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Calcium analysis and sensory evaluation of amaranth-enriched corn tortillas

Rebecca Jane Buckner

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I am submitting herewith a thesis written by Rebecca Jane Buckner entitled "Calcium analysis and sensory evaluation of amaranth-enriched corn tortillas." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Food Science and Technology.

Marjorie P. Penfield, Major Professor

We have read this thesis and recommend its acceptance:

Sharon Melton, John Mount

Accepted for the Council:
Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

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Date April 29, 1993

CALCIUM ANALYSIS AND SENSORY EVALUATION OF AMARANTH-ENRICHED CORN TORTILLAS

A Thesis
Presented for the
Master of Science
Degree
The University of Tennessee, Knoxville

Rebecca Jane Buckner
May 1993

DEDICATION

This thesis is dedicated to my family
whose love and support
made higher education an attainable goal.

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ABSTRACT

Tortillas represent 67% of the daily calories consumed in some countries. Increasing lime level for soaking corn and adding amaranth (high-calcium, high-protein) to tortillas should improve nutritional value. The objectives of this research were to evaluate the nutritive content and sensory acceptability of amaranth-enriched corn tortillas.

Corn (yellow or white) was soaked for 24 hr in limewater (1, 2, or 3% corn weight basis), ground with a stone grinder, formed into masa balls containing 0, 15, or 30% amaranth, pressed into tortillas with a hydraulic laboratory press, and baked on a griddle (236°C). Judges (25) evaluated texture, color, flavor, and overall acceptability of tortillas on 9-point hedonic scales (9=like extremely) in a laboratory study. Panelists (28) also evaluated texture, color, flavor, and overall acceptability of a laboratory-produced and a commercially-produced tortilla in a home placement study. Proximate composition and calcium levels were determined. All data were analyzed by ANOVA.

Texture acceptability increased as lime level increased but was not affected by amaranth level or corn cultivar. Color acceptability decreased as lime level and amaranth level increased. Flavor acceptability was not affected by amaranth level but decreased as lime level increased.

Overall acceptability of the tortillas increased with lime level but was not affected by amaranth. Yellow corn tortillas were more acceptable than white corn tortillas for all attributes except texture. No significant differences were found between the acceptability of the laboratory-produced and the commercially-produced tortilla.

Tortilla moisture increased as lime increased and as amaranth decreased. Fat content was approximately 7% (dry matter basis) and did not vary with treatment. Protein increased with amaranth content and was higher for white corn tortillas. The pH increased as lime level increased but was not affected by amaranth level or corn cultivar. Ash increased with lime level and amaranth level and was significantly higher in white corn.

Experimental methodology made it hard to accurately measure the contribution of the amaranth to the calcium levels of the tortillas. However, an interaction between amaranth and lime for calcium indicated that amaranth might contribute to calcium content in low-lime (< 1%) tortillas.

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CHAPTER I

INTRODUCTION

The 1987-1988 Nationwide Food Consumption Survey (Peterkin et al., 1988) indicated that 96% of all individuals consumed grain products on a daily basis and that consumption was increasing (Tippett and Riddick, 1991). In fact, rice, wheat, and corn are the leading food staples for the world population; people depend on cereals for calories, carbohydrates, and protein more than any other group of food (Gilles, 1990). Cereals are also a vital food resource because they have a reasonable storage life and are easily transported.

Because of their importance and widespread consumption, grains provide an excellent vehicle for enrichment and fortification. Studies indicate that grain products presently provide 32, 18, 20, and 19% of the total U.S. intakes of thiamine, riboflavin, niacin, and iron, respectively (Cook and Welsh, 1987). Grains can also be fortified specifically to meet certain situational or geographical deficiencies.

Tortillas are used as a bread substitute in Central America and provide approximately 65% of daily calories and 69% of the daily calcium intake in some regions (Bressani, 1991). Tortillas are made using a traditional cooking method involving soaking corn in lime water to form a dough or masa; this process is called nixtamalization (Bedolla and Rooney, 1982). The addition of lime to the corn dough is the sole source of calcium for many tortilla consumers (Bass, 1984).

The amount of lime added to the corn and water mixture varies from 1-5% (corn weight basis) depending on the geographical region and traditional custom (Gomez et al., 1989; Martinez-Herrera and Lachance, 1979). Although traditionally tortillas have been considered to be a good source of calcium (Anon., 1988), Saldana and Brown (1984) found the calcium content of tortillas to be highly variable (90-200 mg/100 g) and dependent upon the preparation method.

Amaranth is a pseudocereal and is native to Central and northern South America (Breene, 1991). The 60 species of amaranths are cultivated as vegetables, grains, and as forage for animals (Becker, 1989; Sanchez-Marroquin et al., 1986). The grain is higher in protein, fat, fiber, and several minerals than most conventional cereal grains (Becker, 1989; Teutonico and Knorr, 1985). The fact that amaranth is not lysine deficient makes it ideal for use in combination with other grains to improve product protein quality (Walters, 1987).

Most published research on the seed or the whole-grain flour has been aimed at improving the protein quality of the food into which it was incorporated. As stated before, amaranth is higher in several minerals, particularly calcium, than most other grains (Becker, 1989). Amaranth has been used successfully to enrich the protein in corn tortillas with no significant change in the sensory characteristics of the product (Sanchez-Marroquin et al., 1987). However, no studies have been found in which amaranth was used specifically to improve the calcium or mineral content of grain products.

By enriching corn tortillas with amaranth flour, it could be determined if amaranth incorporation increases the calcium content of the final product. Sensory studies in combination with objective measurements are also important to determine the acceptability of the amaranth/corn tortillas. Information from such a study could be helpful in improving the market value of grain amaranth and also could provide a potential solution to the growing problem of calcium deficiency in some underdeveloped countries.

The objectives of this study were as follows:

(1) To investigate the acceptability of tortillas made with different ratios of amaranth flour to corn masa, different cultivars of corn, and different lime levels for soaking the corn.

(2) To investigate the acceptability of tortillas produced in the laboratory with lime, corn, and water and tortillas produced commercially with lime, corn, and water.

(3) To determine calcium, crude protein, crude fat, ash, pH, and moisture levels in tortillas made with different ratios of amaranth flour to corn masa, different cultivars of corn, and different lime levels for soaking the corn.

CHAPTER II

REVIEW OF LITERATURE

Tortillas

Tortilla production is one of the oldest food industries in Mesoamerica and provides the backbone for many other maize-based commodities (Bedolla and Rooney, 1982). Maize or corn was cultivated in central Mexico as early as 5000 years ago and was instrumental in the rise of the great Mesoamerican civilizations in that same area (Katz et al., 1974). According to Serna-Saldivar and coworkers (1990), the Aztecs and the Mayans both worshiped "corn" gods which represented the welfare of their populations.

Converting corn into tortillas involves alkaline cooking or nixtamalization (Serna-Saldivar et al., 1990). Traditional alkaline sources are lime, lye, or wood ashes. Lime was the customary source in Mexico and there is evidence of lime cooking in Mexico as early as 100 BCE (Katz et al., 1974). Archaeologists have hypothesized that alkaline cooking came about as a means to soften the tough hulls of corn kernels and/or as a digestive aid. There also appears to be a connection between populations that cultivated corn and utilized alkaline cooking techniques and greater sustainability of life and, therefore, more potential for growth and expansion (i.e. the ancient Aztec and Mayan civilizations) (Katz et al., 1974).

Tortilla Production

Corn can be converted to table or taco tortillas (Bedolla and Rooney, 1982). Martinez-Herrera and Lachance (1979) reported that the table tortilla production process is highly variable and the end result is dependent upon the type of corn, proportion of water to corn, lime concentration, cooking time, and cooking temperature. Traditional tortilla production methods (Bedolla and Rooney, 1982; Bressani et al., 1958; Khan et al., 1982; Paredes-Lopez and Saharopulos-Parades, 1983; Serna-Saldivar et al., 1990) combine 1 part corn with 2-3 parts water and 0.5-5.0% lime (corn weight basis). The mixture is then heated to 85-100°C for 5-60 min and allowed to steep for 8-20 hr forming the nixtamal. After steeping the nixtamal is drained and rinsed three times and then ground in a stone grinder to form a masa or corn dough. The masa is hand-shaped into balls (28-30 g) and flattened to form a round approximately 15 cm in diameter. The tortilla is baked on a griddle or comal (hot rock) at 190-260°C for 1.5-4 min. Taco tortillas are produced in the same manner as table tortillas but are deep-fat fried following baking; these products include tacos, tostadas, nachos, and enchiladas (Bedolla and Rooney, 1982; Paredes-Lopez and Saharopulos-Parades, 1983).

Several methods are currently being used to produce corn tortillas (Bedolla and Rooney, 1982). The first is the aforementioned traditional method. The second is a steam-cooking procedure in which steam is injected directly into a corn and lime solution and serves both to heat and agitate the mixture. Depending upon the type of equipment used, the steam-cooking system can operate near the boiling point or more slowly at about 85°C (Serna-Saldivar et al., 1990). Both steam-cooking systems are temperature-controlled and are highly efficient and consistent (Serna-Saldivar et al., 1990). However, the steam procedure produces tortillas that were judged to be too rubbery (Bedolla and Rooney, 1982).

The third method of tortilla production is the pressure-cooking procedure (Bedolla and Rooney, 1982). Also called the continuous cooker, this system employs a continuous feed of corn kernels into a lime solution under pressure. The lime solution is forced upwards through the kernels which removes the pericarp. The resultant nixtamal is ground into masa; the entire process takes only 5-7 hr and requires much less labor and equipment than the other procedures (Bedolla and Rooney, 1982; Serna-Saldivar et al., 1990). Although it is efficient and is the only method that recycles the lime wastewater, the pressure-cooking procedure is rarely used because the tortillas produced are rubbery, sticky, and pale (Bedolla and Rooney, 1982; Khan et al., 1982).

The fourth and final method for producing tortillas is extrusion (Bedolla and Rooney, 1982). This is the most often used commercial process; this process involves little or no steeping in most cases (Khan et al., 1982). Corn and a lime and water solution are mixed, ground, and extruded until a masa of appropriate consistency is reached; this consistency is usually achieved when the masa is approximately 18-20% moisture (Bedolla and Rooney, 1982; Serna-Saldivar et al., 1990). Tortillas made from extruded masa compare favorably with tortillas produced by the traditional method (Bedolla and Rooney, 1982).

The major drawback of all tortilla-making procedures is the lack of a definitive, optimal tortilla for which to strive (Bedolla and Rooney, 1982). Scaling of ingredients notwithstanding, the appropriate cooking time is considered to be the most crucial variable in producing the "perfect" tortilla (Bedolla and Rooney, 1982; Martinez-Herrera and Lachance, 1979). Several methods have been proposed with which to determine the appropriate cooking time. Bedolla and Rooney (1982) have suggested using masa moisture content or viscosity as an indicator; however, the optimal moisture content and viscosity change as the ingredients change.

After noting the highly variable processes used to produce tortillas, Martinez-Herrera and Lachance (1979) stated that a linear relationship exists between raw kernel hardness (peak compression force) and time at the terminal point of cooking. Their equation takes into account lime concentration, cooking temperature, and moisture content of the raw kernels. Although accepted at first, this equation eventually fell into disuse because it is based on a standard endosperm hardness within a particular variety when, in reality, there is much variation in endosperm hardness within variety (Bedolla and Rooney, 1982).

Khan and coworkers (1982) suggested a method for determining optimum cooking time which is still being used and modified. This method measures the nixtamal shear force (NSF) which is a force displacement curve created by the Instron when 30 g of nixtamal is extruded through a cone and a die shear cell. However, there is no universal "ideal" NSF value and it is left to the individual investigator to define his/her own ideal NSF. Serna-Saldivar et al. (1990) found problems with all methods for determining optimal cooking time and concluded that the best method was still the knowledgeable touch of an experienced masa miller.

Although corn tortillas are the focus of this research, wheat can also be used to produce flour tortillas (Saldana and Brown, 1984). Flour tortillas are customarily made with enriched, unbleached flour, baking powder, salt, and shortening (Bello et al., 1991). Three methods are used in the production of flour tortillas; the tortillas can be hot-pressed, hand-stretched, or die-cut. The hot-press method results in the softest and most desirable tortillas (Bello et al., 1991). Much of the current research on flour tortillas involves increasing fiber content which improves the machinability and shelf-stability of the tortilla and increases the perceived health benefits of the product (Friend et al., 1992).

Tortilla Nutritive Value

The alkaline cooking process actually decreases the overall nutrient content of the corn, while it increases the nutritive quality of the corn (Paredes-Lopez and Saharopulos-Parades, 1983). Cravioto et al. (1945) found that alkaline cooking of corn caused a reduction in carotene, thiamine, riboflavin, niacin, and nitrogen in laboratory experiments. These results were duplicated by Bressani and coworkers (1958) in a study of corn tortillas produced by two Guatemalan families in a highland Indian village. However, the lime treatment of the corn also resulted in a 2010% increase in calcium content and a 15% and 37% increase in phosphorus and iron contents, respectively (Cravioto et al., 1945). Alkaline cooking improved protein content by enhancing the balance of essential amino acids, in particular the leucine:isoleucine ratio, and released niacin that was previously unavailable (Bressani and Scrimshaw, 1958; Katz et al., 1974); however, approximately 30% of that niacin was subsequently lost (Cravioto et al., 1945).

Structural damage during liming results in the removal of the outermost layer of the kernel during washing and subsequent loss of vitamins during the steeping and grinding steps. The attachment to the endosperm of the semi-permeable aleurone layer prohibits additional nutrient loss from the kernel (Paredes-Lopez and Saharopulos-Parades, 1983). A decrease in the pH of the masa has been shown to improve vitamin retention (Saldana and Brown, 1984). The overall increase in nutritive quality of the alkaline-cooked product despite some vitamin loss provided a potential explanation for the improved growth of rats fed tortillas as compared to raw corn (Bressani and Scrimshaw, 1958).

