

**FORTIFICATION OF BAKED AND FRIED TORTILLA CHIPS WITH  
MECHANICALLY EXPELLED SOY FLOUR**

A Thesis

by

MONICA DE LA TORRE PINEDA

Submitted to the Office of Graduate Studies of  
Texas A&M University  
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

May 2007

Major Subject: Food Science and Technology

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## ABSTRACT

Fortification of Baked and Fried Tortilla Chips with Mechanically Expelled Soy  
Flour. (May 2007)

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The effects of the fortification of tortilla chips with mechanically expelled soy flour as well as baking and frying processes on the properties of tortilla chips were evaluated. Sensory characteristics, texture, thickness, color, protein and oil content were evaluated. Texture was measured by objective and subjective tests. Sensory properties were evaluated using a nine point hedonic scale.

Soybeans (food grade Hartz) were mechanically expelled to obtain partially defatted soy flour of 6.7% final oil content. Dry masa flour (DMF) was replaced with 0, 10, 20 and 30% mechanically-expelled soy flour (MESF). The equilibrated tortilla was either fried in oil or baked in an air-impingement oven followed by convection oven drying.

Overall, fried tortilla chips were harder and thicker than baked tortilla chips. Fried tortilla chips with 20 and 30% soy flour substitution required less force to break. In fried tortilla chips, as MESF increased, force and work levels decreased, where 20% MESF had the lowest force values. Thickness measurements of

tortilla chips showed that as the thickness increased, the force and work also increased. Protein increased linearly in baked and fried tortilla chips where 30% resulted in the highest protein level. In fried tortilla chips, MESF fortification increased oil levels linearly as well. Baked tortilla chips were lighter than fried tortilla chips.

In a consumer sensory evaluation, fried tortilla chips were preferred more than the baked ones. In fried tortilla chips, 20% had the highest sensory scores overall. Ten and 20% MESF fortification in fried tortilla chips were the most acceptable of all. In all treatments, regardless of type of processing, panelists could not detect any “beany” flavors in any of the samples. Therefore, dry extrusion followed by mechanical expelling proved successful in creating a suitable soy flour for tortilla chip production.

MESF can be added at 10-30% levels in tortilla chips. Up to 20% would be recommended. Frying results in higher acceptability consumer scores over baking.

## DEDICATION

I would like to dedicate this thesis to my beloved husband Nathan Grassel, my mom Soco Pineda de De La Torre and my dad Jose Luis De La Torre. Without their support and unconditional love, I would not have been able to finish this thesis.

Thank you for your patience and help. I love you!

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## INTRODUCTION

Products made out of soy are becoming very popular to increase protein content. According to the FDA, adding more soy to the diet reduces the risk of heart disease, cancer, and decreases discomfort in menopausal women. Twenty five grams of soy combined with a diet low in saturated oil and cholesterol may reduce the risk of heart disease (Lusas 2002).

Soy protein is a subject of intense investigation and has had a increasing role in human nutrition over the last few decades (Riaz 2001). Health benefits include: reduced blood pressure, lower cholesterol levels and improved bone health (Adelekun et al. 2005). Soy protein also contains all nine essential amino acids (Riaz 1999) .

Soy proteins have been widely accepted in applications because they provide desirable functionalities in fabricated foods with lower costs (Amudha Senthil 2002).

Soy has been researched when incorporated in cookies, bread, extruded puffs, pasta (Buck et al. 1987) or in combination with rice (Payumo et al.1982) or with corn.

There are two ways to extract the oil out of soy: mechanical expelling and solvent extraction. Hexane extraction is the most common industry practice. However, this method requires a lot of capital investment and it can be prone to explosions.

Mechanical expelling followed dry extrusion is a more cost-effective way to extract oil and it is safer than hexane extraction. It is also chemical free and requires low capital investment and low operation costs (Riaz 2001).

Beany flavors can occur in foods developed with soy. There have been many experiments to try to minimize the beany flavor and keep the isoflavones, nutrients and bioavailable protein from the soy.

The objectives of this study were:

1. To produce a mechanically-expelled soy flour and evaluate its protein, oil and protein dispersibility levels.
2. To create a tortilla chip fortified with mechanically-expelled soy flour in levels that are most acceptable to the palate of consumers.
3. To measure the texture, thickness, color and sensory properties of tortilla chips.

## LITERATURE REVIEW

### History of Snack Food

The snack food industry has been around for centuries. Popcorn has been around since approximately 3000 B.C. Even the pretzel was created in southern France around 610AD. In the late 1890s, potato chips were invented and became a popular American snack. It started as a small business venture to get chips to locals and caught on and spanned the globe. Thousands of types of chips, fruit snacks, cookies, and anything our hearts desire are available. (McCarthy 2001).

Now the industry seeks healthier foods for snacking. People want low sodium, low oil and low calorie. Companies are baking chips to produce lower oil chips. Tortilla-chip sales boomed in the '90s, enjoying double-digit growth even as other categories plateaued. Naturally, families with children and teenagers are the largest consumers (Mintel International Group, 2006).

