Enhancing the Nutritional Quality of Flour Tortillas: An Investigation of Consumer Receptivity to a Fortified Tortilla Product

Anna M.R. Hayes
St. Catherine University

Recommended Citation
Hayes, Anna M.R., "Enhancing the Nutritional Quality of Flour Tortillas: An Investigation of Consumer Receptivity to a Fortified Tortilla Product" (2014). Antonian Scholars Honors Program. 32.
https://sophia.stkate.edu/shas_honors/32
ENHANCING THE NUTRITIONAL QUALITY OF FLOUR TORTILLAS: AN INVESTIGATION OF CONSUMER RECEPTIVITY TO A FORTIFIED TORTILLA PRODUCT

by

Anna M. R. Hayes

A Senior Project in Partial Fulfillment of the Requirement of the Honors Program

ST. CATHERINE UNIVERSITY

April 1, 2014
Enhancing the Nutritional Quality of Flour Tortillas: An Investigation of Consumer Receptivity to a Fortified Tortilla Product.

Anna M. R. Hayes, Teri L. Burgess-Champoux, PhD, RD, LD

Henrietta Schmoll School of Health, Department of Nutrition and Exercise Sciences
St. Catherine University
2004 Randolph Avenue, Saint Paul, MN 55105

Anna M. R. Hayes
52313 360th Street, Lafayette, MN 56054
(507) 766-0832
amhayes@stkate.edu

Word count of text: 6000 words

Short version of title: Enhancing the nutritional quality of tortillas.
Category: Health, Nutrition, and Food.

NOTE: This draft has been completed following the manuscript guidelines for the Journal of Food Science. (More information regarding this format can be found at http://www.ift.org/AuthorsCorner.)
Abstract

The majority of U.S. adults consume less than the recommended amount of whole grains, dietary fiber, and vegetables on a daily basis. Increased intake of these foods is linked with reduced risks of developing chronic diseases, such as heart attack, cardiovascular disease, and stroke. With increased prevalence of such chronic health conditions and inadequate intakes of whole grains and vegetables, the need for an appealing enriched food product is evident. Over the past decade, the tortilla industry has been the fastest-growing sector of the U.S. baking industry; therefore, enhancing the nutritional content of tortillas could result in healthier food products acceptable to consumers. This research aimed to determine the effects of altering the flour component and adding a legume ingredient, specifically lentils, on the sensory attributes and overall characteristics of flour tortillas. Sorghum, an ancient whole grain variety, is rich in antioxidants, dietary fiber, and iron. Lentils, a type of grain legume, are high in fiber, B vitamins, minerals, proteins, and complex carbohydrates. Ten phases of bench-top product development using standardized preparation techniques were completed, resulting in two optimal fortified tortilla product formulations. Sensory evaluations were conducted among college students and instructors (n=35) for sensory attributes and overall likeability of four samples: two fortified tortilla products, a commercial tortilla made with refined flour, and a commercial health-enhanced tortilla. Results indicate that fortified tortilla products enhanced with pureed cooked lentils and sorghum flour are acceptable among the sampled population. Future research opportunities include conducting sensory evaluations among a larger population, optimizing product formulation for use in commercial production, extending product shelf life, and further enhancing nutritional qualities of tortillas by reducing sodium and fat content.

Keywords: tortillas, whole grains, fiber, legumes, nutrition

Practical Application

This research aimed to investigate the best incorporation of lentils and sorghum flour, two nutritionally beneficial ingredients, into soft-shell tortillas. After optimal tortilla formulas were developed, the tortillas were evaluated by adult consumers in a college setting. Findings indicate that a nutritionally enhanced tortilla product is acceptable in comparison to a commercial refined tortilla product among the sampled population.
# Table of Contents

Introduction .......................................................................................................................................................... 5  
Materials and Methods ....................................................................................................................................... 11  
  Methodology Overview ...................................................................................................................................... 11  
  Formulation / Product Development ................................................................................................................ 13  
  Sensory Evaluations .......................................................................................................................................... 13  
  Data Analysis .................................................................................................................................................. 14  
Results and Discussion ......................................................................................................................................... 15  
  Nutrient Analysis Results .................................................................................................................................. 15  
  Participants – Demographic Data and Survey Results ...................................................................................... 15  
  Sensory Evaluation Results ................................................................................................................................. 16  
  Quantitative Analysis Results ............................................................................................................................. 18  
  Formulation / Product Development Results .................................................................................................... 19  
  Comments on Methodology ............................................................................................................................... 22  
Conclusion ........................................................................................................................................................... 23  
Acknowledgments ............................................................................................................................................... 24  
Author Contributions ......................................................................................................................................... 25  
References ........................................................................................................................................................... 25  
Appendices – Supplementary Materials ............................................................................................................... 28  
  Appendix A: Tables .............................................................................................................................................. 29  
  Appendix B: Analytical Instrument Information ............................................................................................... 35  
  Appendix C: Graphic Images ............................................................................................................................... 40  
  Appendix D: Data Tables & Graphs .................................................................................................................... 51  
  Appendix E: Additional Documentation ............................................................................................................ 61  
  Appendix F: Final Commentary ......................................................................................................................... 71
Introduction

Presently, the typical American adult lifestyle is characterized by the overconsumption of food calories and a lack of physical activity (HHS & USDA 2010). Each individual’s dietary habits and food intake are impacted by a variety of components—including factors such as age and race/ethnicity, environmental setting, industry and media, and social and cultural norms and values. Currently, an abundance of calorically-dense, nutritionally-deficient foods in conjunction with limited access to healthier options and decrement in motivation to maintain healthy nutrition behaviors all contribute to the current dietary habits of U.S. adults (HHS & USDA 2010). Specifically, recent trends show that the majority of the U.S. adult population consumes less than the recommended amount of whole grains and dietary fiber on a daily basis, and fewer than 5 percent of Americans obtain the average recommended 3 ounce amount of whole grains per day (CDC & NCHS 2012). The 2010 Dietary Guidelines recommend individuals consume at least half of their grains as whole grain varieties and to replace refined grains with whole grains (HHS & USDA 2010). Increased intake of whole grains is of utmost importance to the adult population, as this dietary habit has been associated with the reduced risk of high blood pressure, coronary heart disease, diabetes, and, potentially, certain cancers (Jacobs and others 2001).

Additionally, very few Americans obtain the recommended amounts of vegetables in their daily diets. The average U.S. adult consumes only 59 percent of the daily recommended 2½ cups of vegetables (HHS & USDA 2010). Increased consumption of vegetables has been linked with a reduced risk of developing many chronic diseases, including cardiovascular disease, heart attack, and stroke. One notably concerning health complication is metabolic syndrome (MetS), a condition which approximately 27 percent of the U.S. adult population have been diagnosed (Denova-Gutiérrez and others 2010). MetS is characterized by the presence of central obesity, dyslipidemia, hyperglycemia, and hypertension and it can also be a strong predictor of type 2
diabetes mellitus, cardiovascular disease, and all-cause mortality. The majority of people diagnosed with MetS have dietary patterns characterized by the frequent consumption of soft drinks, refined grains, corn tortillas, and pastries along with minimal consumption of dairy products, seafood, and whole grains (Denova-Gutiérrez and others 2010; Rolfes and others 2012). With the increasing prevalence of chronic health conditions and diseases in conjunction with inadequate intakes of whole grains and vegetables observed among adult populations in the U.S., the need for an acceptable whole grain- and vegetable-enhanced product is evident (HHS & USDA 2010; Meyer and others 2000; Denova-Gutiérrez and others 2010).

Composed of amino acids, proteins are a key macronutrient with versatile roles in the human body (HHS & USDA 2010; Rolfes and others 2012). The quality of a protein is determined by the protein’s digestibility and amino acid composition. A high quality protein contains all the essential amino acids in relatively the same amounts and proportions as required by the human body. In general, foods derived from animal sources (such as meats, cheese, eggs, and milk) provide high quality protein, while foods from plant sources (such as seeds, grains, vegetables, and legumes) provide low quality protein because they lack one or more essential amino acids (Rolfes and others 2012). However, different plant proteins can be paired in a strategy called protein complementation in order to provide a complete source of all the essential amino acids. Together, such a combination of plant protein foods supply a complete source of high quality protein. Although the majority of U.S. adults obtain adequate amounts of protein in their daily diets (HHS & USDA 2010; CDC and NCHS 2012), the 2010 Dietary Guidelines emphasize incorporating a wider variety of protein foods and making choices that are lower in saturated fat, cholesterol, and calories (HHS & USDA 2010). Such recommendations afford the need for acquiring high quality proteins from foods that are less calorically-dense. This outcome
can readily be achieved through protein complementation in developing a food product made from plant sources of protein (Rolfes and others 2012).

Grain legumes or pulses include peas, beans, lentils, and chickpeas (Patterson and others 2010). These traditional crops are growing in popularity as ingredients or components in food products, as they are excellent sources of fiber, B vitamins, minerals, proteins, and complex carbohydrates (Brown 2011; Pyler and Gorton 2009; Rebello, Greenway, and Finley 2014). Such legumes contain approximately 20 to 25 percent protein by weight—double the composition level of wheat (Pyler and Gorton 2009)—and are generally gluten-free, high in dietary fiber, and free of cholesterol (Patterson and others 2010). Although legumes can vary by type and variety, they are all identified as having grown as a seed within a pod (Brown 2011). Legumes have notable health benefits, including the ability to enhance glycemic control, reduce heart-related risk factors among individuals with diabetes mellitus (Jenkins and others 2012), and protect against MetS (Hosseinpour-Niazi and others 2011). However, recent surveys indicate that the majority of U.S. adults consume less than half of the recommended amount of legumes (Ervin 2003-2004).

As legumes are unique varieties of vegetable plants, their proteins are low in quality and do not contain all the essential amino acids in relatively the same amounts that human beings require (Rolfes 2012; Brown 2011). However, consuming legumes with cereal grains can provide all of the necessary amino acids, rendering the combination a complete high quality source of protein. In general, legumes and grains are near perfect matches for protein complementation, as one contains the other’s lacking amino acid component.

Lentils are a specific type of legume which have been previously used as a blend with other cereal flours in bread and cake products (Pyler and Gorton 2009). With rich contents of protein, iron, zinc, selenium, and beta-carotene, increased lentil consumption could help decrease
micronutrient deficiency (Thavarajah and others 2011)—an expanding concern among the U.S. adult population. Additionally, lentils have distinguished antioxidant and phenolic characteristics (Hwa and Byung-Kee 2008), notably those of polyphenols and anthocyanins (Silva-Cristobal and others 2010). A growing body of research suggests that the consumption of lentils could have a major role in preventing diabetes and other chronic-degenerative diseases (Thavarajah and others 2011; Hwa and Byung-Kee 2008; Silva-Cristobal and others 2010).

Sorghum, also referred to as milo, is an ancient variety of whole grain that is high in antioxidants, dietary fiber, and iron (Case 2008). However, research suggests that by consuming sorghum the body’s ability to utilize absorbed nutrients is reduced from 15 percent to 3 percent due to the presence of tannins (Waniska and Rooney 2000). The implications of this reduced nutrient bioavailability are two-fold: in cases where overnutrition is a problem, decreased absorption may be desired; however, in cases of nutrient deficiencies decreased absorption is not desirable. This factor must be considered when including sorghum to develop new food products. Alternatively, sorghum’s high levels of phenolic compounds and anti-fungal proteins are beneficial, as they provide natural barriers against molding. Flour milled from sorghum is light in color and has a mild flavor with minimal bitter aftertaste, allowing it to be combined with other flours to produce palatable baked products (Case 2008). As Brown (2011) indicates, one notable application of sorghum flour is its traditional use for tortilla-making in some Latin American regions.

Over the past decade, the tortilla industry has reportedly been the fastest-growing sector of the baking industry in the U.S. (Hartman 2011). This trend stems from the continually increasing influence of Hispanic and Latino culture in the U.S., as population projections from the Pew Research Center indicate that the 2005 Hispanic population of 42 million will triple in size by 2050 to 128 million (Passel & Cohn). With this expanding population comes the increasing
prevalence of traditional Hispanic foods—such as tortillas. As the popularity of tortillas rises, they could also serve as a viable option for introducing nutritionally enhanced foods. A notable rise in awareness of the potential health benefits associated with tortillas has also increased their popularity. According to Pyler and Gorton (2009), a basic flour tortilla is a flat, circular, and light-colored bread with an average thickness of 1/16 inch and a diameter ranging from 6 to 13 inches. Traditional tortillas are indigenous to Central American countries and have often been consumed as a table bread or with a variety of meat and/or vegetable fillings as burritos, tacos, tamales, and enchiladas (Pyler and Gorton 2009; Serna-Saldivar and others 1988). Tortillas made with wheat differ from those made with corn, mainly in their methods of processing and preparation. Furthermore, wheat flour tortillas have higher levels of protein, fat, carbohydrates and the three enrichment vitamins (thiamin, riboflavin, and niacin) compared to corn tortillas (Serna-Saldivar and other 1988).

