EVALUATION OF CORN TORTILLAS FORTIFIED WITH WHOLE AND PARTIALLY DEFATTED FLAX MEAL

by

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(Under the Direction of Yao-Wen Huang)

ABSTRACT

Corn tortilla is a staple food consumed regularly by Mexicans. This staple food is deficient in nutrient content, specially in protein. Flax is a seed rich in protein and has a good amino acid profile which mixed with corn flour may increase the protein and amino acid content in tortillas. Although the use of the oilseed can be expensive, there is potential for the flax meal (by-product) obtained after oil extraction from the seeds, this meal will be less costly than the flax seed. The overall objectives were to develop tortillas higher in protein content and to evaluate the possible changes that the addition of flax meal could produce on the physical, chemical and sensorial properties of corn tortillas. Partially defatted and whole flax meal were added at levels of 10, 15 and 20% to a nixtamalized corn flour. Textural properties and moisture content of tortillas were measured at 30 minutes, 24 hours and 48 hours after preparation. Water absorption capacity and water activity were determined for each treatment dough and tortillas respectively. Textural properties (strength, extensibility and toughness) and moisture content showed a significant difference ($p<0.05$) for tortillas fortified and unfortified; the level of flax addition in the nixtamalized corn flour changed the weight loss as compared to those prepared using only nixtamalized corn flour.

Chemical analysis (protein and fat content) of corn tortillas was determined for each tortilla treatment. Addition of partially defatted and whole flax meal increased protein content in tortillas, as well as possibly improved the amino acid profile specially for lysine and tryptophan. The physical and chemical evaluation of fortified tortillas at levels of 10 and 20% showed acceptable textural and nutritional properties to be tested for sensory evaluation. The variables age and frequency of consumption showed to have a significant effect on acceptability of the samples ($p<0.05$). Color measurements were obtained for tortillas freshly prepared from golden and brown flax meal for each treatment. Brown flax meal gave a negative effect on tortillas color when added to tortilla formulation ($p<0.05$), reducing the acceptability of the product. Golden flax meal decreased this effect.

keywords tortilla texture, flax meal, corn flour, by-product and fortification.

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May 2009

DEDICATION

I dedicate this thesis to my beloved parents and sister for their love and support, los adoro.

This thesis is also dedicated to a very special person who even been so far away from me was always giving me support. Thank you, Philipp for your love and support.

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# CHAPTER 1

# INTRODUCTION

In Mexico, tortilla is a staple food consumed regularly at all socio-economic levels, especially for populations with low incomes, where nutrient deficiency persists. According to FAO (2008), corn consumption in Mexico is approximately 347 g per capita, consumed in a wide variety of food products. Tortillas are cooked products of corn (*Zea mays*) that undergoes the process of nixtamalization, pressing, cutting into a thin flat and circular shape and cooking until puffing (Rooney & Serna-Saldivar, 1987).

Nixtamalization, a traditional method to prepare corn tortillas, was developed by the Latin American Indians (Rooney & Serna-Saldivar, 1987). The nixtamalization process involves cooking in a lime solution, steeping, washing and grinding the corn grains until semi-dried powder is formed. Then a dough can be formed by water addition and used to prepare the tortillas.

Corn tortillas, as other foods made of cereals, do not provide a proper nutrient balance to cover the human's daily requirements. Corn contains a low level of protein with an inadequate essential amino acid profile. The protein is specially low in lysine and trytophan (Burton et al., 2008; Figueroa-Cardenas et al., 2003; Rosado et al., 1999; Uauy et al., 2002; Waliszewski et al., 2002; Waliszewski et al., 2004). Corn composition consists of starch (72 to 73% of kernel weight) and protein (8 to 11% of kernel weight) (Obatolu et al., 2007). However, these components are reduced during the tortillas manufacturing process due to lose of the pericarp and part of the germ.

Tortilla nutritional content can be improved by the addition of other food sources during the manufacturing process that might help increase the nutrients. Flax seed is a food source of interest due to its unique nutritional properties. Similar to soybean, flaxseed or linseed is mainly composed of oil (~36%), carbohydrate (~32%) and protein (~24%). It has also received attention for its potential health benefits that include anticancer, bactericidal, antiviral, anti-inflammatory, laxative and anti-atherogenic effects (Bhathena et al., 2002; Chen et al., 2006; Collins et al., 2003; Cunnane et al., 1995; Jenkins et al., 1999; Morris, 2007; Serraino and Thompson, 1992). But the use of the flaxseed can be costly as a source to fortify corn tortillas; on the other hand oilseeds manufactures produce amounts of spent residue (flax meal) during oil extraction, this residue contains high amount of protein content that can be used to fortify other foods products, such as products based on cereals. The meal obtained from the oilseeds manufactures can be less costly than the flaxseed and with a good nutritional profile since these manufactures used a press cold process and sometimes followed by a short time heat treatment, this avoid oil oxidation, then the meal remained can have protein and amino acid profile in good conditions. In this study tortillas were fortified with whole and partially defatted flax meal in order to see if there was a significant difference by the use of the flaxseed and the partially defatted meal in the physicochemical and acceptability of the product.

The objective of this study is to evaluate the physicochemical and sensorial changes of corn tortillas due to fortification with whole and partially defatted flax meal at levels of 10, 15 and 20%.

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CHAPTER 2

# LITERATURE REVIEW

## Corn

Corn (*Zea mays*), rice (*Oryza sativa*) and wheat (*Triticum aestivum*) are the most consumed and cultivated crops worldwide. Corn is also called maize or Indian corn (Benson & Pearce, 1987). It constitutes an important staple for animals and humans; it is used for the production of starch, oil, protein, food sweeteners, ethanol and fuel (FAO, 1992).

Corn (*Zea mays*) originated in Central America and Mexico and spread to North South America. It had an essential role in festivities, religion and human nutrition. After colonization, its cultivation quickly moved from America to Europe, Asia and Africa. Corn cultivation spread out from Spain through France, Germany, Austria and Eastern Europe. Corn was later introduced to Africa from the United States, Mexico and parts of eastern South America. Nowadays, different corn hybrids are widely cultivated all over the world (Benson & Pearce, 1987; FAO, 1992).

### *Corn plant*

The corn plant is a tall annual plant that forms part of the grass family (*Gramineae*). It consists of an erect stalk, where leaves are situated in two opposite ranks and has a fibrous root system. It is a cross pollinated species and monoecious, which means that it has separate female (ear) and male (tassel) flowers in the same plant. Normally the ears are located at the end of short branches (shanks) and the tassel is found at the top of the stalk (Benson & Pearce, 1987).

Corn is usually cultivated during the warm season, in regions with temperatures between 10 and 45°C. Maturation of corn takes about 130 to 140 days depending on climate of the region, altitude and type of corn. For optimum yields, the corn plant needs abundant sunlight and moisture (Benson & Pearce, 1987).

***Structure of corn kernel or grain***

Corn kernels grow in the female organ called the ear; approximately 800 kernels grow in the inner cylinder of the ear (cob) (Watson, 1987). Botanically the corn kernel is classified as a *caryopsis* (indehiscent, dry, single seeded fruit) where the mature ovary wall (pericarp) does not separate naturally from the seed. This feature is characteristic of all cereal grains (Watson, 1987). Figure 2.1 shows the structure of a corn kernel. The main corn kernel components are: bran, endosperm and germ. The bran is formed by several layers of fibrous material (pericarp, testa and aleurone). They surround the endosperm and protect the germ component. The pericarp and testa are rich in dietary fiber and minerals while the aleurone contains high levels of phytic acid and vitamins. Starch and protein are contained in the endosperm. The germ is the embryo of the plant where protein, fat and vitamins are placed (Wesley & Ranum, 2004). Table 2.1 shows the weight distribution of the kernel components, where the endosperm provides approximately 83% of the total corn kernel weight.

***Corn types***

Corn can be classified as dent, floury, sweet, flint and pop corn, among others. This classification is based on kernel characteristics. 1) Dent corn: this type of corn has a vitrous, horny endosperm at the sides and back of the kernel, whereas the center of the kernel is floury and soft; 2) Flour corn: its endosperm is entirely soft starch and it is easy to grind; 3) Sweet corn: the endosperm is sweet due to several mutant genes conditions that reduce the levels of starch in the kernel, while soluble sugars levels are increased; 4) Flint corn: its endosperm is thick, hard, vitreous and surrounds a small granular center; 5) Pop corn: it is a small flint corn type that is resistant to breakage. It is preferred in the confection industry (Watson, 1987; Zuber & Darrah, 1987).

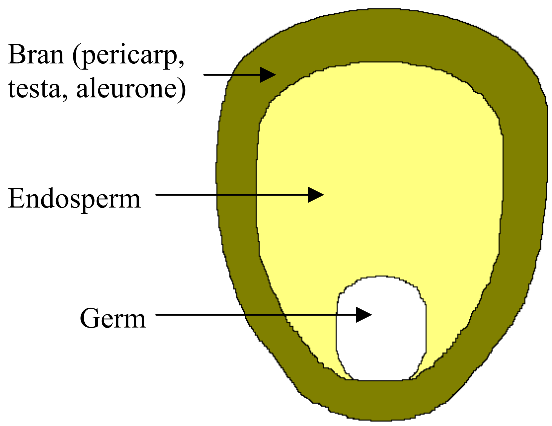


Figure 2.1 Corn kernel main components (Wesley & Ranum, 2004)

Table 2.1 Weight distribution of the kernel components

| Structure | Weight distribution (%) |
|---|---|
| Pericarp | 5-6 |
| Aleurone | 2-3 |
| Endosperm | 80-85 |
| Germ | 10-12 |

(FAO, 1992)

### *Corn production*

According to data provided by USDA (2008a), world corn production has increased between 2003 and 2007 (Table 2.2), where the United States is one of the principal producers and traders of corn in the world, with constant increases in production year after year. High-consumer countries, such as Mexico, have not been successful in keeping constant increases in yield production. In 2007 Mexico's corn production was 2.91% (22, 500 thousand tons) from the total produced in the world (Figure 2.2). In addition, from 2003 to 2007 Mexico has increased its corn imports (Figure 2.3) to keep up with the higher demand resulting from the increased population. Based on the national censuses of 2000 and 2005 conducted by the National Institute of Statistical Geography and Computer Science of Mexico (INEGI, 2008), the increase in population was 5.8 millions during that time.

Table 2.2 Corn production in the world (1000 tones)

| | Year | | | | |
|---|---|---|---|---|---|
| Production | 2003 | 2004 | 2005 | 2006 | 2007 |
| Argentina | 15000 | 20500 | 15800 | 22500 | 21500 |
| Brazil | 42000 | 35000 | 41700 | 51000 | 53000 |
| Canada | 9587 | 8837 | 9361 | 8990 | 11650 |
| China | 115830 | 130290 | 139365 | 145480 | 145000 |
| Egypt | 5740 | 5840 | 5932 | 6149 | 6174 |
| Etiopía | 3000 | 3400 | 4000 | 5000 | 5600 |
| EU-27 | 47905 | 66471 | 61158 | 54835 | 47721 |
| India | 14980 | 14180 | 14710 | 15100 | 16800 |
| Indonesia | 6350 | 7200 | 6500 | 6700 | 7500 |
| Mexico | 21800 | 22050 | 19500 | 22350 | 22500 |
| Nigeria | 5500 | 6500 | 7000 | 7800 | 6500 |
| Philippines | 4900 | 5050 | 5884 | 6231 | 6500 |
| South África | 9700 | 11716 | 6935 | 7300 | 11000 |
| Ukraine | 6850 | 8800 | 7150 | 6400 | 7400 |
| Vietnam | 2800 | 3757 | 3818 | 4312 | 4560 |
| Others | 59096 | 65792 | 65740 | 67600 | 66672 |
| USA | 256278 | 299914 | 282311 | 267598 | 332092 |
| World total | 627316 | 715297 | 696864 | 705345 | 772169 |

(USDA, 2008a)

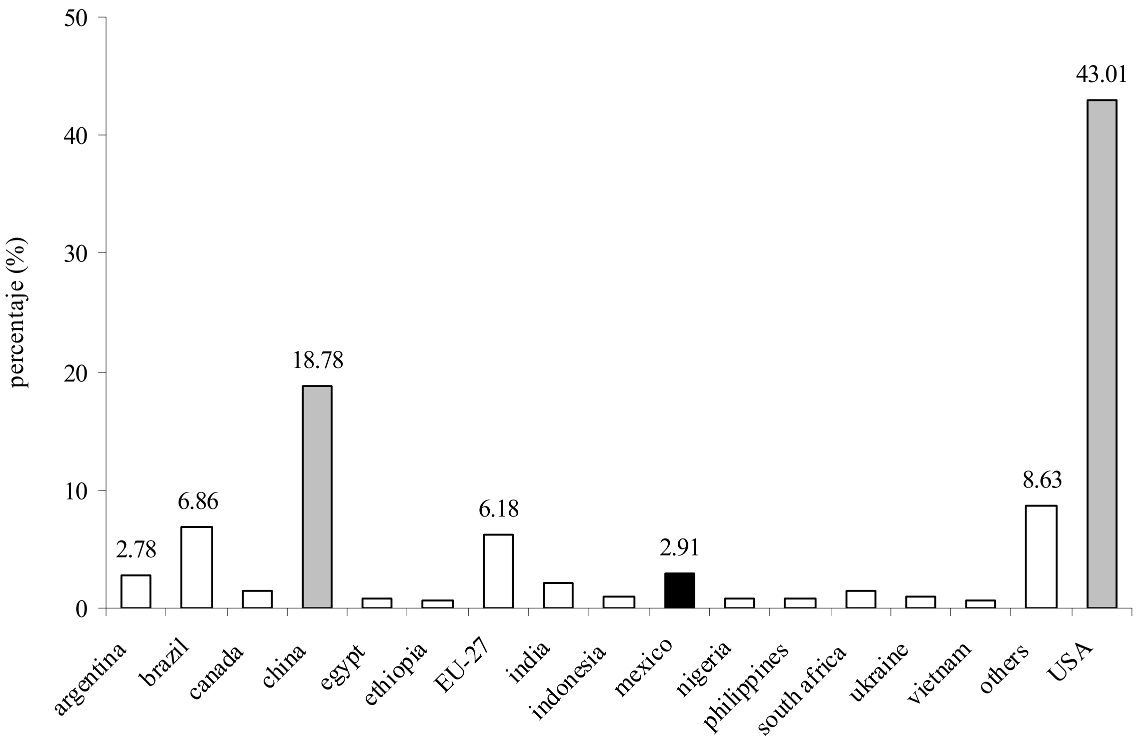


Figure 2.2 Percentage of corn productions in the world during 2007 (USDA, 2008a)