From 2000-2005, total sales of salty snacks grew from \$18.9 million to \$21.5 million, an average growth of 2.8% per year (Mintel International Group, 2006). Potato chips and tortilla chips are the two biggest salty snack segments, with combined sales of \$10.9 billion. These two snacks experienced modest growth from 2003-2005 (4% and 2% respectively) thanks to new flavors and “healthier” choices that helped them against the low-carb diet trend (Mintel International

Group, 2006). The snack nuts and seeds segment proved to be the big winner (sales climbed 25% from 2003-2005), benefiting not only thanks to the low-carb diet trend, but also from growing awareness of the link between nuts and heart health. (Mintel International Group, 2006)

Focus has now shifted to emerging trends: whole grains, organic and no trans fats. From 2001-2005, sales of other salty snacks grew by approximately 7% thanks to “healthier” choices such as Genisoy Soy Crisps for example (Mintel International Group, 2006). Mintel’s consumer research reveals that 30% of salty snack consumers say that “all-natural/organic” is important to them when buying salty snacks, an indication that the organic segment will continue to grow. In fact, the organic food market reached an estimated \$3.6 billion in 2006. This is more than double the size of the market in 2001, when sales were \$1.5 billion. Of the organic market, snacks comprise 15% of the market.

Tortilla chips were ranked number one in the snack market among college women. Since women are the target demographic it is obvious an attempt to appease the target market by creating new and healthier types of tortilla chips is needed. In the USA alone, approximately 1 billion dollars is spent on popcorn while over 5 billion dollars is spent on tortilla chips.



## **History of Tortilla Chips**

The tortilla was first created by either the Aztecs or the Zapotecs. The Zapotecs were an ancient civilization that existed near Oaxaca in the Monte Albán ruins. They created Totopochtli by roasting tortillas on a flat grill. This tortilla had a shelf life of one or two days. The fried tortilla was referred to as a tostado which improved the flavor and extended storage time. If the tostados were cut into pieces they were called Totopos. The tostados allowed them to travel large distances and still have food (Quintero-Fuentes 1997).

Tortilla chips are baked and then fried which gives the chip a firmer texture.

## **History of Soy**

The Chinese domesticated the wild soybean plant, used it for food and medicine. In the eleventh century B.C., the northern Chinese honored soy as one of five sacred grains essential to the existence of Chinese civilization (Lusas 2002). The three main products from soybeans were miso, tempeh, and tofu. By the first century A.D., Central Southern China and Korea were growing the crop. Coming into the seventh century it expanded to Japan, Indonesia, Philippines, Vietnam, Thailand, Malaysia, Burma, Nepal, and northern India. It reached Europe in the eighteenth century in the form of Soy Sauce. Finally in 1765, Samuel Bowen an English seaman grew soy in Savannah, Georgia (Lusas 2002).

Benjamin Franklin sent soybean seeds to his botanist friend in 1770. When Franklin sent the seeds he said they were used in “cheese” which is now Tofu (Lusas 2002). The crop was grown mainly for shipping to England in the form of soy sauce and soy noodles. Brazil, Argentina and Paraguay also grow soy crops and are collectively producing competitively with the U.S. (Lusas 2002).

Though soy reached American soil in 1700s, soy did not become an important food crop until 1920. In 1915 it is believed that W. T. Culpepper began to crush the soybean in his Expeller. At the time there was high demand for oilseeds because of boll weevil devastation (Lusas 2002). In 1929 the U.S. produced some nine million bushels. By 1940 it increased to seventy eight million. Soy was used as in field rations during World War II (Lusas 2002). In 1966, soybeans were accepted as a “protein enrichment resource” as part of the food for peace program (Lusas 2002).

The early sixties marked a benchmark for soybeans since they became a protein source in demand due in part to the faults of fish meal. In 1998 the soybean crop in the U.S. reached a record eight billion bushels (Lusas 2002). Over one third of this crop is sold overseas. Today soy is used in cosmetics, paints, milk, salad oil, pet food, shampoo, tofu and even ice-cream (Lusas, 2002). These are only some of the products soy is used in today.

## **The Role of Soy in Snacks**

Full fat and defatted soy flours have been used as ingredients in the preparation of high protein snacks (Amudha Senthil et al., 2002). Soy proteins have been widely accepted in applications because they provide desirable functionalities in fabricated foods with lower costs (Amudha Senthil et al., 2002). High protein rice-soy snacks have been prepared with full fat soy flour at a level of 13.5% substitution (Che Man et al., 1992).

Malnutrition has been prevalent in many developing countries. Soy flour has been used to enhance and enrich food to overcome this problem with minimal cost (Che Man et al., 1992). Malnourished children tended to be shorter in height, lighter weight, and suffered impaired motor skills. The addition of soy not only increased protein quality but it also reduced blood pressure and cholesterol, improved bone health and protected against heart disease (Adelekun et al., 2005).

Buck et al. (1987) conducted an experiment using soy in cookies, bread, extruded puffs and pasta. The cookies were made with different ratios of soy and corn gluten meal (CGM). The cookie formula contained 20% soy in one, 20% CGM in another and the final type had 20% of each. The flavor of the 20% soy was less strong than that of the cookie with CGM and soy. The breads were done with ratios 10 to 30% individually of soy and CGM and combined 5, 10 and

15% of each. In the bread when CGM, soy or both were added an increase in aroma occurred with more coarse texture and stronger flavor. The extruded puffs were harder, smaller with less desirable texture than the control. The flavor on the other hand was more desirable than the control. The pasta was made with ratios 10 to 20 % individually and 5 and 10% combined. The pasta samples containing soy had lower cooked weights and showed a significantly greater cooking loss than control or corn gluten meal (Buck et al., 1987).

Payumo et al. (1982) undertook a study to develop a calorie-protein rich snack food using rice supplement and full fat soybean through an extrusion cooking process. The extruded rice-soy curls that resulted contained 17 % protein and 485 calories per 100 grams (Payumo et.al., 1982). Che Man et al. (1992) found that by increasing the percentage of full fat soy flour in soy-rice snack formulations they could improve the nutritional value with some loss of acceptability occurring at the highest level of Full fat soy flour (Che Man et al., 1992). When soy flour increases there is an increase in water absorption. In fried savory snacks, protein content increased. When the soy flour was raised from 20 to 40% the rise in protein content in the fried sweet snack was from 15.8 to 21.8%. In sweet snacks irrespective of levels of soy flour there was no significant difference found in protein content (Amudha Senthil et. al., 2002). Soy has been used in pasta, bread, cookies, cakes, donuts and other sweet goods.

