.0001	<.0001	<.0001

[a] Based on SAS proc MIXED.

[b] Stage referred to raw corn, nixtamal (cooked corn), and tortilla.

6.3.14 Qualitative Prediction of Quality

Comparisons of some selected physicochemical properties of lab-made tortillas with tortillas from the Mexican market (Chapter 5) helped to determine which of the five hybrids will yield tortillas with high acceptability ratings. In terms of chemical composition, tortillas from hybrid 4 and 5 (T4 and T5) had similar characteristics to tortillas H1 and S2 (Figure 6.7) from the Mexican market (Chapter 5).

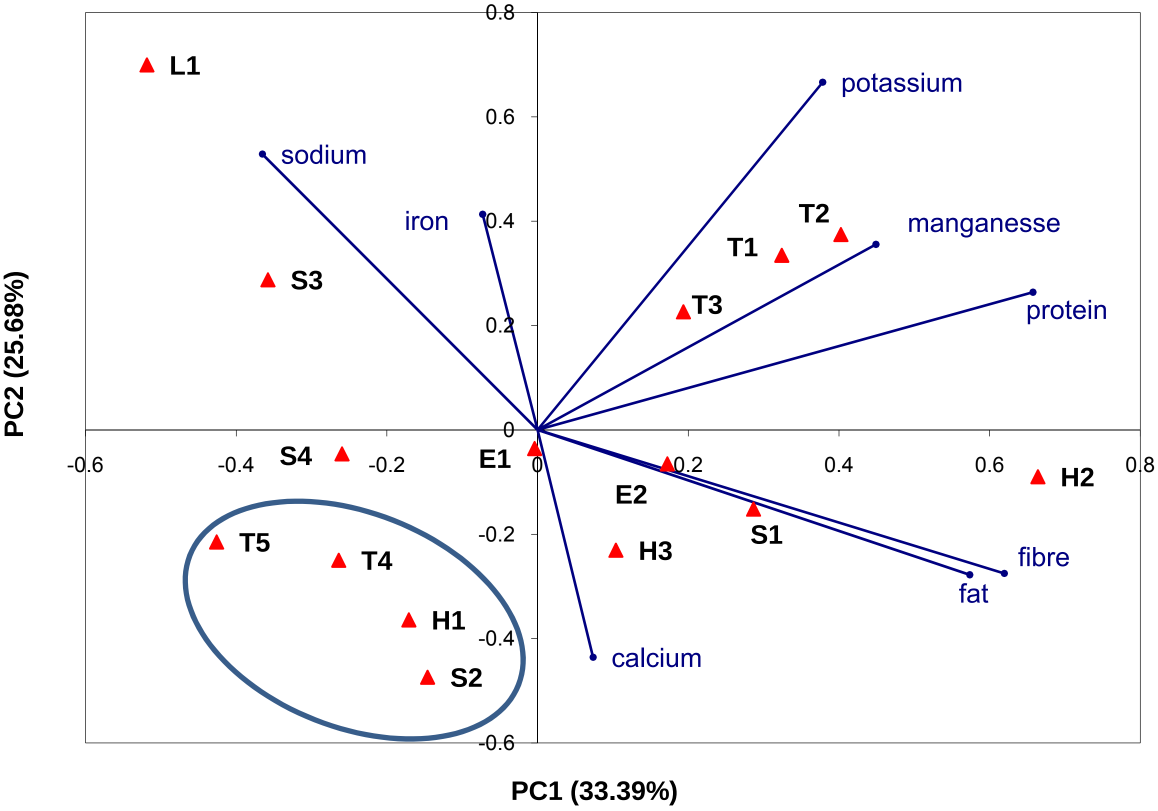

Figure 6.7 – A biplot product-attribute involving tortilla samples and chemical composition for lab-made tortillas and commercial tortillas from the Mexican market. See Tables 5.4 and 5.5 (Chapter 5) for proximate and mineral analysis of tortillas from the Mexican market, and Tables 6.4 and 6.5 for proximate and mineral analysis of lab-made tortillas. See Table 5.1 for description of samples S1, S2, S3, S4, H1, H2, H3, E1, E2, and L1. T1, T2, T3, T4, and T5 are tortillas prepared from hybrids 1-5, respectively (Table 6.1).

Also, in terms of stability during cooking observed with differential thermal analysis, hybrid 4 and 3 seemed to have more consistency showing less variations compared to hybrid 2 allowing, for a better control of overcooking. Tortillas obtained from hybrid 3, 4 and 5 (T3, T4 and T5 respectively) showed the closest values to tortillas from the Mexican market. As observed in Figure 6.8. Tortillas from hybrid 2 (T2) seemed to be different from the others.