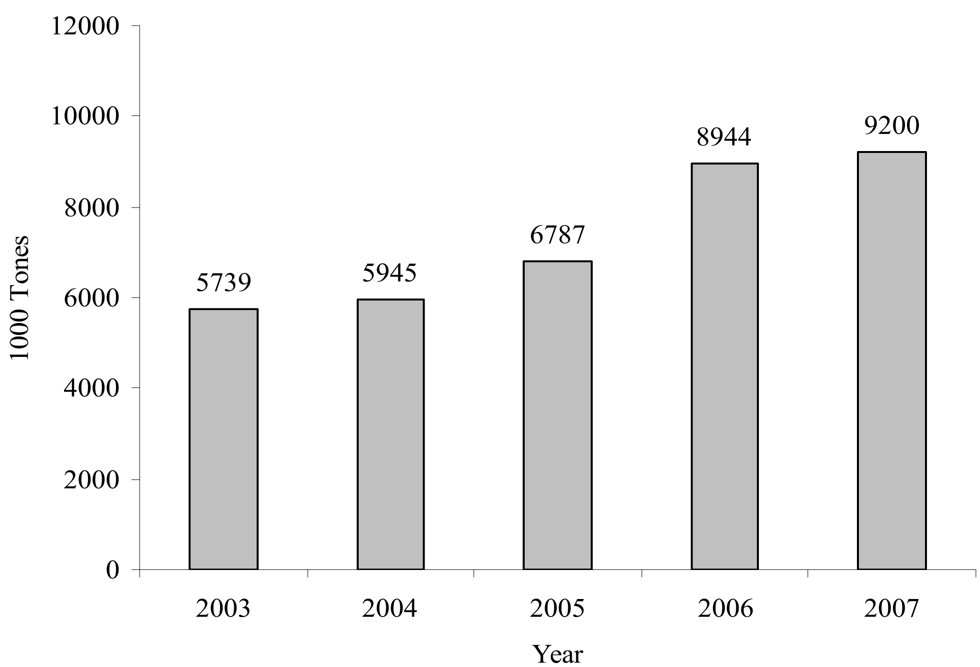


Figure 2.3 Corn imports of Mexico from USA (USDA, 2008a)

## Flaxseed

Similar to soybean, flaxseed or linseed (*Linum unisatisimum*) is mainly composed of oil (~36%), carbohydrate (~32%) and protein (~24%). It has also received attention for its potential health benefits that includes anticancer, bactericidal, antiviral, anti-inflammatory, laxative and anti-atherogenic effects (Bhathena *et al.,* 2002; Chen *et al.,* 2006; Collins *et al.,* 2003; Cunnane *et al.,* 1995; Jenkins *et al.,* 1999; Morris, 2007; Serraino & Thompson, 1992).

### *Flax origin*

It is believed that flaxseed (*Linum unisatisimum*) cultivation started in Europe and Asia. It was not introduced to the United States until the early 1990s as part of the formulation of breads, cereal and other bakery products (Collins *et al.,* 2003). Canada and the United States are the two main producers of flax in America. The flax commonly consumed in Mexico is imported since only a small amount is cultivated in the north of the country mainly in the state of Sonora.

### *Flax plant*

Flax is an annual plant. Depending on variety, soil fertility, plant density and available moisture it can have a height of 40 to 91 cm (16 to 36 in). This plant has a self-pollinating system. Its life cycle consists of 45 to 60 days vegetative period and 30 to 40 days of maturation. Physically it is composed of a main stem that can have two or more branches (tillers) depending on plant density and soil nitrogen. The stem and branches hold the flowers. In the flax plant, the mature fruit is a dry boll that starts to ripen 20 to 25 days after flowering. This boll has five sections, each with one or two seeds, divided by a wall (septum), each section contains up to two seeds. Therefore, a boll can have in total 10 flaxseeds; however the average of flaxseed formation is around 6 to 8 days (FCC & SFDC, 2008). It grows in good conditions when the soil is high in fertility and water holding capacity. It is cultivated in regions with moderate temperatures and rainfall which seems to favor oil content and quality (Oplinger *et al.,* 1997; FCC & SFDC, 2008). The most common varieties of flax are cultivated for oil and fiber where the varieties used for human consumption are different from those to make linen (Morris, 2007; FCC & SFDC, 2008).

***Flaxseed description***

Flaxseed is flat, oval and pointed at the end. It is covered with a coating (mucilage) that gives a shiny appearance. It measures approximately 4 to 6 mm and it has a nutty taste with a crisp and chewy texture. The brown flaxseed is cultivated in Canada while one variety of yellow flaxseed (Omega) is produced in United States of America. Both of them are rich in alpha-linolenic acid (ALA), an omega-3 fatty acid. Another yellow flaxseed known as Solin (Linola) has a low content of ALA and is commonly used in premium margarines in Europe. A new type of flax called Nulin was developed with a higher ALA content than the regular one (FCC & SFDC, 2008; Morris, 2007).

***Flaxseed composition***

Flaxseed is mainly composed of fat, carbohydrate and protein. A proximate composition of whole flaxseed is given by Morris (2007) where 100 g of whole flaxseed provides 450 Kcal, 41 g of total fat, 23 g of ALA, 20 g of protein and 29 g of carbohydrates. Flaxseed has soluble and insoluble dietary fiber, where the fiber fractions in flaxseed are: cellulose, mucilage gums and lignin (Morris, 2007). According to Morris (2007) at least three types of phenolics compounds are also found in this seed such as phenolic acids, flavonoids and lignans. The lignan is also called secoisolariciresinol diglucoside (SDG) which has showed to reduce serum total cholesterol and LDL in hypercholesterolemic animals (Bhathena *et al.,* 2002). Minor amounts of vitamins and minerals are also present in flaxseed (Table 2.3). Flaxseed protein has a similar amino acid pattern as soybean (Table 2.4), which includes essential amino acids such as lysine, tryptophan, among others. The amino acid profile of flaxseed presents the possibility to complement foods prepared with cereals. Carbohydrates (starches and sugars) in flaxseed are minimum (Bhathena *et al.*, 2002; Morris, 2007).

Table 2.3 Proximate vitamins and minerals content in flaxseed

| Vitamins Water soluble | mg/100g | Minerals | mg/100g |
|---|---|---|---|
| Ascorbic acid | 0.50 | Calcium | 236 |
| Thiamin | 0.53 | Copper | 1 |
| Riboflavin | 0.23 | Iron | 5 |
| Niacin | 3.21 | Magnesium | 431 |
| Pyridoxine | 0.61 | Manganese | 3 |
| Pantothenic acid | 0.57 | Phosphorus | 622 |
| | mcg/100g | Potassium | 831 |
| Folic acid | 112 | Sodium | 27 |
| Biotin | 6 | Zinc | 4 |
| Fat soluble | mg/kg in oil | | |
| Vitamin E[a] | | | |
| Alpha-tocopherol | 7 | | |
| Delta-tocopherol | 10 | | |
| Gamma-tocopherol | 552 | | |

[a]Tocopherol values represent the average of four varieties. The following forms of vitamin E were not detected: beta-tocopherol and alpha-, delta- and gamma-tocotrienol
(Morris, 2007)

Table 2.4 Proximate amino acid composition in flaxseed

| Amino acid | Brown flax[a] (g/100g protein) | Yellow flax[a] (g/100g protein) | Soy flour[b] |
|---|---|---|---|
| Alanine | 4.4 | 4.5 | 4.1 |
| Arginine | 9.2 | 9.4 | 7.3 |
| Aspartic acid | 9.3 | 9.7 | 11.7 |
| Cystine | 1.1 | 1.1 | 1.1 |
| Glutamic acid | 19.6 | 19.7 | 18.6 |
| Glycine | 5.8 | 5.8 | 4.0 |
| Hisitidine* | 2.2 | 2.3 | 2.5 |
| Isoleucine* | 4.0 | 4.0 | 4.7 |
| Leucine* | 5.8 | 5.9 | 7.7 |
| Lysine* | 4.0 | 3.9 | 5.8 |
| Methionine* | 1.5 | 1.4 | 1.2 |
| Phenylalanine* | 4.6 | 4.7 | 5.1 |
| Proline | 3.5 | 3.5 | 5.2 |
| Serine | 4.5 | 4.6 | 4.9 |
| Threonine* | 3.6 | 3.7 | 3.6 |
| Tryptophan*[c] | 1.8 | NR | NR |
| Tyrosine | 2.3 | 2.3 | 3.4 |
| Valine* | 4.6 | 4.7 | 5.2 |

NR=Not reported
*Essential amino acids for humans
(Bhatty & Cherdkiatgumchai, 1990; Friedman & Levin, 1989; Oomah & Mazza, 1993)

## Tortilla

Tortillas are cooked products of corn (*Zea mays*) that undergoes the process of nixtamalization, pressing, cutting into a thin, flat and circular shape, and cooking until puffing (Rooney & Serna-Saldivar, 1987). FAO (1992) reported that the corn intake in Mexico was 328.9 g per capita consumed in a wide variety of food products; corn contribute to the daily diet with 1,061 calories per day and 27.1 g per day of proteins. According to FAO (2008), corn consumption during 2001 was approximately 353 g per day; however, by 2003 this amount decreased to approximately 342 g per day. External and internal economic situations might lead to decrease in corn consumption.

### *Tortilla as a food vehicle*

In Mexico, tortilla is a staple food consumed regularly at all socio-economic levels, especially for populations with low income, where nutrient deficiency persists. Tortilla can be prepared using corn or wheat, however, corn tortilla production and consumption is higher than wheat tortilla. Corn tortillas as other foods made of cereals do not provide a proper nutrient balance to cover the human's daily requirements. Corn contains a low level of protein with an inadequate essential amino acids profile. The protein is specially low in lysine and trytophan. Corn has acceptable levels of vitamins and minerals; however micro and macronutrients can be lost during the transformation of corn into tortillas (Burton *et al.,* 2008; Figueroa-Cardenas *et al.,* 2003; Rosado *et al.,* 1999; Uauy *et al.,* 2002; Waliszewski *et al.,* 2002; Waliszewski *et al.,* 2004). The removal of the pericarp and part of the germ is mainly responsible for these nutrients loss. However, this unbalance can be compensated by fortification means. Previous research studies has been done on fortification of tortillas: iron and black bean paste (Davidsson *et al.,* 2002), bean seed (Mora-Aviles *et al.,* 2007), amaranth seed (Sanchez-Marroquin *et al.,* 1987), lysine and tryptophan (Waliszewski *et al.,* 2004), soymilk residue (Waliszewski *et al.,* 2002), premix of vitamins and minerals in combination with soybean (Figueroa-Cardenas *et al.,* 2003, Figueroa-Cardenas *et al.,* 2001), cowpea (Sefa-Dedeh *et al.,* 2003), soybean (Obatolu *et al.,* 2007). However studies using flaxseed as a source of protein to fortify corn tortillas have not been reported.

**Nixtamalization process**

The traditional method to prepare tortillas is mainly base on nixtamalization and it was developed by the Latin American Indians. Nowadays nixtamalized corn flour and ready-to-eat tortillas are produced by the food industry, but the process is based on the traditional process (Bressani *et al.,* 1997; Rooney & Serna-Saldivar, 1987).

***Traditional nixtamalization process***

The nixtamalization process transforms corn kernels into dough to produce edible products such as tortilla. In the traditional process, corn is cooked in a lime solution for 5 to 50 minutes and steeped for 7 to 12 hours. The steeped corn is called “nixtamal” and the steep liquid named “nejayote” (Rooney & Serna-Saldivar, 1987). The lime solution and steeping time softens the pericarp, while the endosperm absorbs water to facilitate its milling (Sefa-Dedeh *et al.,* 2003). The nixtamal is washed to remove alkali or corn solids such as pericarp and germ. Then, it is stone-ground into dough. Small balls of corn dough are made and flattened into thin disks by using a press tortilla maker or by using the ancient method of hand molding. Then, they are cooked on a hot griddle at temperature of 240°C to 320°C for about 20 to 75 seconds on each side (Figure 2.4) (Rooney and Serna-Saldivar, 1987). As mentioned before alkaline-cooking improves water holding capacity, flavor, starch gelatinization and removes the pericarp and part of the germ of the corn kernels. During this process the corn kernel is partially cooked. The steeping step helps distribute lime and moisture in the cooked grains. Subsequently, the pericarp and part of the germ become easier to remove during the washing step. The stone-ground step helps disrupt swollen gelatinized starch granules, along with protein to be distributed around ungelatinized corn endosperms forming dough. The nixtamalization process is critical for the production of tortillas with desired characteristics. Overcooked nixtamal provides sticky dough with undesired handling properties, while undercooked nixtamal is hard to grind. Lime concentration, steeping time, cooking time and temperature are interrelated factors that can affect tortilla characteristics (Rooney & Serna-Saldivar, 1987).

***Industrial nixtamalized process***

Currently, the industrial process for production of corn tortillas is based on the traditional method with some modifications in equipment used (Figure 2.5). Instant nixtamalized corn flour is defined as a fine, dry, white or yellow powder (color depends on the type of corn grain) with the same odor characteristics of corn dough; it can be hydrated to form a dough and make tortillas (FAO, 1992). This flour is commonly composed of fine uniform particles of less than 0.193mm (U.S. sieve No. 75) with a pH between 7.0 and 8.5, maximum viscosity of 220-330 BU, and water absorption of 1.3 cc of water/g of flour at 70°C ( Bressani *et al.,* 1997; Rooney & Serna-Saldivar, 1987). The corn flour has typically a moisture content of 10 to 12 percent, which makes it stable against microbial contamination. In Mexico the minimum time required for the flour to spoil is around four to six months during the winter and three months during the summer (FAO, 1992). Instant nixtamalized corn flours decrease the labor of cooking, washing and grinding the corn. Moreover, ready-to-eat tortillas are processed by the food industry as an extension of the nixtamalized industrial process. Commercial tortillas have a shelf life of approximately three months. According to Rangel-Meza et al. (2004) tortillas with acceptable characteristics are those prepared with dough hardness between $8.7x10^{-4}$ and $1x10^{-5}$ $N/m^2$, adhesiveness between 0.01 and 0.03 N-m, and a actor of compression-tension (FCT) between 2.4 and 2.7.