The nutritional composition of tortillas is very important because maize, usually tortillas, provides 70% of the calories and 50% of the protein in a daily diet in rural areas of Mexico (Katz et al., 1974). Tortillas are used as a bread substitute in Mexico and the average annual tortilla consumption per capita is 120 kg (Paredes-Lopez and Saharopulos-Parades, 1983). Wheat tortillas are nutritionally comparable to bread, but corn tortillas are deficient in protein and the vitamins found in enriched flour (Saldana and Brown, 1984). Tortillas are also the sole source of calcium for many consumers (Bass, 1984; Cravioto et al., 1945; Feria-Morales and Pangborn, 1983; Saldana and Brown, 1984). Since they are a staple food in Mexico, it is important that tortillas continue to provide or be fortified to provide adequate nutrients for consumers of all ages (Katz et al., 1974).

One immediate threat to the traditional nutritional composition of the corn tortilla is the rising popularity of instant dry corn masa flours (Molina et al., 1977). The tortilla-producing industry in Mexico now uses the instant masas almost exclusively (Gomez et al., 1987; Molina et al., 1977; Serna-Saldivar et al., 1990) and use is increasing at the individual level as many people prefer the convenience of the ready-made dough (Paredes-Lopez and Saharopulos-Parades, 1983). Tortillas can be produced in 30 min with the instant dough as opposed to 12-24 hr with the traditional method (Gomez et al., 1987).

Dry corn masa flours are made by preparing fresh nixtamal and then drying, grinding, sieving, and blending it to yield a shelf-stable product (Gomez et al., 1987; Serna-Saldivar et al., 1990). Cooking of the corn and the drying of the nixtamal require considerable energy input and are responsible for a large proportion of the production costs of the product (Molina et al., 1977). Drum drying and flash drying have been proposed as economical improvements to the current freeze drying techniques used to dehydrate the nixtamal (Molina et al., 1977; Paredes-Lopez and Saharopulos-Parades, 1983).

Although the instant masa would be a perfect vehicle for appropriate fortification and/or enrichment of the tortilla, the additional production cost involved in this step makes it unlikely that instant masas will ever be as nutritionally complete as traditional tortillas (Molina et al., 1977). Tortillas produced from instant masa tend to be lower in protein than traditional tortillas (Bazua et al., 1979). Tortillas produced from instant masa also tend to have an unattractive dark color attributable, in some cases, to the extrusion process used to produce the instant masa. Reducing the lime content in the steeping solution appears to solve this color problem; however, it also reduces the calcium content of the tortillas produced with instant masa (Bazua et al., 1979; Gomez et al., 1987; Molina et al., 1977). In sensory studies measuring color, flavor, odor, and texture, instant tortillas did not score as well as traditional tortillas; however, most investigators have found the decrease in production time to be worth the loss in sensory properties (Bazua et al., 1979; Bedolla and Rooney, 1984; Gomez et al., 1987; Molina et al., 1977).

Tortilla Protein Fortification

As mentioned previously, tortillas are a perfect vehicle for fortification and/or enrichment since they are a staple of the Mexican diet. In fact, protein fortification of tortillas is very important in populations that subsist primarily on maize because the protein deficiency of a maize diet is not corrected by other food components as it is in societies that subsist mainly on wheat or rice (Bressani, 1991). Several studies have been conducted to improve the nutritive quality of the tortilla, especially to improve the protein content since corn is deficient in lysine, tryptophan, isoleucine, and threonine (Bressani and Scrimshaw, 1958). In one of the earliest fortification studies, Bressani and coworkers (1962) combined the two most important staple foods in rural Central America, lime-treated corn and black beans, to try and create a combination protein that would have a higher nutritive value than either food separately. A corn/bean combination in which each was providing 50% of the total protein was found to be the best combination in growth studies on rats.

Several investigators have also used oilseed flours to enrich the protein content of tortillas. Green et al. (1976) and McPherson and Ou (1976) found that cottonseed flour supplementation up to 25% improved the protein content of tortillas as shown by amino acid analysis and rat growth studies. Sensory panelists in both studies did not detect differences between cottonseed/corn and corn tortillas. Supplementation with cottonseed flour did cause an increase in color over the control corn tortilla (Green et al., 1976). McPherson and Ou (1976) found that supplementation with cottonseed flour improved the shelf-life of the tortillas.

Tonella et al. (1983) found that supplementing corn tortillas with chickpea and sesame increased the protein content and the protein efficiency ratio (PER) of the tortillas. Acceptability of the fortified tortillas was found to be similar to that of the control. Tortillas fortified with chickpea and sesame flours demonstrated less staling during storage than did the control corn tortilla. The color of the sesame/corn tortilla was found to be unacceptable in sensory studies as the sesame seeds turned the tortilla a pale green. Tonella and coworkers (1983) also noted that the viscosity of mixtures that had undergone lime treatment increased more after 1 hr than did untreated mixtures; this phenomenon was possibly due to a calcium crosslinking which prevented starch granules and protein from swelling and collapsing.

Several investigators have fortified tortillas with soybeans (Collins and Sanchez, 1980; Del Valle and Perez-Villasenor, 1974; Green et al., 1976; Tonella et al., 1983). In all studies, the protein content of tortillas fortified with soybeans was improved. However, sensory acceptability scores for soybean/corn tortillas were lower than those for the all corn control (Collins and Sanchez, 1980; Green et al., 1976; Tonella et al., 1983). Green et al. (1976) found that the color of soy-fortified tortillas (up to 15%) essentially remained the same as the control corn tortilla.

Collins and Sanchez (1980) also fortified tortillas with cheese. Fortification with 10% cheese decreased tortilla firmness, caused small color differences, and improved flavor scores over the all corn control. The addition of cheese also improved the amino acid composition of the tortilla over that of corn alone.

Unlike most of the other foods described previously as potential tortilla fortifiers, sorghum is actually readily available in Central America (Johnson et al., 1980). Sorghum is cheaper than corn and is often used as a replacement for corn when it is not available in Central America (Johnson et al., 1980). Sorghum is currently being explored as a permanent replacement for corn in tortillas because it is cheaper, a hardier crop, and requires less cooking and steeping time (Bedolla et al., 1983; Gomez et al., 1989). Tortillas made from whole sorghum are unacceptable because they have a greenish-yellow color and, therefore, pearled sorghum is usually used to produce tortillas (Bedolla et al., 1983).

Sorghum and corn produce tortillas with very similar proximate compositions (Bedolla et al., 1983; Gomez et al., 1989; Rizley and Suter, 1977). Corn and sorghum tortillas have similar moisture, crude protein, crude fiber, starch, and mineral contents and color. However, corn tortillas have a higher ether extract (Bedolla et al., 1983). Tortillas made from sorghum alone have a higher protein content than those made from corn alone (Rizley and Suter, 1977). Bedolla and coworkers (1983) found that replacement only to 80% of corn with white or red pearled sorghum resulted in acceptable sensory scores, while Rizley and Suter (1977) reported that no significant difference was found between the acceptability of sorghum tortillas and corn tortillas. However, Serna-Saldivar and coworkers (1987) found that lime-treated sorghum is less digestible than lime-treated corn which could present a problem for children.

One of the most promising developments in the protein fortification of tortillas is the genetic engineering of maize to provide higher quality protein (Bressani, 1991). Mertz and coworkers (1964) found that opaque-2 genes of maize could be used to improve the essential amino acid content and protein balance of maize. These genes suppress the synthesis of prolamine protein which represent 45-50% of the total maize protein and are nutritionally poor. The proteins which replaced the absent prolamines had better content and balance of amino acids; this resulted in a higher lysine and tryptophan content and an improved leucine:isoleucine ratio in the maize. High-lysine genes have also been found in barley and a few sorghum lines (Bressani, 1991).

In addition to improving the protein biological value, high-lysine maize also increases niacin availability because of the high tryptophan and low leucine content (Bressani, 1991). Use of high-lysine maize results in improved carbohydrate biological utilization, higher carotene utilization, and improved calcium utilization in products processed with lime (Bressani, 1991). However, Sproule et al. (1988) reported that high-lysine maize hybrids have reduced grain yields, are more susceptible to ear rot, and are difficult to process into tortillas and corn chips. Therefore, the International Maize and Wheat Improvement Center in Mexico developed a type of high-lysine corn, called quality protein maize (QPM), with improved agronomic and processing properties without loss of nutrients (Sproule et al., 1988).

Although many chemical and nutritional studies have been conducted on tortillas, Feria-Morales and Pangborn (1983) noted that no extensive sensory measurements had been performed on tortillas. Tortillas substituted with 12, 24, and 36% of potato, 10, 20, and 30% of rice, and 5, 10, and 15% of pinto beans were evaluated using descriptors that panelists had previously developed. Descriptors were developed for appearance, aroma, manual and oral texture, flavor, and after-effects. Textural differences noted by panelists were confirmed with Instron hardness and elongation measurements. In addition to developing descriptors for sensory evaluation of tortillas, Feria-Morales and Pangborn (1983) showed that corn in tortillas can be substituted with various starches with improved sensory attributes and no loss in nutritional value.

Calcium

Tortillas provide the sole source of calcium for many maize consumers in rural Central and South America (Bass, 1984). The average Mexican consumes 280 g tortillas/ day which furnishes 500 mgs calcium/ day if the tortillas are prepared using traditional methods (Cravioto et al., 1945). The Recommended Dietary Allowance for calcium is 800 mg/day (FNB, 1989). A traditional tortilla diet, as opposed to a diet of tortillas made with instant masa, would provide slightly inadequate calcium intake according to NRC standards.

Research has shown dietary calcium to have a protective effect against high blood pressure, colon cancer, and osteoporosis (Berner et al., 1990). Therefore, adequate calcium intake is important especially for children, adolescents, and pregnant and lactating females (Berner et al., 1990).

The most important factor in determining adequate calcium intake is not the amount in the diet but the bioavailability of the source (Berner et al., 1990; Greger, 1988). Bioavailability can be determined by 4 methods: in vitro analysis, excretion patterns, nutritional status assessment, or functional tests such as growth, bone breaking strength, or enzyme activity tests (Greger, 1988). Bioavailability of calcium is also influenced by other foods consumed; research has shown that protein, sodium chloride, fiber and phytate, and fat may interfere with calcium absorption in the body, while phosphorus, lactose, and vitamin D may improve calcium absorption in the body (Greger, 1988).

The form in which calcium is consumed also is important in determining the degree of utilization (Berner et al., 1990). No differences in absorption of calcium were found among 5 different calcium salts-carbonate, acetate, lactate, gluconate, and citrate-in rats or men (Berner et al., 1990; Greger, 1988). However, the use of calcium phosphate dibasic is not recommended as a fortifier because it has been linked to kidney calcification (Berner et al., 1990). The bioavailability of calcium may also be affected by trace mineral interactions (Berner et al., 1990; Smith, 1988). Studies have shown that calcium may adversely affect the absorption of iron and zinc; however, these studies were not conclusive since trace mineral interactions are numerous and vary depending upon the composition of the meal being consumed (Smith, 1988). Experiments with rats have shown the bioavailability of calcium from tortillas to be similar to that of calcium carbonate and nonfat dry milk (Berner et al., 1990).

Serna-Saldivar and coworkers (1992) measured calcium bioavailability in rats fed diets of raw corn, raw corn with QPM, tortillas, and tortillas made with QPM. Bioavailability was determined by serum calcium levels, femur density and femur breaking strength. The femurs of rats fed tortillas weighed more, were thicker and longer, and contained more calcium, phosphorus, and magnesium than those of rats fed raw grains. The femurs of tortilla-fed rats were also denser and at least 5 times stronger than the femurs of grain-fed rats. Tortillas fortified with QPM produced the densest, strongest, longest, and thickest rat femurs with the best mineral content. Serum calcium levels reflected the results of the femur density and breaking strength tests. It was concluded that calcium from tortillas was highly bioavailable (Serna-Saldivar et al., 1992). No studies have been found on the bioavailability of calcium in amaranth.

Amaranth

One of the oldest known food crops, archaeological records show that amaranth (*Amaranthus cruentus*) was found in Tehuacan puebla, Mexico, about 4000 BCE (Singhal and Kulkarni, 1988; Teutonico and Knorr, 1985). Amaranth is believed to have been a staple food of the pre-conquest Aztecs and to have been important in their religious ceremonies, which required an annual tithe of 200,000 bu of amaranth grain to Montezuma (Saunders and Becker, 1984). Legend has it that amaranth usage dropped to zero virtually overnight when Cortez conquered the Aztecs and realized their affinity for the grain that they believed held the mystical properties of immortality. He banned cultivation and consumption of the grain and it disappeared as a staple crop in Central America (Rodale, 1991).

Amaranth is a pseudocereal that can be consumed as a grain or a vegetable (Breene, 1991). Amaranth is classified as a pseudocereal because it is a dicotyledonous broadleaf plant rather than a monocotyledonous grass (Breene, 1991; Teutonico and Knorr, 1985). The sixty members of the genus *Amaranthus* are widely scattered throughout the world in tropical, subtropical, and temperate regions (Singhal and Kulkarni, 1988). However, 3 species (*A. caudatus, A. cruentus, A. hypochondriacus*) provide most of the grain used in food products (Sanchez-Marroquin et al., 1986).

Robert Rodale (1991) lists amaranth as one of the main crops capable of preventing famine in underdeveloped countries. Amaranth is considered a potential famine-preventer because of its agronomic and nutritional properties (Rodale, 1991). Amaranth is a hardy, adaptable plant that is drought-tolerant and can thrive in areas too dry for corn or soybeans (RRC/AAI, 1990). Amaranths utilize a C_4 pathway for photosynthesis and process CO_2 more efficiently than most cereal grains which increases drought tolerance (Singhal and Kulkarni, 1988).