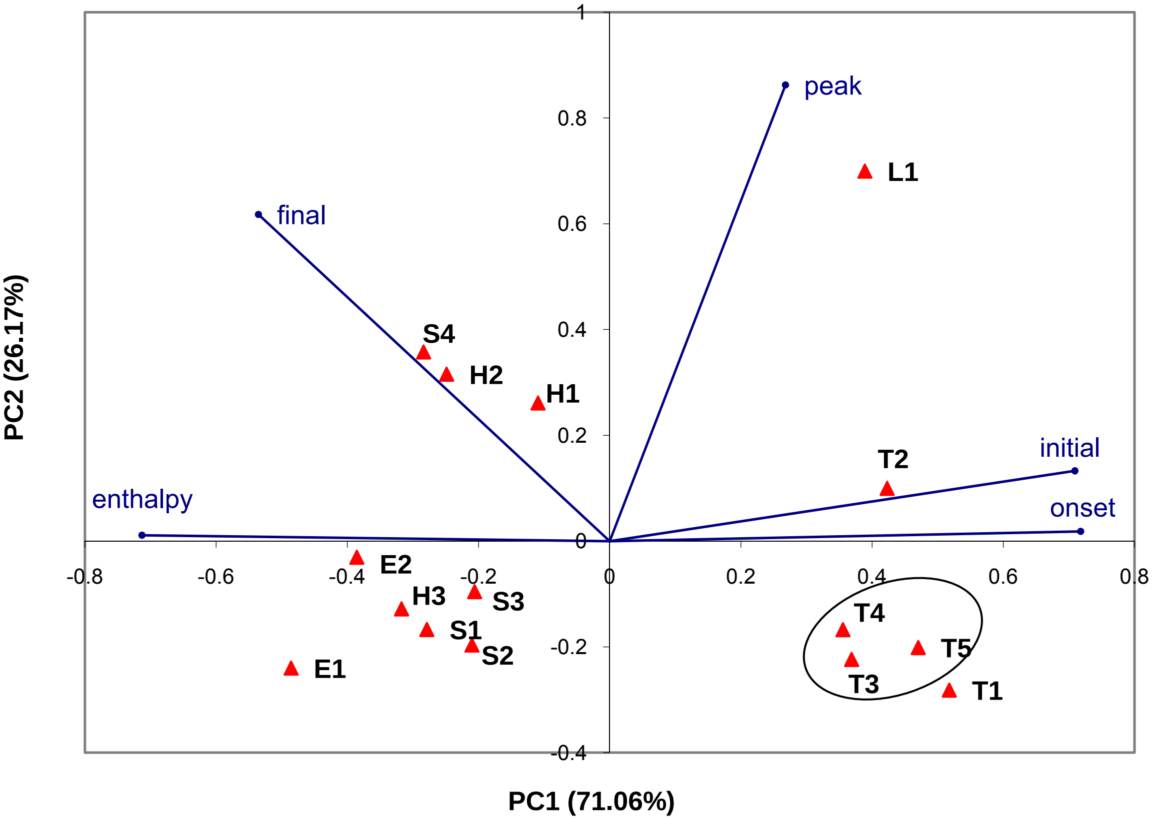

Figure 6.8 – A biplot product-attribute involving tortilla samples and thermal characteristics for lab-made tortillas and commercial tortillas from Mexican market. See Table 5.6 (Chapter 5) for DSC analysis of tortillas from Mexican market and Table 6.7 for lab-made tortillas. See Table 5.1 for description of samples S1, S2, S3, S4, H1, H2, H3, E1, E2, and L1. T1, T2, T3, T4, and T5 are tortillas prepared from hybrids 1-5, respectively (Table 6.1).

Finally, color of tortillas from white hybrids 2, 4, and 5 (T2, T4, and T5 respectively) showed closer values of L*, a*, and b* (Figure 6.9) to those from the Mexican market, indicating a good potential for matching with the tortillas (S2 and H2) with higher acceptability by consumers (Table 5.2). Based on Figures 6.7, 6.8, and 6.9, it is likely that hybrids 4 and 5 may yield tortillas with high acceptability ratings. However, more research need to be done to confirm this speculation.