Previous wheat flour tortilla product formulations have yielded favorable incorporations of flavors such as sun-dried tomato, spinach, and other vegetables (Pyler and Gorton 2009), indicating the potential for further manipulation of ingredients to create nutritionally enhanced flour tortilla products. Additionally, tortillas have successfully been made using triticale and sorghum in place of wheat or corn as flour components (Serna-Saldivar and others 1988). Four major ingredients comprise the traditional tortilla formulation: flour, water, shortening/oil, and salt (Pyler and Gorton 2009; Serna-Saldivar and others 1988). Tortillas made with only these ingredients have a shelf life of two to four days due to their high moisture content, rendering them highly susceptibility to molding. In the U.S., most commercial formulations also contain preservatives, chemical leavening agents, emulsifiers, gums, and other ingredients to improve the tortilla products’ overall flavor, texture, softness, functionality, and shelf life (Bello and others 1991). For the purposes of this investigation, the majority of such ingredients were not used in
attempts to create a more traditional tortilla product. However, xanthan gum was added to the tortilla formula in order to improve texture and sensory attributes of the enhanced product (Case 2008).

One of the primary aims of this research project was to develop a consumer friendly tortilla product that, in comparison to a baseline refined flour tortilla, was 3 times higher in whole grain composition and 3 times higher in dietary fiber content than the control—specifically, increasing the amount from 1 gram to 3 grams. Ideally, this product would provide at least 20 percent of the daily recommended amount of vegetables for adults by incorporating a minimum of ½ cup cooked lentils per serving, which equals 20 percent of the 2½ cup daily recommended amount. Additionally, with its combination of sorghum flour and lentils, this tortilla product would provide a complete source of high quality protein. Such a product enables consumers to obtain a nutritionally dense meal component with one simple choice instead of many. Choosing the enhanced tortilla creates a simpler inclusion of whole grains and vegetables into one’s diet by eliminating the necessity to accompany tortillas with vegetable greens and beans. Due to the lack of previous research regarding formulation of flour tortillas with both a whole grain and a vegetable/legume component, exact ingredient production methods and substitution levels required experimentation for optimal application (Patterson and others 2010; Pyler and Gorton 2009). It was hypothesized that the nutritionally enhanced tortilla product would be well-received by sensory panelists due to completing many phases of product development to formulate a tortilla product with acceptable tenderness, taste, and overall texture. Previously, sorghum flour has successfully been individually incorporated in tortilla recipes (Pyler and Gorton 2009), but, to the knowledge of the investigator, lentils had not. Furthermore, this project aimed to reveal the best incorporation of both nutritional components in one product.
Materials and Methods

Methodology Overview

Independent variables in this project were the alterations to the flour variety and the addition of a vegetable/legume component to a tortilla product through bench-top product development. The baseline recipe (Holt and Juarez 1984; Pyler and Gorton 2009; Appendix A.1.) was adapted by changing the dry flour component to a mixture of all-purpose (AP) flour and sorghum flour. The inclusion of a lentil vegetable component varied by experimental trial—for some trials the lentil ingredient was added as a puree, while for others it was a dry flour (Appendices A.1 & A.2.). The trial-and-error recipe development process consisted of a series of 10 phases that began during the month of August 2013 in the Research and Development (R&D) test kitchen at Michael Foods, Inc., in Gaylord, MN, and was completed in November 2013 in the Saint Catherine University (SCU) Food Science Lab. Phases 1 to 5 took place at Michael Foods, while Phases 6 to 10 were completed at SCU. Recipe costing was completed for budgetary and planning purposes (Appendix A.3.). Manipulations for the phases involved altering the flour component with different combinations of all-purpose (AP) flour, sorghum flour, and lentils and adjusting the water component (Appendix A.4.). Nutritional analyses were completed using Genesis R&D SQL (Version 10.11.0, 2011, ESHA Research, Inc., Salem, Oregon) and Food Processor Software (Version 10.11.0, 2012, ESHA Research, Inc., Salem, Oregon) to assess whole grain, fiber, and other standard nutrient compositions for each phase of tortillas (Appendix A.5.).

Qualitative sensory evaluation of the tortillas were conducted for the parameters of appearance, aroma, texture, tenderness, taste, and overall likeability of the tortilla samples served plain. A 9-point hedonic scale with descriptive anchors was used to evaluate each parameter (1 = dislike extremely; 9 = like extremely; Appendix E.5.). This scale had been scientifically
validated for use in hedonic testing, which involves rating sensory characteristics according to individual preference; the use of such a scale did not require the standardization of a rating scale and provided a more accurate indication of the preferences of the general consumer population (Meilgaard and others 1999). Two stages of evaluation were conducted as follows:

Stage 1: Sensory evaluation of initial enhanced products by the R&D staff at Michael Foods, Inc., in Gaylord, MN (August 21, 2013).

Stage 2: Sensory evaluation of the final enhanced products by students and faculty instructors of the fall 2013 Food Science (FSNU 2900), Topics: Controversies in Food and Nutrition Science (FSNU 4994), and The Reflective Woman D12 (CORE 1000) courses at Saint Catherine University (October-November 2013).

Additional dependent variables measured for this investigation were the quantitative laboratory measurements of color, moisture/solids, water activity, and texture (force to puncture/break) for tortilla products. Quantitative values obtained through the use of calibrated laboratory instruments provided a more scientifically sound set of results than qualitative sensory evaluations alone. Additional information about the significance and underlying processes for each instrument can be found in the supplementary materials (Appendix B). For phases 1 to 5, analytical tests were conducted in the research and development food laboratory at Michael Foods, Inc. (MFI), in Gaylord, MN. Laboratory resources at the University of Minnesota (UMN) were utilized for quantifying measurement of color, water activity, and texture (force to puncture/break) of the tortilla products from phases 9 and 10. Moisture/solids analysis was not conducted at UMN due to significant discrepancies in instrumentation and methodology. Instrument specifications for all equipment and instruments is included in the supplementary materials (Appendix B.1). Photos of the instruments/equipment and certain stages of their utilization are included in the supplementary materials (Appendices C.1.-C.4.).
Formulation / Product Development

For recipe formulation and product development, a baseline traditional flour tortilla recipe was made to serve as a standard of reference (Holt and Juarez 1984; Pyler and Gorton 2009). A series of experimental phases followed, each manipulating the flour component and adding a lentil legume/vegetable component. For phases 1 to 5, a Vulcan™ commercial frying surface was used to cook the tortillas and a PTC Spot Check™ surface thermometer was used to ensure a consistent temperature (400-425°F) was maintained. For phases 6 to 10, a Hamilton Beach™ electric griddle (model 38515) was used to cook the tortillas while maintaining a consistent temperature. The amount of all ingredients in the recipes was measured using a calibrated balance for increased consistency and precision (±0.1 g). Although cost was not a major factor in this project, costing for several formulas was completed (Appendix A.3.). This factor is important in considering the marketing applications of the products developed. Nutritional analyses were also calculated for each phase of enhanced tortillas, noting the amounts of total carbohydrate, protein, and fiber. The nutritional information for phases 1 to 5 was determined using Genesis R&D software (Genesis R&D SQL, Version 10.11.0, 2011, ESHA Research, Inc., Salem, Oregon), while the nutritional information for phases 6 to 10 was determined using Food Processor software (Food Processor Software, Version 10.11.0, 2012, ESHA Research, Inc., Salem, Oregon) (Appendix A.4.).

Sensory Evaluations

After several subjectively deemed acceptable combinations of sorghum flour and lentils in a tortilla product were developed, the initial baseline product (control), two enhanced products (phases 4 and 5), and a commercially purchased tortilla product were introduced to a voluntary panel of employees in the R&D department at Michael Foods, Inc., for sensory evaluation (Appendix C.6.a.). Institutional Review Board (IRB) approval was granted for all stages of this
study through Saint Catherine University. Participants were asked to first complete a brief survey and then complete a food sensory and taste evaluation of the tortilla products using a semi-structured hedonic scale (Meilgaard and others 1999; Appendices E.3. & E.5.). A ranked scale of 1 (“dislike extremely”) to 9 (“like extremely”) was used to rate appearance, aroma, texture, tenderness, taste, and overall likeability of the tortilla samples served plain and warmed (Appendix E.4.).

According to Moskowitz and others (2006), the use of a 9-point hedonic scale has been widely researched, utilized, and validated in the scientific literature for measuring product preference and acceptance by consumers. Such a scale is easily understood and provides the optimal number of categories for discrimination, as panelists typically do not use the two extreme ends of the scale (thus 7 points are viable from a 9-point scale).

Upon completion of the initial sensory evaluation, further product development was conducted to refine the enhanced tortilla products in phases 6 to 10 (Appendix C.5.). Additional sensory evaluations were conducted with student and faculty participants at St. Catherine University (Appendix C.6.). Participants were asked to complete a survey and complete a food sensory and taste evaluation of the two final enhanced products (phases 9 and 10), a commercial health-enhanced tortilla, and a commercial refined flour tortilla (Appendices C.6.f.-C.6.i.).

As suggested by Toma and others (2008), demographic and behavioral data were collected from all participants for the parameters of age, gender, race, ethnicity, frequency of vegetable consumption, effort to include whole grains in one’s diet, and frequency/manner of tortilla consumption (Appendix E.3.).

Data Analysis

Data analysis techniques of descriptive statistics, including measures of central tendency, were obtained using IBM SPSS Statistics (SPSS, Version 20.0.0, 2011, IBM, Armonk, New
York). One-way Independent Groups ANOVA tests were conducted for the results of the first stage of sensory evaluation data in order to determine the presence of differences in the mean participant ratings for each sensory characteristic between the baseline (control) tortilla product, the commercial tortilla product, and phases 4 and 5 of the enhanced tortilla products ($P<0.05$).

One-way Independent Groups ANOVA tests were conducted for the results of the second stage of sensory evaluation data in order to determine the presence of differences in the mean participant ratings for each sensory characteristic between the commercial refined tortilla product, the commercial health-enhanced tortilla product, and phases 9 and 10 of the enhanced tortilla products ($P<0.05$). Measures of central tendency (mean and standard deviation) were calculated for the quantitative analytical tests of texture and color (Microsoft Excel 2013, Version 15.0.4454.1510, Microsoft, Redmond, Washington).

**Results and Discussion**

**Nutrient Analysis Results**

Per serving (60 g), the phase 9 tortilla product contained 2.58 g of dietary fiber, while the phase 10 tortilla product contained 2.69 g of dietary fiber (Appendix A.5.c., Food Processor Software, Version 10.11.0, 2012, ESHA Research, Inc., Salem, Oregon). According to the Nutrition Facts Panel information for the commercial refined tortilla product, each serving (60 g) provided 0.88 g of dietary fiber (Appendix A.5.d., http://frescadostortillas.com/products/flour-tortillas/10-chimichanga-flour-tortilla/). Therefore, the phase 10 tortilla product contained 3 times the dietary fiber content of the commercial refined tortilla product.

**Participants – Demographic Data and Survey Results**

Nine (9) staff members and employees from Michael Foods, Inc., participated in stage 1 of sensory evaluations (Appendix D.1.a.). The average participant age was 44 years and the
majority of participants were white, had 4+ years of college education, and were currently working full-time. The majority of participants reported consuming tortillas fewer than one time per week, and most consumed tortillas as an ingredient or meal component (as opposed to plain). Self-reported frequency of whole grain and vegetable consumption varied among participants, but most were lower than recommendations from the 2010 Dietary Guidelines; all but one participant had an intake of less than 3 ounces of whole grains daily and less than 2½ cups, or approximately 5 servings, of vegetables per day (HHS & USDA 2010).

Thirty-five (35) students and faculty members from Saint Catherine University participated in stage 2 of sensory evaluations (Appendix D.2.a.). Ages of participants ranged from 18 to 59 years, with an average age of 23 years. All participants were female, and a majority were white with some college/technical school. The majority of participants consumed tortillas as an ingredient or meal component less than one time per week. More participants reported consuming soft regular wheat flour tortillas than soft whole wheat, soft corn, or hard-shell varieties. Self-reported frequency of whole grain consumption varied, with 34 percent of participants reporting daily consumption and 29 percent reporting very infrequent consumption. The majority of participants reported consuming 2 servings of vegetables per day.

*Sensory Evaluation Results*

In general, mean ratings for the baseline and commercial tortilla products in stage 1 sensory evaluations were slightly higher than those for the phase 4 and phase 5 tortilla products, and overall likeability for the baseline product was highest with a mean value of 5.8 (Appendix D.1.b.). The phase 4 tortilla product had the lowest ratings for all the parameters with a mean overall likeability rating of 4.0. Since One-Way Independent Groups ANOVA tests indicated general differences in mean ratings among the tortilla products, Tukey HSD tests were completed to determine which specific groups varied. The Tukey HSD tests showed statistically
significant differences between mean appearance ratings among the baseline, phase 4, and phase 5 tortilla products. No other statistically significant differences were found.

Results from stage 2 sensory evaluations at Saint Catherine University indicated that the mean sensory characteristic ratings for the commercial refined tortilla product were highest compared to the commercial health-enhanced, phase 9, and phase 10 tortilla products for all parameters except taste (Appendices D.2.b. & D.2.c.). However, mean ratings for the phase 10 tortilla product were generally within a 1-point range of those for the commercial refined tortilla product for all parameters except appearance and texture. Although the commercial health-enhanced tortilla product had the second-highest rating for appearance, it had the lowest ratings for aroma, texture, tenderness, and overall likeability. The phase 10 tortilla product was rated higher in all parameters than the phase 9 product. The amount of lentils in the formula distinguished the phase 9 tortilla product (152 g) from the phase 10 tortilla (190 g). The phase 9 and phase 10 tortilla products had generally low ratings for appearance.