***Chemical composition of corn tortillas***

The chemical composition of corn tortillas produced in Mexico may vary depending on the corn type, process and equipment used (Table 2.5). According to Muñoz-deChavez et al. (2002) 100 g of tortilla has around 4.40 g and 4.60 g of protein using white and yellow dent, respectively. The chemical composition of yellow and white corn, home-made and industrially produced tortillas is shown in Table 2.6. According to FAO (1992), changes in the chemical composition of corn during the transformation to tortillas decreases the content of fat, crude fiber, carbohydrate and protein, while in some cases mineral content, especially calcium, improved.

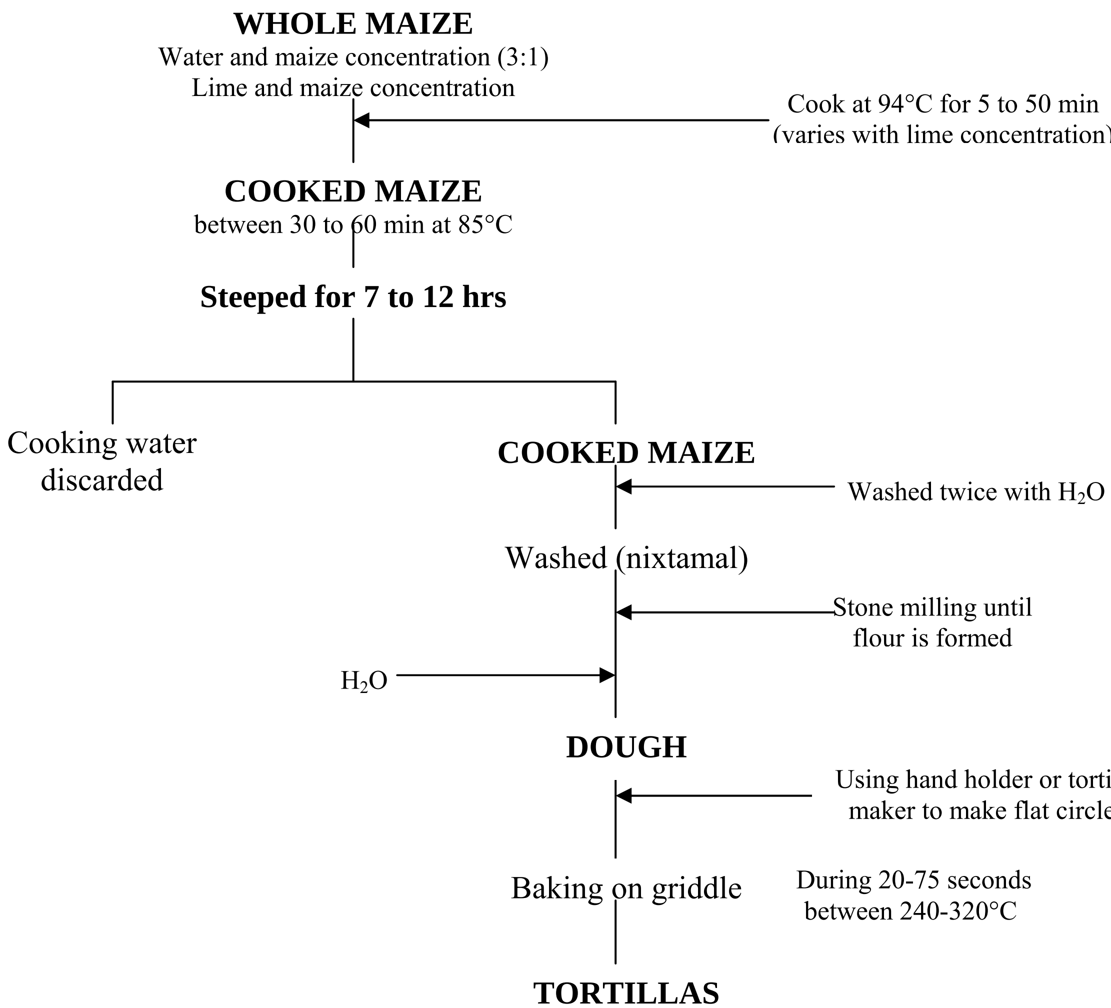


Figure 2.4 Traditional process of corn tortillas (Rooney & Serna-Saldivar, 1987)

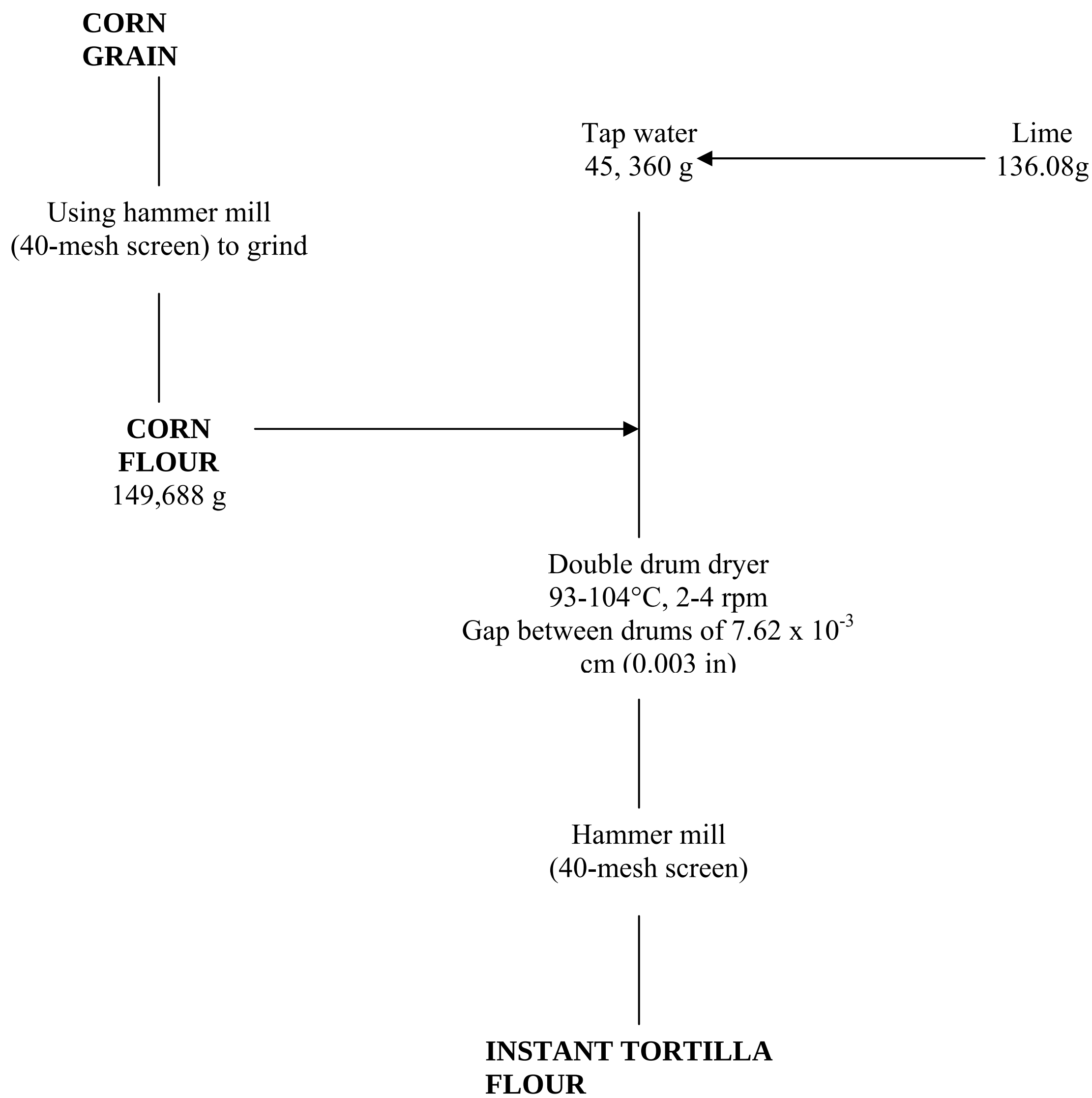


Figure 2.5 Production of instant nixtamalized corn flours (Rooney & Serna-Saldivar, 1987)

Table 2.5 Proximate chemical composition of tortillas produced in Mexico (100 g)

| Nutrients | Corn color | |
|---|---|---|
| | White | Yellow |
| Moisture, % | 42.4 | 47.5 |
| Energy, kcal | 246 | 216 |
| Protein, g | 4.4 | 4.6 |
| Fat, g | 4.4 | 1.8 |
| Carbohydrate, g | 47.2 | 45.3 |
| Dietary fiber, g | 1.47 | 1.09 |
| Calcium, mg | 108 | 146 |
| Phosphorus, mg | 111 | 182 |
| Iron, mg | 2.5 | 1.6 |
| Magnesium, mg | 79 | 82 |
| Sodium, mg | 0.6 | 1.0 |
| Potassium, mg | 148 | 145 |
| Zinc, mg | 0.9 | 0.9 |
| Thiamin, mg | 0.17 | 0.15 |
| Riboflavin, mg | 0.08 | 0.05 |
| Niacin, mg | 0.9 | 1.00 |
| Retinol equiv., µg | 1.0 | 9.0 |

(Muñoz-deChavez et al., 2002)

Table 2.6 Proximate composition of corn grain and tortillas produced at home-made and industrially

| Product | Moisture (%) | Protein (%) | Fat (%) | Ash (%) | Crude fibre (%) | Carbo-hydrates (%) | Carlories per 100 g |
|---|---|---|---|---|---|---|---|
| **Corn** | | | | | | | |
| White | 15.9 | 8.1 | 4.8 | 1.3 | 1.1 | 70.0 | 356 |
| Yellow | 12.2. | 8.4 | 4.5 | 1.1 | 1.3 | 73.9 | 370 |
| **Tortillas** | | | | | | | |
| HMTW | 47.8 | 5.4 | 1.0 | 0.8 | 0.7 | 44.5 | 204 |
| HMTY | 47.8 | 5.6 | 1.3 | 0.8 | 0.6 | 44.4 | 212 |
| IT | 40.5 | 5.8 | 0.9 | 1.1 | 1.4 | 50.3 | 226 |
| IT | 44.0 | 5.3 | 3.4 | 1.2 | 0.7 | 42.8 | 215 |

HMW=home-made tortilla from white corn, HMY=home-made tortilla from yellow corn, IT=industrial tortilla
(FAO, 1992)

***Changes of nutrient content in tortillas***

During the nixtamalization process, the transformation of corn into tortilla causes loss of carbohydrates, nitrogen-containing compounds, minerals and vitamins. Depending on the type of corn, lime concentration, water concentration, heat treatment, washing, steeping time, grinding and final cooking, changes in the corn structure such as chemical composition and nutritive value can occur. However there are nutrients that are enhanced by the nixtamalization process. Calcium content and niacin availability are increased, while phytic acid levels are reduced. Corn products with lime treatment are still deficient in lysine, tryptophan, vitamin A, vitamin C, vitamin B complex and iron (Bressani *et al.,* 1997). Dietary fiber in corn and corn tortillas is shown in Table 2.7. During the nixtamalization process insoluble dietary fiber is decreased (FAO, 1992). Rosado et al. (1992), reported that dietary fiber can affect availability of some nutrients, such as minerals, protein, fat, carbohydrate and also energy. Dietary fiber gives the sensation of satiety, therefore the nutrient intake decreases. On the other hand calcium is improved during the manufacturing of corn tortillas (Table 2.8). Thiamine and riboflavin levels decrease when tortillas are produced (Table 2.9). Niacin, which helps to prevent pellagra, is more available due to the nixtamalization process (FAO, 1992). Lysine and tryptophan levels are the most affected during the nixtamalization process (Table 2.10).

Table 2.7 Proximate dietary fiber in corn grain and corn tortillas (%)

| Product | Insoluble dietary fiber | Soluble dietary fiber | Total dietary fiber |
|---|---|---|---|
| Corn grain | 11.0 | 1.4 | 12.4 |
| Corn tortilla | 9.5 | 1.4 | 10.9 |

(FAO, 1992)

Table 2.8 Proximate mineral content of corn grains in comparison with home-made and industrial tortilla samples (mg/100g)

| Product | P | K | Ca | Mg | Na | Fe | Cu | Mn | Zn |
|---|---|---|---|---|---|---|---|---|---|
| Corn | 300 | 325 | 48 | 108 | 54 | 4.8 | 1.3 | 1.0 | 4.6 |
| HMT | 309 | 273 | 217 | 123 | 71 | 7.0 | 2.0 | 1.0 | 5.4 |
| IT | 240 | 142 | 198 | 60 | 2 | 1.2 | 0.17 | 0.41 | 1.2 |

HMT=home made tortilla, IT=industrial tortilla
(FAO, 1992)

Table 2.9 Proximate vitamin content in corn grain and tortillas (mg/100g)

| Product | Thiamine | Riboflavin | Niacin |
|---|---|---|---|
| Corn | | | |
| White | 0.38 | 0.19 | 2.00 |
| Yellow | 0.48 | 0.10 | 1.85 |
| Tortillas | | | |
| White | 0.10 | 0.04 | 1.01 |
| Yellow | 0.11 | 0.05 | 1.01 |
| Industrial | 0.13 | 0.08 | 1.11 |
| Industrial | 0.07 | 0.04 | 1.61 |

(FAO, 1992)

Table 2.10 Proximate amino acid changes during the nixtamalization process (g/16g N)

| Amino acids | Corn | Without pericarp | Without germ |
|---|---|---|---|
| Cysteine | 2.2 | 2.2 | 2.3 |
| Lysine | 3.0 | 2.6 | 1.9 |
| Methionine | 2.1 | 2.2 | 2.3 |
| Tryptophan | 0.8 | 0.7 | 0.5 |
| Threonine | 3.5 | 3.5 | 3.3 |

(FAO, 1992)

### Fortification

Fortification is the addition of nutrients to foods where they may or may not be present in the food originally and it is done to prevent or correct deficiencies that are present in specific populations. Food fortification is carried out using an indigenous diet without changing the consumers' dietary behaviors and food habits. fortified foods are usually produced at very low cost (Berry-Ottaway *et al.,* 2008; Wirakartakusumah & Hariyadi, 1998).