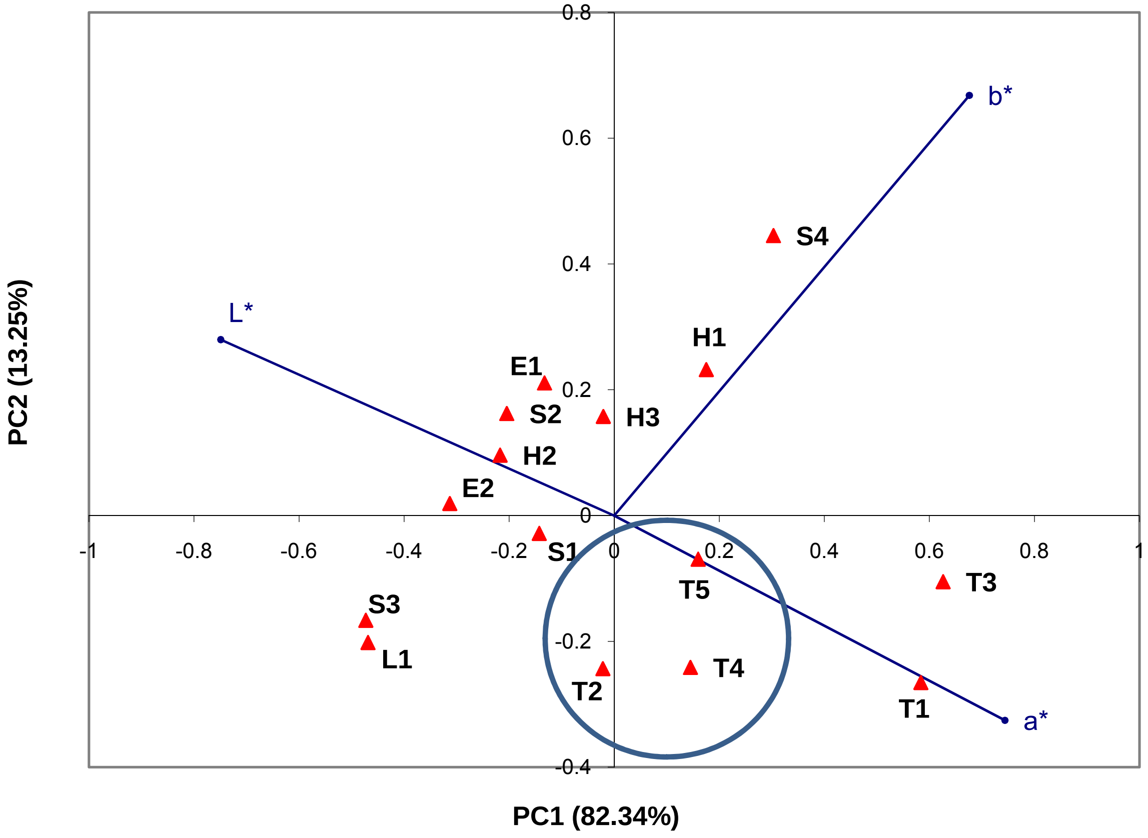

Figure 6.9- A biplot product-attribute involving color in lab-made tortillas and commercial tortillas from Mexican market. See table 5.7 (Chapter 5) for color characteristics from commercial tortillas and Table 6.6 for lab-made tortillas. See Table 5.1 for description of samples S1, S2, S3, S4, H1, H2, H3, E1, E2, and L1. T1, T2, T3, T4, and T5 are tortillas prepared from hybrids 1-5, respectively (Table 6.1).

6.4 Conclusions

Corn kernel of hybrids varied in terms of physical and chemical characteristics. Both hybrid and processing stage (raw, nixtamalized corn, and tortilla) generally had significant effects on proximate composition, color, thermal (DSC), and pasting (RVA) properties. Physical characteristics related to kernel structural composition and hardness affected water uptake and cooking performance, and showed further effects on textural properties such as extensibility. Information obtained from this study is helpful for the selection of corn hybrids for tortilla production. However, further studies should also be conducted on processing in order to determine how processing conditions can be modified to produce tortilla products oriented to satisfy consumer acceptance.

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CHAPTER 7

SUMMARY, CONCLUSION, AND RECOMENDATIONS

Corn tortilla has turned from being a staple food prepared at a household level to an international ethnic food produced industrially. Although there are many advantages from industrial production of corn tortilla such as yield and shelf life, the disadvantages (such as the undesirable sensory quality) are evident resulting in a low acceptance of industrially produced tortilla by consumers. Given the paramount importance of this product for Mexico and Central American countries and the recent increase in the consumption of tortilla in other countries such as the United States, this work was devoted to determining (1) the sensory attributes driving consumer acceptance and purchase intent, (2) the differences of these sensory drivers among two Mexican consumer segments with different life style (education/profession), (3) the relationships of sensory attributes with chemical and instrumental analysis, and (4) the effect of corn hybrid characteristics on physicochemical properties of raw, cooked, and tortilla as related to sensory acceptability of tortilla.