Amaranth is fast-growing and can tolerate low-quality soil (RRC/AAI, 1990). Amaranth provides a good yield of seeds compared to other cereal grains (RRC/AAI, 1990). When grown in monoculture, amaranth yields 3 tons of seeds/ha in 3-4 months and 4-5 tons of vegetable dry matter/ha in 4 weeks (Saunders and Becker, 1984; Singhal and Kulkarni, 1988).

Amaranth plants can reach heights over 2 m when mature with leaves ranging in color from dark green to magenta and flowers of orange, yellow, crimson, and purple (Rodale, 1991; Saunders and Becker, 1984). Amaranth grain is produced in sorghum-like influorescences. The seeds are small, 1.0-1.5 mm in diameter, and are pale beige or black (Breene, 1991). The black seeds are undesirable because of their color and are usually found on the smaller amaranths utilized as vegetables (Singhal and Kulkarni, 1988).

Vegetable amaranth can be eaten raw or cooked; the taste was reported by sensory panelists to be similar to spinach (Teutonico and Knorr, 1985). Although the leaves of all 60 species are edible, approximately 10 of the 60 species are customarily utilized as vegetable amaranths. These plants tend to be smaller than the species used as grain amaranths (Singhal and Kulkarni, 1988; Teutonico and Knorr, 1985). Vegetable amaranth is high in protein, unsaturated fatty acids, vitamins C and A, and potassium, iron, magnesium, and calcium (Saunders and Becker, 1984; Singhal and Kulkarni, 1988; Teutonico and Knorr, 1985). The leaves of the amaranth plant can also be used to produce a red-violet pigment used as a natural food coloring (Singhal and Kulkarni, 1988; Teutonico and Knorr, 1985).

Amaranth is utilized as a grain far more than as a vegetable; traditional grain amaranth foods are still consumed in Central and South America, India, and the Himalayas (Breene, 1991; Teutonico and Knorr, 1985). Most of these foods combine roasted or popped amaranth seeds with syrup to form a confection or with water to form a gruel. In the Himalayas, whole-seed amaranth flour is used to make chapatti-like pancakes (Breene, 1991; Teutonico and Knorr, 1985).

Grain amaranth is higher in fat (5.6-8.1%), crude fiber (3.2-5.8%) and protein (15.3-18.2%) than most other cereal sources (Breene, 1991). Amaranth is a superior protein source because lysine is not the limiting amino acid in amaranth which makes it ideally suited for blending with other grains to improve product protein quality (Becker, 1989; Walters, 1987). Amaranth can also be used by persons with grain allergies as a substitute for other cereals because it contains no gluten (Saunders and Becker, 1984). Although it is deficient in thiamin, amaranth has approximately 3 times as much iron and calcium as other conventional cereal grains (Becker, 1989).

Becker and coworkers (1981) analyzed the composition of 10 samples of grain amaranth. In addition to protein, fat, fiber, and calcium, amaranth was found to be higher in ash and sodium than most other grains. Leucine was found to be the limiting amino acid in amaranth. Sucrose was determined to be the most abundant free sugar and starch the most abundant carbohydrate component (62% of the total grain weight). Amaranth starch had less amylose than wheat, was less viscous, had higher water-binding values and higher gelatinization temperatures (Becker et al., 1981). Oleic and linoleic were the most abundant fatty acids and high levels of squalene were detected.

Morphological studies have shown that an amaranth seed consists of a seed coat surrounding an endosperm with a starchy perisperm in the center (Irving et al., 1981). The embryo is campylotropous and contains spherical bodies embedded in a spongy matrix. The spherical bodies appear to contain proteinaceous material and be embedded in a lipid-like matrix. The perisperm is made up of starch granules containing amylopectin (Irving et al., 1981).

Betschart and coworkers (1981) used a barley pearler to successively mill amaranth seeds to determine the nutrient distribution within the seed. The nutrients were found to be highly concentrated in the seed coat-embryo fraction. This fraction contained 2.3-2.6 times as much nitrogen, fat, fiber, and ash, 2.4-3.0 times as much thiamin, riboflavin, and niacin, and 1.4-2.5 times as much calcium, sodium, and magnesium as the remainder of the seed. Iron was mostly concentrated in the embryo portion of the seed. Betschart et al. (1981) also found that hot-air popping did not affect the nutritional content of the seeds.

Like many other seeds, amaranth can be used to produce a plant oil (Becker, 1989; Breene, 1991; Saunders and Becker, 1984). Pale amaranth seeds are used to produce the best oil. The fatty acid composition of refined amaranth oil was found to be similar to wheat germ, oat, and rice bran oil in that it contains 77% unsaturated fatty acids and is rich in linoleic oil (Becker, 1989). The most abundant sterol in amaranth oil is spinasterol. In digestibility studies, amaranth oil was found to be less digestible than cottonseed oil (Becker, 1989). Although amaranth oil was found to contain considerable amounts of squalene, no deleterious effects of increased squalene have been reported in studies (Becker, 1989). Amaranth can be easily converted into a usable plant oil; however, the cost of the raw material makes it unlikely that amaranth will be utilized in this manner in the near future (Becker, 1989; Breene, 1991).

Several investigators have studied the baking potential of amaranth flour and its air-classified fractions (Becker et al., 1986; Lorenz, 1981; Mendoza and Bressani, 1987; Paredes-Lopez et al., 1990; Sanchez-Marroquin et al., 1985). Becker and coworkers (1986) found that the nutrient distribution within the amaranth seed made it possible to produce flours with different nutritional properties by changing the gap setting on a stone mill. With the four gap settings tested, it was possible to produce four flours with differing and reproducible nutritional properties. The only procedural limitation found was that milling moisture content of the flour must be below 17.8% for the seeds to pass through the mill.

Lorenz (1981) characterized the starch and the baking potential of amaranth flour. Amaranth starch was found to be small, angular, and polygonal. Amaranth flour was found to have higher water absorption and retention and lower paste viscosity than wheat flour. Shorter mixing times are necessary when using an amaranth composite flour. Lorenz (1981) reported that breads had lowered volumes when wheat flour was substituted with amaranth flour at levels of 10% or higher. However, sensory panelists preferred the nutty flavor of the amaranth-enriched breads to the white bread control.

Amaranth flour can also be produced by extrusion (Mendoza and Bressani, 1987). Extruded flour was found to contain more protein and fat than raw flour. Available lysine was not affected by the extrusion process. The overall protein quality of amaranth flour was improved by the heating process; this could be explained by the presence of a heat-labile growth inhibitor in the amaranth or a heat-dependent increase in nutrient availability (Mendoza and Bressani, 1987). Extruded flours had higher water absorption and retention, decreased viscosity, and more damaged starch than did raw flours.

High-protein amaranth flour was produced by both air-classification and enzymatic solubilization (Paredes-Lopez et al., 1990; Sanchez-Marroquin et al., 1985). Air-classified high-protein amaranth flour was added to bakery products, muffins, and cookies. Mexican children asked to do sensory evaluation of the products found them acceptable and, for certain properties, an improvement over the products without amaranth flour. Sanchez-Marroquin and coworkers (1985) found that high-protein amaranth flour could be used as a protein supplement in school lunches without altering the acceptability of the products into which it was incorporated.

Paredes-Lopez et al. (1990) produced high-protein and carbohydrate-rich amaranth flours enzymatically. Using alpha-amylase and glucoamylase, high-protein amaranth flour yields were 38-39% and carbohydrate-rich fraction yields were 55-56%. The high-protein fraction can be used as an extender in soups, baking products, and flavored drinks, while the carbohydrate-rich fraction can be converted to a high-fructose syrup (Paredes-Lopez et al., 1990). Enzymatic solubilization is an efficient means of producing high-protein amaranth flour.

Although amaranth is touted as providing excellent nutritional value in a grain, Ologunde and coworkers (1991) hypothesized that the iron in amaranth might not be bioavailable because of the negative influence of phytates and tannins. Phytates chelate metallic ions and tannins interfere with protein digestibility. Rat growth studies were used to compare amaranth grain fortified with ferrous fumerate to unfortified amaranth and to a casein control fortified with ferrous fumarate. Weight gain by rats fed the fortified amaranth diet was significantly higher than weight gain by rats on unfortified or control diets (Ologunde et al., 1991). Phytates and tannins in the grain did not interfere with the bioavailability of the fortified iron.

As amaranth is a good source of protein, fiber, and several minerals, it is a logical vehicle for fortification of foods. Sanchez-Marroquin et al. (1986) combined whole amaranth and air-classified protein and starchy portions of amaranth flour with wheat and oats in an effort to improve infant formula. Mixed in 50:50 or 40:60 (amaranth:wheat or oats) blends, the PER and the mineral content of the whole amaranth and the air-classified protein fraction blends with oats were found to be suitable to produce low-cost infant formulas.

One study was found in which amaranth was used to enrich corn tortillas. Sanchez-Marroquin and coworkers (1987) combined whole amaranth flour and air-classified protein and starchy fractions with instant masa to try and improve the protein quality of corn tortillas. The methodology used in combining the amaranth with the instant masa is unclear and, therefore, the extent to which the corn masa was substituted with amaranth flour is not known. The investigators found that, although lysine content decreased in the samples, the overall PER was improved by substitution with amaranth. Fat and linoleic acid contents were also improved by substitution, but no significant change was found in mineral content. Sensory evaluation of the appearance, aroma, texture, flavor, and aftertaste of the tortillas revealed no significant differences between the instant masa reference and the tortillas substituted with amaranth flour (Sanchez-Marroquin et al., 1987).

CHAPTER III

MATERIALS AND METHODS

In order to evaluate the effects of lime level, corn cultivar, and amaranth to masa ratio on nutritive value and acceptability of tortillas, the 3 factors were studied in an experiment with a completely randomized, incomplete block design (Appendix A (Evolutionary Software, Inc., 1991)). The experiment involved 3 lime levels (1%, 2%, and 3% corn weight basis), 2 corn cultivars (Asgrow 405Y (yellow) and Asgrow 405W (white)), and 3 amaranth to masa ratios (0:100, 15:85, and 30:70). Each treatment combination was replicated three times and interspersed in the design.

The tortillas were formulated by combining 1 part yellow or white corn (Corn Processors, Inc., Uvalde, TX), the appropriate lime (Tom's Snack Foods, Inc., Knoxville, TN) level, and 3 parts deionized water (Bedolla and Rooney, 1982). The mixture or nixtamal was heated in a 2.8-L sauce pan and allowed to boil for 20 min. The nixtamal was transferred to a 2000-mL beaker immediately following boiling, covered, and left to steep for 24 hr.

After steeping, the nixtamal was drained and rinsed with approximately 3000 mL of deionized water. The nixtamal was ground using a hand-cranked Corona mill with a stone grinding attachment (R&R Mill Co, Inc., No. 4CKC, Smithfield, Utah). Following grinding, either 0, 27, or 54 g (based on masa weight of 180 g) of hydrated amaranth flour (Arrowhead Mills, Inc., Hereford, TX) was combined with the masa using a LeChef food processor with a metal blade (Sunbeam Corp., No. 14-11, Chicago, IL). All treatments were blended in the food processor whether or not they contained amaranth.

Following blending, the masa was hand-shaped into balls weighing 30.0 ± 0.5 g. The masa balls were stored in an airtight container in a refrigerator (35-40°F) until cooked. The morning of sensory testing the masa balls were placed between two square pieces of wax paper and pressed into tortillas using a hydraulic laboratory press (Fred S. Carver, Inc., Model C, Serial No. 25576-675, Menomonee Falls, WI). The masa balls were flattened with the press until the edges of the tortilla were visible at the edges of the wax paper. Average tortilla diameter was 155 mm and average tortilla thickness was 1.3 mm.

The tortillas were baked on a griddle (Hobart Corp., Model HG2, 2.25/3 kW, Troy, OH) at 450°F for 1 min per side. Each tortilla was divided into 6 pie-shaped portions; five were used for sensory evaluation and 1 was saved for objective testing.

The masa balls were stored in the refrigerator no longer than 24 hr between grinding and cooking. All samples were cooked the day of testing to concur with panelist scheduling and held until served wrapped in a cotton napkin in a 60 x 36 x 11-cm chafing dish with a perforated insert on a warming tray (Salton, Inc., Model H-132, New York, NY).

Sensory Testing

The tortilla testing involved sensory evaluation and objective measurements. The sensory evaluation was done first and involved 25 untrained panelists in an acceptability study in the laboratory and 28 panelists in a home placement acceptability study. All panelists in the laboratory study were graduate students in the Department of Food Science and Technology, University of Tennessee, Knoxville and ranged in age from 20 to 40. Panelists in the home placement study ranged in age from 10 to 40.

For both studies, panelists were asked to evaluate the color, flavor, texture, and overall acceptability of the tortillas. Since the scale used was hedonic, panelists did not need to be trained or have any extensive prior knowledge of the product (Stone and Sidel, 1993). Samples of scorecards are shown in Appendix B and C.

Although the panelists in the laboratory study were not trained, it became apparent, after an initial practice panel, that a sign in each of the booths reminding the judges that they were evaluating a baked tortilla, not a fried tortilla chip, was necessary. Several of the judges were unfamiliar with baked corn tortillas and found the triangular shape of the portions confusing.

All sensory testing in the laboratory was done in individual booths under white lighting; testing took place for 5 wk, 2 da per wk, 9:00 am - 1:00 pm. Each panelist received 6 samples per session; each sample was one-sixth of a whole tortilla. Samples were presented individually on white paper plates in random order. Panelists were asked to rinse their mouths with room-temperature water between each sample.