### **Nutritional Benefits of Soy**

A soybean contains 18% oil, 38 % protein, 15 % dietary fiber, 15% soluble carbohydrate and 14 % moisture and other minor contents (Liu 1999).

According to the FDA, adding soy to the diet reduces the risk of heart disease, cancer, and decreases discomfort in menopausal women. Twenty five grams of soy combined with a diet low in saturated oil and cholesterol may reduce the risk of heart disease (Lusas 2002). For a product to display the FDA claim it must contain at least 6.25 grams of soy protein (Lusas 2002).

Recent experiments have produced evidence suggesting that phytochemicals are responsible for the beneficial effects that enhance bone health (Liu 1999). The isoflavones help reduce the effects of osteoporosis. The structure of an isoflavone is chemically similar to the structure of estrogen. The two isoflavones contained in soybeans are daidzein and genistein. The anticarcinogens in soy are isoflavins, phytosterols, phytates, saponins, and protease inhibitors (Liu 1999). Phytosterols are believed to reduce cholesterol by inhibiting cholesterol absorption and may reduce the risk of heart disease. Phytates may help prevent cancer. Saponins are used to solubilize membrane proteins in cells. Protease inhibitors protect against radiation (Liu 1999).

Soy protein is low in sulfur containing amino acids. Methionine is the most limiting amino acid followed by cysteine and threonine (Liu 1999). Most cereal proteins are deficient in lysine but soy protein contains sufficient quantity of lysine. It is quite valuable to combine soy with cereal proteins since lysine and methionine are complementary (Liu 1999)

Lipoxygenase (LOX) catalyzes the oxidation of certain polysaturated fatty acids; producing conjugated unsaturated fatty acid hydro peroxides (Liu 1999). The enzyme forms free radicals that attack other constituents. Lipoxigenases are found in plants, fungi and animals. Among plants they are most commonly found in legume seeds. In soybeans the LOXs are interesting because they are the main cause of the undesirable “beany” flavor associated with soy (Liu 1999). The richest known source of LOX is soybean seeds. There are four LOX isozymes known as L-1,L-2,L-3a,and L3b. L-3a and L-3b are often combined as L-3 since they are so similar. L-3 is the most abundant isoenzyme on a protein basis in mature soybeans. LOX catalyzes hydroperoxidation of linoleic acid along with other polyunsaturated lipids containing cis-1,4-pentadiene moieties (Liu 1999). The primary products are referred to as hydroperoxides; first activation of the native enzyme followed by removal of a proton from the activated methylene group and finally oxygen is inserted into the substrate molecule with the forming of hydroperoxide. Initially the products of lipoxygenase activity can be degraded to a variety of c-6 and c-9 products through isomerases

or hydroperoxide lyases. These volatile compounds are alcohols, aldehydes, and ketones. Many of these compounds have undesirable flavor or odor which causes the off flavors associated with soy (Liu, 1999).

Hexanal is mainly responsible for the “greeny” flavor of soy because of its low flavor threshold (less than 1ppm.). LOX is also a catalyst for cooxidation of pigments such as carotenoids and chlorophyll by free radical mechanisms that require the presence of polyunsaturated fatty acids (Liu, 1999). This is a reason that the enzyme-active full fat soy flour is used in bleaching wheat flour. It helps release bound lipids which improves dough rheology and increases the loaf volume of bread. Due to the off flavors caused by this enzyme it is only used up to 0.5% in wheat flour since the most important cause of the off flavors caused by soy is the effect of LOX on linoleic and linolenic acids. Many attempts have been made to improve soy flavors by inactivating the enzymes. Heat treating whole beans and grinding them allows the beans to hold good flavor for up to two years of storage (Mustakas et. al. 1969). A downside to heating the LOX is that it leads to some insolubilization of the soy proteins, loss of functionality of protein and the introduction of a toasted or cooked flavor. Because of these side effects, milder heat treatment techniques were developed (Liu 1999).

The heat treatment of soy has many purposes such as to inactivate antinutritional factors such as trypsin inhibitors and lectins which occur naturally

in soybeans (Liu 1999). Another purpose is to denature soy proteins to increase digestibility. It will also increase the shelf life of soy products by killing the microbes that are from raw materials or processing equipment. Heating also plays an important role in the inactivation of LOX so that the lipid oxidation and the resulting beany flavor are minimized (Liu 1999).

Trypsin inhibitors can bind to trypsin in the intestine which causes an increase in pancreatic secretion of cholecystinin (CKK) causing an increase in pancreatic secretion of trypsinogen leading to pancreatic hypertrophy. The ingestion of raw soy beans results in growth inhibition because of the protease inhibitors contained in the soy which causes the loss of amino acids because of enzyme secretion. Trypsin and chymotrypsin are rich in sulfur amino acids these acids are the limiting amino acids in soybeans. There has been little evidence that protease inhibitors are harmful in adults but a lot of concern has been directed toward infant children. There is also a lot of research into anticarcinogenic activity of soy foods (Liu 1999).

### **Solvent Oil Extraction**

Most commercial oil extraction is currently done by hexane extraction. (Liu 1999). It is possible to extract up to ninety nine percent of the oil (Said 1998). The solvent extraction is very efficient in the recovery of oil and production of meal for further processing into food and feed ingredients (Nelson et. al., 1987).