Tukey’s HSD tests were also conducted to determine statistically significant differences between mean ratings among groups after One-Way Independent ANOVA tests indicated general differences (Appendices D.2.b. & D.2.c.). Most notably, statistically significant differences were found for mean ratings of appearance, texture, and taste between the commercial refined tortilla and each of the other tortilla products ($P<0.05$). For taste and overall likeability, statistically significant differences for mean ratings were found between the commercial refined tortilla product and both the commercial health-enhanced tortilla product and the phase 9 tortilla product ($P<0.05$); however, no significant differences were found between the commercial refined product and the phase 10 product for these characteristics, and the mean rating for taste was slightly higher for the phase 10 product.
Although the appearances of the nutritionally enhanced developed tortillas (phases 9 and 10) were not rated as high as the commercial products, their ratings for the other sensory attributes indicated that they may be preferred over or comparable to currently existing health-enhanced products (Appendices D.2.b. & D.2.c.). The higher ratings for the phase 10 tortilla product, which incorporated more lentils, than the phase 9 tortilla product suggested that consumers might have enjoyed the characteristics that a legume component (lentils) imparted on final the tortilla product.

Quantitative Analysis Results

Due to the limited number of samples and financial resources, no tests to assess statistically significant differences were completed for all data collected from analytical testing.

For stage 1 analytical results, the texture value (force to break/puncture the tortilla product) decreased with higher phase of tortilla development, with the baseline tortilla product withstanding 705 Newtons of force (N) before breaking and the phase 5 tortilla product withstanding 263 N (Appendix D. Table D.3.a.). This suggested a decreased level of starch structure with lower levels of gluten from the AP flour in the nutritionally enhanced tortilla products. With less AP flour but more sorghum flour and lentils, the tortilla products contained less gluten and thus less structure to withstand force. The average “L,a,b” (L=lightness, a=red-green, b=blue-yellow) color values were similar for the phase 2 through phase 5 tortilla products. The “L” and “a” values differed most between the baseline tortilla product and the phase 2 through 5 tortilla products. Water activity values were similar for all tortilla products, which indicated that approximately the same amount of water was available for microbial growth in each. The baseline tortilla product had approximately 5 percent lower moisture content than the phase 3 through phase 5 tortilla products; no data was available for the phase 2 tortilla product.
due to insufficient sample available during the time of testing. An increased moisture content in the nutritionally enhanced products indicated increased susceptibility to spoilage.

For the stage 2 analytical results, the average force to break the phase 10 tortilla product was lowest of the products tested at the University of Minnesota Food Science Lab, withstanding 291 N (Appendix D.4.a.). However, no notable differences existed among the phase 9, commercial health-enhanced, and commercial refined tortilla products. “L” color values were similar among the phase 9, phase 10, and commercial health-enhanced tortilla products. This indicated that such products were darker than the commercial refined tortilla. Substantial differences existed between the “a” color values for the phase 9 and phase 10 tortilla products and those for the commercial health-enhanced tortilla product and the commercial refined tortilla product. All the “b” color values among all the tortilla samples were similar. The water activity values were nearly the same (all rounding to 0.95) for the phase 9, phase 10, and commercial health-enhanced tortilla products. The water activity value was slightly lower (0.91) for the commercial refined tortilla product (Appendix D.4.a.). This result may have been due to the presence of additives and preservatives in the commercial refined tortilla product—none of the other tortilla products tested had such components in their formulations. However, all water activity values fell within the range of those typically characteristic of tortillas (0.91-0.95, Appendix B.3.).

**Formulation / Product Development Results**

A variety of challenges were faced during recipe formulation and experimentation. The use of lentil flour resulted in harder dough and less cohesive enhanced tortillas (de la Hera and others 2010). The alterations in starch content, starch structure, and moisture absorption necessitated formulation adjustments in the amount of water component among phases (Brown 2011). Good quality tortillas should resist tearing, cracking, and crumbling upon being rolled (Pyler and
Gorton 2009; Bello and others 1991). Therefore, the enhanced tortilla products’ decreased ability to withstand force indicated that they might not closely resemble an ideal tortilla (Appendix D. Tables D.3.a & D.3.b.). Typically, the protein content of most commercial tortillas ranges from 9 to 11 percent. Previous research indicates that flour with a protein content similar to bread flour is best for tortilla formulation. Since lentils are composed of approximately 20 to 25 percent protein, this increased level of protein affected the enhanced tortilla products by making them less elastic and more crumbly (Pyler and Gorton 2009). Despite initial research objectives, incorporating enough lentils in the formula to provide ½ cup of lentils (vegetable) per serving of tortilla was not feasible.

Additionally, whole grain varieties of flour absorb approximately 2 to 3 percent more water than refined flour due to their increased content of pentosans, a group of polysaccharide sugars with a high water binding capacity (Serna-Saldivar and others 1988). Pentosans are 5-carbon pentose rings called hemicelluloses which interact with proteins in doughs to affect bread-making properties, and they absorb 10 times their weight or more in water (setting them apart from starches). The presence of pentosans contributes to oxidative gelation during baking—increasing dough viscosity and decreasing dough extensibility (Pyler and Gorton 2009). Despite these challenges, pentosans serve as important sources of soluble and insoluble dietary fiber and have health benefits. In order to offset the changes characterized by increased pentosan content – harder dough and drier/less flexible cooked tortillas – caused by the addition of a whole grain component (in this case, sorghum flour), xanthan gum was added to the tortilla formula (Pyler and Gorton 2009; Case 2008). Gums such as guar gum and xanthan gum act as water control agents by altering viscosity or by forming gels and helping to stabilize food products.

Additionally, particle size was another important factor to consider in evaluating the quality and acceptability of flour tortillas enhanced with whole grain waxy barley (Prasopsunwattana and
others 2009). Similar results were found during formulation/product development, as the further extent of cooking and pureeing the lentils, the more readily they were incorporated into the tortilla dough.

Careful manipulation of ingredients was required during mixing, as, during this process, water becomes absorbed by the flour—enabling gluten to develop and gain strength (Brown 2011; Pyler and Gorton 2009). Gluten formation occurs when two types of wheat proteins, gliadin and glutenin, combine after hydration and kneading to create an elastic network that provides the structure for the end product (Brown 2011). Over mixing can lead to gluten breakdown, loss of gluten strength, increased stickiness of the dough, and thus an inferior tortilla product. However, since sorghum and lentils do not contain gluten, other sources were required to provide the structure and support for the enhanced tortilla product, and xanthan gum was added (Case 2008).

Past research suggests that white and black bean purees can be incorporated into corn tortilla products with reasonable acceptance among consumers (Machado and others 2007; Grajales-García and others 2012; Maya-Cortes and others 2010). Further evidence has indicated that levels of dietary fiber (insoluble and soluble fiber) and protein can be enhanced in corn tortillas (Obatolu and others 2007). In addition, whole barley flour, soybean flour, and chia seeds have successfully been incorporated in flour tortillas with favorable consumer acceptance (Toma and others 2008; Obatolu and others 2007; Rendón-Villalobos and others 2012), and growing bodies of evidence suggest consumers may be more willing to pay higher prices for a healthier, higher fiber food option (Bugera and others 2013). Yet, an acceptable enhancement of flour tortillas with both a whole grain and a legume/vegetable component, resulting in a final product with more “bang for the buck” and easy inclusion into one’s daily diet, has not been developed until now. The variance in receptivity to the phase 9 and phase 10 tortilla products suggested that
openness to try new foods and/or familiarity may be the key issues to address when introducing such a nutritionally enhanced product to a new audience. Notably, one participant rated one nutritionally enhanced tortilla products highly and commented, “Yum! I’d eat this all the time. The taste is excellent.” Meanwhile, another rated the same product low and commented, “This product is something I’m not familiar with tasting and eating. So it’s not my type of food to eat.”

Some participants raised concerns about the nutritionally enhanced products’ appearance and application (fold ability/bendability) as a tortilla or burrito. These valid concerns highlight some challenges that would need to be addressed before this nutritionally enhanced product could be produced and sold on a commercial scale. However, the fact that the developed nutritionally enhanced tortillas were rated higher than a currently sold commercial health-enhanced tortilla product on average for many sensory attributes suggests a positive market potential (Appendix D.2.c.).

Comments on Methodology

This study had its set of limitations. Ideally, recipe formulation/product development, both stages of sensory evaluations, and all analytical testing would have been conducted at one location. However, resources did not allow for such consistency to be maintained throughout the entire course of the study. The means of recipe formulation/product development were bench-top and exploratory, and, in order to establish precision and accuracy, certain tortilla characteristics were affected. Namely, to maintain consistent thickness, a tortilla press was used; however, this press did not produce tortillas that were as thin as some consumers desire. This ultimately impacted the participants’ ratings of the enhanced tortilla products, as several commented that they were “too thick.”

When considering the sensory evaluations, the small participant sample sizes (n=9 and n=35) and the relative similarities in demographics among participants should be noted. Such
groups are likely not representative of the entire U.S. population. Additionally, when completing sensory evaluations, some participants did not “check the box” on the sensory evaluation forms to actually rate certain parameters even though they wrote comments. The order in which participants evaluated the tortilla products may have affected their ratings; in efforts to mitigate this, participants were presented with all the samples at one time and could freely choose their own order for testing. This method may have introduced a slight bias of comparison, as one participant commented, “Did not notice difference from sample 583.” Furthermore, the tortilla samples were intended to be evaluated when they were slightly warmed, but ensuring that all participants received heated samples simultaneously was a challenge. As the samples were set out and as the participants completed the evaluation, certain samples were able to sit longer and may have become dry. A more scientifically structured random order of presentation in a room where all the tortilla samples could have been served at the same temperature without drying out would have been more ideal testing conditions for the sensory evaluations. Further methods of evaluating the tortillas could involve serving them with other food components, as this is how many consumers typically eat tortillas.

**Conclusion**

This project provides a basis for understanding the amount and correct ratio of sorghum flour and lentils in flour tortillas, a typically highly refined staple food with increasing popularity among the general population of the U.S. (Hartman 2011). Because of potential health and disease risks, it is important for the majority of adults to increase their intake of whole grains, dietary fiber, and vegetables (Jacobs and others 2001; Meyer and others 2000). The primary research objectives to develop a consumer friendly tortilla product that, in comparison to a baseline commercial refined flour tortilla, was 3 times higher in whole grain composition and 3
times higher in dietary fiber content, provided a complete source of protein, and yielded an optimal incorporation of sorghum flour and lentils in the formula were achieved with the phase 10 tortilla product. However, the aim to provide at least 20 percent of the daily recommended amount of vegetables for adults by incorporating a minimum of ½ cup cooked lentils per serving was not met. Solutions to challenges with appearance and texture may be required before this nutritionally enhanced tortilla product becomes well-received by the general U.S. population. Potential future research opportunities with nutritionally enhanced tortillas include evaluating the feasibility of commercial production, conducting sensory evaluations with a larger and more diverse group of participants, extending shelf life, incorporating different types of grains and legumes, and improving additional nutritional parameters such as sodium and fat content.

Acknowledgments

- Many thanks to Michael Foods, Inc., in Gaylord, MN, for the use of test kitchen and laboratory equipment. Additionally, thanks to sensory evaluation participants from the Michael Foods, Inc., Research and Development department for their contributions to the initial stages of sensory evaluations.
- Thanks to Sue Tomlinson from General Mills for her guidance in creating sensory evaluation and survey data collection instruments.
- Thanks to Dr. John Schmitt and Ms. Debbie Yang from the Institutional Review Board (IRB) at Saint Catherine University for the accommodations and flexible collaboration throughout the IRB approval process.
- Thanks to Dr. Zata Vickers, Emily del Bel, Dr. Ted Labuza, and Dr. Qinchun Rao at the University of Minnesota – Twin Cities for the opportunity to tour the Sensory Evaluation Center and use analytical testing equipment in the Food Science Lab to characterize later phases of tortilla products.
- Many thanks to Mr. Mark Rodriguez and Ms. Mary Schaffhausen from Catallia Mexican Foods, LLC, for the opportunity to visit with them and tour their facilities.
- Many thanks to Professor Jacquelyn Nyenhuis, Professor Debra Sheats, and Dr. Teri Burgess-Champoux for allowing sensory panelist recruitment from their college courses.
- Thanks to the Saint Catherine University Nutrition and Exercise Science department and Honors Program for the resources and financial support.
- Finally, Dr. Teri Burgess-Champoux, Dr. James Wollack, Professor Hilda Kachmar, Professor Kristina Bonsager, and Professor Debra Sheats all deserve substantial recognition for their
continuous guidance and assistance throughout the process of completing this project. Without their support, this endeavor would not have been possible.

Author Contributions

A. Hayes designed the study, conducted the research, completed the analyses, interpreted the results, and transcribed the manuscript.
T. Burgess-Champoux guided the project process, provided materials and support, oversaw data collection and analysis, and aided in transcribing and revising the manuscript.