The first study demonstrated that overall acceptance of tortilla products was influenced by overall liking and chewiness, while purchase intent was influenced by overall liking, taste, chewiness, rollability, and overall appearance. The second study showed that differences in the drives of acceptance and purchase intent among two consumer segments (faculty/graduate students vs. field laborers) exist. It was observed, in general, that both segments of consumers preferred the same samples and they used the same attributes to differentiate samples. However, field laborers were more discriminative and demanding in the tortilla attributes they took into account to judge overall product acceptance and purchase intent. The third study demonstrated that to some extent instrumental readings and chemical characteristics of tortilla could be correlated with levels of attribute acceptability of corn tortilla. Values of moisture content, crude fat content, sulphur content, force to extend a tortilla strip and work and force to roll a piece of tortilla were the measurements that had more tendencies of being related to hedonic ratings of tortilla. The last study was conducted using five different varieties of corn and a fixed cooking method to compare the effects of hybrids on the tortilla quality, particularly physical and chemical characteristics. Differences in corn hybrids influenced changes during cooking (such as transition enthalpy), as well as the resulting physical and chemical characteristics of tortilla products that may be related to sensory acceptability (such as color).

In conclusion results from this dissertation can be used by tortilla manufacturers in order to improve the sensory acceptability of tortilla products and to select corn hybrids that are suitable for tortilla making. However, there is still a need to conduct more research on how different processing conditions affect the sensory acceptability of the tortilla products.

APPENDIX 1

QUESTIONNAIRE

A. Age ? (Select one)

18- 24 years ____25-34 years ____ 35-44 years ____ 45-54 years ____ More than 55 years __

B. Gender? Male _____ Female_____

C. Which is the main characteristic of tortilla affecting your acceptance? (Select one)

☐ Overall appearance
☐ Color
☐ Thickness
☐ Rollability
☐ Resistance to tearing
☐ Chewiness
☐ Taste
☐ Aroma
☐ Aftertaste
☐ Overall Liking

SAMPLE _____

1. How would you rate the OVERALL APPEARANCE of this product?

Dislike Extremely	Dislike Very much	Dislike Moderately	Dislike Slightly	Neither Like nor Dislike	Like Slightly	Like Moderately	Like Very much	Like Extremely
[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]
1	2	3	4	5	6	7	8	9

2. How would you rate the COLOR of this product?

Dislike Extremely	Dislike Very much	Dislike Moderately	Dislike Slightly	Neither Like nor Dislike	Like Slightly	Like Moderately	Like Very much	Like Extremely
[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]
1	2	3	4	5	6	7	8	9

3. How would you rate the THICKNESS of this product?

Dislike Extremely	Dislike Very much	Dislike Moderately	Dislike Slightly	Neither Like nor Dislike	Like Slightly	Like Moderately	Like Very much	Like Extremely
[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]
1	2	3	4	5	6	7	8	9

4. How would you rate the ROLLABILITY of this product?

Dislike Extremely	Dislike Very much	Dislike Moderately	Dislike Slightly	Neither Like nor Dislike	Like Slightly	Like Moderately	Like Very much	Like Extremely
[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]
1	2	3	4	5	6	7	8	9

5. How would you rate the RESISTANCE TO TEARING of this product?

Dislike Extremely	Dislike Very much	Dislike Moderately	Dislike Slightly	Neither Like nor Dislike	Like Slightly	Like Moderately	Like Very much	Like Extremely
[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]
1	2	3	4	5	6	7	8	9

6. How would you rate the CHEWINESS of this product?

Dislike Extremely	Dislike Very much	Dislike Moderately	Dislike Slightly	Neither Like nor Dislike	Like Slightly	Like Moderately	Like Very much	Like Extremely
[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]
1	2	3	4	5	6	7	8	9

7. How would you rate the OVERALL FLAVOR of this product?

Dislike Extremely	Dislike Very much	Dislike Moderately	Dislike Slightly	Neither Like nor Dislike	Like Slightly	Like Moderately	Like Very much	Like Extremely
[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]
1	2	3	4	5	6	7	8	9

9. How would you rate the AFTERTASTE of this product?

Dislike Extremely	Dislike Very much	Dislike Moderately	Dislike Slightly	Neither Like nor Dislike	Like Slightly	Like Moderately	Like Very much	Like Extremely
[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]
1	2	3	4	5	6	7	8	9

10. How would you rate the OVERALL LIKING of this product?

Dislike Extremely	Dislike Very much	Dislike Moderately	Dislike Slightly	Neither Like nor Dislike	Like Slightly	Like Moderately	Like Very much	Like Extremely
[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]
1	2	3	4	5	6	7	8	9

11. Is this product ACCEPTABLE? YES [ ] NO [ ]

12. Would you BUY this product if it were commercially available? YES [ ] NO [ ]

APPENDIX 2

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