In the home placement study, each panelist evaluated two pre-cooked tortillas; one formulated in the manner described in the laboratory sensory testing outlined above (yellow corn, 3% lime, 0% amaranth) and one obtained from a local supermarket (Fontova Foods, Loveland, OH). Each Tuesday for two weeks panelists were given a tortilla in a sealed plastic bag to use by Friday, a scorecard, and instructions for preparing the tortilla by either warming or frying (See Appendix C). Samples were given to panelists in a balanced design. Samples formulated in the laboratory were ground, pressed, and cooked on the day on which they were distributed to panelists; panelists were asked to keep all samples refrigerated until ready for use.

Objective Testing

Objective measurements were done on samples used in the sensory studies. Moisture content of the samples was determined and then the samples were powdered using a coffee grinder (Krups "Touch Top" Coffee Mill, Model 203, Hong Kong) and stored in a freezer (-5 — -10°C) in plastic bags until used in further testing. The following objective measurements were studied in this experiment.

1. Tortilla diameter (mm). Tortilla diameter was determined by measuring the diameter of the raw tortillas, rotating a half turn and measuring again. The average diameter was determined for each tortilla; average tortilla diameter per treatment was calculated by averaging the diameter of the 6 tortillas prepared for each treatment.
2. Tortilla stack height (mm). Tortilla stack height for each treatment was determined by measuring the height of a stack of 6 raw tortillas prepared for each treatment with Vernier calipers.
3. Moisture. Moisture content was determined in duplicate for each treatment by AACC Method 44-40 (AACC, 1983).
4. Ash. Ash was determined in duplicate for each treatment by AACC Method 8-03 (AACC, 1983).
5. Calcium. The calcium content was determined in duplicate for each treatment by atomic absorption, AACC Method 40-70 (AACC, 1983).

6. Protein. Protein content was determined in duplicate for each treatment by Micro-Kjeldahl, AACC Method 46-13 (AACC, 1983).
7. Fat. Fat content was determined in duplicate for each treatment by AACC Method 30-25 (AACC, 1983).
8. pH. The pH was determined in triplicate for each treatment on the corn masa and the cooked tortillas. The pH was determined by preparing a slurry of 5 g masa and 40 mL deionized water or 2 g ground tortilla and 10 mL deionized water in an Osterizer blender (Oster Corp., Model No. 857-05J, Milwaukee, WI) and measuring with a pH meter (Corning Science Products, Model No. 215, Serial No. 3796, Corning, New York).

Samples of dried Asgrow 405W and 405Y were analyzed to confirm data supplied by the producer (Corn Processors, Inc., 1993). Moisture, fat, ash, and protein contents were determined for the dried corn samples using the same AACC (1983) procedures outlined for the tortilla samples.

Statistical Analysis

Data were analyzed using PROC GLM (SAS Institute, Inc., 1985) to determine the significance and interactions of corn cultivar, lime level, and amaranth to corn ratio on tortilla color, flavor, texture, and overall acceptability. PROC GLM was also used to determine the significance and interactions of corn cultivar, lime level, and amaranth to corn ratio on tortilla moisture, pH, ash, calcium content, and crude protein and fat content. Means for both data sets were separated using the PDIFF option with least-squares means.

CHAPTER IV

RESULTS, DISCUSSION, AND CONCLUSIONS

The effects of lime level (1, 2, and 3%), amaranth level (0, 15, and 30%), corn cultivar (yellow and white), and any significant interactions on sensory attributes and proximate composition of corn tortillas are presented and discussed in this section. ANOVA tables and interaction means are presented in Appendix D. Data will be discussed as follows: a) sensory evaluation, b) objective tests, and c) conclusions based upon the results of sensory evaluation and objective testing.

Sensory Evaluation

Sensory evaluation of the corn tortillas was performed in two settings. A nine-week study was conducted initially in the laboratory to determine color, flavor, texture, and overall acceptability of corn tortillas formulated with 3 lime levels, 3 amaranth levels, and 2 corn cultivars. Analyzing the data of the initial sensory studies resulted in a desire for hedonic scores on a commercially-produced corn tortilla to provide information for interpretation of the scores from the first study. A two-week home placement study was conducted to determine panelist response to the color, flavor, texture, and overall acceptability of a commercially-produced and a laboratory-produced tortilla containing no amaranth.

Laboratory Sensory Testing

Analyses of sensory evaluation data were based on means for 25 panelists. Although panelist responses varied considerably, there was no consistent pattern in the differences among panelists as expected for hedonic data. Following an initial practice session, it was determined, based on panelist response, that many panelists did not understand the difference between a baked corn tortilla which should have a "rollable" texture and a fried tortilla chip which should have a crispy texture. Although signs explaining the difference were posted in each sensory booth, panelists still seemed confused as to the type of texture to expect in the baked product.

1. Color

The effects of lime level, amaranth level, and corn cultivar on color hedonic score of corn tortillas are shown in Tables 1, 2, and 3, respectively. Means for significant interactions are shown in Tables D.2 and D.3. On the hedonic scale used in the sensory tests, the mean scores for color all fell on or between the choices "like slightly" and "like moderately".

Table 1--Least-squares means and standard errors of least-squares means of sensory characteristics of corn tortillas formulated with 3 levels of lime[a]

	Lime levels (%-corn weight basis)		
Characteristic[b]	1.0	2.0	3.0
Color	6.3x ± 0.07	6.0y ± 0.07	6.2xy ± 0.07
Flavor	6.0x ± 0.06	5.8y ± 0.06	5.9xy ± 0.06
Texture	5.3x ± 0.08	5.3x ± 0.08	5.6y ± 0.08
Overall acceptability	5.5xy ± 0.07	5.4x ± 0.07	5.7y ± 0.07

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[a] Means across 3 amaranth levels, 2 corn cultivars, 25 panelists, and 3 replications. Means followed by different letters within a row are significantly different ($P \leq 0.05$).

[b] Sensory characteristics were evaluated on a 9-point hedonic scale: Dislike extremely = 1, Dislike very much = 2, Dislike moderately = 3, Dislike slightly = 4, Neither like nor dislike = 5, Like slightly = 6, Like moderately = 7, Like very much = 8, Like extremely = 9.

Table 2--Least-squares means and standard errors of least-squares means of sensory characteristics of corn tortillas formulated with 3 levels of amaranth[a]

	Amaranth levels (% of hydrated amaranth flour to masa)		
Characteristic[b]	0	15	30
Color	6.6x ± 0.07	6.0y ± 0.07	5.8z ± 0.07
Flavor	6.0x ± 0.06	5.9x ± 0.07	6.0x ± 0.07
Texture	5.3x ± 0.08	5.5x ± 0.08	5.4x ± 0.08
Overall acceptability	5.6x ± 0.07	5.5x ± 0.07	5.5x ± 0.07

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[a] Means across 3 lime levels, 2 corn cultivars, 25 panelists, and 3 replications. Means followed by different letters within a row are significantly different ($P \leq 0.05$).

[b] Sensory characteristics were evaluated on a 9-point hedonic scale: Dislike extremely = 1, Dislike very much = 2, Dislike moderately = 3, Dislike slightly = 4, Neither like nor dislike = 5, Like slightly = 6, Like moderately = 7, Like very much = 8, Like extremely = 9.

Table 3--Least-squares means and standard errors of least-squares means of sensory characteristics of corn tortillas formulated with 2 cultivars of corn[a]

Characteristic[b]	Corn cultivar	
	White	Yellow
Color	5.4x ± 0.06	6.9y ± 0.06
Flavor	5.8x ± 0.05	6.1y ± 0.05
Texture	5.4x ± 0.07	5.4x ± 0.07
Overall acceptability	5.3x ± 0.06	5.8y ± 0.06

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[a] Means across 3 lime levels, 3 amaranth levels, 25 panelists, and 3 replications. Means followed by different letters within a row are significantly different ($P \leq 0.05$).

[b] Sensory characteristics were evaluated on a 9-point hedonic scale: Dislike extremely = 1, Dislike very much = 2, Dislike moderately = 3, Dislike slightly = 4, Neither like nor dislike = 5, Like slightly = 6, Like moderately = 7, Like very much = 8, Like extremely = 9.

Significant interactions between lime and amaranth for color and lime and corn for color are illustrated in Figs. 1 and 2, respectively. As Fig. 1 shows, color scores increased with lime level at 0% amaranth, decreased sharply from 1 to 2% lime and then increased slightly from 2 to 3% lime at 15% amaranth, and decreased steadily as the lime level increased at 30% amaranth. The mean color score for 30% amaranth was significantly lower than the score for 0% amaranth at all lime levels; the mean score for 15% amaranth was significantly lower than the score for 0% amaranth at 2 and 3% lime. The negative effect of the amaranth on the color acceptability of the tortillas was evident in the interaction as well as in the main effect where color scores decreased as the amaranth level increased. The decrease in color acceptability as amaranth levels increased is probably due to the combination of corn masa and brown amaranth dough which resulted in an unappealing grayish-colored tortilla. In fact, several panelists commented that the tortillas looked "gray" or "pale" on their scorecards.

The mean color scores for yellow corn tortillas were significantly higher at all lime levels than those for white corn tortillas. The scores for both yellow and white corn decrease as lime level is increased from 1 to 2%. However, the color score for yellow corn tortillas levels off between 2 and 3% lime, while the score for white corn tortillas increases between 2 and 3% lime (Fig. 2). These scores are

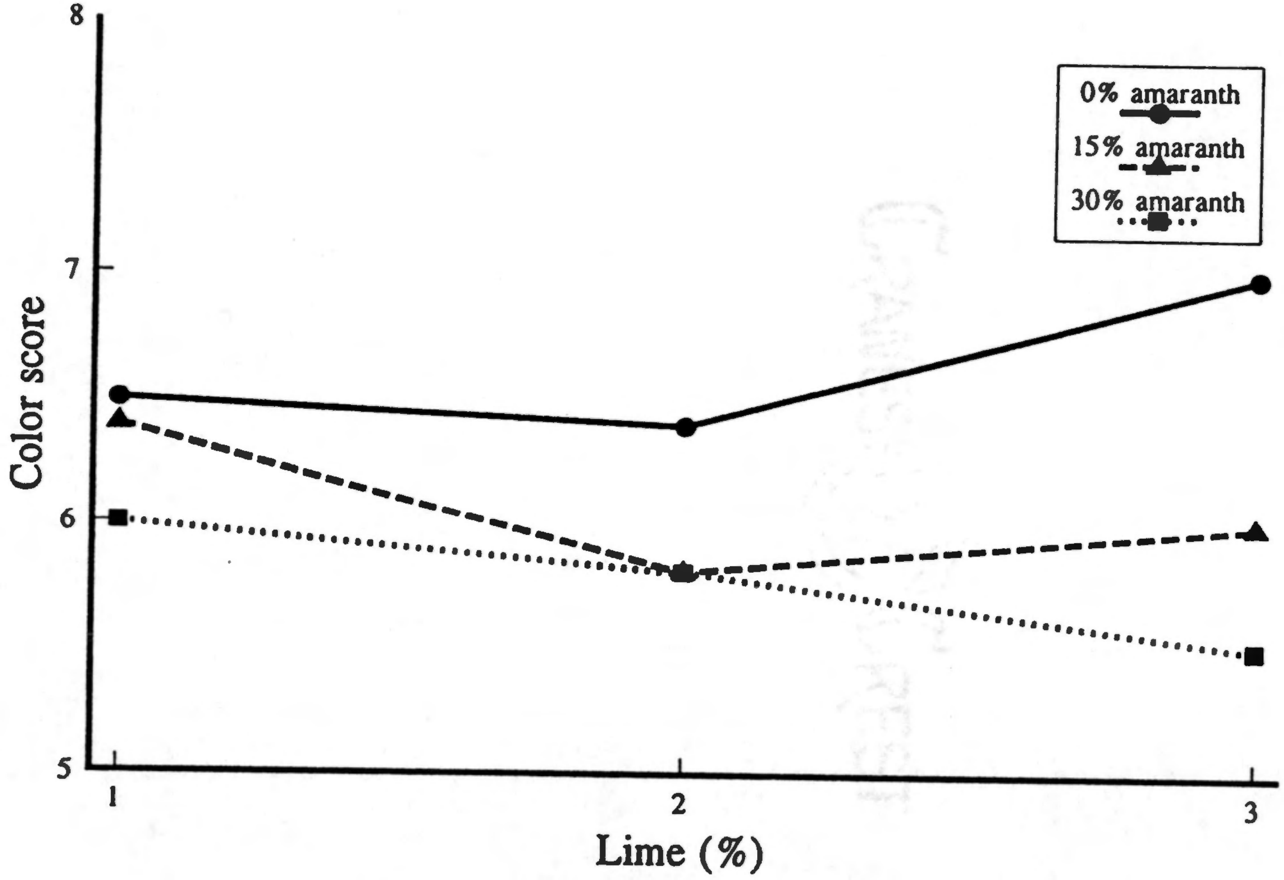

Fig. 1--Tortilla color (1=dislike extremely, 9=like extremely) as a function of lime level and amaranth level. Each point represents the mean across 25 panelists, 2 corn cultivars, and 3 replications.