Solvent oil extraction requires heavy investment by companies, and a highly developed infrastructure (Nelson et. al., 1987). It is necessary to have the means to collect, store, and distribute both the raw material and the finished product (Riaz 1997).

During solvent extraction, oil is removed from the soy flakes by an organic solvent to form an oil/solvent mixture called a miscella. The oil is recovered from the miscella by removing the solvent by steam stripping. Factors that affect oil extraction are: thickness of the flakes, moisture, mixture of lipids and minor components in soy oil, retention time, oil solubilization, solvent type, efficiency of equipment, etc (Liu, 1999).

### **Mechanical Extraction**

Another way to extract the oil from soybeans is to use a process called mechanical expelling. Mechanical extraction is often preferred by small extraction plants throughout the world to remove the oil (Liu 1999). Dry extrusion processing of soybeans was developed in the 1960s to prepare trypsin inhibitor-inactivated full fat soy flour for feeding swine and poultry on small farms (Wang et al. 2002).

The advantages to mechanical extraction are low initial cost and no solvent requirements (Liu 1999). The non-use of organic solvents in extruded-expelled

soybean meal production makes partially-defatted soy flour attractive to producers of natural foods (Endres 2001). Partially defatted soy flour with a varied Protein Dispersibility Index (PDI) (12-69) and residual oil content (4.5 – 13%) is possible by adjusting the processing parameters during extruding and expelling (Endres 2001).

In extrusion-expelling process, dry extrusion is used as a heat pretreatment to denature the protein and interrupt the cellular structure of the seed. A screw press is then used to press out the oil and to separate oil and meal. Screw presses are composed of a shaft with an interrupted worm gear that rotates in a cage of metal bars with small spaces between them (Liu 1999). Oil is forced out by the high pressure generated between the cage bars as the press cake moves along the shaft. Material that is intended to be expelled must first be flaked and cooked before extracting the oil to enhance the oil removal (Snyder 1987). Friction is the only source of heat to deactivate antinutritional factors present in oilseeds (Wang et al. 2002).

### **Production of Fried Tortilla Chips**

Tortilla chips require coarser flour in order to obtain lower water retention. This is necessary to prevent blisters in the tortilla chips as well as to make sure that the correct amount of oil is absorbed. Masa for tortilla chips needs 0.9 to 1L/kg of flour (Serna-Saldivar et al. 1990).

A sheeter with two rolls at variable speeds is used to make and cut the tortillas into round pieces. The raw tortilla pieces are scraped from the front roll, onto a belt and baked in the oven. Tortillas are equilibrated at room temperature for 20 min or less.

Frying temperatures range from 340° F to 385° F. The typical range is 360° F - 375° F. The time in the fryer ranges from 40 seconds to 2 minutes (Chen 1996). This depends on moisture content of tortilla chips prior to frying, distribution and range of masa particle size, thickness of the chips, time in the oven and temperature of the oven belt. Any of these variables affect the time needed to fry the chips (Mehta 2001). The absorption of oil relates to frying time and frying temperature, oil deterioration, surface area, structure of product and moisture content (Chen 1996). The more oil that is absorbed the higher the oil content in the chips.

### **Baking Tortilla Chips for Lower Oil**

Baking tortilla chips is a way to reduce the oil content in tortilla chips. Heat transfer is by conduction and convection. Radiated heat is done through microwave, infrared or dielectric heating. When a substance is heated, the molecules begin to vibrate more rapidly. Conduction baking transfers the heat directly to the product by the metal band the product is placed on. Convection is

more complicated in that it involves transferring heat through a moving heated fluid.

Most convection ovens are heated using steam or air. The flow of the convection fluids is regulated by flow systems and dampers (Quintero-Fuentes 1997). Impingement ovens are used to bake chips through a method known as forced-convection heat transfer. By using high capacity blowers and jet nozzles which are placed both above and below the conveyor, forced heat is placed onto the product. The surface of the product is heated with high-velocity treatment which contacts the product surface directly with sufficient force for increasing heat transfer to the product. There is a principal resistance to this heating method which is commonly called the boundary layer. This layer which is adjacent to the air interface of the product is a relatively stagnant laminar layer of air (Quintero-Fuentes 1997).

### **Evaluating Qualities of a Tortilla Chip**

Flavor, texture and appearance of the chip affect acceptability of tortilla chips. There have been a number of tests developed to give good correlation to sensory evaluation of texture in limited numbers of foods. Tests are being developed attempting to mimic the conditions food is subjected to on a plate or in one's mouth.

Vickers and Bourne et al, (1976b) found that the slope of the force-deformation curve increased with crispiness. The area under the curve was greater for a chewier chip. Potato chips varied in crispiness because they were shaped differently. Different sizes and shapes leads to an inconsistent shaped force-deformation curve. Palau-Echeverry (1993) used a TA-XT2 texture analyzer compression test characterizing changes in texture in tortilla chips during frying. A 0.203 cm in diameter cylindrical probe with a cylindrical base 25.5 mm outside diameter and a 19mm orifice was used to test a chip with a one bite compression at a velocity of 10mm/s. Chen (1996) would later use .635 cm diameter ball probe to rupture tortilla chips. Chips would be placed on a base and a probe would travel at 4mm/s until it reached 10g of force at which time it would puncture 3mm through the chips on the base. The initial slope and peak force were measured using ten replicates. The crunchiness of tortilla chips was measured as the peak force (Chen 1996).

Tortilla chips are strongly affected by texture and objective measures of texture properties are the key to modifying and accepting regular and reduced oil products (Quintero-Fuentes 1997). Sensory panels are used to test for taste, texture and appearance of products. In these panels, people taste samples and describe their reactions to the texture such as crunchiness. They are also asked how they feel about the flavor and what they think about the appearance of the

product. There is a lot of variability with test panels as they are inconsistent as well.