References


Appendices – Supplementary Materials

Appendix A: Tables
   A.1 Product Development – Recipe Formulation Template
   A.2 Mixing Procedure
   A.3 Recipe Costing
   A.4 Product Development – Phase Manipulations
   A.5 Nutritional Analyses

Appendix B: Analytical Instrument Information
   B.1 Instrument/Equipment Overview
   B.2 Color Spectrophotometer
   B.3 Moisture Analyzer
   B.4 Water Activity Meter
   B.5 Texture Analyzer

Appendix C: Graphic Images
   C.1 Color Spectrophotometer
   C.2 Moisture Analyzer
   C.3 Water Activity Meter
   C.4 Texture Analyzer
   C.5 Tortilla Phases
   C.6 Sensory Evaluations

Appendix D: Data Tables & Graphs
   D.1 MFI Sensory Evaluations – Stage 1
   D.2 SCU Sensory Evaluations – Stage 2
   D.3 MFI Analytical Analysis Results – Stage 1
   D.4 UMN Analytical Analysis Results – Stage 2

Appendix E: Additional Documentation
   E.1 Recruitment Flyer
   E.2 Consent Form
   E.3 Demographic Survey
   E.4 Sensory Characteristic Definitions
   E.5 Sensory Evaluation Instrument

Appendix F: Final Commentary

MFI = Michael Foods, Inc.
SCU = St. Catherine University
UMN = University of Minnesota – Twin Cities
### Appendix A: Tables

<table>
<thead>
<tr>
<th>Ingredient (grams)</th>
<th>True %</th>
<th>Baseline</th>
<th>With Gum</th>
<th>True %</th>
</tr>
</thead>
<tbody>
<tr>
<td>All-purpose (AP) Flour</td>
<td>0.5602</td>
<td>456</td>
<td>228</td>
<td>152</td>
</tr>
<tr>
<td>Lentils</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lentil Flour</td>
<td>0.5406</td>
<td></td>
<td>228</td>
<td>152</td>
</tr>
<tr>
<td>Sorghum Flour</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Xanthan Gum</td>
<td>0.0196</td>
<td></td>
<td>2.53</td>
<td>2.53</td>
</tr>
<tr>
<td>Butter</td>
<td>0.1394</td>
<td>113.5</td>
<td>0.1394</td>
<td>113.5</td>
</tr>
<tr>
<td>Water (100-105°F)</td>
<td>0.2899</td>
<td>236</td>
<td>0.2899</td>
<td>157.33</td>
</tr>
<tr>
<td>Baking Powder</td>
<td>0.0021</td>
<td>1.71</td>
<td>0.0021</td>
<td>1.71</td>
</tr>
<tr>
<td>Salt</td>
<td>0.0084</td>
<td>6.84</td>
<td>0.0084</td>
<td>6.84</td>
</tr>
<tr>
<td></td>
<td>1.0000</td>
<td>814.05</td>
<td>1.0000</td>
<td>737.91</td>
</tr>
</tbody>
</table>

### A.1. Product Development – Recipe Formulation Template

**MIXING PROCEDURE:**

If using a processor, the flour and butter may need to be divided into two batches. Whirl until well blended (1 minute). Add water, baking powder, and salt and blend until a ball is formed (30 seconds). Combine both batches, cover, and set aside for 15 minutes. Do not refrigerate.

Heat a griddle to 425 degrees Fahrenheit. Knead dough again for one to two minutes, then take a piece of the dough and roll it into a ball about two inches in diameter (60 g) [For phases 9 and 10, balls were 45 g]. Press the ball evenly onto a floured board. With a rolling pin, roll the ball of dough into a seven-inch circle, paper thin [For phases 9 and 10, a tortilla press was used in place of rolling pin technique – three presses per tortilla with 45 degree rotations between each press. Less than 1 g flour was used to dust the press to prevent the dough from sticking.]

With each press, turn the dough around to keep it circular.

Place the dough on the ungreased griddle. It should sizzle as the dough touches it. Leave it for 1 minute and twenty seconds. If it puffs up, flatten it back on the griddle with the back of a spatula. Turn the tortilla over and cook it for a slightly shorter time (1 minute and 15 seconds) on the other side. When cooked, place each tortilla in a plastic bag, one atop the other with paper towels in between. They should be thin and flexible. Make them in advance and warm them slightly on the griddle just prior to serving.

**Lentil cooking instructions:** Before cooking, always examine, sort, and rinse lentils well to assure maximum wholesomeness. No soaking is required. In a large pot, for each pound of lentils (about 2 cups) add 6 to 8 cups hot water. Simmer gently with lid tilted until desired tenderness is reached, about 15 to 20 minutes.

1 cup dry lentils = 2 to 2-1/2 cups cooked
1 pound dried lentils = 2-1/4 cups dry
1 pound dried lentils = 5 cups cooked

### A.2. Mixing Procedure
### A. Tables - continued

<table>
<thead>
<tr>
<th>Food Products</th>
<th>Amount Needed</th>
<th>Additional comments</th>
<th>Cost per unit</th>
<th>Total cost per item</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Dairy</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Butter</td>
<td>½ cup (113.5 g)</td>
<td>Crystal Farms™, unsalted</td>
<td>$3.57 / 1 lb (= 454 g = 16 oz)</td>
<td>$0.89</td>
</tr>
<tr>
<td><strong>Staples (Flour, Sugar, etc.)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wheat Flour</td>
<td>1 lb (~3.6 cups, 456 g)</td>
<td>Gold Medal™ All-Purpose, bleached</td>
<td>$2.97 / 5 lbs</td>
<td>$0.59</td>
</tr>
<tr>
<td>Baking Powder</td>
<td>0.342 tsp (1.71 g)</td>
<td>Calumet™ double-acting</td>
<td>$2.45 / 7 oz (= 198 g)</td>
<td>$0.02</td>
</tr>
<tr>
<td>Salt</td>
<td>1.2 tsp (6.84 g)</td>
<td>Non-iodized</td>
<td>$0.85 / 26 oz (= 737 g)</td>
<td>$0.01</td>
</tr>
<tr>
<td>Water</td>
<td>1 cup (236 g)</td>
<td>lukewarm</td>
<td>$0.00</td>
<td>$0.00</td>
</tr>
<tr>
<td><strong>TOTAL COST:</strong></td>
<td></td>
<td></td>
<td></td>
<td>$1.51</td>
</tr>
</tbody>
</table>

#### A.3.a. Costing per recipe – Baseline

<table>
<thead>
<tr>
<th>Food Products</th>
<th>Amount Needed</th>
<th>Additional comments</th>
<th>Cost per unit</th>
<th>Total cost per item</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Dairy</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Butter</td>
<td>½ cup (113.5 g)</td>
<td>Crystal Farms™, unsalted</td>
<td>$3.57 / 1 lb (= 454 g = 16 oz)</td>
<td>$0.89</td>
</tr>
<tr>
<td><strong>Staples (Flour, Sugar, etc.)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Baking Powder</td>
<td>0.342 teaspoon (1.71 g)</td>
<td>Calumet™ double-acting</td>
<td>$2.45 / 7 oz (= 198 g)</td>
<td>$0.02</td>
</tr>
<tr>
<td>Salt</td>
<td>1.2 teaspoons (6.84 g)</td>
<td>Non-iodized</td>
<td>$0.85 / 26 oz (= 737 g)</td>
<td>$0.01</td>
</tr>
<tr>
<td>Water</td>
<td>1 cup (236 g)</td>
<td>lukewarm</td>
<td>$0.00</td>
<td>$0.00</td>
</tr>
</tbody>
</table>

**Other ingredients**

<table>
<thead>
<tr>
<th>Food Products</th>
<th>Amount Needed</th>
<th>Additional comments</th>
<th>Cost per unit</th>
<th>Total cost per item</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lentils</td>
<td>228 g</td>
<td>dried</td>
<td>$1.78 / 1 lb (16 oz = 454g)</td>
<td>$0.89</td>
</tr>
<tr>
<td>Sorghum Flour</td>
<td>228 g</td>
<td>Bob’s Red Mill™, Whole Grain ‘Sweet’ White</td>
<td>$3.88 / 1 lb, 6 oz (22 oz = 623 g)</td>
<td>$1.42</td>
</tr>
</tbody>
</table>

**TOTAL COST:** $3.23

#### A.3.b. Costing per recipe – Enhanced 1 (50:50 lentils and sorghum flour)
### A. Tables - continued

<table>
<thead>
<tr>
<th>Food Products</th>
<th>Amount Needed</th>
<th>Additional comments</th>
<th>Cost per unit</th>
<th>Total cost per item</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Dairy</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Butter</td>
<td>½ cup (113.5 grams)</td>
<td>Crystal Farms™, unsalted</td>
<td>$3.57 / 1 lb (= 454 g = 16 oz)</td>
<td>$0.89</td>
</tr>
<tr>
<td><strong>Staples (Flour, Sugar, etc.)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Baking Powder</td>
<td>0.342 teaspoon (1.71 grams)</td>
<td>Calumet™ double-acting</td>
<td>$2.45 / 7 oz (= 198 g)</td>
<td>$0.02</td>
</tr>
<tr>
<td>Salt</td>
<td>1.2 teaspoons (6.84 grams)</td>
<td>Non-iodized</td>
<td>$0.85 / 26 oz (= 737 g)</td>
<td>$0.01</td>
</tr>
<tr>
<td>Water</td>
<td>1 cup (236 g)</td>
<td>lukewarm</td>
<td>$0.00</td>
<td>$0.00</td>
</tr>
<tr>
<td><strong>Other ingredients</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sorghum Flour</td>
<td>1 pound (~3.6 cups, 456 grams)</td>
<td>Bob’s Red Mill™, Whole Grain</td>
<td>$3.88/1 lb, 6 oz (22 oz = 623 g)</td>
<td>$2.84</td>
</tr>
</tbody>
</table>

**TOTAL COST:** $3.76

---

### A.3.c. Costing per recipe – Enhanced 2 (sorghum flour only)

<table>
<thead>
<tr>
<th>Tortilla type</th>
<th>Manipulations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phase 1</td>
<td>Baseline</td>
</tr>
<tr>
<td>Phase 2</td>
<td>Enhanced 1 Replaced all-purpose (AP) flour with equal parts of sorghum flour and cooked lentils</td>
</tr>
<tr>
<td>Phase 3</td>
<td>Enhanced 2 Changed the original AP flour amount with equal thirds of AP flour, cooked lentils, and sorghum flour</td>
</tr>
<tr>
<td>Phase 4</td>
<td>Enhanced 3 Changed the original AP flour amount with equal thirds of AP flour, cooked lentils, and sorghum flour; reduced the water</td>
</tr>
<tr>
<td>Phase 5</td>
<td>Enhanced 4 Changed the original AP flour amount with equal thirds of AP flour, cooked lentils, and sorghum flour; reduced the water; increased the baking powder</td>
</tr>
<tr>
<td>Phase 6</td>
<td>Enhanced 5 Changed the original AP flour amount to equal halves of AP flour and cooked lentils; reduced the water (since this was the first phase completed at SCU, it served as a standard for comparison between locations)</td>
</tr>
<tr>
<td>Phase 7</td>
<td>Enhanced 6 Changed the original AP flour amount with equal thirds of AP flour, lentil flour, and sorghum flour; slightly reduced the water</td>
</tr>
<tr>
<td>Phase 8</td>
<td>Enhanced 7 Changed the original AP flour amount with equal thirds of AP flour, canned lentils, and sorghum flour; reduced the water</td>
</tr>
<tr>
<td>Phase 9</td>
<td>Enhanced 8 Changed the original AP flour amount with equal thirds of AP flour, thoroughly cooked lentils, and sorghum flour; reduced the water</td>
</tr>
<tr>
<td>Phase 10</td>
<td>Enhanced 9 Changed the original AP flour amount with the same amounts of AP flour and sorghum flour as used in phase 9; increased the amount of thoroughly cooked lentils; further reduced the water</td>
</tr>
</tbody>
</table>

---

### A. 4. Product Development – Phase Manipulations
### A. Tables - continued

<table>
<thead>
<tr>
<th></th>
<th>Baseline</th>
<th>Phase 2 (lentils &amp; sorghum flour)</th>
<th>Phase 3 (sorghum flour only)</th>
<th>Phase 4 (lentil flour only)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calories (kcal)</td>
<td>172.27</td>
<td>139.04</td>
<td>178.86</td>
<td>183.58</td>
</tr>
<tr>
<td>Calories from fat (kcal)</td>
<td>59.99</td>
<td>65.01</td>
<td>68.88</td>
<td>63.13</td>
</tr>
<tr>
<td>Total fat (g)&lt;sup&gt;b&lt;/sup&gt;</td>
<td>6.79 (11%)</td>
<td>7.34 (11%)</td>
<td>7.77 (12%)</td>
<td>7.14 (11%)</td>
</tr>
<tr>
<td>Saturated fat (g)&lt;sup&gt;b&lt;/sup&gt;</td>
<td>4.30 (23%)</td>
<td>4.31 (23%)</td>
<td>4.30 (23%)</td>
<td>4.35 (23%)</td>
</tr>
<tr>
<td>Trans fat (g)</td>
<td>0.20</td>
<td>0.20</td>
<td>0.20</td>
<td>0.20</td>
</tr>
<tr>
<td>Cholesterol (mg)&lt;sup&gt;b&lt;/sup&gt;</td>
<td>17.99 (7%)</td>
<td>17.99 (7%)</td>
<td>17.99 (7%)</td>
<td>17.99 (7%)</td>
</tr>
<tr>
<td>Total Carbohydrate (g)&lt;sup&gt;b&lt;/sup&gt;</td>
<td>24.71 (8%)</td>
<td>15.81 (5%)</td>
<td>24.78 (8%)</td>
<td>20.89 (7%)</td>
</tr>
<tr>
<td>Protein (g)</td>
<td>3.42</td>
<td>3.56</td>
<td>4.03</td>
<td>10.31</td>
</tr>
<tr>
<td>Sodium (mg)&lt;sup&gt;b&lt;/sup&gt;</td>
<td>210.23 (9%)</td>
<td>210.57 (9%)</td>
<td>210.23 (9%)</td>
<td>213.88 (9%)</td>
</tr>
<tr>
<td>Potassium (mg)</td>
<td>46.82</td>
<td>64.02</td>
<td>2.01</td>
<td>332.07</td>
</tr>
<tr>
<td>Fiber (g)&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.56 (4%)</td>
<td>2.81 (12%)</td>
<td>2.97 (12%)</td>
<td>3.89 (16%)</td>
</tr>
<tr>
<td>Sugar (g)</td>
<td>1.13</td>
<td>0.31</td>
<td>0.01</td>
<td>1.97</td>
</tr>
<tr>
<td>Vitamin A (IU)&lt;sup&gt;b&lt;/sup&gt;</td>
<td>209.06 (4%)</td>
<td>210.40 (4%)</td>
<td>209.06 (4%)</td>
<td>209.06 (4%)</td>
</tr>
<tr>
<td>Vitamin C (mg)&lt;sup&gt;b&lt;/sup&gt;</td>
<td>--</td>
<td>0.25 (&lt;1%)</td>
<td>--</td>
<td>2.27 (4%)</td>
</tr>
<tr>
<td>Calcium (mg)&lt;sup&gt;b&lt;/sup&gt;</td>
<td>10.31 (2%)</td>
<td>13.51 (2%)</td>
<td>10.31 (2%)</td>
<td>28.91 (2%)</td>
</tr>
<tr>
<td>Iron (mg)&lt;sup&gt;b&lt;/sup&gt;</td>
<td>1.21 (6%)</td>
<td>1.27 (8%)</td>
<td>1.43 (8%)</td>
<td>3.29 (20%)</td>
</tr>
<tr>
<td>Vitamin D (IU)</td>
<td>5.02</td>
<td>5.02</td>
<td>5.02</td>
<td>5.02</td>
</tr>
<tr>
<td>Vitamin B2 (mg)</td>
<td>0.11</td>
<td>0.02</td>
<td>--</td>
<td>0.09</td>
</tr>
<tr>
<td>Vitamin B12 (mcg)</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
</tr>
<tr>
<td>Folate (mcg)</td>
<td>45.06</td>
<td>30.67</td>
<td>0.25</td>
<td>0.25</td>
</tr>
</tbody>
</table>