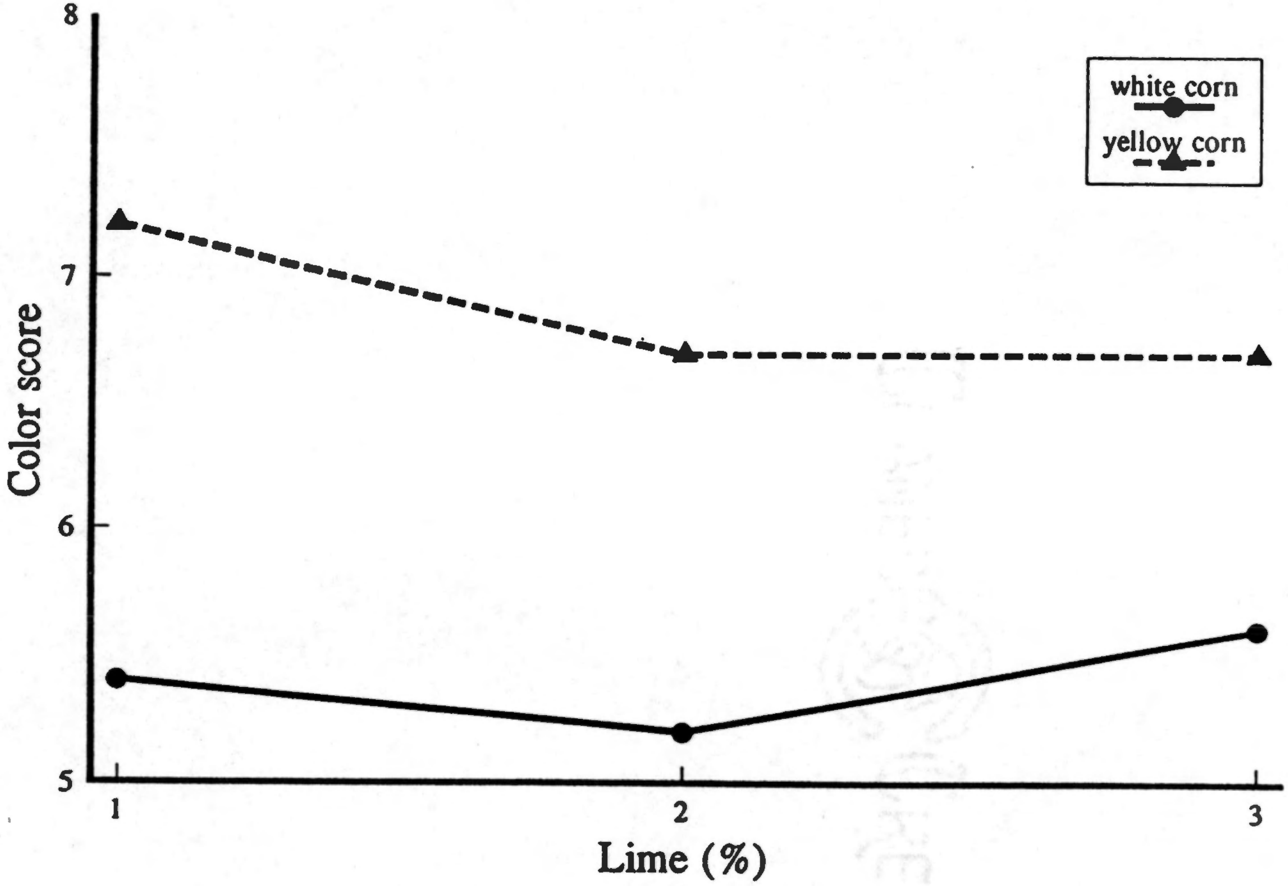

Fig. 2--Tortilla color (1=dislike extremely, 9=like extremely) as a function of lime level and corn cultivar. Each point represents the mean across 25 panelists, 3 amaranth levels, and 3 replications.

in accord with a study by Bedolla and coworkers (1983) which reported that U.S. consumers tend to prefer yellow corn tortillas, while Hispanic consumers tend to prefer white corn tortillas. Most of the unfavorable panelist comments pertaining to color on scorecards were made about the white corn tortillas; panelists thought they looked "too pale" or "too dull".

A significant interaction between corn cultivar and amaranth for color is illustrated in Fig. 3. At each of the three amaranth levels tested, color scores were fairly uniform for yellow corn tortillas. However, color acceptability decreased sharply as the amaranth level increased for white corn tortillas. This illustrates the combined effects of the unappealing color of amaranth and the consumer preference for yellow corn tortillas. The grayish-brown color of the amaranth would also have been much more evident in the pale white tortillas as compared to the darker yellow ones.

2. Flavor

The effects of lime level, amaranth level, and corn cultivar on flavor of corn tortillas are shown in Tables 1, 2, and 3, respectively. Flavor was significantly more acceptable in tortillas with 1% lime than tortillas with 2% lime; however, the flavor score of neither was significantly different from that of those with 3% lime. All mean sensory

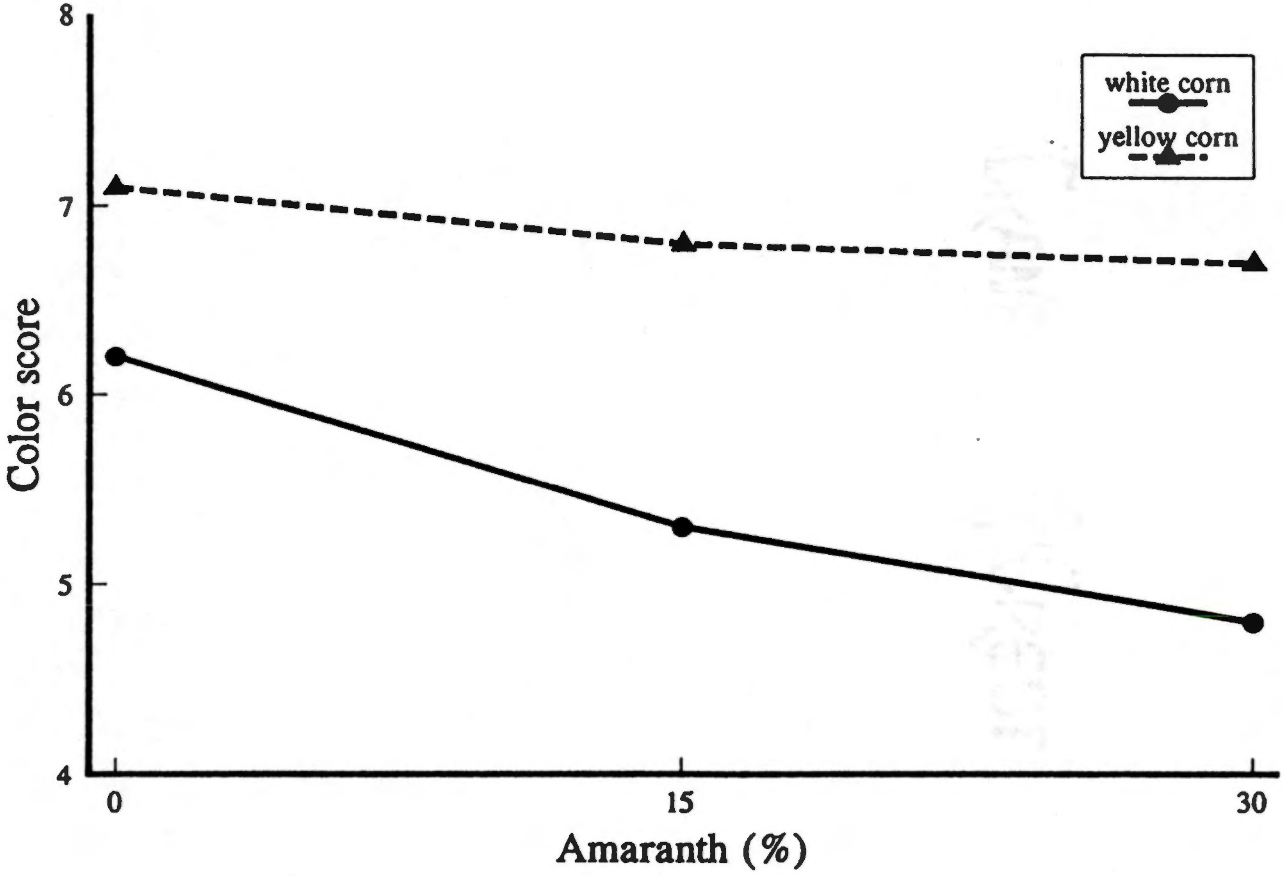

Fig. 3--Tortilla color (1=dislike extremely, 9=like extremely) as a function of amaranth level and corn cultivar. Each point represents the mean across 25 panelists, 3 lime levels, and 3 replications.

scores for flavor fell between or on the hedonic responses "neither like nor dislike" and " like slightly" for all lime levels. Panelists did not find the tortilla flavor overwhelmingly favorable at any lime level as the highest mean sensory score (1% lime=6.0) translated to a hedonic response of "like slightly". These results generally agree with Jackson and coworkers' (1987) findings that high-lime (level undefined) tortillas have a lower overall acceptability because of their alkaline flavor.

Panelists found no significant difference in flavor among the three amaranth levels. Mean flavor scores for all amaranth levels generally translated to a hedonic response of "like slightly". Although Sanchez-Marroquin et al. (1985) found that incorporation of amaranth improved sensory acceptability of baked products, these sensory scores agree with the results of Breene (1991) and Walters (1987) who found that amaranth flour could be substituted for another grain up to 20% of product without affecting product quality or acceptability. Sanchez-Marroquin and coworkers (1987) also reported that no difference in flavor was noted by panelists comparing amaranth-enriched tortillas to plain corn tortillas. However, many panelists commented on the "dirt" flavor that the amaranth gave to the tortillas and some said they preferred it to the "bland" taste of the tortillas with no amaranth.

Flavor of yellow corn tortillas was significantly more acceptable than flavor of white corn tortillas. The mean sensory score for white corn tortillas fell between the hedonic choices of "neither like nor dislike" and "like slightly", while the mean sensory score for yellow corn tortillas translated to a hedonic response between "like slightly" and "like moderately". As stated earlier, these findings concur with a reported U.S. consumer preference for yellow corn tortillas (Bedolla et al., 1983).

3. Texture

The effects of lime level, amaranth level, and corn cultivar on texture of corn tortillas are shown in Tables 1, 2, and 3, respectively. Means for significant interactions are shown in Tables D.2 and D.3. The texture of tortillas with 3% lime was significantly more acceptable than that of those with 1 or 2% lime. Most of the comments made by panelists pertained to the texture of the tortillas; for the most part, panelists found the texture objectionable. "Tough" and "too dry" were the most common statements; however, at 3% lime the negative comments were not as numerous and some panelists commented that these tortillas seemed "chewier" or "more bready" which they seemed to prefer.

Texture was not significantly affected by corn cultivar; however, a significant interaction was found between lime and corn cultivar for texture. Fig. 4

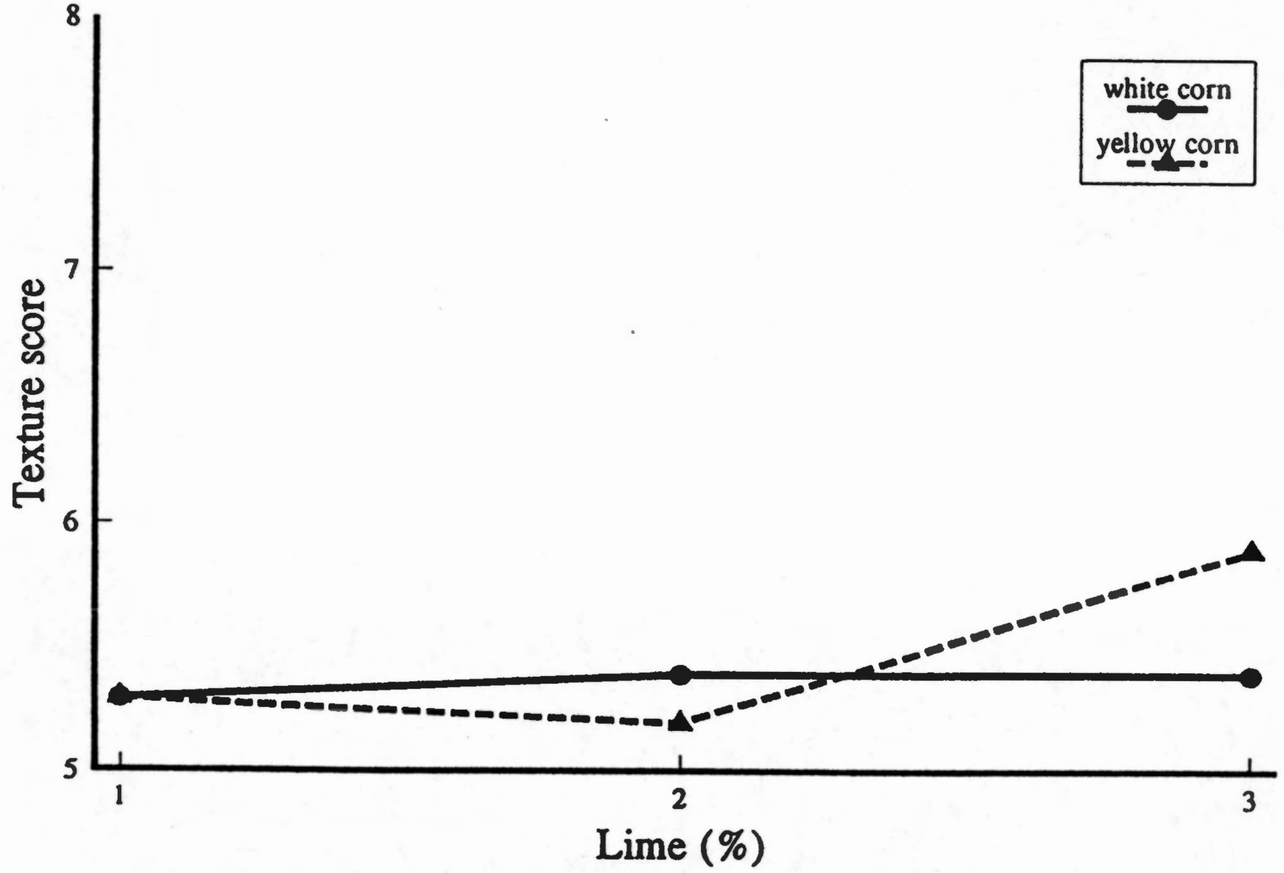

Fig. 4--Tortilla texture (1=dislike extremely, 9=like extremely) as a function of lime level and corn cultivar. Each point represents the mean across 25 panelists, 3 amaranth levels, and 3 replications.

illustrates the slight increase in texture acceptability scores as lime levels increased for white corn tortillas and the slight decrease followed by the sharp increase in texture scores for yellow corn tortillas. None of the mean scores at any lime level for either corn cultivar were significantly different from the others except the score for yellow corn tortillas at 3% lime; this score was significantly different from all of the other scores. This significantly higher score could perhaps be explained by the consumer preference for yellow corn tortillas; the natural yellow color of the tortillas would have been enhanced by the addition of the lime, especially at the highest lime level.