## MATERIALS AND METHODS

### Raw Materials

#### *Mechanically-Expelled Soybean Flour (MESF)*

Food grade #1 soybeans (Hartz, Stuttgart, AR Des Moines, IA, USA) were used to process the soybean flour. Soybeans were heated for 10 min. to 160°F in a French Oil Machinery Company 5-ring stack cooker to facilitate dehulling. Then they were cracked into 6-8 pieces using corrugated rolls (10x16, Ferrel-Ross, Oklahoma City, OK), the hulls were removed by a Kice Industries Co zig-zag aspirator (Model 6DT4-1, KICE Industries Inc., Wichita, KS), the cotyledons were heated to 170°F and flaked to (0.011 in) with a Bauer Bros. twin 16 x 24 roll stand flaker (17762, Bauer Bross, Springfield, OH), extruded at 210°F with an Insta-Pro Model 600 (Insta-Pro International, Inc., Des Moines, IA) which yielded fine shreds of full-oil soybean. The oil content was reduced to 6% by using the Komet IBG Monoforts Screw oil expeller (Model DD 85 G-1, Komet IBG Monoforts) resulting in a “soy cake”. Then, the pressed soy cake was milled by a Fitzpatrick Hammer mill (Serial No. 7438, Fitzpatrick Co., Elmhurst, IL) resulting in the mechanically-expelled soybean flour.

#### *Oil, Protein and Protein Dispersibility Index Content of Soybeans*

Oil, Protein and Protein Dispersibility Index of raw soybeans and partially defatted soybean flour were determined according to AOCS (1993) approved

methods oil Soxhlet extraction approved method 39.1.07, Ac 4-91 and Ba 10a-05 respectively. Factor of 6.25 was used to convert Kjeldahl nitrogen to protein.

#### *Nixtamalized Corn Flour (NCF)*

NCF, Tortilla Chip # 1 without additives (Minsa, Muleshoe, TX, USA), was used to prepare the tortilla chips.

### **Tortilla Chip Preparation**

#### *Preparation and Sheeting of Masa*

Masa was prepared by replacing nixtamalized corn flour (NCF) with 0, 10, 20 and 30% mechanically-expelled soy flour (MESF) to yield a total of 1000g. Then, the blend was mixed for 5 min at low speed with a paddle using a 20 qt mixer (Model A-200, Hobart, Troy, OH, USA). 0 and 10% MESF fortification were hydrated with 1100 g of distilled water, whereas 20 and 30% MESF fortification required 1175 g of distilled water. They were mixed with a hook for 30 seconds at low speed and 90 seconds at medium speed.

Masa was allowed to rest in a polyethylene bag and equilibrated for 10 min. After equilibration the masa was fed through a sheeter/former (Model CH4-STM, Superior Food Machinery, Inc., Pico Rivera, CA, USA) to form the tortillas. The weight of the raw tortillas was 30 g pieces to allow for machinability of the masa.



### *Baked Tortilla Chip Preparation*

Tortillas were baked in a gas-fired three-tier oven (Model C-0440, Superior Food Machinery, Pico Rivera, CA, USA) for a total of 65 seconds. Baking temperatures were: top tier 320°C, middle tier 280°C and bottom tier 250°C (bottom). Tortillas were cooled and stored in polyethylene bags for 10 min, then cut into round pieces ( $\frac{1}{2}$  in diameter) with a steel hollow cylinder.

The round pieces were placed on a round metal screen of an air impingement oven (Patent Smith Corp. Dallas, TX, Model No. 2) and then covered with a second metal screen. These two screens were fastened together with 3 metal clips to produce flat baked tortilla chips. Finally, baked tortilla chips were dried for 12 h at 60 °F in a forced air oven to reduce the moisture content to 2%.

### *Fried Tortilla Chip Preparation*

Tortillas for tortilla chip production were cut into round pieces ( $\frac{1}{2}$  in mm diameter) and then deep oil fried (Frymaster Products Model MJ-35, Shreveport, LA) at 180°C. To control color (minimize burnt pieces) and make sure that the chips were at the right moisture (<3% for optimal texture): the control chips were fried for 70 seconds. 10% MESF (Mechanically-expelled soy flour) substitution required 55 seconds, 20 and 30% MESF substitution required 50 seconds for frying in oil. Tortilla chips were drained, cooled, and stored in polyethylene bags.

## **Analytical Procedures**

### *Moisture*

Moisture of tortilla chips was evaluated the same day they were processed and the AACC method 44-15A, one-stage moisture oven was utilized (AACC 2000). The sample was dried in a forced air oven (model 16, Precision Scientific, Chicago, IL) for 24 hr at 130°C. Moisture was then calculated by weight lost.

### *Thickness*

Tortilla chip thickness was measured with a caliper in triplicate. Means were recorded. Ten tortilla chips were measured one-by-one.

### *Color*

The color of tortilla chips was evaluated by using a colorimeter (Model CR-310 Minolta Co., LTD. Ramsey, NJ). Ten whole tortilla chips that represented the color of the batch were selected from each sample, ground for one minute in a household coffee grinder and color was evaluated. Color was measured and recorded as average  $L^*$  = lightness (0=black, 100=white),  $a^*$  ( $-a^*$ =greenness,  $+a^*$ =redness) and  $b^*$  ( $-b^*$ =blueness,  $+b^*$ =yellowness) values.

### *Oil Content*

Oil content was determined by following AOAC Soxhlet extraction approved method 39.1.07. where finely ground material was placed in filter paper, and

petroleum ether was the solvent used during evaporation. Flasks were cooled in desiccator and then material was weighed.