<sup>a</sup>Nutritional information determined using Genesis R&D SQL (Version 10.11.0, 2011, ESHA Research, Inc., Salem, Oregon).

<sup>b</sup>Percent Daily Values are based on a 2,000 calorie diet.

A.5.a. Nutritional content per tortilla (60 g serving)<sup>a</sup>
### A. Tables - continued

<table>
<thead>
<tr>
<th></th>
<th>Phase 5</th>
<th>Phase 6</th>
<th>Phase 7</th>
<th>Phase 8</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calories (kcal)</td>
<td>165.79</td>
<td>149.95</td>
<td>141.60</td>
<td>184.94</td>
</tr>
<tr>
<td>Calories from fat (kcal)</td>
<td>69.80</td>
<td>66.74</td>
<td>51.65</td>
<td>77.37</td>
</tr>
<tr>
<td>Total fat (g)</td>
<td>7.89 (12%)</td>
<td>7.55 (12%)</td>
<td>5.83 (9%)</td>
<td>8.74 (14%)</td>
</tr>
<tr>
<td>Saturated fat (g)</td>
<td>4.74 (23%)</td>
<td>4.75 (23%)</td>
<td>3.44 (18%)</td>
<td>5.20 (25%)</td>
</tr>
<tr>
<td>Trans fat (g)</td>
<td>0.30</td>
<td>0.30</td>
<td>0.22</td>
<td>0.33</td>
</tr>
<tr>
<td>Cholesterol (mg)</td>
<td>19.82 (7%)</td>
<td>19.82 (7%)</td>
<td>14.28 (5%)</td>
<td>21.63 (7%)</td>
</tr>
<tr>
<td>Total Carbohydrate (g)</td>
<td>20.91 (7%)</td>
<td>17.60 (6%)</td>
<td>18.69 (6%)</td>
<td>23.18 (8%)</td>
</tr>
<tr>
<td>Protein (g)</td>
<td>3.88</td>
<td>3.60</td>
<td>4.34</td>
<td>4.28</td>
</tr>
<tr>
<td>Sodium (mg)</td>
<td>237.76 (10%)</td>
<td>237.88 (10%)</td>
<td>167.79 (7%)</td>
<td>253.65 (10%)</td>
</tr>
<tr>
<td>Potassium (mg)</td>
<td>64.23</td>
<td>95.24</td>
<td>105.98</td>
<td>66.56</td>
</tr>
<tr>
<td>Fiber (g)</td>
<td>2.45 (8%)</td>
<td>1.95 (8%)</td>
<td>3.19 (12%)</td>
<td>2.82 (12%)</td>
</tr>
<tr>
<td>Sugar (g)</td>
<td>0.64</td>
<td>0.96</td>
<td>0.49</td>
<td>0.28</td>
</tr>
<tr>
<td>Vitamin A (IU)</td>
<td>231.37 (4%)</td>
<td>231.86 (4%)</td>
<td>168.24 (4%)</td>
<td>252.79 (6%)</td>
</tr>
<tr>
<td>Vitamin C (mg)</td>
<td>0.19 (&lt;1%)</td>
<td>0.28 (&lt;1%)</td>
<td>0.39 (&lt;1%)</td>
<td>0.20 (&lt;1%)</td>
</tr>
<tr>
<td>Calcium (mg)</td>
<td>18.33 (2%)</td>
<td>19.50 (2%)</td>
<td>14.69 (2%)</td>
<td>17.24 (2%)</td>
</tr>
<tr>
<td>Iron (mg)</td>
<td>1.38 (8%)</td>
<td>1.29 (8%)</td>
<td>1.65 (10%)</td>
<td>1.65 (10%)</td>
</tr>
<tr>
<td>Vitamin D (IU)</td>
<td>5.53</td>
<td>5.53</td>
<td>3.99</td>
<td>6.04</td>
</tr>
<tr>
<td>Vitamin B2 (mg)</td>
<td>0.05</td>
<td>0.08</td>
<td>0.06</td>
<td>0.08</td>
</tr>
<tr>
<td>Vitamin B12 (mcg)</td>
<td>0.02</td>
<td>0.02</td>
<td>0.01</td>
<td>0.02</td>
</tr>
<tr>
<td>Folate (mcg)</td>
<td>39.08</td>
<td>58.49</td>
<td>63.01</td>
<td>49.35</td>
</tr>
</tbody>
</table>

---


**Percent Daily Values** are based on a 2,000 calorie diet.

---

A.5.b. **Nutritional content per tortilla (60 g serving)**

<p>| | | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Vitamin D (IU)</td>
<td>5.53</td>
<td>5.53</td>
<td>3.99</td>
<td>6.04</td>
</tr>
<tr>
<td>Vitamin B2 (mg)</td>
<td>0.05</td>
<td>0.08</td>
<td>0.06</td>
<td>0.08</td>
</tr>
<tr>
<td>Vitamin B12 (mcg)</td>
<td>0.02</td>
<td>0.02</td>
<td>0.01</td>
<td>0.02</td>
</tr>
<tr>
<td>Folate (mcg)</td>
<td>39.08</td>
<td>58.49</td>
<td>63.01</td>
<td>49.35</td>
</tr>
</tbody>
</table>
### A. Tables - continued

<table>
<thead>
<tr>
<th>Phase 9</th>
<th>Phase 10</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calories (kcal)</td>
<td>169.62</td>
</tr>
<tr>
<td>Calories from fat (kcal)</td>
<td>70.96</td>
</tr>
<tr>
<td>Total fat (g)&lt;sup&gt;b&lt;/sup&gt;</td>
<td>8.02 (12%)</td>
</tr>
<tr>
<td>Saturated fat (g)&lt;sup&gt;b&lt;/sup&gt;</td>
<td>4.77 (25%)</td>
</tr>
<tr>
<td>Trans fat (g)</td>
<td>0.30</td>
</tr>
<tr>
<td>Cholesterol (mg)&lt;sup&gt;b&lt;/sup&gt;</td>
<td>19.84 (7%)</td>
</tr>
<tr>
<td>Total Carbohydrate (g)&lt;sup&gt;b&lt;/sup&gt;</td>
<td>21.26 (7%)</td>
</tr>
<tr>
<td>Protein (g)</td>
<td>3.92</td>
</tr>
<tr>
<td>Sodium (mg)&lt;sup&gt;b&lt;/sup&gt;</td>
<td>232.65 (10%)</td>
</tr>
<tr>
<td>Potassium (mg)</td>
<td>61.04</td>
</tr>
<tr>
<td>Fiber (g)&lt;sup&gt;b&lt;/sup&gt;</td>
<td>2.58 (12%)</td>
</tr>
<tr>
<td>Sugar (g)</td>
<td>0.26</td>
</tr>
<tr>
<td>Vitamin A (IU)&lt;sup&gt;b&lt;/sup&gt;</td>
<td>231.86 (4%)</td>
</tr>
<tr>
<td>Vitamin C (mg)&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.19 (&lt;1%)</td>
</tr>
<tr>
<td>Calcium (mg)&lt;sup&gt;b&lt;/sup&gt;</td>
<td>15.97 (2%)</td>
</tr>
<tr>
<td>Iron (mg)&lt;sup&gt;b&lt;/sup&gt;</td>
<td>1.51 (8%)</td>
</tr>
<tr>
<td>Vitamin D (IU)</td>
<td>5.54</td>
</tr>
<tr>
<td>Vitamin B2 (mg)</td>
<td>0.02</td>
</tr>
<tr>
<td>Vitamin B12 (mcg)</td>
<td>0.02</td>
</tr>
<tr>
<td>Folate (mcg)</td>
<td>45.26</td>
</tr>
</tbody>
</table>

<sup>a</sup>Nutritional information determined using Food Processor Software (Version 10.11.0, 2012, ESHA Research, Inc., Salem, Oregon).
<sup>b</sup>Percent Daily Values are based on a 2,000 calorie diet.

### A.5.c. Nutritional content per tortilla (60 g serving)<sup>a</sup>

<table>
<thead>
<tr>
<th></th>
<th>Commercial Refined Tortilla (60 g)&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Commercial Health-enhanced Tortilla (57 g)&lt;sup&gt;c&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calories (kcal)</td>
<td>176</td>
<td>150</td>
</tr>
<tr>
<td>Calories from fat (kcal)</td>
<td>44</td>
<td>30</td>
</tr>
<tr>
<td>Total fat (g)&lt;sup&gt;b&lt;/sup&gt;</td>
<td>5.28 (8%)</td>
<td>3.50 (6%)</td>
</tr>
<tr>
<td>Saturated fat (g)&lt;sup&gt;b&lt;/sup&gt;</td>
<td>1.32 (7%)</td>
<td>0.50 (3%)</td>
</tr>
<tr>
<td>Trans fat (g)</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Cholesterol (mg)&lt;sup&gt;b&lt;/sup&gt;</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Total Carbohydrate (g)&lt;sup&gt;b&lt;/sup&gt;</td>
<td>26.40 (9%)</td>
<td>24.00 (8%)</td>
</tr>
<tr>
<td>Protein (g)</td>
<td>4.4</td>
<td>6.0</td>
</tr>
<tr>
<td>Sodium (mg)&lt;sup&gt;b&lt;/sup&gt;</td>
<td>378.40 (16%)</td>
<td>140.00 (6%)</td>
</tr>
<tr>
<td>Potassium (mg)</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Fiber (g)&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.88</td>
<td>5.00</td>
</tr>
<tr>
<td>Sugar (g)</td>
<td>0.88</td>
<td>--</td>
</tr>
<tr>
<td>Vitamin A (IU)&lt;sup&gt;b&lt;/sup&gt;</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Vitamin C (mg)&lt;sup&gt;b&lt;/sup&gt;</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Calcium (mg)&lt;sup&gt;b&lt;/sup&gt;</td>
<td>9%</td>
<td>4%</td>
</tr>
<tr>
<td>Iron (mg)&lt;sup&gt;b&lt;/sup&gt;</td>
<td>9%</td>
<td>10%</td>
</tr>
</tbody>
</table>

<sup>a</sup>Values adapted from http://frescadostortillas.com/products/flour-tortillas/10-chimichanga-flour-tortilla/. Accessed August 4, 2013. No values were listed for potassium, Vitamin D, Vitamin B2, Vitamin B12, and Folate.
<sup>b</sup>Percent Daily Values are based on a 2,000 calorie diet.
# Appendix B: Analytical Instrument Information

## B.1. Instrument/Equipment Overview

<table>
<thead>
<tr>
<th>Equipment/instrument</th>
<th>Objective</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Color – MFI</strong></td>
<td>Evaluate color using the “L,a,b” scale (L=brightness, a=redness, and b=yellowness)</td>
</tr>
<tr>
<td>Hunterlab™ ColorFlex EZ</td>
<td></td>
</tr>
<tr>
<td><strong>Moisture/solids – MFI</strong></td>
<td>Determine the percent moisture/solids; gain insight to product spoilage and susceptibility to molding</td>
</tr>
<tr>
<td>Computrac™ MAX 4000XL Moisture Analyzer (Arizona Instrument LLC)</td>
<td></td>
</tr>
<tr>
<td><strong>Water activity – MFI</strong></td>
<td>Gain insight to the extent of starch absorption, food safety, and shelf stability; investigate the amount of water available for microbial growth</td>
</tr>
<tr>
<td>AquaLab™ Series 4TE DewPoint Water Activity Meter</td>
<td></td>
</tr>
<tr>
<td><strong>Texture – MFI</strong></td>
<td>Record the deformation of the tortillas under an applied force and therefore determined some of their rheological or mechanical properties (toughness and resistance); determine the force to break the product</td>
</tr>
<tr>
<td>TA-XT2i TMS – Pro™ Texture Analyzer</td>
<td></td>
</tr>
<tr>
<td><strong>Color – UMN</strong></td>
<td>Evaluate color using the “L,a,b” scale (L=brightness, a=redness, and b=yellowness)</td>
</tr>
<tr>
<td>Minolta™ Chroma Meter with CR – 221 Lens Head</td>
<td></td>
</tr>
<tr>
<td><strong>Water activity – UMN</strong></td>
<td>Gain insight to the extent of starch absorption, food safety, and shelf stability; investigate the amount of water available for microbial growth</td>
</tr>
<tr>
<td>AquaLab™ Vapor Sorption Analyzer</td>
<td></td>
</tr>
<tr>
<td><strong>Texture – UMN</strong></td>
<td>Record the deformation of the tortillas under an applied force and therefore determined some of their rheological or mechanical properties (toughness and resistance); determine the force to break the product</td>
</tr>
<tr>
<td>TA.XT.plus™ Texture Analyzer</td>
<td></td>
</tr>
</tbody>
</table>