Depending on the nutrient deficiency the consequences of under nutrition can be growth stunting, susceptibility to infections, anorexia, learning disabilities, behavioral changes, and death (Mehansho, 2006; Yeung, 1998). One cause for these problems is the deficiency of nutrients in the diet. Therefore, fortification can help to correct, or prevent nutritional inadequacy in populations where nutrient deficiency has been identified (Wirakartakusumah & Hariyadi, 1998). However, considerations must be taken before applying it, such as: the target population, food vehicle, fortifications selected, nutrient interactions between the fortifications and food vehicle, stability of fortifications added during processing and storage, safety, bioavailability, technology, and cost.

#### *Food vehicle selection*

Food vehicles commonly used for fortification are staple foods such as sugar, wheat flour, salt, corn flour, cooking oil, among others. Selecting a suitable food vehicle can be challenging for rural populations where processed foods products are less available and therefore low consume. Some fortified foods are mostly consumed by groups of middle or high income but not by groups of lower income which are the major populations at risk of nutrient deficiencies and mainly concentrated at rural locations. Hence, to identify an appropriate food vehicle, data is needed on food production, imports, exports and level of consumption. Important factors for vehicle selection must be considered: 1) the food vehicle has to be consumed regularly and in predictable amounts by the target population, and it should also be affordable; 2) the nutrients added to the food must stay stable during use and storage, and maintaining a constant high bioavailability; 3) the fortified food should not present significant organoleptic changes, such as taste, color or appearance, when nutrients are added; 4) the addition of nutrients must not be expensive when an industrial process is carried out; 5) nutrient addition should be done in controlled amounts in order to avoid a risk of excessive intake or toxic effects; 6) technology for measuring and controlling the levels of essential nutrients added to food should be available (PAHO, 2004; Nilson & Piza, 1998; OMNI, Roche & USAID, 1997; Wirakartakusumah & Hariyadi, 1998).

***Mexican diet: Food intake***

According to USDA (2008b) the human diet for a better daily performance should be based on a healthy diet that contains grains, vegetables, fruits, milk, meat, beans and oils. The recommended daily allowance for the Mexican population is based on the NOM-086-SSA1-1994 established by the Ministry of Health (SSA, 1994). Cereals, such as corn, wheat and rice, (Table 2.11) comprise the principal food group consumed by the Mexican population (FAO, 2007). Rooney et al. (1987) reported that from the total corn production in Mexico, 72% is used for human consumption, mostly in the shape of tortillas; however, tortillas as well as other food products made of cereals do not contain nutrients required for daily life. According to Rosado et al. (1992) , the typical Mexican diet consists of corn tortillas, beans, vegetables and fruits (Figure 2.6).

Table 2.11 Recommended Daily Allowances for Mexicans

| Nutrients | Values |
|---|---|
| Protein, g | 75 |
| Vitamin A, µg (equivalents of retinol) | 1,000 |
| Vitamin E, mg (tocopherols) | 10 |
| Vitamin $B_1$, mg (Thiamin) | 1.5 |
| Vitamin $B_2$, mg (Riboflavin) | 1.7 |
| Vitamin $B_6$, mg (Pyridoxin) | 2 |
| Niacin, mg (eq. Nicotinic acid) | 20 |
| Folic acid, µg (Folacin) | 200 |
| Vitamin $B_{12}$, mg (Cobalamin) | 2 |
| Vitamin C, mg (Ascorbic acid) | 60 |
| Calcium, mg | 800 |
| Phosphorus, mg | 800 |
| Iron, mg | 15 |
| Magnesium, mg | 350 |
| Zinc, mg | 15 |
| Iodine, µg | 150 |

(SSA, 1994)

Table 2.12 Food balance of Mexico 2000-2002 (1000 Tons)

| Food groups | Production (+) | Exports (-) | Imports (+) | Seed, feed, other uses (-) | Consumption (=) |
|---|---|---|---|---|---|
| Cereals | 29, 184 | 869 | 16, 344 | 27, 025 | 17, 634 |
| Vegetable oils | 898 | 51 | 784 | 707 | 924 |
| Sugar and Sw. | 5, 156 | 538 | 387 | 79 | 4, 926 |
| Roots and tub. | 1, 738 | 28 | 324 | 375 | 1, 659 |
| Meat | 4, 639 | 89 | 1, 213 | -4 | 5, 767 |
| Milk | 9, 620 | 128 | 2, 946 | 1, 011 | 11, 427 |

(FAO, 2007)

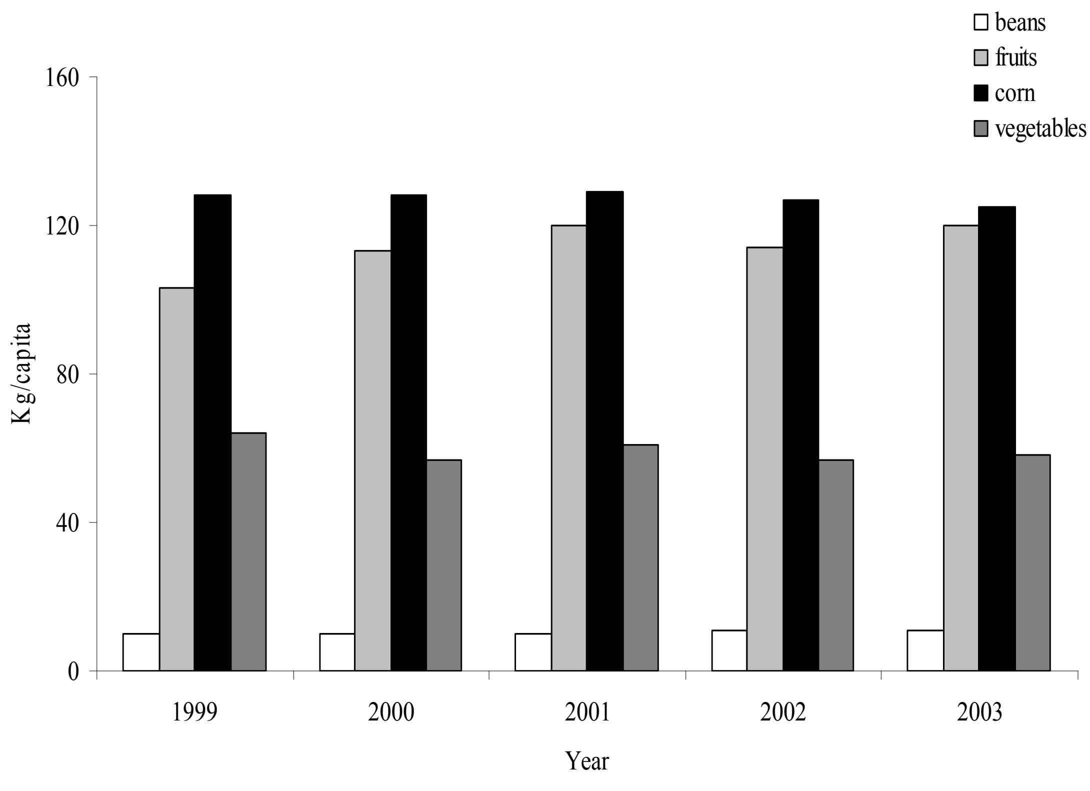


Figure 2.6 Mexico: Food consumption of beans fruits, corn and vegetables (FAO, 2008)

**Problem statement**

Corn tortilla is a staple food consumed regularly by Mexicans. This staple food is deficient in nutrient content, specially in protein. Hence the population may present deficiency in nutrition due to the low content of protein that tortillas can provide. Flax is a seed rich in protein and has a good amino acid profile which mixed with corn flour may increase the protein and amino acid content in tortillas. The flax seed besides to provide a good amino acid profile has an essential fatty acid (Alfa- Linolenic Acid) that the human body can not produce by itself. Although the use of the oilseed can be expensive, there is potential for the flax meal (by-product) obtained after oil extraction from the seed, this meal will be less costly than the flax seed. The amount of protein and amino acid profile will not be reduced since the oilseed manufactures use a cold press process followed by sometimes a short time heat treatment, this process ensures that the oil obtained is not oxidized, and as a result a good protein quality can be also obtained. Besides, the meal obtained is partially defatted, which means that certain amount of oil will remains.

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# CHAPTER 3

# PHYSICAL QUALITY OF CORN TORTILLAS FORTIFIED WITH WHOLE AND PARTIALLY DEFATTED FLAX MEAL

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[1]Santiago-SanMartin D. I., Huang Y.-W. To be submitted to International Journal of Food Science & Technology, 2009

**Abstract**

Tortillas fortified with whole and defatted flax meal were evaluated to determine the effect of flax addition on the physical properties of corn tortillas. Partially defatted flax and whole flax were added at levels of 10, 15 and 20% to a nixtamalized corn flour. Textural properties (strength, extensibility and toughness) and moisture content of tortillas were measured 30 minutes, 24 hours and 48 hours after preparation. Water absorption capacity and water activity were determined for each treatment dough and tortillas respectively. There was a significant difference ($p<0.05$) in strength, extensibility, toughness and moisture content for tortillas fortified and unfortified. The level of flax addition in the nixtamalized corn flour changed the texture of the tortillas and the weight loss as compared to those prepared using only nixtamalized corn flour.

Keywords tortilla texture, flax meal, corn flour, by-product and fortification.

## Introduction

In Mexico, the tortilla is a staple food consumed regularly at all socio-economic levels, especially for populations with low incomes, where nutrient deficiency persists. According to FAO (2008), corn consumption in Mexico is approximately 347 g per capita, which is consumed in a wide variety of food products. Tortillas are cooked products of corn (*Zea mays*) that undergoes the process of nixtamalization, pressing, cutting into a thin flat and circular shape and cooking until puffing (Rooney and Serna-Saldivar, 1987).

The nixtamalization process involves cooking in a lime solution, steeping, washing and grinding the corn grains until a semi-dried powder is formed. Then, a dough used to prepare the tortillas can be formed by water addition. Corn composition consists of starch (72 to 73% of kernel weight) and protein (8 to 11% of kernel weight) (Obatolu et al., 2007). However, these components are reduced, especially the protein content, during the tortillas manufacturing process due to lose of the pericarp and part of the germ. Hence, corn tortillas with a lack of protein content and amino acid profile are obtained.

Tortilla protein can be improved by the addition of other food sources during the manufacturing process that might help increase the nutrients. Flax seed is a food source of interest due to its unique nutritional properties. Similar to soybean, flaxseed or linseed is mainly composed of oil (~36%), carbohydrate (~32%) and protein (~24%). It has also received attention for its potential health benefits that include anticancer, bactericidal, antiviral, anti-inflammatory, laxative and anti-atherogenic effects (Bhathena et al., 2002; Chen et al., 2006; Collins et al., 2003; Cunnane et al., 1995; Jenkins et al., 1999; Morris, 2007; Serraino & Thompson, 1992). But the use of the oilseed can be expensive as a source to fortify corn tortillas; on the other hand oilseeds manufactures produce amounts of flax meal, a by-product obtained during oil extraction that can be purchased at a lower price than the flaxseed. This meal can be used as an alternative to fortify corn tortillas, because it can provide a good protein content since these manufactures used a press cold process and sometimes followed by a short time heat treatment, this avoids oil oxidation and a meal in good conditions is obtained.

However, in fortification one of the main issues is that the incorporation of a different material to the original does not represent higher changes in the physical properties. This issue is important in order to ensure the acceptability of the product. Over time many studies have focused on the fortification of corn tortillas, but few results have been put in practice due to physical changes that reduce the acceptability of the product (Waliszewski, 2002). The aim of this study is to evaluate the possible changes in the physical properties of tortillas due to the incorporation of whole and partially defatted flax meal in tortilla formulation.

## Materials and Methods

### Materials

Nixtamalized Corn Flour (MASECA) (Azteca Milling L.P., Irving, TX) purchased from a local supermarket (Athens, GA), was used to prepare corn tortillas. Whole flax seed, provided by Heartland Flax Company (Valley City, ND), partially defatted flax meal, provided by Sila Nutrition Organic Flax Products Inc. (Toronto, ON, Canada), were used for fortification of corn tortilla. Commercial tortillas (Ole, Mexican Foods, Inc., Crescent Dr. Norcross, GA., USA and Mission, Gruma Corp., Irving, TX., USA) were purchased from a local supermarket in Athens, GA and used as a control for water activity measurements.

**Flaxseed milling**

Whole and partially defatted flax meals were prepared using a commercial grinder (Smart grind, Black & Decker, Towson, MD) and then passing the meal through a sieve (U.S. sieve no. 20, Seedburo Equipment Co., Chicago, IL).

**Water absorption capacity (WAC)**

Water absorption capacity of the samples was performed according to Sefa-Dedeh et al. (2004), with some modifications. Four grams of each treatment were weighed into centrifuge tubes and mixed with 24 ml of distilled water at 25°C. The samples were stirred until the flour was completely wet. Samples were left to stand for 30 minutes; and then the samples were centrifuged using a Beckman Coulter (model Allegra X-22R, California, USA) at 3000 rpm for 15 minutes. The supernatant formed was discarded and the precipitate was weighed. The water absorption capacity was calculated using Formula (1). WAC for each sample was done in triplicate.

$$WAC = \frac{\text{weight of precipitate} - \text{weight of dry sample}}{\text{Weight of dry sample}} \quad (1)$$

**Preparation of tortilla**

Nixtamalized corn flour was separately mixed with partially defatted and whole flax meal at levels of 10, 15 and 20% for 2 minutes at 181 rpm using a stand mixer (Kitchen Aid, St. Joseph, MI). Water was then added and mixed for another 2 minutes to form the dough. The dough was wrapped in a plastic bag and kept for 5 minutes before making tortillas.