### **Texture Evaluation of Tortilla Chips**

A texture analyzer (TA.XT2, Texture Technologies Corp., Scarsdale, NY/Stable Micro Systems, Godalming, Surrey, UK) was used to evaluate the texture of tortilla chips with a ball probe (0.25 in) and an 18 mm diameter hollow cylindrical base following Zelaya-Montes (2001) procedures. Peak force (N) and work required to break the tortilla chip (area under the force versus distance curve) was measured on 80 chips.

### **Breakage Susceptibility**

Breakage susceptibility of tortilla chips was evaluated using a tumbler technique (Quintero-Fuentes et al. 1999). Ten unbroken tortilla chips were weighed and placed inside rigid plastic bottles containing one 3.8-cm diameter rubber ball. Bottles were attached to a tumbler that rotated for 1 min at 37.4 rpm. The number and weight of all the different sizes of broken pieces (large= 100-95% of an unbroken chip, small pieces are 5-50% the size of an unbroken chip and fine pieces = less than 5% of an unbroken chip) were recorded.

### **Environmental Scanning Electron Microscopy (ESEM)**

Several tortilla chips from each treatment and from each of the different levels of fortification with mechanically-expelled soy flour were selected. They were observed using an environmental scanning electron microscope (Electroscan Model E-3, Electroscan Corp., Wilmington, MD) at an accelerating voltage of 20 KV, a condenser setting of 46, and a working distance of approximately 8 mm.

### **Sensory Evaluation**

Ninety untrained panelists were recruited from several classes at Texas A&M University. They were first screened for “nut” allergies to avoid any allergic reactions to soybeans. They evaluated a total of 8 tortilla chips (4 fried and 4 baked) for overall acceptability, overall flavor, intensity of flavor, overall texture, intensity of crunchiness and overall friability. In addition the ballot included 3 qualitative questions in regards to like/dislike of flavor and additional comments not previously discussed in the ballot. The products were rated using a nine-point hedonic scale where 9= like extremely, 5= neither like nor dislike, and 1= dislike extremely. Panelists evaluated the tortilla chips at the sensory analyses facility at TAMU in separate booths to minimize bias. Water was given to each panelist in between samples.

**Statistical Analysis**

The experiment consists of a 2 x 4 factorial design. Analyses were conducted using Proc Mixed in SAS (SAS Inc.). Least square means were calculated and the significance of pairwise differences between the means was adjusted using the Tukey-Kramer multiple comparison procedure at a confidence level of 95%."

## RESULTS AND DISCUSSION

### Production of Mechanically-Expelled Soy Flour

#### *Chemical Composition*

A picture of the two flours is shown in figure 1. The chemical composition of food grade Hartz soybeans and MESF is shown in figure 2. Protein content of MESF was increased significantly from 46% (d.b.) soybean vs. 47.9% (d.b.) MESF). Oil levels were reduced from 23.6% (d.b.) in the soybean to 8.9% (d.b.) in MESF. These results were expected since 62% of the oil was extracted. In previous research done at the Food Protein Research and Development Center at Texas A&M, oil levels of the soybean meal ranged from 7 to 9% (Riaz and Lusas 1995). This shows that the oil extraction in this research was adequate. Conditions used for oil extraction were also adequate.

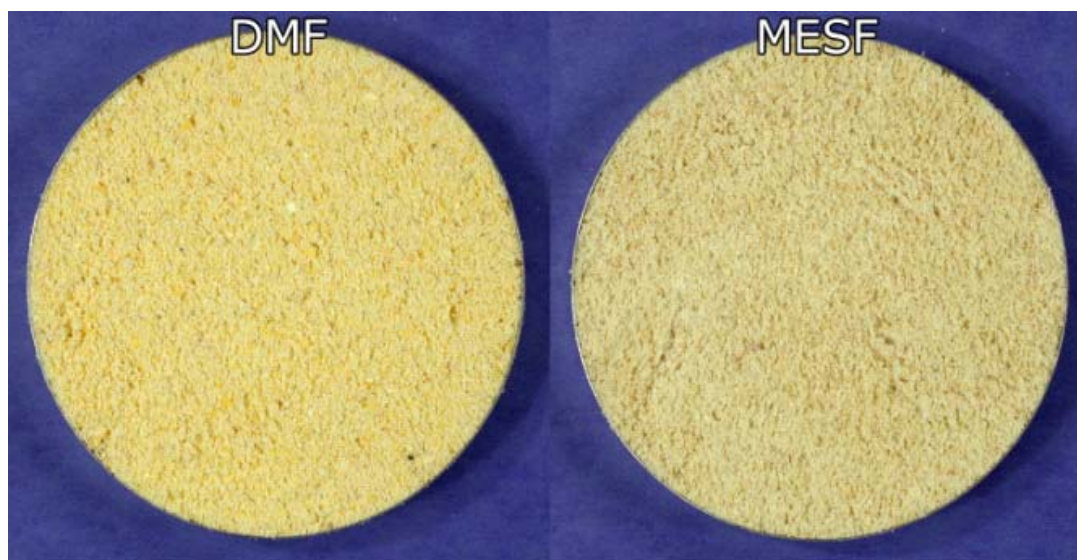
During this research, at about 96°C over 90% of LOX activity was inactivated by the extruder and the protein dispersibility index was of about 45 for the soybean protein (Riaz and Lusas 1995). In this case, the protein dispersibility index for the soybean protein decreased from 89.2-38. Untoasted flours with a PDI of 90% give an off-flavor in bread. Soy flours with 70% PDI (slightly toasted) generally have a cereal taste and does not affect flavor (Riaz 1999). Soy flours with a PDI of 20 have a slightly nutty flavor that may be suitable for bread. (Riaz

1999). Because the soy flour produced in this research study did not have an off-flavor, it was suitable to combine it with DMF to produce tortilla chips.