MFI = Michael Foods, Inc.
UMN = University of Minnesota – Twin Cities
B.2. Color Spectrophotometer

Measuring color:

- A light source is used to illuminate the sample being evaluated with a color spectrophotometer
- The light reflected is broken down into spectral components as it passes through a "grating"
- As the sample signal reaches a diode array, the amount of light at each wavelength is quantified
- The resulting spectral data is sent to the processor where it is multiplied with user-selected illuminant and observer color values
- The Hunter L,a,b color space is a 3-dimensional rectangular color space based on the opponent-colors theory
  - L (lightness) axis – 0 is black, 100 is white, and 50 is middle grey
  - A (red-green) axis – positive values are red, negative values are green, and 0 is neutral
  - B (blue-yellow) axis – positive values are yellow, negative values are blue, and 0 is neutral
- For the purposes of this research, a 2 by 2 inch square of tortilla product was cut using a standard template and scalpel. This sample was placed on top of the calibrated spectrophotometer lens, enclosed with a black metal cover, and evaluated through quantification of the L,a,b scale.

Information adapted from:

B.3. Moisture Analyzer

A Computrac® MAX® 4000XL instrument was used during stage 1 of analytical testing to assess the percentage of moisture composition for the tortilla products. This instrument analyzes loss-on-drying technology and provides faster results than standard vacuum oven and convection oven drying procedures. A Test Program is created for the specific type of sample with programmed controls for temperature. Within the instrument’s test chamber, a sensitive electronic force balance supports an aluminum sample pan. As the product sample is added to the sample pan, the force balance records the initial weight of the sample before testing. After the chamber is closed and the test program initiated (by selecting the appropriate parameters and pressing the “test” button), the heater located on the underside of the test chamber lid heats up, raising the temperature of the chamber (and thus the sample). The temperature in the chamber is monitored by a Resistance Temperature Device (RTD) and sent to the instrument’s microprocessor. This microprocessor controls the heater, enabling it to cycle on and off to bring the chamber to the programmed temperature.

As the sample is heated, it loses weight due to moisture evaporation. The force balance records this weight loss and sends this data to the microprocessor to be assessed in comparison to a standard drying curve. Comparisons are made between the sample’s initial weight and its decreasing weight with heating. After being matched with the curve for the specified program (the predicted moisture concentration must agree with a certain percentage of the actual moisture concentration), the final moisture concentration is extrapolated and results become available in minutes (instead of the 4+ hours necessary for vacuum oven or convection oven techniques).

For the purposes of this research, 5 g samples of each tortilla product were evaluated using the Flour Test Program (programmed temperature of 266°F or 130°C).

Information adapted from:
B.4. Water Activity Meter

- Water activity is the ratio of the water vapor pressure over a food to that over pure water.
  - Thus, multiplication of the water activity by 100 gives the relative humidity of the atmosphere in equilibrium with the food being evaluated.
  - The water activity is also a measure of the energy status of the water in a system.
  - Water activity measurements are indicative of the shelf life of products.
- Water activity is a better index for microbial growth than water content.
  - Since microorganisms can only use ‘available’ water, which differs depending on the solute, water activity is a better predictor of microbial growth.
  - On average, ions bind the most water, while polymers bind the least; sugars and peptides bind a medium amount of water.
  - At the same molecular concentration, salt lowers water activity more than sugar.
- Water activity should be regarded as an external parameter like pH or temperature. Under certain conditions, it will act synergistically with other environmental parameters, while under other conditions it will be the sole factor determining the outcome of a certain process.
- Water activity influences non-enzymatic browning, lipid oxidation, degradation of vitamins, enzymatic reactions, protein denaturation, starch gelatinization, and starch retrogradation.
- The lower the water activity, the less free water for microbial growth and the more favorable conditions for extended shelf life and food safety.
- Standard values for tortillas: 0.91-0.95.

- How the AquaLab 4TE worked for the purposes of this project:
  - A sample (4 g) was placed in the chamber, which was then sealed.
  - After a short period of time (~10 minutes) vapor equilibrium was reached.
  - An infrared beam focused on a tiny mirror in the chamber determined the precise dewpoint temperature of the sample; that dewpoint temperature was then translated into water activity through programmed calculations in the instrument.

*Information adapted from:*
B.5. Texture Analyzer

TA.XT.plus™ or TA-XT2i TMS – Pro™ Texture Analyzers can be used for measuring a wide variety of physical tests for food samples. Different test cells, probes, and fixtures are used for measuring the compression, extension, extrusion, penetration, puncture, and snapping for a broad range of foods or food ingredients. Programs in computer controlled texture analyses are created and standardized, enabling food technologists to manipulate forces and actions applied to food samples. In each test, the energy put into the sample is absorbed, stored, or returned. This response is then measured and depicted in graphical form (usually on a computer) to aid in understanding and quantifying sensory characteristics.

For the purposes of this research, the force to puncture the tortilla products was measured by securing a 2 by 2 inch tortilla sample with a ring clamp (extensibility fixture) to the analyzer and puncturing it with a 1 inch cylinder probe (or its equivalent). The probe was set with a 0.050 N force and moved with a test speed of 400 mm/min; the probe was programmed to travel 20 mm total before returning to its original position. With this test program, the force to puncture the sample was measured for each type of tortilla (peaks on graphical results), providing quantitative data for assessing rollability, flexibility, and tear strength of each product.

*Information adapted from:*
Appendix C: Graphic Images

C.1.a. Color: Hunterlab™ ColorFlex EZ instrument – Michael Foods, Inc. (MFI)

C.1.b. Color: Hunterlab™ ColorFlex EZ instrument in the testing process – MFI

C.1.c. Color: Minolta™ Chroma Meter – University of Minnesota (UMN)

C.1.d. Color: Minolta™ Chroma Meter CR – 221 Lens Head – UMN
C. Graphic Images - continued

C.2.a. Computrac™ MAX 4000XL Moisture Analyzer (Arizona Instrument LLC) – MFI

C.2.b. Computrac™ MAX 4000XL Moisture Analyzer (Arizona Instrument LLC) during testing process – MFI

C.2.c. Computrac™ MAX 4000XL Moisture Analyzer (Arizona Instrument LLC) during testing process – MFI
C.3.a. Water Activity Meter: AquaLab™ Series 4TE DewPoint Water Activity Meter – MFI

C.3.b. Water Activity Meter: AquaLab™ Series 4TE DewPoint Water Activity Meter during testing process – MFI

C.3.c. Water Activity Meter: AquaLab™ Vapor Sorption Analyzer – UMN
C. Graphic Images - continued

C.4.a. TA-XT2i TMS – Pro™ Texture Analyzer – MFI

C.4.b. TA-XT2i TMS – Pro™ Texture Analyzer during testing process – MFI

C.4.c. TA-XT2i TMS – Pro™ Texture Analyzer sample preparation – MFI

C.4.d. TA-XT2i TMS – Pro™ Texture Analyzer during testing process – MFI
C.4.e. TA.XT.plus™ Texture Analyzer – UMN

C.4.f. TA.XT.plus™ Texture Analyzer Set-up – UMN

C.4.g. TA.XT.plus™ Texture Analyzer Probe – UMN
C.5. Tortilla Phases

C.5.a. Baseline – Phase 1

C.5.b. Phase 2

C.5.c. Phase 3

C.5.d. Phase 4

C.5.e. Phase 5

C.5.f. Phase 6
C.5. Tortilla Phases - continued

C.5.g. Phase 7
C.5.h. Phase 8
C.5.i. Tortilla Press – used for Phases 9 and 10
C.5.j. Phase 9
C.5.k. Phase 10
C.6. Sensory Evaluations


C.6.b. Sensory Evaluation #1 Set-up at St. Catherine University – October 22, 2013
C.6. Sensory Evaluations – continued

C.6.c. Sensory Evaluation #2 Set-up at St. Catherine University – October 23, 2013

C.6.d. Partial Set-up for Sensory Evaluation #3 at Saint Catherine University – October 31, 2013
C.6. Sensory Evaluations – continued

C.6.e. Partial Set-up for Sensory Evaluation #4 at Saint Catherine University – November 18, 2013
C.6. Tortilla Samples Displayed for Sensory Evaluations at Saint Catherine University

C.6.f. Phase 9 Tortilla

C.6.g. Phase 10 Tortilla

C.6.h. Commercial Health-enhanced Tortilla

C.6.i. Commercial Refined Tortilla
Appendix D: Data Tables & Graphs

D.1.a. MFI Sensory Evaluations – Stage 1 – Demographic Data & Survey Results

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of participants(^a)</td>
<td>9 (89% female; 11% male)</td>
</tr>
<tr>
<td>Average age (years)</td>
<td>44 (range of 30 to 58)</td>
</tr>
<tr>
<td>Ethnicity</td>
<td>White – 7 (78%)</td>
</tr>
<tr>
<td></td>
<td>Asian – 1 (11%)</td>
</tr>
<tr>
<td></td>
<td>Hispanic/Latino – 0 (0%)</td>
</tr>
<tr>
<td>Education level</td>
<td>4+ years of college – 7 (78%)</td>
</tr>
<tr>
<td></td>
<td>Some college/technical school – 1 (11%)</td>
</tr>
<tr>
<td>Employment</td>
<td>Full-time – 8 (89%)</td>
</tr>
<tr>
<td>Frequency of tortilla consumption</td>
<td>Less than once/week – 6 (67%)</td>
</tr>
<tr>
<td></td>
<td>1 to 3 times/week – 2 (22%)</td>
</tr>
<tr>
<td>Tortilla consumption method</td>
<td>As an ingredient or meal component – 5 (56%)</td>
</tr>
<tr>
<td></td>
<td>Plain and warmed – 2 (22%)</td>
</tr>
<tr>
<td></td>
<td>Plain at room temperature – 1 (11%)</td>
</tr>
<tr>
<td>Estimated frequency of whole grain consumption(^b)</td>
<td>&lt;3 times/week – 3 (33%)</td>
</tr>
<tr>
<td></td>
<td>3 to 5 times/week – 3 (33%)</td>
</tr>
<tr>
<td></td>
<td>Daily – 1 (11%)</td>
</tr>
<tr>
<td>Estimated frequency of vegetable consumption(^c)</td>
<td>2 servings/day – 4 (44%)</td>
</tr>
<tr>
<td></td>
<td>3 servings/day – 3 (33%)</td>
</tr>
<tr>
<td></td>
<td>4+ servings/day – 1 (11%)</td>
</tr>
</tbody>
</table>

\(^a\)One participant did not respond to all questions of the survey.

\(^b\)Whole grain foods were defined as containing “the entire seed of grain—consisting of the bran, germ, and endosperm—in the same relative proportions as those found in an intact grain.” Examples of wild rice, popcorn, buckwheat, oatmeal, rolled oats, brown rice, whole grain barley, and whole grain rye were listed on the survey.

\(^c\)One serving of vegetables was described on the survey as any vegetable (fresh, frozen, canned, or juiced) that is the equivalent of 1 medium potato, ½ cup peas, or 1 cup salad.

---

D.1.b. MFI Sensory Evaluations – Stage 1

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Baseline</th>
<th>Commercial</th>
<th>Phase 4</th>
<th>Phase 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Appearance</td>
<td>6.6±0.4(^a)</td>
<td>6.9±0.3</td>
<td>4.5±0.6(^b)</td>
<td>4.5±0.5(^c)</td>
</tr>
<tr>
<td>Aroma</td>
<td>6.0±0.3</td>
<td>5.2±0.4</td>
<td>5.2±0.4</td>
<td>5.5±0.7</td>
</tr>
<tr>
<td>Texture</td>
<td>5.5±0.5</td>
<td>5.1±0.6</td>
<td>3.9±0.2</td>
<td>4.6±0.5</td>
</tr>
<tr>
<td>Tenderness</td>
<td>5.1±0.7</td>
<td>5.9±0.6</td>
<td>4.8±0.4</td>
<td>4.4±0.5</td>
</tr>
<tr>
<td>Taste</td>
<td>6.3±0.4</td>
<td>4.9±0.6</td>
<td>4.4±0.5</td>
<td>5.5±0.7</td>
</tr>
<tr>
<td>Overall Likeability</td>
<td>5.8±0.7</td>
<td>5.1±0.4</td>
<td>4.0±0.4</td>
<td>4.8±0.6</td>
</tr>
</tbody>
</table>

\(^a,b,c\)Means with different letters indicate statistically significant differences (Tukey’s HSD, \(P<0.05\)).