The dough remains were passed through a press tortilla maker (Maquina Tortilladora Gonzalez, CD. Guadalupe, N. L., MEX) and simultaneously cut into a flat, circular, thin tortilla.

A radiant wall oven (Pyramid Food Processing Equipment MFG., Inc., Tewksbury, MA) was used to cook the fresh tortillas at 315°C for 75 seconds. Cooked tortillas were cooled for 30 minutes before recording their weight, diameter and thicknesses by using a vernier (Mitutoyo Corp., Japan). Samples prepared are as followed: Treatment #1 is control (Ct), Treatment #2 is prepared using whole flax meal (WF), and Treatment #3 is prepared using partially defatted flax meal (PDF). The tortillas prepared from these treatments were used for further evaluations. Tortillas used for evaluation at 24 and 48 hours after preparation were stored at commercial refrigeration temperature and reheated prior to texture analysis using a microwave at high temperature for 20 seconds.

**Tortilla weight loss during cooking**

The weight loss of tortillas was determined by weighing a random tortilla before and after it was cooked by using an analytical balance (B3001-S Mettler Toledo, Switzerland). The results were reported as a percentage by using the following formula (2). Tortilla weight loss was done in triplicate, where each replicate had 5 measurements.

$$\%\ \text{weight loss} = \frac{\text{weight of raw tortilla} - \text{weight of cooked tortilla}}{\text{Weight of raw tortilla}} \times 100 \qquad (2)$$

**Moisture content**

Moisture was determined by using the Association of Official Analytical Chemist Approved Methods 44-40 (AACC, 1986) with some modifications. Two grams of a grounded sample tortilla were weighed into aluminum dishes, which were previously dried at 98°C for one hour. A vacuum oven (Cole-parmer Instrument Company, Vernon Hills, IL) was used to dry the sample at 99°C for 24 hours with a pressure of 44 KPa. Samples were then placed into desiccators to cool before weighing. The moisture content was calculated using the following equation (3). Moisture content was done in triplicate.

$$\% \text{ moisture} = \frac{\text{weight of wet sample} - \text{weight of dry sample}}{\text{Weight of wet sample}} \times 100 \qquad (3)$$

**Water activity**

The water activity for tortillas prepared in this study and commercial tortillas was performed by using a water activity meter AquaLab CX-2 (Decagon Devices, Inc., Pullman, Wa.). Water activity was done in triplicate.

**Dough and tortilla evaluation**

The texture of dough and tortillas was determined using the texture analyzer TA-XT2 (Texture Technologies, Corp., Scarsdale, N.Y.). Hardness and adhesiveness of the dough (35±0.4 g of sample dough in the form of a cylinder with 6.1±0.2 cm of radius and 1.1±0.1 cm thickness) was measured by penetrating a TA-3 acrylic probe with a radius of 2.5 cm and a height of 35 mm at a speed of 2.0 $mms^{-1}$ to a depth of 4 mm. Dough evaluation was done in triplicate, where each replicate had 3 measurements. Strength, extensibility and toughness of the tortillas were also measured using the device tortilla/film fixture TA-108 and the probe TA-108a 7/16" (Texture Technologies, Corp., Scarsdale, N.Y.). Tortilla samples were placed on the TA-108; and then the strength, extensibility and toughness were measured by penetrating a TA-108a at a speed of 2.00$mms^{-1}$ to a depth of 16mm. The average dimensions of the tortillas used in this study were: weight 21±0.2g, thickness 1.2±0.1mm, and diameter of 12.8±0.5cm. Tortilla evaluation was done in triplicate, where each replicate had 5 measurements.

## Statistical analysis

General linear model (GLM) was used for analysis of water absorption capacity, texture of dough and tortillas, weight loss and moisture content using the Statistical Analysis System v9.1 (Statistical Consulting Center, Athens, GA). Differences between means were assessed using Tukey test analysis.

## Results and Discussion

### Water Absorption Capacity of Nixtamalized Corn Flour

The water absorption capacity (WAC) is an important parameter in the production of nixtamalized corn flour (NCF). WAC is related to the degree of gelatinization, particle size and the percent of starch damage (Gaytan-Martinez et al., 2000; Flores-Farias et al., 2000). The WAC of PDF at 25°C were slightly lower than Ct and higher than WF, but the differences were not significant ($P>0.05$). WF at 25°C showed a lower WAC than Ct ($P<0.05$) (Figure 3.1). The behavior present in WAC for WF could be attributed to the effect of water trapping into gel formation and the amount of oil present. Oil being hydrophobic prevents water molecules to engage and form other hydrogen bonds. Therefore, a reduction in water absorption capacity can be seen.

### Dough physical properties

Hardness and adhesiveness of samples were analyzed. The treatments (Ct, PDF and WF) showed significant differences in the hardness ($p<0.05$), and adhesiveness ($p<0.05$) of the dough, resulting from the different levels of flaxseed incorporated (Figure 3.2). Ct corn dough presents similar hardness from the samples prepared with WF at a level of 10% and PDF ($p<0.05$), while

WF samples at levels of 15 and 20% show a higher hardness when compared with PDF and Ct samples. Ct corn dough presents similar adhesiveness to WF at levels of 15 and 20%, whereas samples prepared with WF at a level of 10% and PDF present a higher adhesiveness than Ct and WF at levels of 15 and 20%.

The results obtained in this study were significantly lower to those reported by Burton et al. (2008) of the hardness of regular nixtamalized dough and corn dough with vitamins (12.297 $kg_f$ and 13.878 $kg_f$, respectively). Figueroa-Cardenas et al. (2001) reported that the adhesiveness of dough prepared with nixtamalized corn flour and soy at 4 and 6% (treatment + 4% soya = 0.025 $kg_f$, treatment + 6% soya = 0.0245 $kg_f$ and nonfortified dough = 0.0307 $kg_f$) were lower than these results. The adhesiveness values obtained in this study for Ct were higher that those reported by Martinez-Bustos et al. (2001) (0.021$kg_f$ and 0.036 $kg_f$). Burton et al. (2008) reported that the adhesiveness for nonfortified and fortified dough with vitamins (nonfortified dough = 0.08 $kg_f$ and fortified dough = 0.09$kg_f$) were lower in comparison with our results except for Ct and WF at level of 20%.

Texture of dough in this study was significantly affected by the type and level of flaxseed incorporated. Hardness of PDF treatment remained similar to Ct measurement regardless of the incorporation level. The low incorporation level of WF at 10% did not significantly change the hardness of the corn flour, which remained similar to Ct.

**Tortilla physical properties**

The water activity measured in this study present a similar results for all the treatments (Ct, PDF and WF) and commercial tortillas ($p>0.05$). The water activity range of the fortified, control and commercial tortillas in this study was from 0.97 to 0.99. The differences in type and incorporation level of flaxseed affected the weight loss of tortillas ($p<0.05$). PDF and WF tortillas samples present the lower weight loss when compared to Ct tortillas. The results suggest that at higher flax incorporation a lower weight loss is seen (Table 3.1). The weight loss is an important parameter for the production of tortillas; the lower the weight loss the more soft a tortilla is expected (Figueroa-Cardenas et al., 2001).

The moisture content of tortillas was evaluated after 30 minutes, 24 and 48 hours of elaboration. The results show that Ct and PDF samples present similar moisture content ($p>0.05$), but different from WF samples ($p<0.05$) that present a lower moisture content. These results can suggest that PDF and Ct samples can have a similar behavior, when a textural measure is performed. After 24 and 48 hours of elaboration and a second reheat, the moisture content of tortillas was significantly reduced ($p<0.05$). The tortillas elaborated with WF reduced their moisture content more dramatically than PDF and Ct. The result of time and the second reheat show to have an impact in the moisture content of tortillas (Table 3.1). The moisture content of tortillas at 0 hrs of storage is similar from those reported by Suhendro et al. (1998).

The analysis of strength, extensibility and toughness was performed for tortillas elaborated at 0, 24 and 48 hours. The results show that time, treatment, interaction time-treatment and reheat-treatment affected the strength, extensibility and toughness of tortillas significantly ($p<0.0001$). At 0 hours of elaboration tortillas prepared with WF have a higher strength when compared to PDF and Ct tortillas ($p<0.0001$), while PDF tortillas show similar strength than Ct samples ($p>0.05$). Tortilla strength for control samples at 0 hours of elaboration has been reported by different authors and the range can vary from 0.195 to 0.767 Kgf. At 24 and 48 hours of elaboration and a second reheat, the tortillas increased their strength when compared with tortillas elaborated at 0 hours ($p>0.05$) (Figure 3.3), which can be explained by the loss of moisture in the samples. Tortillas elaborated at 0 hours show higher extensibility when compared with tortillas at 24 and 48 hours of elaboration ($p<0.05$). At 0 hours of elaboration PDF samples present similar extensibility than Ct samples ($p>0.05$), while WF samples show a higher extensibility than Ct samples ($p<0.05$), but not different of PDF samples ($p>0.05$) (Figure 3.4).

At 0 hours Ct, WF and PDF samples have a lower toughness than tortillas measured after 24 and 48 hours of elaboration ($p<0.05$) (Figure 3.5). PDF results remains similar to Ct before and after storage ($p>0.05$). WF presents a higher toughness than Ct and PDF at 0 hours ($p<0.05$). After 24 hours WF samples at levels of 10 and 20% are similar to Ct and PDF at levels of 10 and 15% ($p>0.05$), but at 48 hours WF at levels of 15 and 20% are higher than the other treatments and WF at 10% ($p<0.05$).

Tortillas with higher toughness require more force to fracture. The increase of strength and toughness in the samples during the time can be related to stale, which can make the tortilla more rigid or firmness and therefore reduce its flexibility. The staling is a process that can start after a tortilla has been elaborated. This process involves retrogradation of starch, moisture loss over time, gelatinization of starch granules, and interaction between other ingredients in the tortilla (Weber, 2008)

**Conclusion**

Addition of partially defatted or whole flax meal at different levels to nixtamalized corn flour affected the strength, extensibility and toughness of tortillas ($p<0.05$). The strength of tortillas prepared with WF at 0 hours presented higher strength when compared with PDF and Ct. Tortillas elaborated with PDF at 0 hours remained similar to Ct ($p>0.05$). Over time and when reheat was applied, the strength of tortillas was increased as well as the overall energy required to fracture the sample (toughness), therefore a reduction in extensibility (flexibility) was also seen. These changes were due to the loss of moisture content in the samples. The addition of flax meal reduce the weight loss, softness of defatted and whole flax tortillas compared with control was expected. However higher values were seen in strength and toughness for tortillas fortified with whole flax meal at 0 hours of elaboration.

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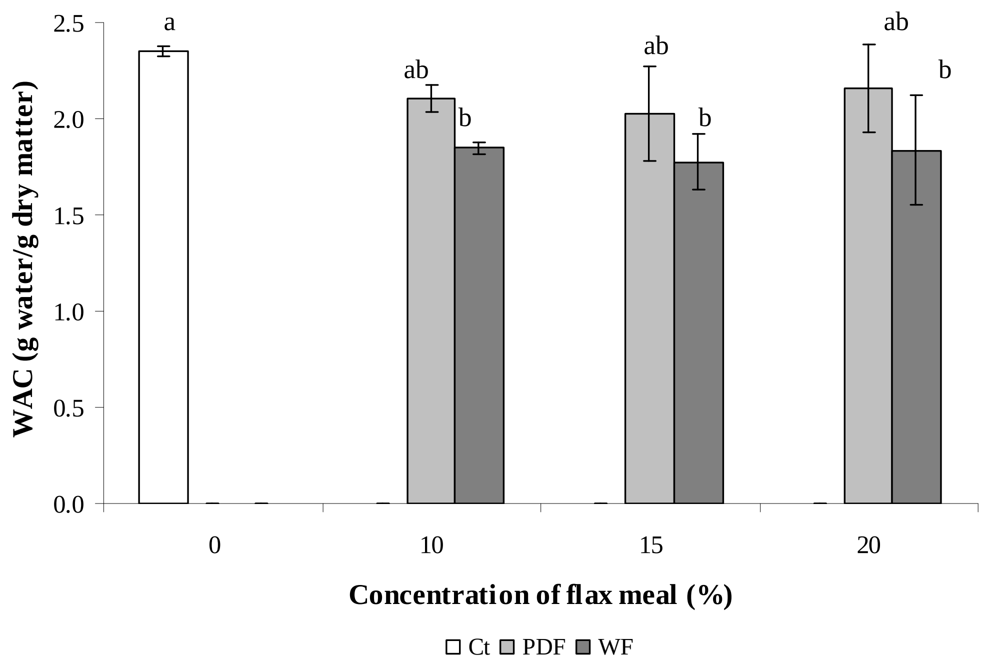
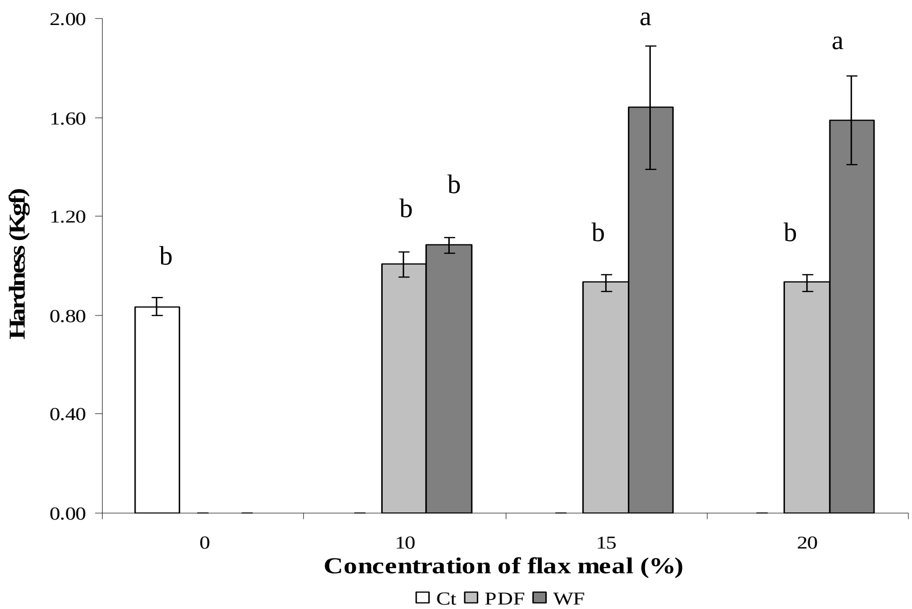



Figure 3.1 Effect of flax meal concentration on water absorption capacity at 25°C of nixtamalized corn flour, results are expressed as mean ± SD (n=3). Means with the same letter on the bars are not significantly different (P<0.05). Ct=control (nixtamalized corn flour), PDF=dough fortified with partially defatted flax meal, WF=dough fortified with whole flax meal.