This process resulted in the disruption of cell tissues and release of oil within the extrudate (Riaz and Lusas 1995). The high temperature short time extrusion cooking treatment accomplishes other desirable functions like: reduction of microbial load, denaturation of proteins, destruction of antinutritional factors, and partial removal of moisture from the product (Riaz and Lusas 1995).

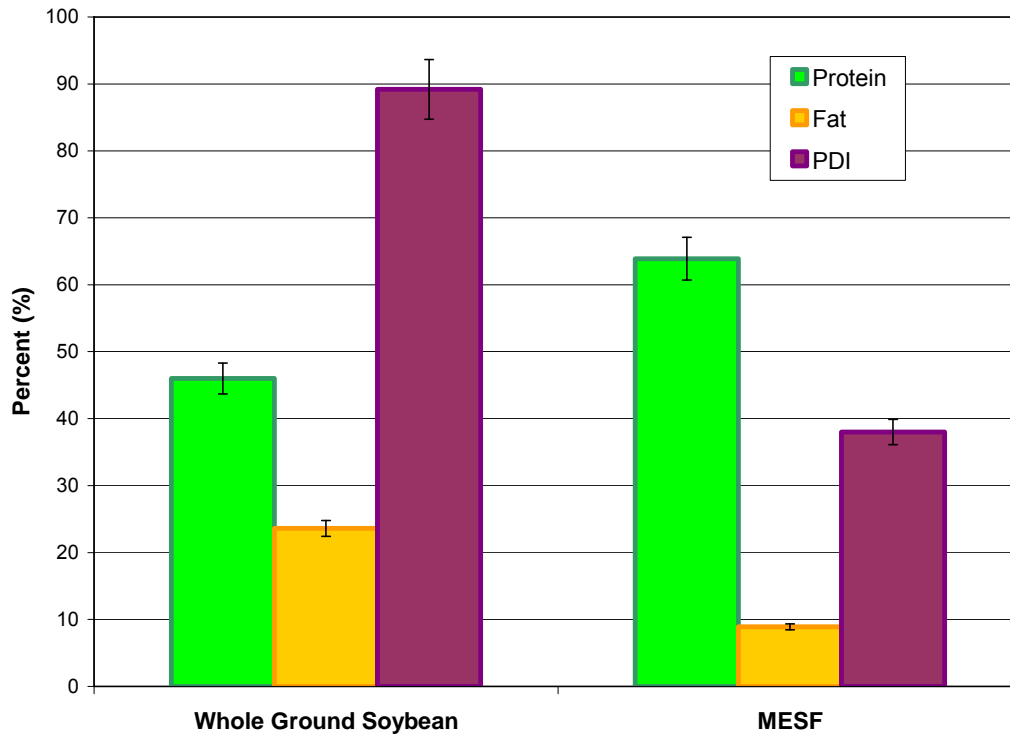
Adequate heat treatment is necessary to produce soybean into edible soy flour for human consumption. About 80% inactivation of the trypsin inhibitor activity is necessary for maximum nutritional value in the processed product (Wang et al. 2002). The extrusion following by screw pressing process results in inactivation of over 90% of the trypsin inhibitory activity. (Wang et al. 2002). Short cooking time in the extruder minimizes the damage to nutritional quality but at the same time inactivates the growth inhibitors (Mustakas et al. 1969).

Soy flour produced in this research could potentially be utilized for producing meat analogs as well.



**Figure 1.** Dry masa flour (DMF) and mechanically expelled soy flour (MESF).





**Figure 2.** Chemical composition of food-grade Hartz soybeans and mechanically expelled soy flour on a dry basis. Factor of 6.25 was used to convert Kjeldahl nitrogen to protein.

## **Moisture, Protein and Oil of Fried and Baked Tortilla Chips Fortified with Mechanically Expelled Soy Flour**

### *Fried Tortilla Chips*

**Moisture.** Moisture content of fried tortilla chip ranged from 1.8 to 2.2% (Table 1). A significant difference was found between the 30% MESF and the rest of the 3 treatments (0, 10 and 20% MESF). This was expected since tortillas' moisture was significantly different between treatment fortified with 30% MESF and the rest (0, 10 and 20% MESF). Fortification of 30% MESF required more water to hydrate in order to make machinable masa. Soy absorbs more water than corn masa flour and holds tightly to it because of a higher protein content. (Cosgrove, 2002) As soy flour increased, more water had to be removed during frying. In bread loaf preparation, the economic benefit of adding soy flour was obtained by adding more water to the dough than is typically possible and by a portion of the added water being held through baking (Porter, M.A. and Skarra, L.L 1999).

The final moisture content in the fried chip must be less than 2% to ensure a crisp texture (McDonough et al 2001). Higher moisture contents result in tough, chewy texture. Moisture of tortilla chips with and with out mechanically expelled soy flour was in 2% range, which indicates that the adjustments made for each of the frying treatments as described previously were adequate.