Panelists found no significant difference in tortilla texture among the three amaranth levels. All mean scores for texture as affected by amaranth level generally fell halfway in between the hedonic choices "neither like nor dislike" and "like slightly". These results agree with several studies in which no textural difference was found between amaranth-enriched and plain corn tortillas (Sanchez-Marroquin et al., 1987) and no effect on product acceptability was found with amaranth substitution up to 20% of total product (Breene, 1991; Walters, 1987).

4. Overall Acceptability

The effects of lime level, amaranth level, and corn cultivar on overall acceptability of corn tortillas are shown in Tables 1, 2, and 3, respectively. Overall the tortillas with 3% lime were significantly more acceptable than the tortillas with 2% lime; however, neither was significantly different from the 1% lime tortillas. Mean scores for overall acceptability at each lime level fell between the hedonic choices "neither like nor dislike" and "like slightly"; however, generally overall acceptability increased as lime level increased. Of the 4 sensory characteristics evaluated at each lime level, color and flavor were given the most favorable scores while texture and overall acceptability were rated less favorably. Acceptability of the color and flavor of the tortillas also decreased as the lime level increased, whereas overall acceptability and texture scores tended to increase as the lime level increased. These results agree with Jackson and coworkers' (1987) findings that texture usually has the biggest influence on overall preference for corn tortillas.

Panelists found no significant differences in overall acceptability among the 3 amaranth levels. Mean sensory scores at each amaranth level translated to a hedonic response midway between "neither like nor dislike" and "like slightly". The sensory scores given for color and flavor at all amaranth levels were more favorable than those given for texture and overall acceptability. These results are again supported by Jackson et al. (1987) who indicated that texture has the largest influence on overall acceptability of corn tortillas. The lack of significant differences among the 3 amaranth levels is in accord with studies by Breene (1991) and Walters (1987) in which no affect on acceptability was found when amaranth was substituted up to 20% of product.

Yellow corn tortillas were significantly more acceptable overall than white corn tortillas. However, both mean scores for overall acceptability fell between the hedonic responses "neither like nor dislike" and "like slightly". In this case texture did not seem to be related to overall preference since texture of the yellow and white tortillas was not judged to be significantly different by panelists. Overall acceptability scores followed the pattern of significance found for the attributes color and flavor which again indicates that U.S. consumers tend to prefer yellow corn tortillas over white (Bedolla et al., 1983).

Home Placement Sensory Testing

Analyses of home placement sensory evaluation data were based on means for 28 panelists. Although panelist responses varied considerably, there was no consistent pattern in the differences as expected with hedonic data.

Unlike the laboratory sensory testing, the formulation of the commercially-produced and laboratory-produced tortillas was essentially the same. Therefore, the effect of sample on color, flavor, texture, and overall acceptability was studied in the home placement evaluation. As seen in Table 4, there were no significant differences between samples for color, flavor, texture, or overall acceptability. Mean scores for the four attributes fell between 6.0 and 7.0 which is similar to or slightly more favorable than the range of means from the laboratory sensory testing. The higher scores can possibly be attributed to the fact that in home placement testing panelists were able to prepare and embellish the tortillas in any manner they chose. In any case, the range of the home placement scores indicated that the range of the laboratory sensory scores was not abnormally low or unusual.

Objective Results

The effects of lime level (1, 2, and 3%), amaranth level (0, 15, and 30%), and corn cultivar (white and yellow) on corn tortilla moisture, protein, fat, ash, pH, and calcium content are presented and discussed in this section. All results are based on duplicate samples of 18 treatments (3 lime levels x 3 amaranth levels x 2 corn cultivars) replicated 3 times.

Table 4--Means and standard deviations of sensory characteristics of commercially-produced and laboratory-produced corn tortillas formulated with yellow corn, lime, and water[a]

Characteristic[b]	Commercial	Laboratory
Color	6.9x ± 1.45	6.9x ± 1.65
Flavor	6.4x ± 2.10	6.6x ± 1.83
Texture	7.1x ± 1.70	6.2x ± 2.19
Overall acceptability	6.8x ± 1.73	6.4x ± 1.85

[a] Means across 28 panelists. Means followed by different letters within a row are significantly different ($P \leq 0.05$).

[b] Sensory characteristics were evaluated on a 9-point hedonic scale: Dislike extremely = 1, Dislike very much = 2, Dislike moderately = 3, Dislike slightly = 4, Neither like nor dislike = 5, Like slightly = 6, Like moderately = 7, Like very much = 8, Like extremely = 9.

Moisture

The effects of lime level, amaranth level, and corn cultivar on moisture content of corn tortillas are shown in Tables 5, 6, and 7, respectively. No significant interactions were found among variables for moisture content. The average mean moisture content of the tortillas ranged from 24 to 29%. Moisture contents reported by other investigators ranged from 20 to 45% depending mainly on corn cultivar and method of preparation (McPherson and Ou, 1976; Molina et al., 1977; Paredes-Lopez and Saharopulos-Paredes, 1983; Saldana and Brown, 1984; Sanchez-Marroquin et al., 1987; Stewart and Tamaki, 1992).

As shown in Table 5, moisture content of the tortillas increased as the lime level increased. Moisture content did not increase between 1 and 2% lime. However, at 3% lime the moisture content was about 28%; this moisture level was significantly different from the levels at 1 and 2% lime.

Table 6 illustrates the fact that the moisture content of the tortillas decreased as the amaranth level increased. There was no significant change in moisture content as the amaranth level increased from 0 to 15%. However, at 30% amaranth the moisture level was about 24%; this level was significantly lower from the levels at 0 and 15% amaranth. Although the amaranth flour was hydrated prior to addition to the masa, it was probably less moist than the masa which would account for the drop in overall moisture content at

Table 5--Least-squares means and standard errors of least-squares means of objective measurements of corn tortillas formulated with 3 levels of lime[a]

	Lime levels (%-corn weight basis)		
Measurement	1.0	2.0	3.0
Moisture,%	25.4x ± 0.56	26.1x ± 0.56	27.8y ± 0.56
pH	7.2x ± 0.09	7.6y ± 0.09	7.7y ± 0.09
Protein,%[b] (N x 5.7)	10.3x ± 0.04	10.3x ± 0.04	10.2x ± 0.04
Fat,%[b]	6.6x ± 0.14	6.8x ± 0.14	6.8x ± 0.14
Ash,%[b]	1.8x ± 0.01	2.0y ± 0.01	2.0y ± 0.01
Calcium[b], mg/100g	246.3x ± 4.1	331.0y ± 4.1	351.0z ± 4.0

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[a] Means across 3 amaranth levels, 2 corn cultivars, and 3 replications. Means followed by different letters within a row are significantly different ($P \leq 0.05$).

[b] Measurements reported on a dry-weight basis.

Table 6--Least-squares means and standard errors of least-squares means of objective measurements of corn tortillas formulated with 3 levels of amaranth[a]

	Amaranth levels (% of hydrated amaranth flour to masa)		
Measurement	0	15	30
Moisture,%	28.2x ± 0.56	27.0x ± 0.56	24.1y ± 0.59
pH	7.5x ± 0.09	7.3x ± 0.09	7.6x ± 0.10
Protein,%[b] (N x 5.7)	9.5x ± 0.04	10.4y ± 0.04	11.0z ± 0.04
Fat,%[b]	6.9x ± 0.14	6.8x ± 0.14	6.8x ± 0.14
Ash,%[b]	1.7x ± 0.01	1.9y ± 0.01	2.0z ± 0.01
Calcium[b], mg/100g	323.8x ± 4.1	307.9y ± 4.1	296.6y ± 4.3

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[a] Means across 3 lime levels, 2 corn cultivars, and 3 replications. Means followed by different letters within a row are significantly different ($P \leq 0.05$).

[b] Measurements reported on a dry-weight basis.

Table 7--Least-squares means and standard errors of least-squares means of objective measurements of corn tortillas formulated with 2 cultivars of corn[a]

	Corn cultivar	
Measurement	White	Yellow
Moisture,%	26.7x ± 0.46	26.1x ± 0.46
pH	7.5x ± 0.08	7.4x ± 0.08
Protein,%[b] (N x 5.7)	10.5x ± 0.03	10.1y ± 0.03
Fat,%[b]	6.7x ± 0.11	7.0x ± 0.11
Ash,%[b]	1.9x ± 0.01	1.8y ± 0.01
Calcium[b], mg/100g	324.2x ± 3.3	294.7y ± 3.3

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[a] Means across 3 lime levels, 3 amaranth levels, and 3 replications. Means followed by different letters within a row are significantly different ($P \leq 0.05$).

[b] Measurements reported on a dry-weight basis.

the higher amaranth levels. Sanchez-Marroquin and coworkers (1987) found that amaranth enrichment of corn tortillas reduced moisture content to below 10% in some cases.

Moisture content did not change significantly between cultivars as seen in Table 7. According to the corn producer (Corn Processors, Inc., 1993), there is no significant compositional difference between the two corn cultivars. Moisture evaluation of dried yellow and white corn samples confirmed that both samples had a moisture content of approximately 12%.

pH

The effects of lime level, amaranth level, and corn cultivar on pH of corn tortillas are shown in Tables 5, 6, and 7, respectively. No significant interactions were found among variables for pH. Traditional corn tortillas have a pH range of 6.8 to 7.8 (Bedolla and Rooney, 1984). Tortillas in this study had a pH range of 7.0 to 7.7.

As Table 5 indicates, the pH of the tortillas generally increased as the lime level in the tortillas increased. The pH increased significantly between 1 and 2% and 1 and 3%; however, it did not increase between 2 and 3%. Lime level has traditionally been used in formulating tortillas to manipulate pH in order to improve tortilla flavor and to increase microbial resistance. However, these two manipulations are mutually exclusive; a pH of approximately

7.0 is considered optimum for flavor (Bedolla and Rooney, 1984), while a much higher pH is required to effectively increase microbial resistance (Johnson et al., 1980).

Amaranth level did not significantly effect the tortilla pH (Table 6). At all three amaranth levels, the pH was approximately 7.5 which was well within the range of "normal" tortilla pH. No information was found pertaining to the pH effect of adding amaranth to tortillas. These results would indicate that amaranth has no effect on the pH of corn tortillas.

As seen in Table 7, corn cultivar did not significantly effect tortilla pH. No pH differences were anticipated between the yellow and white corns.

Protein

The effects of lime level, amaranth level, and corn cultivar on protein content of corn tortillas are shown in Tables 5, 6, and 7, respectively. No significant interactions among any of the main effects were found for protein. Mean protein content of the tortillas varied between 9.0 and 11.0%. Traditional corn tortillas, without the amaranth, contain approximately 5-7% protein (McPherson and Ou, 1976; Molina et al., 1977; Saldana and Brown, 1984; Sanchez-Marroquin et al., 1987; Stewart and Tamaki, 1992). Whole amaranth flour has 15-20% protein (Breene, 1991; Mendoza and Bressani, 1987; Paredes-Lopez et al., 1990;

Sanchez-Marroquin et al., 1987).

As shown in Table 5, lime level had no effect on the protein level. The protein level was approximately 10.3% at all three lime levels. Lime is mostly mineral in content and, therefore, was not expected to have any significant effect on the protein level of the tortillas. Bazua and coworkers (1979) found that lime did not affect total protein content.

Unlike lime, Table 6 indicates that amaranth level had a pronounced effect on mean protein values. As the amaranth level increased in the formulation so did the protein content of the tortillas. The protein content was approximately 2% higher with 30% amaranth than it was with 0% amaranth. All protein levels were significantly different from one another. Amaranth is unusually high in protein for a cereal grain and as a result increased the overall protein content of the tortilla when included in the formulation (Breene, 1991; Mendoza and Bressani, 1987; Paredes-Lopez et al., 1990; Sanchez-Marroquin et al., 1987).

Corn cultivar also had a significant effect on protein level (Table 7). White corn tortillas were significantly higher in protein than were yellow corn tortillas. According to the producer (Corn Processors, Inc., 1993), the two cultivars of corn should have similar protein contents; proximate analysis on the dried corn samples revealed that both the yellow and the white corn have approximately 9%

protein. However, the nature of alkaline cooking can result in significant dry matter losses, including solubilized proteins which are rinsed away with the rest of the liquor from the boiling and steeping process (Bressani et al., 1958). It is possible that the yellow corn simply disintegrated more than the white cultivar during cooking.

Fat

The effects of lime level, amaranth level, and corn cultivar on fat content of corn tortillas are shown in Tables 5, 6, and 7, respectively. No significant interactions among main effects were found on fat content. Fat content of the tortillas in this study varied from 5 to 7%. The fat content of tortillas reported by other investigators ranged between 2 and 5%. (Molina et al., 1977; Saldana and Brown, 1984; Sanchez-Marroquin et al., 1987; Stewart and Tamaki, 1992). Amaranth flour ranges from 3 to 10% in fat (Breene, 1991; Mendoza and Bressani, 1987; Sanchez-Marroquin et al., 1986, 1987).

Table 5 shows that lime level did not effect the fat content of the tortillas. The mean fat values were between 6.6 and 6.8% for all lime levels. No significant differences were found between any of the levels. Again, lime is mostly mineral in content and, therefore, would not be expected to contribute to differences in fat content of the tortillas.