(A)




(B)

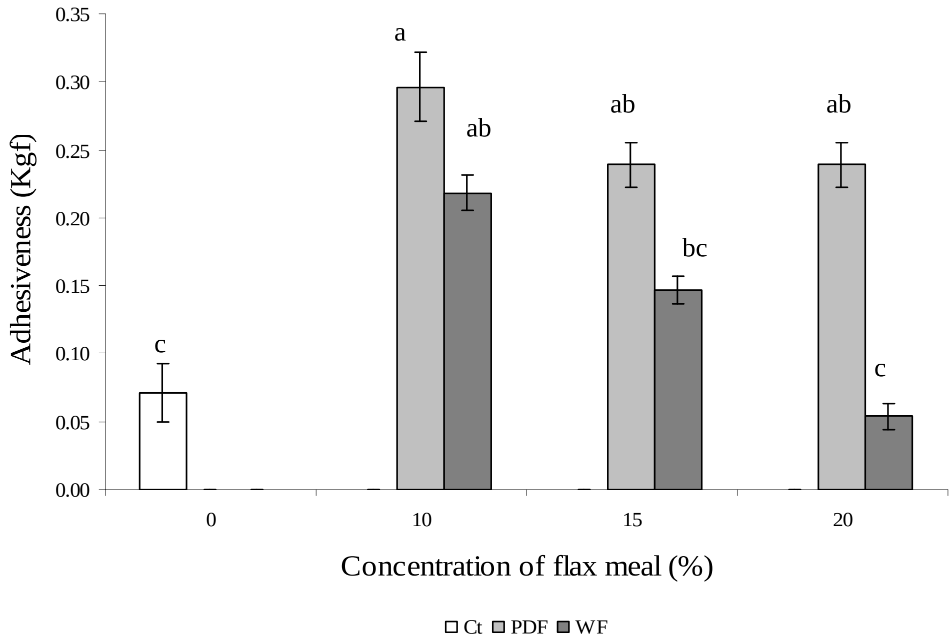



Figure 3.2 Hardness (A) and adhesiveness (B) of control and fortified corn dough, results are expressed as mean ± SD (n=3). Means with the same letter on the bars are not significantly different ($P<0.05$). Ct=control (nixtamalized corn flour), PDF=dough fortified with partially defatted flax meal, WF=dough fortified with whole flax meal.

Table 3.1 Characteristics of cooked tortillas

| Treatment | Weight loss (%) | Moisture content (%) | | |
|---|---|---|---|---|
| | | 0hrs of storage | 24hrs of storage | 48hrs of storage |
| Ct | 22.60±0.47a | 43.85±0.89ab | 38.81±1.49a | 38.27±2.75b |
| PDF10 | 19.33±0.82c | 44.28±1.03ab | 37.38±2.02a | 40.53±2.97ab |
| PDF15 | 18.37±0.84d | 44.61±0.93ab | 38.94±1.62a | 42.62±0.63a |
| PDF20 | 17.37±0.56e | 45.46±0.80a | 39.44±1.11a | 42.45±1.40a |
| WF10 | 21.69±0.22b | 40.80±1.17c | 34.88±2.29ab | 37.15±3.99b |
| WF15 | 21.62±0.28b | 40.96±0.65c | 30.65±2.28b | 37.20±3.09b |
| WF20 | 19.99±0.46c | 42.45±0.33bc | 30.81±0.61b | 37.52±0.80ab |

Results are expressed as means ±SD (n=3). Means with the same letter in the same column are not significantly different ($p<0.05$)
Treatment includes:

Ct= tortillas elaborated with nixtamalized corn flour (control),
PDF10, 15 and 20= tortillas fortified at 10, 15 and 20% with partially defatted flax meal,
WF10, 15 and 20= tortillas fortified at 10, 15 and 20% with whole flax meal.

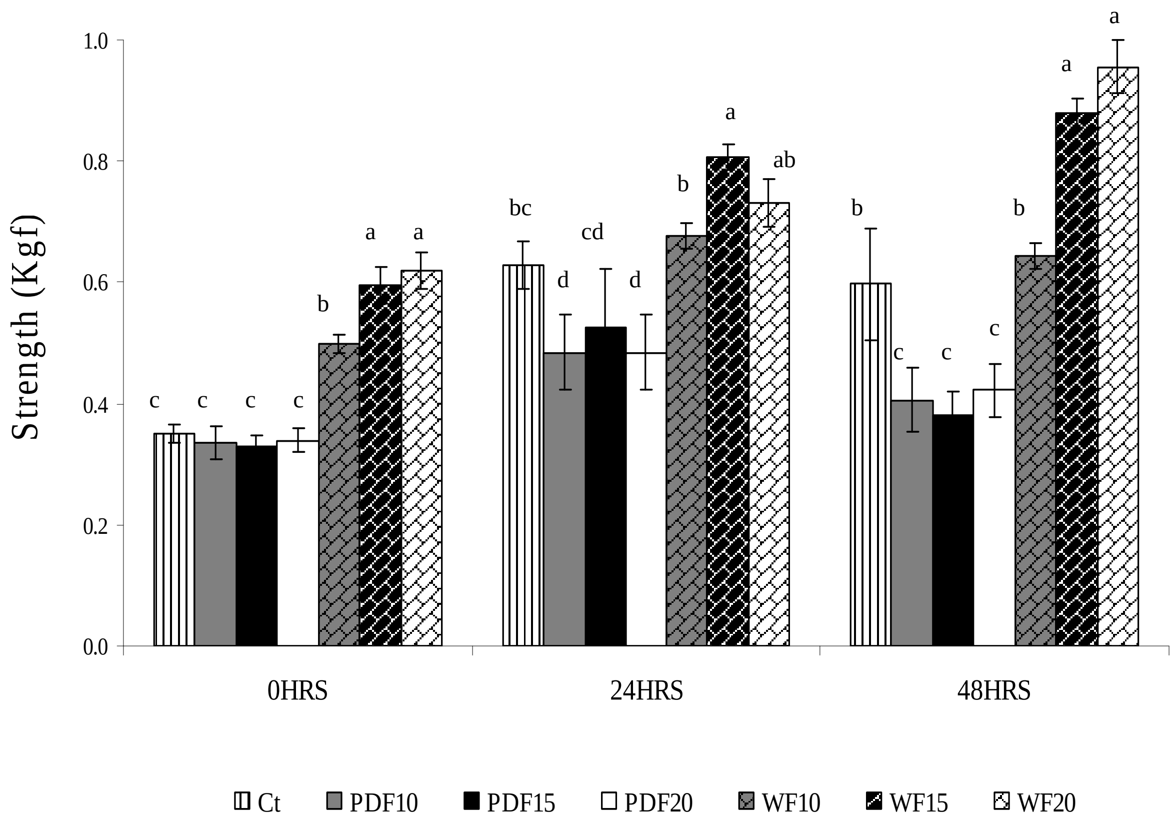



Figure 3.3 Strength of Control and fortified corn tortillas, results are expressed as mean ± SD (n=3). Means with the same letter on the bars are not significantly different (P<0.05). Ct=control (nixtamalized corn flour), PDF10, 15 and 20= tortillas fortified at 10, 15 and 20% with partially defatted flax meal, WF10, 15 and 20= tortillas fortified at 10, 15 and 20% with whole flax meal.

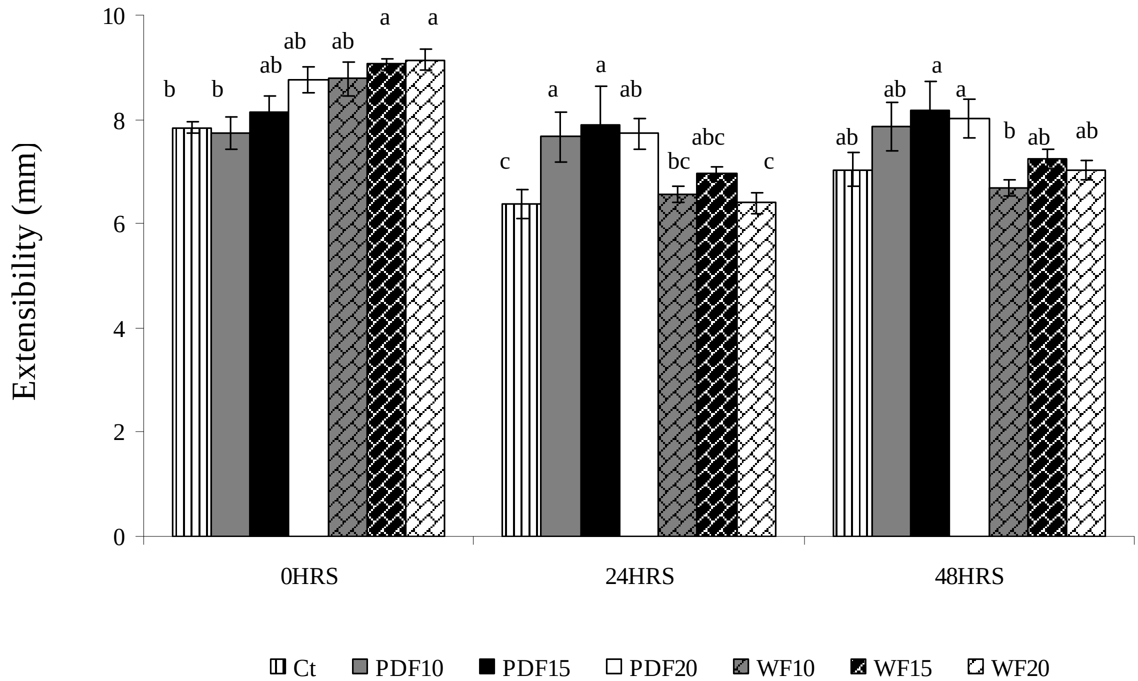



Figure 3.4 Extensibility of Control and fortified corn tortillas, results are expressed as mean ± SD (n=3). Means with the same letter on the bars are not significantly different (P<0.05). Ct=control (nixtamalized corn flour), PDF10, 15 and 20= tortillas fortified at 10, 15 and 20% with partially defatted flax meal, WF10, 15 and 20= tortillas fortified at 10, 15 and 20% with whole flax meal.

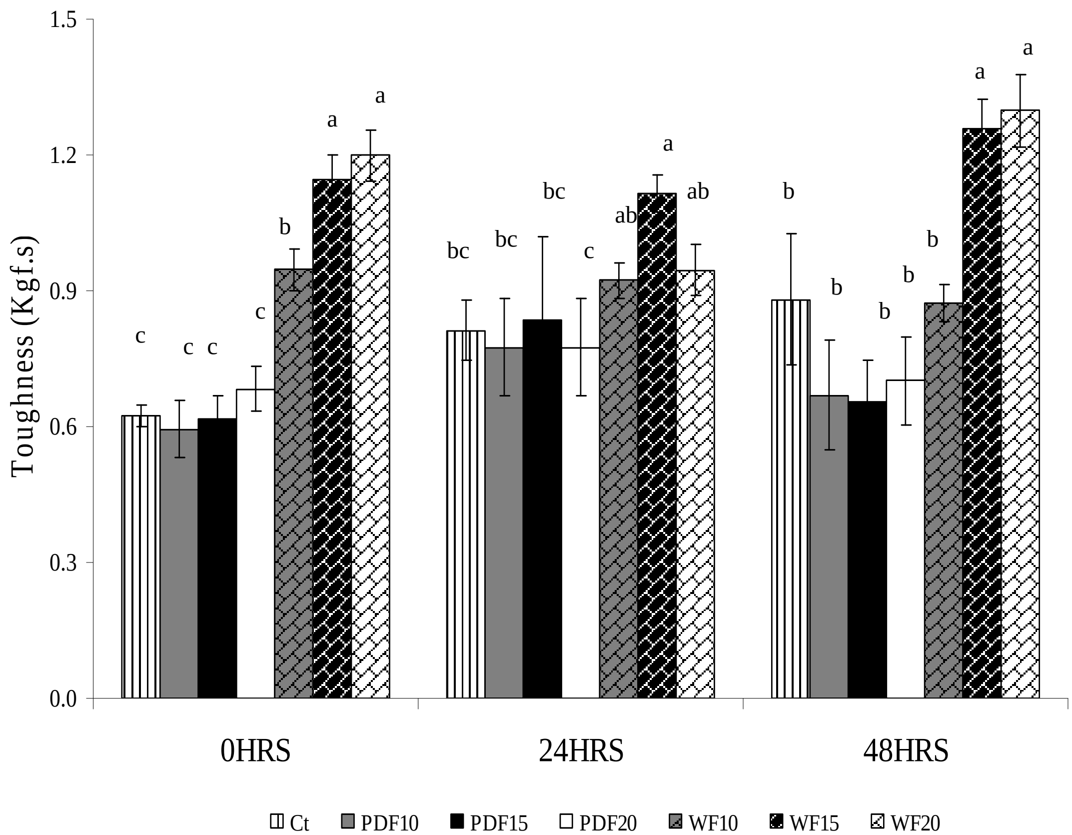



Figure 3.5 Toughness of Control and fortified corn tortillas, results are expressed as mean ± SD (n=3). Means with the same letter on the bars are not significantly different (P<0.05). Ct=control (nixtamalized corn flour), PDF10, 15 and 20= tortillas fortified at 10, 15 and 20% with partially defatted flax meal, WF10, 15 and 20= tortillas fortified at 10, 15 and 20% with whole flax meal.