Scale for all characteristics: 1=dislike extremely, 2=dislike very much, 3=dislike moderately, 4=dislike slightly, 5=neither like nor dislike, 6=like slightly, 7=like moderately, 8=like very much, 9=like extremely.
D. Data Tables & Graphs – continued

D.2.a. SCU Sensory Evaluations – Stage 2 – Demographic Data & Survey Results

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of participants</td>
<td>35 (100% female)</td>
</tr>
<tr>
<td>Average age (years)</td>
<td>23 (range of 18 to 59)</td>
</tr>
</tbody>
</table>
| Ethnicity\(^a\)                                                          | White – 29 (83%)  
Asian – 5 (14%)  
Other – 1 (3%)  
Hispanic/Latino – 2 (6%)                                                                                                                                                                                                                                                    |
| Education level                                                          | 4+ years of college – 5 (14%)  
Some college/technical school – 30 (86%)                                                                                                                                                                                                                                                                                                  |
| Employment\(^a\)                                                         | Full-time – 4 (11%)  
Part-time – 17 (49%)  
Not employed – 3 (9%)  
Student – 21 (60%)                                                                                                                                                                                                                                                          |
| Frequency of tortilla consumption                                        | Less than once/week – 26 (74%)  
1 to 3 times/week – 8 (23%)  
More than 3 times/week – 1 (3%)                                                                                                                                                                                                                                                                                     |
| Variety of tortilla product typically consumed\(^a\)                    | Soft regular wheat – 21 (60%)  
Soft whole wheat – 12 (34%)  
Soft corn – 8 (23%)  
Hard-shell – 7 (20%)  
Not typically consumed – 8 (23%)                                                                                                                                                                                                                                                                                 |
| Tortilla consumption method\(^a\)                                        | As an ingredient or meal component – 24 (69%)  
Plain and warmed – 7 (20%)  
Plain and chilled – 1 (3%)  
Plain at room temperature – 7 (20%)                                                                                                                                                                                                                         |
| Estimated frequency of whole grain consumption\(^b\)                    | Never/infrequently – 10 (29%)  
3 to 5 times/week – 10 (29%)  
4 to 6 times/week – 4 (11%)  
Daily – 11 (31%)                                                                                                                                                                                                                                                                                                               |
| Estimated frequency of vegetable consumption\(^c\)                       | <1 serving/day – 4 (11%)  
1 serving/day – 5 (14%)  
2 servings/day – 17 (49%)  
3 servings/day – 5 (14%)  
4+ servings/day – 4 (11%)                                                                                                                                                                                                                                                                                             |

\(^a\)Survey questions were “mark all that apply,” so total number of responses exceeded 35.

\(^b\)Whole grain foods were defined as containing “the entire seed of grain—consisting of the bran, germ, and endosperm—in the same relative proportions as those found in an intact grain.” Examples of wild rice, popcorn, buckwheat, oatmeal, rolled oats, brown rice, whole grain barley, and whole grain rye were listed on the survey.

\(^c\)One serving of vegetables was described on the survey as any vegetable (fresh, frozen, canned, or juiced) that is the equivalent of 1 medium potato, ½ cup peas, or 1 cup salad.
D. Data Tables & Graphs – continued

D.2.b. SCU Sensory Evaluations – Stage 2

**Table D.2** Characteristics (sensory and acceptability) of commercial refined, commercial health-enhanced, phase 9, and phase 10 tortilla products (n=32-35; participant size variance was due to incomplete evaluations).

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Commercial Refined</th>
<th>Commercial Health-enhanced</th>
<th>Phase 9</th>
<th>Phase 10</th>
</tr>
</thead>
<tbody>
<tr>
<td>Appearance</td>
<td>7.2±0.3&lt;sup&gt;a&lt;/sup&gt;</td>
<td>6.1±0.3&lt;sup&gt;bd&lt;/sup&gt;</td>
<td>5.0±0.3&lt;sup&gt;cd&lt;/sup&gt;</td>
<td>5.1±0.3&lt;sup&gt;bd&lt;/sup&gt;</td>
</tr>
<tr>
<td>Aroma</td>
<td>6.0±0.3</td>
<td>5.3±0.3&lt;sup&gt;a&lt;/sup&gt;</td>
<td>5.7±0.3</td>
<td>6.3±0.2&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Texture</td>
<td>7.2±0.3&lt;sup&gt;a&lt;/sup&gt;</td>
<td>4.6±0.3&lt;sup&gt;b&lt;/sup&gt;</td>
<td>5.7±0.3&lt;sup&gt;cd&lt;/sup&gt;</td>
<td>5.9±0.3&lt;sup&gt;cd&lt;/sup&gt;</td>
</tr>
<tr>
<td>Tenderness</td>
<td>6.8±0.2&lt;sup&gt;a&lt;/sup&gt;</td>
<td>4.7±0.3&lt;sup&gt;b&lt;/sup&gt;</td>
<td>5.9±0.3&lt;sup&gt;acd&lt;/sup&gt;</td>
<td>6.3±0.3&lt;sup&gt;acd&lt;/sup&gt;</td>
</tr>
<tr>
<td>Taste</td>
<td>7.1±0.3&lt;sup&gt;a&lt;/sup&gt;</td>
<td>5.2±0.3&lt;sup&gt;b&lt;/sup&gt;</td>
<td>5.5±0.4&lt;sup&gt;c&lt;/sup&gt;</td>
<td>6.2±0.3</td>
</tr>
<tr>
<td>Overall Likeability</td>
<td>7.2±0.2&lt;sup&gt;a&lt;/sup&gt;</td>
<td>5.2±0.3&lt;sup&gt;b&lt;/sup&gt;</td>
<td>5.6±0.3&lt;sup&gt;c&lt;/sup&gt;</td>
<td>6.1±0.3</td>
</tr>
</tbody>
</table>

<sup>abcd</sup>Means with different letters indicate statistically significant differences (Tukey’s HSD, \(P<0.05\)).

Scale for all characteristics: 1=dislike extremely, 2=dislike very much, 3=dislike moderately, 4=dislike slightly, 5=neither like nor dislike, 6=like slightly, 7=like moderately, 8=like very much, 9=like extremely.
D.2.c. Stage 2 Sensory Evaluation Results Graph

Means with different letters indicate statistically significant differences (Tukey’s HSD, $P<0.05$). Error bars indicate ± 1 standard error of the mean for each characteristic.
# Data Tables & Graphs – continued

<table>
<thead>
<tr>
<th></th>
<th>Texture (Newton) ±std dev</th>
<th>Color Average (L, a, b)</th>
<th>Water Activity (aw)</th>
<th>Moisture (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline</td>
<td>705±82</td>
<td>L: 74.5</td>
<td>0.932</td>
<td>23.4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>a: 1.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>b: 21.7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Phase 2</td>
<td>417±32</td>
<td>L: 53.2</td>
<td>0.949</td>
<td>no data</td>
</tr>
<tr>
<td></td>
<td></td>
<td>a: 4.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>b: 20.7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Phase 3</td>
<td>444±124</td>
<td>L: 55.1</td>
<td>0.945</td>
<td>27.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>a: 4.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>b: 20.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Phase 4</td>
<td>305±21</td>
<td>L: 58.9</td>
<td>0.935</td>
<td>29.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>a: 4.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>b: 21.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Phase 5</td>
<td>263±64</td>
<td>L: 57.7</td>
<td>0.942</td>
<td>28.4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>a: 4.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>b: 22.5</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

D.3.a. MFI Analytical Analysis Results – Stage 1
D. Data Tables & Graphs - continued

D.3.b. Texture Graphical Results – Baseline

Peak = force to rupture/break tortilla product

D.3.c. Texture Graphical Results – Phase 2

Peak = force to rupture/break tortilla product
D. Data Tables & Graphs – continued

D.3.d. Texture Graphical Results – Phase 3

D.3.e. Texture Graphical Results – Phase 4
D. Data Tables & Graphs – continued

D.3.f. Texture Graphical Results – Phase 5

Texture Average
(Newtons) ±st dev

<table>
<thead>
<tr>
<th>Phase</th>
<th>Texture Average (Newtons) ±st dev</th>
<th>Color Average (L, a, b) ±st dev</th>
<th>Water Activity (aw)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phase 9</td>
<td>440.8±66.6</td>
<td>L: 62.7±0.9 a: 1.9±0.3 b: 16.8±0.6</td>
<td>0.949</td>
</tr>
<tr>
<td>Phase 10</td>
<td>291.3±69.1</td>
<td>L: 60.4±1.9 a: 2.1±0.2 b: 16.4±0.6</td>
<td>0.952</td>
</tr>
<tr>
<td>Commercial Health-enhanced</td>
<td>520.2±79.4</td>
<td>L: 63.6±1.9 a: 5.2±0.8 b: 17.0±1.0</td>
<td>0.948</td>
</tr>
<tr>
<td>Commercial Refined</td>
<td>439.9±38.4</td>
<td>L: 83.7±0.7 a: -1.1±0.2 b: 17.0±0.8</td>
<td>0.913</td>
</tr>
</tbody>
</table>

D.4.a. UMN Analytical Analysis Results – Stage 2

Peak = force to rupture/break tortilla product
D. Data Tables & Graphs – continued

D.4.b. Texture Graphical Results – Phase 9

D.4.c. Texture Graphical Results – Phase 10

Peak = force to rupture/break tortilla product
D. Data Tables & Graphs – continued

D.4.d. Texture Graphical Results – Commercial Health-enhanced

Peak = force to rupture/break tortilla product

D.4.e. Texture Graphical Results – Commercial Refined

Peak = force to rupture/break tortilla product
YOU ARE INVITED TO PARTICIPATE…

...in a Food Sensory Evaluation of Whole Grain & Legume Food Products

Developed by a Fellow Katie!

Your participation in this project will entail completing a brief survey followed by a food sensory evaluation, together which will last between 30 to 45 minutes. During the session, you will be asked a few demographic questions and a couple questions regarding your dietary habits. There is no direct benefit for participating. Individuals with known food allergies are excluded from participating. The food sensory evaluation sessions will be held on [add dates and times here] in the Food Science Lab – Fontbonne Hall 2. Please contact Anna Hayes at amhayes@stkate.edu or 507-766-0832 if you plan to attend.

Date: ________________  Time: ________________

For more information, contact:
Anna Hayes
507-766-0832
amhayes@stkate.edu

E.1. Recruitment Flyer
Introduction:
You are invited to participate in a research study investigating the sensory attributes of new food products containing whole grains and legumes developed by a student researcher for her HNRS 4970 Senior Honors Project. This study is being conducted by an undergraduate nutrition student at St. Catherine University under the supervision of Teri L. Burgess-Champoux, PhD, RD, LD, a faculty member in the Department of Nutrition and Exercise Sciences. You were selected as a possible participant in this research because you are [add appropriate inclusion group here]. Please read this form and ask questions before you agree to participate in the study.

Background Information:
The purpose of this study is to evaluate the sensory attributes associated with new food products. Approximately 20-30 people are expected to participate in this research. Individuals with known food allergies are excluded from participating in the study.

Procedures:
If you decide to participate, you will be asked to taste test several food samples and complete written sensory evaluation forms. You will be asked to provide some of your basic demographic information such as age, gender, race/ethnicity, and education level. This study will take approximately 30-45 minutes to complete in 1 session.

Risks and Benefits of being in the study:
The study has minimal risks. The possibility of a reaction to an undiagnosed food allergy is always a potential risk in studies involving food sampling. There are no direct benefits to participation in this study.

Confidentiality:
Any information obtained in connection with this research study that can be identified with you will be disclosed only with your permission; your results will be kept confidential. In any written reports or publications, no one will be identified or identifiable and only group data will be presented.

We/I will keep the research results in a locked file cabinet in Dr. Burgess-Champoux’s office and only the student researcher and Dr. Burgess-Champoux will have access to the records while we/I work on this project. We/I will finish analyzing the data by May 16, 2014. We/I will then destroy all original reports and identifying information that can be linked back to you.

E.2. Consent Form
Voluntary nature of the study:

Participation in this research study is voluntary. Your decision whether or not to participate will not affect your future relations with St. Catherine University in any way. If you decide to participate, you are free to stop at any time without affecting these relationships.

Contacts and questions:

If you have any questions, please feel free to contact Dr. Burgess-Champoux at 651-690-8750. You may ask questions now, or if you have any additional questions later, the faculty advisor, (Teri L. Burgess-Champoux, PhD, RD, LD at 651-690-8750), will be happy to answer them. If you have other questions or concerns regarding the study and would like to talk to someone other than the researcher(s), you may also contact Dr. John Schmitt, Chair of the St. Catherine University Institutional Review Board, at (651) 690-7739.

You may keep a copy of this form for your records.

Statement of Consent:

You are making a decision whether or not to participate. Your signature indicates that you have read this information and your questions have been answered. Even after signing this form, please know that you may withdraw from the study at any time.

___________________________________________________________________________

I consent to participate in the study.