There were also no significant differences in fat content among the three amaranth levels (Table 6). The mean value for fat was roughly 6.8% at all amaranth levels. Amaranth is higher in fat than corn and, therefore, might have been expected to increase the fat content in the tortillas formulated with amaranth, especially 30%. Testing on the dried corn showed that both samples were approximately 4% fat; according to the producer (Arrowhead Mills, 1993), the amaranth flour was approximately 5% fat. However, the mean fat content of the tortillas ranged between 5 and 7%. It is probable that the tortillas picked up additional fat off of the surface of the griddle on which they were baked. This would account for the lack of difference in fat content among the tortilla formulations and the unusually high fat values (9%) in some of the tortillas.

Corn cultivar did not significantly affect the fat content of the tortillas. The two corn cultivars had similar compositional traits and, therefore, were probably similar in fat content. Evaluation of the two samples showed that both yellow and white samples had approximately 4% fat.

Ash

The effects of lime level, amaranth level, and corn cultivar on the ash content of corn tortillas are shown in

Tables 5, 6, and 7, respectively. Means for significant interactions are shown in Tables D.2 and D.3. Fig. 5 illustrates a significant interaction between lime and amaranth on ash content. Ash content of the tortillas ranged between 1.5 and 2.2%. Traditional tortillas contain approximately 1.2% ash (Stewart and Tamaki, 1992), while amaranth flour contains 2-4% ash (Sanchez-Marroquin et al., 1987).

A significant interaction between lime and amaranth on ash content is illustrated in Fig. 5. As expected, increasing the level of both lime and amaranth separately resulted in a significant increase in the ash content of the tortillas. However, as the figure indicates, the ash content increases more sharply between 1 and 2% lime at 0% amaranth than it does at 15 and 30% amaranth. The ash content at 1% lime and 0% amaranth is significantly lower than all of the other values. The high mineral content of the amaranth must have compensated somewhat for the difference in mineral content found between tortillas formulated with 1 and 2% lime and no amaranth.

Table 7 shows that the ash content of the tortillas also varied with corn cultivar. White corn tortillas had more ash ($p<0.01$) than yellow corn tortillas. The corn producer indicated that the corn cultivars might differ in mineral and vitamin content (Corn Processors, Inc., 1993); this information was confirmed by ashing the dried corn

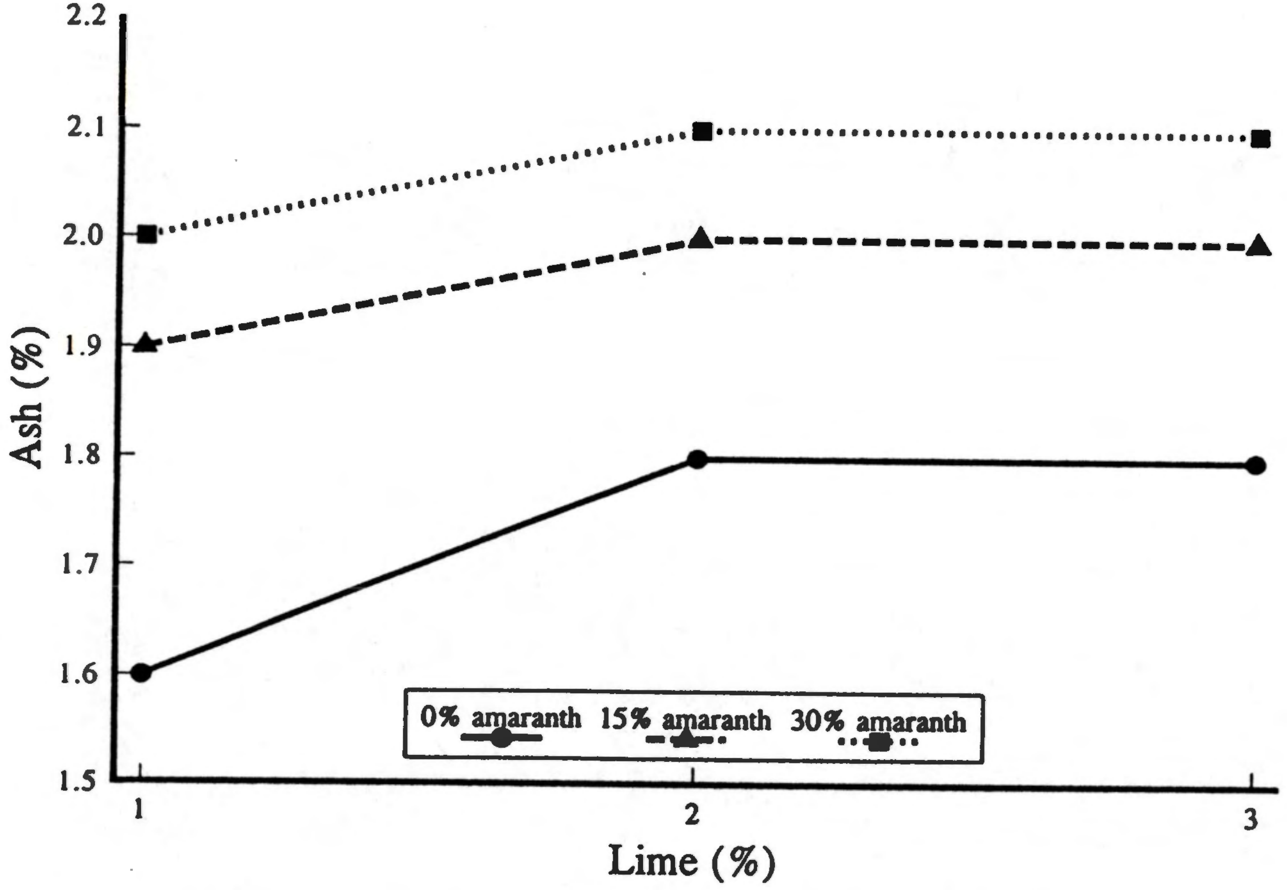

Fig. 5--Ash content for tortillas formulated with 3 amaranth levels and 3 lime levels. Each point represents the mean across 2 corn cultivars and 3 replications.

samples. However, this difference was not of concern in this study nor was the difference pronounced enough to result in an interaction with another main effect.

Calcium

The effects of lime level, amaranth level, and corn cultivar on calcium content of corn tortillas are shown in Tables 5, 6, and 7, respectively. Means for significant interactions are shown in Tables D.2 and D.3. A significant interaction between amaranth and lime for calcium content is illustrated in Fig. 6. Calcium values ranged from approximately 210 to 435 mg/100g. Tortillas traditionally contain 90 - 200 mg/100g calcium when formulated with 1% lime (Paredes-Lopez and Saharopulos-Paredes, 1983; Saldana and Brown, 1984; Stewart and Tamaki, 1992). Traditional tortilla samples obtained prior to this study in Santa Cruz, Mexico contained approximately 200 mg/100g calcium.

There were significant differences in the calcium content of the tortillas due to amaranth levels; however, not the one hypothesized in this study. As Table 5 indicates, calcium content decreased as amaranth level increased; this is the opposite of the desired result. The calcium content dropped about 25 mg/100g as the amaranth level increased from 0 to 30%. The calcium level at 0% amaranth was significantly different from the other two levels, but the calcium levels at 15 and 30% amaranth were

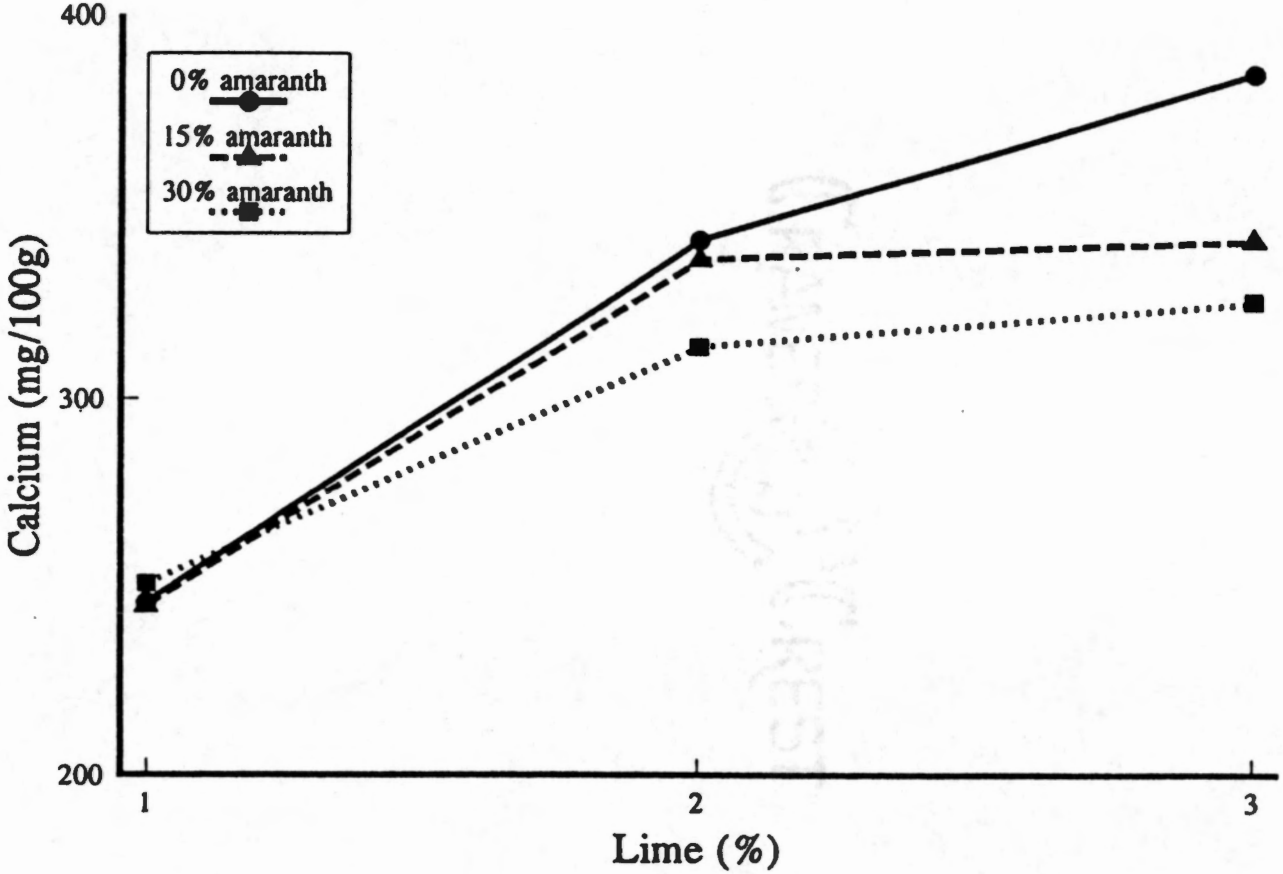

Fig. 6--Calcium content for tortillas formulated with 3 amaranth levels and 3 lime levels. Each point represents the mean across 2 corn cultivars and 3 replications.

not significantly different from one another.

Amaranth is much higher in calcium than the average cereal grain including corn (Becker, 1989), so the addition of the amaranth to the tortillas should have resulted in at least a slight increase in overall tortilla calcium content. However, the nature of the experimental methodology resulted in an obscuring of any calcium contribution from the amaranth. Amaranth was added at 15 or 30% by weight to two-thirds of the formulations, thus reducing the amount of lime-soaked corn (major source of tortilla calcium) that went into these formulations. To accurately study the effect of amaranth on the calcium content of the tortillas, the amount of masa used in each of the formulations should have been held constant.

There was a significant interaction between amaranth and lime for calcium content. As expected the calcium content increased significantly as the lime content increased (Table 5). As Fig. 5 illustrates, at 1% lime the calcium content at all three amaranth levels is not significantly different; however, at 3% lime the calcium content of the 15 and 30% amaranth tortillas is significantly lower than the content of the 0% amaranth tortilla. The drop in calcium levels can be attributed to the aforementioned reduction in masa in the 15 and 30% amaranth formulations. The interaction indicates that the potential calcium contribution of amaranth might be significant in tortillas formulated with less than 1% lime, while it is negligible at higher lime levels.

Corn cultivar significantly affected the calcium content of the tortillas as shown in Table 7. White corn tortillas had a higher mean calcium content than did yellow corn tortillas. Corn is not known to be a good source of calcium; therefore, it is unlikely that the two cultivars would be so different in calcium content. However, it is plausible that yellow cultivar lost its pericarp more readily during alkaline processing and, therefore, retained less calcium from the lime soaking. Gomez and coworkers (1989) noted that most of the calcium is in the pericarp which can be lost during cooking and subsequent rinsing and Bressani et al. (1958) documented differences in physical and chemical losses during alkaline cooking between white and yellow corns. Confirmation of pericarp disintegration differences is beyond the scope of this study.

Conclusions

Data analysis revealed that lime level, amaranth level, and corn cultivar have several significant impacts on the sensory attributes and proximate composition of corn tortillas. Sensory evaluation indicated that increasing the lime level from 1 to 3% decreases acceptability of the color and the flavor of the tortilla and, therefore, does not result in an optimum tortilla, although it does improve texture acceptability. Manipulating amaranth levels from 0 to 30% had no effect on texture, flavor, or overall acceptability of tortillas; although it did decrease color acceptability, amaranth level would not be a primary concern in formulating an acceptable tortilla. In all cases, however, yellow corn was more acceptable than white corn.

Home placement sensory evaluation indicated that there was no apparent difference in sensory acceptability between a laboratory-produced tortilla of the type used in the other sensory study and a commercially-produced tortilla. There was no significant difference between the two tortillas for texture, color, flavor, or overall acceptability.

Proximate analysis revealed that increasing the lime level increases moisture, pH, ash, and calcium content. Increasing the amaranth content resulted in an increase in protein, ash, and potentially calcium. Differences in proximate composition between corn cultivars were mainly attributable to the alkaline-cooking process rather than any inherent compositional difference in the two cultivars of corn. Fat content did not vary with treatment.