# CHAPTER 4

# NUTRITIONAL, COLOR AND SENSORY EVALUATION OF CORN TORTILLAS FORTIFIED WITH WHOLE AND PARTIALLY DEFATTED FLAX MEAL

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[1]Santiago-SanMartin D. I., Huang Y.-W. To be submitted to International Journal of Food Science & Technology, 2009

**Abstract**

The physicochemical and sensory attributes of corn tortillas fortified with partially defatted and whole flax meals were analyzed. Fat, protein and amino acid profile were evaluated for whole and partially defatted flax meals, and nixtamalized corn flour. Partially defatted flax and whole flax meals were added at levels of 10 and 20% to fortify nixtamalized corn flour tortillas. Fortified tortillas samples were analyzed for fat and protein content. The fortified tortillas resulted in a better overall protein content compared to control tortillas. Addition of brown flax meal significantly affected the color of tortilla ($p<0.05$). Among the subjects, the variables, age and frequency of consumption had significant effects on the acceptability of the samples ($p<0.05$). The target population accepted the overall liking of fortified tortillas.

Keywords: tortilla texture, flax meal, corn flour, by-product and fortification.

**Introduction**

Corn is one of the major cereals consumed by the Mexican population. It has a protein content between 8 and 11% (Obatolu et al., 2007), however its protein is specially low in lysine and tryptophan ((Burton et al., 2008; Figueroa-Cardenas et al., 2003; Rosado et al., 1999; Uauy et al., 2002; Waliszewski et al., 2002; Waliszewski et al., 2004). Corn tortillas are one of the main products made with this cereal. The processing of corn into tortillas further reduces protein content as well as lysine and tryptophan content due to the lose of the pericarp and part of the germ. Therefore, many studies have been developed to fortify corn tortillas, but few results have been used in practice due to changes in sensorial properties of tortilla (Waliszewski et al., 2002). Some of these published studies include fortification of corn tortillas with sorghum, soybean and soy milk (Guisselle-Cedillo, 2005; Obatolu et al., 2007; Waliszewski et al., 2002).

Flaxseed supplementation can be used to increase the content of protein in corn tortilla. Recently, flaxseed has been extensively studied for its nutritional properties and health benefits (Morris, 2007). The application of a flaxseed oil by-product, partially defatted flax meal, could significantly reduce the cost impact of protein fortification in the production of corn tortillas.

In a previous work (Santiago-Sanmartin & Huang, 2009) we reported that tortilla fortification with 10 and 20% of partially defatted flax meal did not have significant effects on the rheological properties of fortified corn tortilla compared to regular tortillas prepared with 100% of nixtamalized corn flour. Also, fortification of tortillas using 10 and 20% of whole flax meal showed significant difference in the rheological properties of tortillas compared to the regular 100% corn tortillas. The objective of this study is to determine acceptability, color differences and chemical composition of tortillas fortified with whole and partially defatted flax meal at 10 and 20%.

## Materials and Methods

### Materials

Nixtamalized Corn Flour (MASECA) (Azteca Milling L.P., Irving, TX) purchased from a local supermarket (Athens, GA). Whole flax seed was provided by Heartland Flax Company (Valley City, ND), and partially defatted flax meal was provided by Sila Nutrition Organic Flax Products Inc. (Toronto, ON, Canada).

### Flaxseed milling

Whole and partially defatted flax meals were prepared using a commercial grinder (Smart grind, Black & Decker, Towson, MD), followed by passing the meal through a sieve (U.S. sieve no. 20, Seedburo Equipment Co., Chicago, IL).

### Chemical analysis

The chemical analysis of protein and fat for composite meals and tortillas were done according to the Association of Official Agricultural Chemists method 990.03 (AOAC, 1996) and American Oil Chemists' Society method 5-04 (AOCS, 2004), respectively. Protein and fat analyses were done by using a rapid combustion nitrogen analyzer (Vario Max CN, Elementar, Hanau, Germany) and an extractor analyzer (XT15, Ankom Technology, Macedon, NY), respectively. Amino acids analyses were determined by a commercial analytical laboratory (Eurofins Scientific Inc., Des Moines, IA). Amino acid analysis for nixtamalized corn flour, whole and partially defatted flax meal were done according to the Association of Official Agricultural Chemists method 982.30 (AOAC, 1996).

### Preparation of tortilla

Dried whole and partially defatted flax meals were mixed with nixtamalized corn flour at levels of 10 and 20% for 2 min at 181 rpm using a stand mixer (Kitchen Aid, St. Joseph, MI). Water was then added and mixed for another 2 min to form the dough. The dough was wrapped in a plastic bag and kept for 5 min before making tortillas. The dough was then passed through a press tortilla maker (Maquina Tortilladora Gonzalez, CD. Guadalupe, N. L., MEX) and simultaneously cut into a flat, circular and thin tortilla. A radiant wall oven (Pyramid Food Processing Equipment MFG., Inc., Tewksbury, MA) was used to cook the fresh tortillas at 315°C for 75 s. Samples prepared are as follows: Treatment #1, control (Ct); Treatment #2, prepared using whole golden flax meal (WF); Treatment #3, prepared using whole brown flax meal (WBF), and Treatment #4, prepared using brown partially defatted flax meal (PDF). The tortillas prepared from these treatments were used for further evaluations.

### Color values

The color of the tortillas samples were recorded using a Chroma meter CR-400 (Minolta Co., LTD, Osaka, Japan). The parameters recorded were L, a, and b; where “L” measure the luminosity of the samples (0=black and 100=white); “a” measure the difference between the light reflected by the samples in the zone of red and green (negative values indicate green, positive values indicate red); while “b” measure the difference in the zone yellow and blue (negative indicate blue, positive values indicate yellow). Measurements were done in duplicate, and each replicate was measured 5 times.

**Sensory analysis**

Sensory evaluation was performed using subjects from the Latin American community in Athens, GA. A total number of 100 Latin Americans (32 males and 61 females) that consume tortilla on a regular basis participated in the project. Panelists were between 13 to 74 years of age.  A total of three sessions were required to complete the evaluation, two sessions in the morning and one in the afternoon, for three days, once a week.

Properties of tortillas such as appearance, color, flavor, texture and overall liking were rated by panelists using a nine-point hedonic scale (1=dislike extremely, 5=neither like nor dislike, 9=like extremely). Tortillas were prepared 24 hours prior to sensory evaluation, and kept in plastic bags under refrigeration. Before the consumer test began, control, partially defatted and whole flax tortillas (Ct, PDF and WBF, respectively) were cut into 4 pieces and reheated at high temperature in microwave for 60 seconds. Tortillas served had a temperature between 45 to 50°C. The tortilla samples (Ct and PDF and WBF at levels of 10 and 20% of fortification) were coded and randomly presented to subjects. The sensory evaluation was conducted in Spanish. The panelists were instructed to take an unsalted cracker and water before starting the evaluation and between samples in order to clean their palate. This experiment was approved by the Office of Human Subjects of the University of Georgia.

**Statistical analysis**

General linear model (GLM) was used for color values and sensory analysis data using the Statistical Analysis System v9.1 (Statistical Consulting Center, Athens, GA). Differences between means were assessed using Tukey test analysis for color values and sensory analysis.

## Results and discussions

### Chemical analysis

Fat and protein analysis were performed for nixtamalized corn flour (NCF), whole and partially defatted flax meal (WBF and PDF), as well as for tortillas fortified with WBF and PDF at levels of 10 and 20% (Table 4.1). Tryptophan and lysine contents in tortillas were calculated by using the proximate amino acid composition of the raw ingredients (NCF and PDF or WF). The protein and fat contents of flax meal (WBF and PDF) were higher than that of NCF. According to Obatolu et al. (2007), the reduction of protein content in NCF can be related to swelling of protein bodies that can result in a physical destruction or shape loss, during nixtamalization process. Protein content in fortified tortillas was higher than control tortillas due to the incorporation of flax meal in tortilla formulation. Therefore, the high amount of protein present in flax meal could be used to complement the protein content of nixtamalized corn flour. As expected, tortillas fortified with WBF and PDF had higher fat contents than control tortillas, due to the high oil contained in flaxseed. According to USDA (2005), nixtamalized corn flour has a fat content of approximately 3.33%; however we found that our control samples had a fat content of 1.59%. The calculated amount of Tryptophan and lysine of fortified tortillas increased in comparison to control samples.

The amino acid profile of NCF, WBF and PDF are shown in Table 4.2. WBF and PDF had higher contents of lysine and tryptophan compared to NCF. Lysine and tryptophan are limiting amino acids of nixtamalized corn flour. According to Waliszewski et al. (2002), the FAO/WHO required daily intake of lysine and tryptophan is 5.44 and 0.96g/100g of protein, respectively, where NCF covers the 55% of the required lysine. Low lysine and tryptophan content in nixtamalized corn flour was obtained due to loss of the pericarp and part of the germ from the corn during the nixtamalization process. On the other hand, WBF and PDF had high tryptophan and acceptable lysine content, thus, flax meal could be considered  a good source of tryptophan and lysine. The amino acid profiles of WBF and PDF showed in this study were very similar to the results reported by Morris (2007).

**Color values and sensory analysis**

The significant differences ($p<0.05$) in type and incorporation level of flaxseed affected the color values of tortillas prepared in this study (Table 4.3). The addition of brown flax meal increased the darkness, redness and yellowness of the tortilla samples ($p<0.05$). Fortified tortillas using golden flax meal at levels of 10 and 20% also changed the color values of tortillas samples at lower extent ($p<0.05$). The less variation in color values of fortified tortillas using golden flax meal is due to the color of the flax seed which is less dark than the brown flax seed; hence tortillas could result in a less color change than the regular ones.

Sensory evaluation was performed for the treatments (Ct, PDF and WBF) using a nine point hedonic scale to measure appearance, texture, flavor, color and overall acceptability of five samples. Table 4.4 shows the general responses for each treatment where color attribute seemed to have the lower scores in every treatment due to addition of brown flax meal, which changed the color of tortillas. At higher concentration of flax meal, tortillas were less accepted by the target population. The target population appeared to show a slight acceptance for the overall appearance of fortified tortillas.

Also, demographic information was used to group the data in gender, age and frequency of consumption to determine if these variables could have an impact on the acceptability of the samples. The variable, gender, as well as the interaction between these variables (gender, age and frequency of consumption) was analyzed, but this variable and the interactions seemed not to have significant difference in the responses obtained in this study ($p>0.05$). However, the variables age and frequency of consumption had an impact on the acceptability of the samples ($p<0.05$). Table 4.5 shows the effect of the variable, age, on acceptability of fortified and unfortified tortillas. The participants were grouped into three age groups such as participants less than 20 years old (<20), between 20 and 40 years old (20-40), and greater than 40 years old (>40). Panelists less than 20 years old tended to gave lower scores for some of the samples. Appearance acceptability of Ct and PDF20 tortillas was significantly under score by panelist <20 years old in comparison to the group 20-40 years old ($p<0.05$), while the age group >40 years old remained similar to both of them ($p>0.05$).

For samples PDF10 and WBF10 panelists <20 years old tended to dislike the appearance of the sample ($p<0.05$), while the other two groups had high acceptance of the sample's appearance ($p>0.05$). The variable age did not present significant impact on the acceptability of the sample's appearance for WBF20 ($p>0.05$).

The color acceptability for sample PDF10 showed to have lower values from participants <20 years old, while participants in the age group >40 years old seemed to have higher acceptability on the sample's color than participants <20 years old ($p<0.05$). The color for samples PDF20 and WBF10 was less acceptable to participants <20 years old than the age group 20-40 years old ($p<0.05$). The variable, age, did not show a significant difference on acceptability of the sample's color for WBF20 and Ct tortillas ($p>0.05$).

The variable, age, had a significant difference in the participant's response for flavor acceptability of WBF10 sample, where participants >40 years tended to accept more the sample's flavor than participants <20 years ($p<0.05$). The variable age did not show a significant difference on acceptability of the sample's flavor for PDF10, PDF20, WBF20 and Ct ($p>0.05$).

The texture and overall acceptability for sample PDF20 was significantly less acceptable for participants <20 years old when comparing to the other age groups ($p<0.05$). The variable age did not show significant difference on acceptability of the sample's flavor for PDF10, WBF10, WBF20 and Ct tortillas ($p>0.05$).

The variable, frequency of consumption, was shown to have significant difference in the participant's response on acceptability of fortified and unfortified tortillas ($p<0.05$) (Table 4.6). The participants were grouped in three levels of consumption, participants who eat tortillas monthly, weekly and daily.

The appearance acceptability for samples Ct, PDF10, PDF20 and WBF20 showed that participants who eat tortillas daily gave higher values than people who eat tortillas monthly ($p<0.05$), but not significantly different from people who eat tortilla weekly ($p>0.05$). The variable frequency of consumption did not show significant difference on acceptability of sample color ($p>0.05$). Of the 100 subjects, 66 said they consume tortillas daily, whereas 25 consume tortillas weekly and the remaining 9 consume tortillas monthly.

**Conclusion**

Addition of partially defatted and whole flax meal increased protein content in tortillas, and improved the contents of lysine and tryptophan, the principal limiting amino acids in nixtamalized corn flour. One of the advantages of using partially defatted flax meal is that it is inexpensive since it is a by-product of oil industry. Brown flax meal gave a negative effect on the color of tortillas when it was used in tortilla formulation ($p<0.05$). On the other hand, the use of golden flax meal could decrease this effect. The target population accepted the overall liking of fortified tortillas. The variables, age and frequency of consumption, were shown to have significant effects on acceptability of the samples ($p<0.05$).