___________________________________________________________________________

Signature of Participant Date

___________________________________________________________________________

Signature of Student Researcher Date

___________________________________________________________________________

Signature of Faculty Advisor Date

E.2. Consent Form – continued
Survey of Demographic Information:

1. Please check (✓) only one box about yourself.

<table>
<thead>
<tr>
<th>YOUR ETHNICITY</th>
</tr>
</thead>
<tbody>
<tr>
<td>Please check (✓) only one box.</td>
</tr>
<tr>
<td>□ Hispanic or Latino. A person of Cuban, Mexican,</td>
</tr>
<tr>
<td>Puerto Rican, South or Central American, or other</td>
</tr>
<tr>
<td>Spanish culture or origin, regardless of race.</td>
</tr>
<tr>
<td>□ Not Hispanic or Latino.</td>
</tr>
</tbody>
</table>

2. How would you best describe yourself with respect to race?

<table>
<thead>
<tr>
<th>YOUR RACE</th>
</tr>
</thead>
<tbody>
<tr>
<td>You may check (✓) more than one box.</td>
</tr>
<tr>
<td>□ Black or African American. A person having origins</td>
</tr>
<tr>
<td>in any of the Black racial groups of Africa.</td>
</tr>
<tr>
<td>□ White. A person having origins in any of the</td>
</tr>
<tr>
<td>original peoples of Europe, the Middle East, or North</td>
</tr>
<tr>
<td>Africa.</td>
</tr>
<tr>
<td>□ Alaska native or American Indian. A person having</td>
</tr>
<tr>
<td>origins in any of the original peoples of North,</td>
</tr>
<tr>
<td>Central and South America, and who maintains tribal</td>
</tr>
<tr>
<td>affiliation or community attachment.</td>
</tr>
<tr>
<td>□ Asian. A person having origins in any of the</td>
</tr>
<tr>
<td>original peoples of the Far East, Southeast Asia, or</td>
</tr>
<tr>
<td>the Indian subcontinent including for example,</td>
</tr>
<tr>
<td>Cambodia, China, India, Japan, Korea, Malaysia,</td>
</tr>
<tr>
<td>Pakistan, the Philippine Islands, Thailand and</td>
</tr>
<tr>
<td>Vietnam.</td>
</tr>
<tr>
<td>□ Native Hawaiian or other Pacific Islander. A</td>
</tr>
<tr>
<td>person having origins in any of the original peoples</td>
</tr>
<tr>
<td>of Hawaii, Guam, Samoa, or other Pacific Islands.</td>
</tr>
<tr>
<td>□ Other. A group not mentioned above.</td>
</tr>
</tbody>
</table>

If Other is checked, please describe:

3. Please indicate your age: ________ years

E.3. Demographic Survey
4. Please indicate your gender:
   ○ Male
   ○ Female

5. What is your highest level of formal education?
   ○ Have not completed high school
   ○ Received high school diploma or GED
   ○ Some college or technical school
   ○ 4-year college, university degree or advanced degree

6. Which of the following best describes your employment status? (Mark all that apply)
   ○ Student
   ○ Not employed
   ○ Employed part-time (≤ 20 hours per week)
   ○ Employed full-time (> 20 hours per week)

7. In a 1-week period of time, how often do you consciously choose to include whole grain foods in your diet?
   Whole grain foods contain the entire seed of grain—consisting of the bran, germ, and endosperm—in the same relative proportions as those found in an intact grain. Whole grains can be single foods (wild rice, popcorn) or ingredients in foods (buckwheat, oatmeal, rolled oats, brown rice, whole grain barley, whole rye, whole wheat).
   ○ Daily
   ○ 4 to 6 times
   ○ 3 to 5 times
   ○ Fewer than 3 times
   ○ Never

8. On average, how many serving of vegetables—fresh, frozen, canned, or juiced—do you eat per day? One serving is the same as one potato, half a cup of peas, or a cup of salad.
   For example, 2 medium potatoes + ½ cup of peas = 3 servings
   ○ 4 or more servings
   ○ 3 servings
   ○ 2 servings
   ○ 1 serving
   ○ Less than one serving per day
   ○ Never

9. Of the following list, which food products do you typically consume? (Mark all that apply)***
   ○ Soft regular wheat flour tortillas
   ○ Soft whole wheat flour tortillas
   ○ Soft corn tortillas
   ○ Hard-shell tortillas
   ○ None of the above

   ***Continue to questions 10 and 11 if you checked any of the first three options for number 9. If none of these three apply to you, the survey is now complete.

E.3. Demographic Survey – continued
10. In a 1-week period of time, how frequently do you consume soft tortillas (including wraps)?

- More than 3 times
- 1 to 3 times
- Less than 1 time
- Never

11. How do you typically consume soft tortillas? (Mark all that apply)

- Plain, chilled
- Plain, at room temperature
- Plain, warmed
- As an ingredient or meal component (burrito, taco, enchilada, etc.)
- Other (please indicate): ____________________________

Thank you!

E.3. Demographic Survey – continued
Sensory Characteristic Definitions

Appearance: the way a sample looks/seems on the outside; its external aspects/characteristics

Aroma: the noticeable smell/scent of a sample

Texture: the way a sample feels in one’s mouth; for example, coarse, smooth, light, and dense/heavy are several words used to describe texture

Tenderness: the force to chew or bite through and cut a sample; how easily a sample gives way to the pressure of the teeth

Taste: the particular quality that allows different foods to be recognized when they are put in one’s mouth

Overall Likeability: the final rating of a sample as pleasing or unpleasing
Tortilla Sensory Evaluation

Please rate sensory characteristics of the sample by checking the appropriate box using the following scale.

EXAMPLE:

☐ Dislike Extremely
☐ Dislike Very Much
☐ Dislike Moderately
☐ Dislike Slightly
☐ Neither Like nor Dislike
☐ Like Slightly
☐ Like Moderately
☐ Like Very Much
☐ Like Extremely

First, record your participant number and today’s date in the upper right-hand corner of this form. Next, take one plate with a labeled sample and record its code in the upper right-hand corner of this form. Before you begin to taste the sample, assess its appearance and aroma. Take a normal-sized bite, chew it 8 times, and then rate it for texture, tenderness, taste, and overall likeability according to your preference. Additional bites can be taken and the entire sample does not need to be eaten. You may either consume or expectorate (chew and spit out) the sample.

Feel free to ask questions regarding the tasting instructions during any point of the sensory evaluation.

Appearance:

☐ Dislike Extremely
☐ Dislike Very Much
☐ Dislike Moderately
☐ Dislike Slightly
☐ Neither Like nor Dislike
☐ Like Slightly
☐ Like Moderately
☐ Like Very Much
☐ Like Extremely

Specifically, what did you like/dislike about the sample’s appearance?
Aroma:

- Dislike Extremely
- Dislike Very Much
- Dislike Moderately
- Dislike Slightly
- Neither Like nor Dislike
- Like Slightly
- Like Moderately
- Like Very Much
- Like Extremely

Specifically, what did you like/dislike about the sample’s aroma?

Texture:

- Dislike Extremely
- Dislike Very Much
- Dislike Moderately
- Dislike Slightly
- Neither Like nor Dislike
- Like Slightly
- Like Moderately
- Like Very Much
- Like Extremely

Specifically, what did you like/dislike about the sample’s texture?

Tenderness:

- Dislike Extremely
- Dislike Very Much
- Dislike Moderately
- Dislike Slightly
- Neither Like nor Dislike
- Like Slightly
- Like Moderately
- Like Very Much
- Like Extremely

Specifically, what did you like/dislike about the sample’s tenderness?

E.5. Sensory Evaluation Instrument – continued
**Taste:**

- [ ] Dislike Extremely
- [ ] Dislike Very Much
- [ ] Dislike Moderately
- [ ] Dislike Slightly
- [ ] Neither Like nor Dislike
- [ ] Like Slightly
- [ ] Like Moderately
- [ ] Like Very Much
- [ ] Like Extremely

Specifically, what did you like/dislike about the sample’s taste?

---

**Overall Likeability:**

- [ ] Dislike Extremely
- [ ] Dislike Very Much
- [ ] Dislike Moderately
- [ ] Dislike Slightly
- [ ] Neither Like nor Dislike
- [ ] Like Slightly
- [ ] Like Moderately
- [ ] Like Very Much
- [ ] Like Extremely

Specifically, what did you like/dislike about the sample overall?

---

**E.5. Sensory Evaluation Instrument – continued**
Appendix F: Final Commentary

This research investigation was truly a rewarding experience. Through the numerous opportunities I was fortunate enough to pursue, I was able to explore diverse aspects of research as they relate to my future area of study and career. The initial literature review portion of this project, complete with a project proposal, was an excellent way to boost my understanding of current health concerns and discover any “gaps” or avenues for potential research. Having to plan ahead—with a timeline, succinct objectives, budget, and many other details—enabled me to accomplish all that I set out to do in a thorough and comprehensive manner. Looking back, I am thankful to have started this project in the summer. I cannot imagine trying to fit it all in during one semester, along with having other classes and work to divide my attention. Thanks to proper direction from my advisor and committee, I began the Fall 2013 semester with a strong sense of direction and adhered to the deadlines throughout the year, enabling me to complete all parts/phases to my satisfaction.

Although having deadlines and a fairly rigid timeline were beneficial, one thing I learned throughout this project was the importance of being flexible. Yes, it is ideal to have (and maintain) deadlines, but sometimes circumstances beyond one’s control pose barriers and require adjustments to the timeline. For the purpose of this project, conducting the sensory evaluations was particularly challenging, as fewer participants engaged in the sessions than I had originally anticipated. However, I merely had to recruit from a wider audience and prolong the sensory evaluation stage by holding more sessions (I had four instead of two). This was a key learning point for me—sometimes things do not go as planned; instead of becoming frustrated or giving up, one needs to stay composed and continue forward. Everything will fall into place with persistence. Furthermore, no matter how much planning has been done, obstacles almost always
intervene. Being able to handle these circumstances well is likely what sets great researchers apart from the rest.

Research is just that—research! This project has provided me with insight to the differences between scholastic research and industry initiatives. In fact, there are many gaps between these two, even though they should be closely related. Simply because the results of research have indicated that a particular product (or treatment/method) is effective or beneficial does not mean that these results will translate and actually be used in industry initiatives. Furthermore, some research studies may not implement scientifically valid methods or might involve conflicting interests (such as funding from a company or organization who would benefit from certain results). Whether it is these concerns, a lack of publication, or the inability of findings to reach a wider audience, much research is left unrecognized in the food industry. Mitigating this gap is an aim I hope to achieve as a future food scientist.

During this project, I had the unique opportunity to visit a tortilla manufacturing company—to see both the academic and industrial sides of spectrum. For this visit, I met with staff of the Research & Development and Marketing departments at Catallia Mexican Foods and also had a tour of the facilities. This exposure was eye-opening at minimum. A complex and efficient method is currently implemented to manufacture thousands of tortillas on a daily basis. The machines are programmed to identify and remove the “defective” products from the assembly line—all without human intervention. I was astounded by this remarkable process, and now I understand how complicated implementing new products in such manufacturing facilities can be. Not only must new products be evaluated to see how they “perform” on the complex equipment, but conducting such evaluations is very expensive. Before trying out a new product or a new formula, companies must to be certain that the time and effort will be worthwhile.
However, despite these considerations, companies are largely driven by consumers—what are people willing to purchase? With recent health trends, many companies are beginning to look toward making “healthy” options to meet consumer needs. This calls for heeding meaningful research from validated studies.

Learning and research take time. Collecting data is great—but drawing meaningful conclusions from that data is more important. These were additional lessons I discovered during the process of this project. I tend to become overly excited about conducting certain tests or doing certain tasks, and I sometimes end up expecting results too quickly or forgetting my purpose. This was especially evident as I conducted analytical tests with the tortilla products. As I worked in the food science laboratory at the University of Minnesota, the lab supervisor emphasized the importance of knowing exactly what tests I was conducting, with what equipment, under what settings, and so forth. Making sense of my data was largely contingent upon these circumstances. I have always considered myself to be a detail-oriented person, but now I know that I must not allow my over-anticipation to infringe upon analytical testing procedures in a laboratory setting. Furthermore, in meetings with my committee, I realized that I myself did not fully understand the purpose and method for some of the tests I completed. However, upon gleaning this insight, I immediately became inspired to seek this information out. Now, I can confidently state that I have a working knowledge for each of the analytical tests I conducted—texture, moisture, color, and water activity—and know what my results signify. With time, proper research and learning can and will take place.

This project has served as a springboard. To what? More avenues, ideas, and opportunities than I can count. Now I can think of a dozen other research avenues to pursue—both with and without tortillas. This project has served as a springboard for me to continue questioning and
learning, as are key goals of a liberal arts education. Yet, an integral part of questioning and learning is confronting challenges—something I have also had to do throughout this project. One challenge I have faced is confining my research itself. With product development, analytical testing, and sensory evaluations, this project was quite expansive. Although it may have been better to focus on only one or two of these three parts of investigation, engaging in all three has provided me with notably beneficial experiences as I further my education in food science.

Initially, I set out to complete product development with sensory evaluations, but the project evolved when the opportunity to complete analytical tests became available. As a hopeful future food scientist, having this exposure was incredibly meaningful for me, so I decided to pursue this part of the research as well. Additionally, because there were so many parts to this project, I had to set limits on each. For product development, I had constrain myself to ten phases—when I had a fairly optimal tortilla product. However, I know that I could have kept on trying different formulations had time and resources permitted. For analytical testing, I had to limit the number of trials due to constraints in the number of available samples. Furthermore, for sensory evaluations, I had a goal of obtaining data from at least twenty participants, as a sample size of at least twenty is required in order to perform statistical analyses with results. If I had the option, ideally I would have conducted sensory evaluations with a wider, more diverse population (sensory centers can often obtain more than 200 participants to test products). However, I am completely satisfied with what I was able to accomplish. This brings a couple final thoughts to mind: being reasonable and realistic. There will always be constraints and limitations—no matter the location, study method, or circumstances. I am eternally grateful to have received the opportunity to complete this project and learn numerous key insights from doing so. I have been empowered and further inspired to continue questioning—to continue learning.