Manipulation of both the lime and the amaranth level would result in an increase in the nutritive value of the tortilla. Although the calcium content of the tortillas could be increased by increasing the lime level, the corresponding decrease in sensory acceptability might make this prohibitive. However, the protein of the tortilla can easily be enhanced with the addition of amaranth with no loss in sensory acceptability.

Calcium content data indicates that amaranth might be useful in supplementing calcium levels in tortillas formulated with low lime levels (< 1%). This would be particularly useful in underdeveloped countries where calcium content of homemade tortillas is variable and use of low-calcium commercial masa mixes is becoming widespread. A study in which the calcium contribution from the lime-soaked corn was carefully controlled in the tortillas would be useful in verifying the potential calcium contribution of the amaranth.

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APPENDIXES

APPENDIX A

EXPERIMENTAL DESIGN

```
The number of factors in the design is........4
The number of levels of AMARANTH is...........3
The number of levels of LIME is...............3
The number of levels of CORN is...............2
The number of levels of REP is................3
The number of observations in the design is...54

AMARANTH:  1=0%, 2=15%, 3=30%
LIME:  1=1%, 2=2%, 3=3%
CORN:  1=White, 2=Yellow

Obs   AMARANTH  LIME      REP       CORN      BLOCK


  1        3        2        3        2        1
  2        2        1        3        2        1
  3        3        2        2        1        1
  4        3        3        1        1        1
  5        1        2        2        1        1
  6        3        1        1        2        1
  7        1        1        2        2        2
  8        2        3        3        2        2
  9        1        1        3        2        2
 10        3        1        3        1        2
 11        1        1        3        1        2
 12        2        2        2        1        2
 13        1        1        2        1        3
 14        2        1        1        1        3
 15        1        2        1        2        3
 16        2        2        2        2        3
 17        1        3        2        2        3
 18        3        3        2        2        3
 19        2        1        1        2        4
 20        3        3        3        1        4
 21        2        3        1        2        4
 22        3        2        1        1        4
 23        1        2        1        1        4
 24        2        2        3        1        4
 25        2        1        2        1        5
 26        1        3        1        2        5
 27        3        3        3        2        5
 28        2        2        1        1        5
 29        3        2        2        2        5
 30        3        2        3        1        5
 31        3        1        2        2        6
 32        1        2        2        2        6
 33        1        3        3        2        6
 34        2        3        1        1        6
 35        3        1        3        2        6
 36        3        3        1        2        6
 37        1        3        3        1        7
 38        2        1        2        2        7
```

39	2	3	3	1	7
40	1	1	1	1	7
41	2	2	1	2	7
42	1	3	2	1	7
43	1	1	1	2	8
44	3	1	2	1	8
45	3	3	2	1	8
46	3	2	1	2	8
47	2	2	3	2	8
48	1	3	1	1	8
49	1	2	3	2	9
50	2	1	3	1	9
51	2	3	2	2	9
52	3	1	1	1	9
53	1	2	3	1	9
54	2	3	2	1	9

APPENDIX B

SAMPLE SCORECARD

LABORATORY SENSORY TESTING

Sample Scorecard

Judge Number _____

Sample Code _____

Thank you for participating in the sensory panel today. You will receive 6 samples. Please check the term that best reflects your attitude about the specific sample characteristic. Please rinse your mouth with water between samples.

Color

Like extremely ___
Like very much ___
Like moderately ___
Like slightly ___
Neither like or dislike ___
Dislike slightly ___
Dislike moderately ___
Dislike very much ___
Dislike extremely ___

Texture

Like extremely ___
Like very much ___
Like moderately ___
Like slightly ___
Neither like or dislike ___
Dislike slightly ___
Dislike moderately ___
Dislike very much ___
Dislike extremely ___

Flavor

Like extremely ___
Like very much ___
Like moderately ___
Like slightly ___
Neither like or dislike ___
Dislike slightly ___
Dislike moderately ___
Dislike very much ___
Dislike extremely ___

Overall Acceptability

Like extremely ___
Like very much ___
Like moderately ___
Like slightly ___
Neither like or dislike ___
Dislike slightly ___
Dislike moderately ___
Dislike very much ___
Dislike extremely ___

Comments:

APPENDIX C

PREPARATION INSTRUCTIONS & SAMPLE SCORECARD

HOME PLACEMENT SENSORY TESTING

KEEP REFRIGERATED UNTIL READY TO USE

Tortilla Preparation Instructions

On the stove

Tortilla is pre-cooked so it only needs to be warmed. Place a pan (cast iron skillet is best) or griddle on the stove and heat to a medium-high temperature or do the same with an electric skillet. Place tortilla on heated surface and heat each side until warm (usually 10-15 seconds per side). Place in a cloth napkin or towel to retain heat and moisture. Serve as desired.

Deep frying for tortilla chips

Cut tortilla into small pieces. Place into hot oil and fry until crispy (approximately 1 minute). Check frequently as over-frying will cause chips to become chewy. Cool slightly and serve as desired (remember to note any salt added in method of preparation section of scorecard).

Sample Scorecard-Home Placement

PRODUCT: Corn Tortillas

Sample number ______ Household number ______

Prepare the tortilla as indicated on the attached instruction sheet and eat as you normally would.

Describe method of preparation (baked or fried, with or without salsa or other toppings, etc).

Information about individuals who ate the tortillas		Person number					
		1	2	3	4	5	6
Gender (Male (M) or Female (F))							
Indicate the age of each person by placing a check under their number across from the appropriate category	10 or younger						
	11-20						
	21-30						
	31-40						
	41-50						
	51-60						
	61-70						
How well did you like the tortilla color? Place a check mark corresponding to each person's response under their number.	Liked extremely						
	Liked very much						
	Liked moderately						
	Liked slightly						
	Neither like nor dislike						
	Disliked slightly						
	Disliked moderately						
	Disliked very much						
	Disliked extremely						

Information about individuals who ate the tortillas		Person number					
		1	2	3	4	5	6
How well did you like the tortilla texture? Place a check mark corresponding to each person's response under their number.	Liked extremely						
	Liked very much						
	Liked moderately						
	Liked slightly						
	Neither like nor dislike						
	Disliked slightly						
	Disliked moderately						
	Disliked very much						
	Disliked extremely						

How well did you like the tortilla flavor? Place a check mark corresponding to each person's response under their number.	Liked extremely						
	Liked very much						
	Liked moderately						
	Liked slightly						
	Neither like nor dislike						
	Disliked slightly						
	Disliked moderately						
	Disliked very much						
	Disliked extremely						

How well did you like the tortilla overall? Place a check mark corresponding to each person's response under their number.	Liked extremely						
	Liked very much						
	Liked moderately						
	Liked slightly						
	Neither like nor dislike						
	Disliked slightly						
	Disliked moderately						
	Disliked very much						
	Disliked extremely						

Sample number ______ Household number _______

Comments: Please indicate why you and/or others in your family did or did not like the tortillas.

How often do you consume corn tortillas?

Never _____

Once a month _____

Once every 3-4 months _____

Once a year _____

Where do you usually purchase corn tortillas (check all appropriate)?

Grocery store (pre-formed) _____

Grocery store (mix) _____

Mexican restaurant _____

Other (please explain) _______________________

APPENDIX D

ANOVA TABLES AND INTERACTION MEANS
FOR CORN TORTILLA STUDY

Table D.1--Mean squares from analysis of variance of objective and sensory values for corn tortilla study

Value	Source	df	Mean squares
Sensory			
<u>Laboratory Testing</u>			
Color	lime	2	9.64*
	amaranth	2	65.19*
	corn	1	562.88*
	block	8	5.33*
	judge	24	37.48*
	lime*corn	2	7.87*
	lime*amaranth	4	11.57*
	amaranth*corn	2	21.30*
	error	1197	1.86
Flavor	lime	2	4.11*
	amaranth	2	1.09
	corn	1	26.02*
	block	8	3.28*
	judge	24	49.85*
	error	1205	1.64
Texture	lime	2	16.66*
	amaranth	2	2.50
	corn	1	1.51
	block	8	17.52*
	judge	24	74.83*
	lime*corn	2	9.46*
	error	1203	2.50
Overall acceptability	lime	2	6.45*
	amaranth	2	0.80
	corn	1	72.42*
	block	8	6.83*
	judge	24	53.91*
	error	1204	1.92
<u>Home Placement Testing</u>			
Color	sample	1	0.02
	panelist	27	1.70
	error	27	3.13

Continued

Table D.1 Continued

Value	Source	df	Mean squares
Flavor	sample	1	0.28
	panelist	27	5.41*
	error	27	2.36
Texture	sample	1	9.44
	panelist	27	3.15
	error	27	4.52
Overall acceptability	sample	1	2.16
	panelist	27	3.45
	error	27	2.98
Objective			
Moisture	lime	2	25.15*
	amaranth	2	64.86*
	corn	1	5.09
	block	8	10.31
	rep	2	3.00
	error	38	5.31
pH	lime	2	1.17*
	amaranth	2	0.29
	corn	1	0.02
	block	8	0.94*
	rep	2	0.04
	error	38	0.15
Protein	lime	2	0.03
	amaranth	2	8.82*
	corn	1	2.69*
	block	8	0.02
	rep	2	0.02
	error	38	0.02

Continued

Table D.1 Continued

Value	Source	df	Mean squares
Fat	lime	2	0.03
	amaranth	2	0.11
	corn	1	0.84
	block	8	2.51*
	rep	2	2.81*
	error	38	0.32
Ash	lime	2	0.13*
	amaranth	2	0.34*
	corn	1	0.02*
	block	8	0.01
	rep	2	0.05*
	amaranth*lime	4	0.01*
	error	34	0.003
Calcium	lime	2	49730.75*
	amaranth	2	2770.04*
	corn	1	10437.55*
	block	8	999.60*
	rep	2	343.72
	amaranth*lime	4	1662.45*
	error	34	279.60

*P<0.05.

Table D.2--Interaction least-squares means and standard errors of least-squares means for sensory characteristics and objective measurements of corn tortillas formulated with 3 levels of lime and 3 levels of amaranth

		Amaranth (% hydrated amaranth flour to masa)		
Value[a]	Lime (%)	0	15	30
Color[b]	1	6.5b ± 0.1	6.4bc ± 0.1	6.0cd ± 0.1
	2	6.4bc ± 0.1	5.8de ± 0.1	5.8de ± 0.1
	3	7.0a ± 0.1	6.0d ± 0.1	5.5e ± 0.1
Ash, (%)[c]	1	1.6a ± 0.02	1.9b ± 0.02	2.0c ± 0.02
	2	1.8b ± 0.02	1.9c ± 0.02	2.1d ± 0.02
	3	1.8b ± 0.02	2.0cd ± 0.02	2.1d ± 0.02
Calcium,[c] (mg/100g)	1	244.7a ± 7.9	244.1a ± 7.1	250.1a ± 7.3
	2	341.9b ± 7.3	337.4b ± 7.1	313.8c ± 7.6
	3	384.7d ± 7.3	342.3b ± 7.4	325.9bc ± 7.1

---

[a] Means followed by different letters within a value are significantly different ($P \leq 0.05$).

[b] Means across 2 corn cultivars, 25 panelists, and 3 replications. Sensory characteristics were evaluated on a 9-point hedonic scale: Dislike extremely = 1, Dislike very much = 2, Dislike moderately = 3, Dislike slightly = 4, Neither like nor dislike = 5, Like slightly = 6, Like moderately = 7, Like very much = 8, Like extremely = 9.

[c] Means across 2 corn cultivars and 3 replications. Measurements reported on a dry-weight basis.

Table D.3--Interaction least-squares means and standard errors of least-squares means for sensory characteristics of corn tortillas formulated with 2 cultivars of corn and 3 levels of lime or 3 levels of amaranth

		Corn cultivar	
Value[a]		White	Yellow
	Lime (%)		
Color[b]	1	5.4a ± 0.1	7.2c ± 0.1
	2	5.2b ± 0.2	6.7a ± 0.1
	3	5.6a ± 0.1	6.7c ± 0.1
Texture[b]	1	5.3a ± 0.1	5.3a ± 0.1
	2	5.4a ± 0.1	5.2a ± 0.1
	3	5.4a ± 0.1	5.9b ± 0.1
	Amaranth (%)		
Color[c]	0	6.2a ± 0.1	7.1b ± 0.1
	15	5.3d ± 0.1	6.8bc ± 0.1
	30	4.8e ± 0.1	6.7c ± 0.1

---

[a] Means followed by different letters within a value are significantly different ($P \leq 0.05$). Sensory characteristics were evaluated on a 9-point hedonic scale: Dislike extremely = 1, Dislike very much = 2, Dislike moderately = 3, Dislike slightly = 4, Neither like nor dislike = 5, Like slightly = 6, Like moderately = 7, Like very much = 8, Like extremely = 9.

[b] Means across 3 levels of amaranth, 25 panelists, and 3 replications.

[c] Means across 3 levels of lime, 25 panelists, and 3 replications.

VITA

Rebecca Jane Buckner was born in Knoxville, Tennessee on April 1, 1964. She attended public school in Knoxville and graduated from West High School in 1982. She spent the next 4 years at Furman University, Greenville, South Carolina where she received a Bachelor of Science degree in Biology in 1986.

Following graduation, Rebecca took a job as a research assistant with a mammalian genetics research group at the Oak Ridge National Laboratory in Oak Ridge, Tennessee. While employed at the Oak Ridge National Laboratory, she took classes in genetic biochemistry at the Biomedical School of the Oak Ridge Associated Universities.

In August of 1990, Rebecca began her masters program in Food Science and Technology at The University of Tennessee, Knoxville. As part of her graduate assistantship, she was employed by the Food Services Purchasing Department at UTK as an assistant buyer. After a year and a half, she left that job to become a part-time graduate assistant for Dr. Marjorie Penfield. In May 1993 Rebecca received a Master of Science degree in Food Science and Technology. She is a member of the Institute of Food Technologists and Gamma Sigma Delta.