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Table 4.1 Chemical analysis of control and fortified tortillas

| **Nutrient** | **NCF** | **PDF** | **PDF10** | **PDF20** | **WBF** | **WBF10** | **WBF20** |
|---|---|---|---|---|---|---|---|
| Fat (%) | 1.59 | 13.62 | 2.55 | 2.95 | 36.56 | 6.99 | 9.56 |
| Protein (%) | 9.10 | 30.30 | 12.04 | 14.48 | 25.38 | 12.09 | 13.68 |
| Tryptophan (g/100g of protein) | 0.77 | 1.72 | 0.96* | 1.15* | 1.77 | 0.89* | 1.17* |
| Lysine (g/100g of protein) | 2.96 | 3.91 | 3.10* | 3.79* | 4.10 | 3.17* | 3.86* |

Data is given in dry matter basis and values are averages of composite samples.
*Calculated amount of lysine and tryptophan by using the amino acid profile analysis of NCF, PDF and WBF.
Treatments include:

NCF=nixtamalized corn flour (control),
PDF meal=partially defatted flax meal,
PDF10 and 20= tortillas fortified at 10 and 20% with partially defatted brown flax meal,
WBF meal=whole brown flax meal,
WBF10 and 20= tortillas fortified at 10 and 20% with whole brown flax meal.

Table 4.2 Amino acid profile of nixtamalized corn flour, partially defatted and whole flax meal

| Amino acid (g/100g of protein) | Nixtamalized corn flour (NCF) | Partially defatted flax meal (PDF) | Whole brown flax meal (WF) |
|---|---|---|---|
| trypthopan* | 0.77 | 1.72 | 1.77 |
| lysine* | 2.97 | 3.91 | 4.10 |
| methionine* | 1.98 | 1.82 | 1.85 |
| threonine* | 3.51 | 3.81 | 3.90 |
| valine* | 4.72 | 5.01 | 5.36 |
| isoleucine* | 3.40 | 4.08 | 4.41 |
| leucine* | 9.33 | 5.90 | 6.15 |
| phenylalanine* | 4.94 | 4.54 | 4.89 |
| histidine* | 2.86 | 2.09 | 2.25 |
| cystine | 1.87 | 1.59 | 1.66 |
| aspartic acid | 6.59 | 8.98 | 10.05 |
| tyrosine | 2.97 | 2.29 | 2.52 |
| serine | 4.83 | 4.61 | 4.89 |
| glutamic acid | 18.23 | 19.33 | 20.57 |
| arginine | 4.61 | 9.22 | 10.56 |
| alanine | 7.25 | 4.51 | 4.81 |
| glycine | 3.84 | 6.17 | 6.23 |
| proline | 8.35 | 3.65 | 3.87 |

Data is given in dry matter basis and values are averages of composite samples.
* Essential amino acids

Table 4.3 Color values of control and fortified corn tortillas

| Treatment | Color values[a] | | |
|---|---|---|---|
| | L | a | b |
| Ct | 74.70±0.31a | 0.27±0.13f | 27.27±0.23b |
| PDF10 | 51.05±.57e | 5.81±0.18ab | 12.76±0.17c |
| PDF20 | 45.73±0.26g | 5.95±0.11a | 11.06±0.15d |
| WFB10 | 54.87±0.62d | 4.08±0.14d | 13.59±0.22c |
| WFB20 | 46.79±0.16gf | 5.12±0.15bc | 11.66±0.13d |
| WF10 | 69.59±0.26b | 2.69±0.14e | 27.51±0.52ab |
| WF20 | 66.74±0.75c | 4.88±0.29c | 28.45±0.34a |

Results are expressed as means ±SD (n=3). Means with the same letter in the same column are not significantly different ($p<0.05$).
[a] Determined with a Chroma meter CR-400 (Minolta Co., LTD, Osaka, Japan). Where L, 0=black, 100=white; a, negative values indicate green, positive values indicate red; b, negative indicate blue, positive values indicate yellow.
Treatment includes:

Ct= tortillas elaborated with nixtamalized corn flour (control),
PDF10 and 20= tortillas fortified at 10 and 20% with partially defatted brown flax meal,
WF10 and 20= tortillas fortified at 10 and 20% with whole golden flax meal,
WBF10 and 20= tortillas fortified at 10 and 20% with whole brown flax meal.

Table 4.4 Acceptability of control and fortified corn tortillas

| | Appearance | Color | Flavor | Texture | Overall acceptability |
|---|---|---|---|---|---|
| Ct | 7.10±0.48 | 7.40±0.52 | 6.80±0.53 | 7.00±0.49 | 7.1±0.45 |
| PDF10 | 6.13±0.48 | 5.97±0.52 | 6.44±0.53 | 6.46±0.49 | 6.61±0.45 |
| PDF20 | 5.47±0.48 | 4.92±0.51 | 5.79±0.53 | 5.95±0.49 | 5.94±0.45 |
| WBF10 | 6.45±0.48 | 6.15±0.52 | 6.64±0.53 | 6.54±0.49 | 6.70±0.45 |
| WBF20 | 6.19±0.48 | 5.84±0.52 | 6.52±0.53 | 6.44±0.49 | 6.47±0.45 |

Treatment includes:

Ct= tortillas elaborated with nixtamalized corn flour (control),

PDF10 and 20= tortillas fortified at 10 and 20% with partially defatted brown flax meal,

WBF10 and 20= tortillas fortified at 10 and 20% with whole brown flax meal.

Table 4.5 Effect of age on acceptability of control and fortified corn tortillas

| Attribute | age | Ct | PDF10 | PDF20 | WBF10 |
|---|---|---|---|---|---|
| appearance | <20 | 6.07±0.70b | 3.80±0.76b | 4.00±0.86b | 4.35±0.80b |
| | 20-40 | 7.44±0.61a | 6.18±0.67a | 6.17±0.75a | 6.60±0.70ab |
| | >40 | 7.07±0.87ab | 6.32±0.95a | 5.60±1.07ab | 6.76±0.99a |
| | <20 | | 4.77±0.62b | 3.83±0.60b | 4.82±0.85b |
| Color | 20-40 | - | 5.76±0.73ab | 5.18±0.79a | 6.37±0.64a |
| | >40 | | 6.51±1.02a | 5.14±1.13ab | 6.38±0.65a |
| | <20 | | | | 5.57±0.70b |
| Flavor | 20-40 | - | - | - | 6.52±0.73ab |
| | >40 | | | | 7.11±0.50a |
| | <20 | | | 4.52±0.65b | |
| texture | 20-40 | - | - | 6.03±0.70a | - |
| | >40 | | | 6.13±0.84a | |
| | <20 | | | 4.50±0.52b | |
| Overall | 20-40 | - | - | 6.44±0.66a | - |
| | >40 | | | 6.15±0.93a | |

[ab] Means with the same letter in the same column are not significantly different ($p<0.05$) as determined by Tukey's paired comparison test analysis. Means values not present in the table were not significantly different.

Treatment includes:

Ct= tortillas elaborated with nixtamalized corn flour (control),
PDF10 and 20= tortillas fortified at 10 and 20% with partially defatted brown flax meal,
WBF10= tortillas fortified at 10 and 20% with whole brown flax meal.

Table 4.6 Effect of frequency of consumption on acceptability of control and fortified corn tortillas

| Attribute | Frequency | Ct | PDF10 | PDF20 | WBF20 |
|---|---|---|---|---|---|
| appearance | monthly | | 4.78±0.64b | | |
| | weekly | - | 5.09±0.81ab | - | - |
| | daily | | 6.44±0.52a | | |
| | monthly | | | 3.77±1.51b | |
| Flavor | weekly | - | - | 5.31±0.96ab | - |
| | daily | | | 6.16±0.62a | |
| | monthly | 5.19±1.29b | | | 4.02±1.36b |
| texture | weekly | 6.51±0.82a | - | - | 6.19±0.85ab |
| | daily | 7.08±0.53a | | | 6.77±0.55a |
| | monthly | | 5.03±1.16b | 4.22±1.26b | 4.09±1.31b |
| Overall | weekly | - | 5.87±0.73ab | 5.39±0.79ab | 6.20±0.83a |
| | daily | | 6.84±0.47a | 6.31±0.51a | 6.83±0.53a |

[ab] Means with the same letter in the same column are not significantly different ($p<0.05$) as determined by Tukey's paired comparison test analysis. Means values not present in the table were not significantly different.

Treatment includes:

Ct= tortillas elaborated with nixtamalized corn flour (control),
PDF10 and 20= tortillas fortified at 10 and 20% with partially defatted brown flax meal,
WBF20= tortillas fortified at 10 and 20% with whole brown flax meal.

# CHAPTER 5

# CONCLUSIONS

The first part of the study was focused on the physical properties of fortified tortillas at different levels of flax concentration (0, 15 and 20%) over time. The addition of flax meal to nixtamalized corn flour tended to change the textural properties of tortillas especially from those samples prepared with whole flax meal. Tortillas fortified with partially defatted flax meal at levels of 10, 15 and 20% showed similar behavior in strength, extensibility and toughness than regular tortillas, demonstrating that partially defatted flax meal can be a good material to fortify corn tortillas. Addition of whole flax meal to tortillas formulation tended to increase the strength and toughness of the samples. The increase of strength and toughness in the samples during the time can be related to stale, which can make the tortilla more rigid or firmness and therefore reduce its flexibility. The staling process starts after a tortilla is cooked due to starch retrogradation. However, the staling process can be reduced by using antistaling agents that prologue the shelf life of the product.

In the second part of the study, the protein and amino acid profile of flax meals and nixtamalized corn flour was evaluated. Both flax meals showed to have higher fat, protein and amino acid content. Tortillas fortified with flax meal presented a higher amount of protein than regular tortillas. Flax meals increased the protein content in tortillas; therefore amino acid profile is also expected to be increased, specially for tryptophan, because flax meals are rich in tryptophan content. The acceptability of the samples was affected by the type of flax meal used, brown flax meal tended to give a darker appearance than regular tortillas. The variables age and frequency of consumption showed to have a significant influence in the panelists' responses for some samples. Panelists less than 20 years old gave the lower scores when compared with the groups between 20 to 40 and greater than 40 years old. The sensory evaluation demonstrated that tortillas elaborated with whole flax meal presented acceptable scores even when in the textural evaluation had a higher strength and toughness.

The present work shows that whole flax meal can be a good source to fortify tortillas. However the results obtained in this study can be complemented with the analysis of the amino acid and fatty acid profile for tortillas samples, as well as evaluations that involve the analysis of the internal structure of tortillas samples in order to understand better the arrangement that corn and flax meal components could present. Other study that can complement this work is by performing clinical research.

# APPENDIX I

## Tortilla survey

**Hello, my name is Diana Santiago and I am conducting this sensory evaluation. The main objective of my research is to fortify corn tortillas.**

**With your volunteer participation you will help to decide if corn tortillas fortified with flax meal are acceptable for consumption.**

**General instructions of the procedure of the experiment**

1. You will receive a survey and a sheet with the scale that will be used to fill the survey
2. Write your age and gender, read the first question and answer it
3. Please, rinse your mouth before to start tasting the samples (tortillas)
4. Evaluate the first product that you have in front. Observe it, touch it and taste it
5. Read every question and the possible options. Mark your answer with an X in one of the boxes
6. Please, make sure to mark one answer per each question
7. Between each sample eat a little bit of the cracker and drink a little bit of water
8. Repeat the steps from 4 to 7 with the samples that you will receive

.

**Please, write your age and gender**

**Age________________** **Gender** **F** ☐ **M** ☐

1. **How many times have you consumed corn tortillas? Give your opinion by checking one box [X]**

| Once/ month | 2/month | 1/wk | 2-3/wk | 4-6/wk | 1/day | 2/day | 3/day |
|---|---|---|---|---|---|---|---|
| | | | | | | | |

This is the scale that will be used to answer all the questions, each number represents a different opinion

| | |
|---|---|
| Like extremely | 9 |
| Like very much | 8 |
| Like moderately | 7 |
| Like slightly | 6 |
| Neither like nor dislike | 5 |
| Dislike slightly | 4 |
| Dislike moderately | 3 |
| Dislike very much | 2 |
| Dislike extremely | 1 |

**1.** Code number ____________

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **How do you feel about the apparance** | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| **How do you feel about the color ?** | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| **How do you feel about the flavor?** | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| **How do you feel about the texture?** | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |

**Considering all characteristic (appearance, color, texture and flavor) indicate your overall opinión by checking one box [X]**

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |

**Comments (optional):**

For example What do you like or dislike from the product? and why? What Could be your suggestions to improve the product?

**2.** Code number ____________

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **How do you feel about the apparance** | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| **How do you feel about the color ?** | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| **How do you feel about the flavor?** | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| **How do you feel about the texture?** | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |

**Considering all characteristic (appearance, color, texture and flavor) indicate your overall opinión by checking one box [X]**

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |

**Comments (optional):**

For example What do you like or dislike from the product? and why? What Could be your suggestions to improve the product?

**3.** Code number ____________

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **How do you feel about the apparance** | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| **How do you feel about the color ?** | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| **How do you feel about the flavor?** | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| **How do you feel about the texture?** | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |

**Considering all characteristic (appearance, color, texture and flavor) indicate your overall opinión by checking one box [X]**

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |

**Comments (optional):**

For example What do you like or dislike from the product? and why? What Could be your suggestions to improve the product?

**4.** Code number ____________

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **How do you feel about the apparance** | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| **How do you feel about the color ?** | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| **How do you feel about the flavor?** | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| **How do you feel about the texture?** | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |

**Considering all characteristic (appearance, color, texture and flavor) indicate your overall opinión by checking one box [X]**

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |

**Comments (optional):**

For example What do you like or dislike from the product? and why? What Could be your suggestions to improve the product?

**5.** Code number ____________

**How do you feel about the apparance ?**

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **How do you feel about the color ?** | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| **How do you feel about the flavor?** | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| **How do you feel about the texture?** | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |

**Considering all characteristic (appearance, color, texture and flavor) indicate your overall opinión by checking one box [X]**

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |

**Comments (optional):**

For example What do you like or dislike from the product? and why? What Could be your suggestions to improve the product?

______________________________________________________________________________

**6. Assuming that tortillas fortified with flax meal cost the same as tortillas currently produced, would you be willing to purchase?**

Yes ☐

No ☐

**Thank you for your participation!!!!!!!**