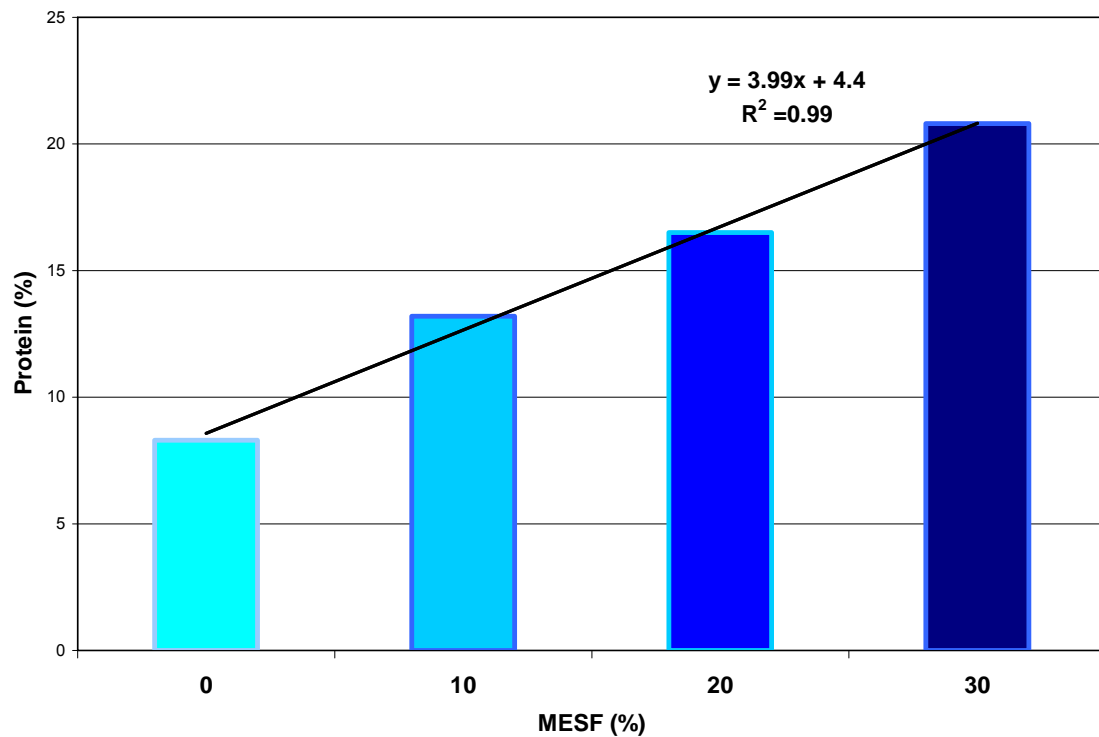
**Table 1.** Moisture (%), protein (%) and oil (%) of fried tortilla chips and moisture (%) of tortilla. Values are means of 3 replicates in duplicates on a dry basis. Columns followed by the same letter are not significantly different ( $\alpha = 0.05$ ). For the acronym, the number indicates the percentage of MESF added. T.C. = Tortilla Chip. Ctrl = Control. MESF= mechanically expelled soy flour. Factor of 6.25 was used to convert Kjeldahl nitrogen to protein.

Treatment	Tortilla Moisture	Tortilla Chip Moisture	Tortilla Chip Protein	Tortilla Chip Oil
Ctrl	47.7 ± 1.53 b	1.96 ± 0.11 b	8.3 ± 0.26 d	21.4 ± 0.33 c
10	47.5 ± 1.47 b	1.84 ± 0.12 b	13.2 ± 0.15 c	21.7 ± 0.27 c
20	49.8 ± 1.25 b	1.98 ± 0.10 b	16.5 ± 0.27 b	22.4 ± 0.32 b
30	54.5 ± 1.12 a	2.21 ± 0.11 a	20.8 ± 0.12 a	25.9 ± 0.25 a

**Protein.** Protein for fried tortilla chips increased linearly as MESF levels increased. (Table 2). There are significant differences among each of the treatments. 30% MESF fortification gave the highest protein level, followed by 20%, 10% and the control MESF. Similar results were found when Che man et al. (1992) fortified rice-cake snacks with full fat soy flour at 4.5, 8, 9.0 and 13.5%. Protein content increased from 9.5 to 15.44%. Payumo et al. (1982) showed that 35% soy-supplemented snack food (rice-soy extruded curls) had approximately 2¼ times more protein than the commercial sample. Adalakun et al. (2004) also reported protein content of kokoro (a finger-shaped corn snack)

increased with increasing levels of full fat soy flour. Figure 3 shows a strong linear correlation between the MESF% added and protein levels in fried tortilla chips. ( $R^2 = 0.99$ ).

**Oil.** Oil content of fried tortilla chips ranged from 21.4 to 25.9 (d.b.). (Table 2). Significant differences were found among all treatments except between 0 and 10% MESF. 30% MESF fortification had the highest level of oil, followed by 20%, then by 10 and 0% MESF. No significant differences were found between 0 and 10% MESF fortification. This was expected as soy fortification was achieved by using a soy flour that had 8.9% oil (d.b) from the beginning. Similar results were seen by Adalakun et al. (2004) by fortifying a fried corn snack with full fat soy flour. They attributed the higher oil content in their snacks, to higher oil content in soybeans than in corn. Another reason for this effect is that moisture was higher for chips that were fortified with 30% MESF. Generally, the higher the moisture content of the material to be fried, the higher the oil uptake (Serna-Saldivar et al. 1990). During the frying process, the water is evaporated and the oil enters the tortilla chip through the air tunnels, the higher the moisture, the higher the final oil content.



**Figure 3.** Correlation between MESF percentage added and protein levels in fried tortilla chips. MESF= mechanically expelled soy flour. Factor of 6.25 was used to convert Kjeldahl nitrogen to protein.

**Table 2.** Moisture (%), protein (%) and oil (%) of baked tortilla chips. Values are means of 3 replicates in duplicates on a dry basis. Columns followed by the same letter are not significantly different ( $\alpha= 0.05$ ). For the acronym, the number indicates the percentage of MESF added. B indicates baking processing. Ctrl = Control. Factor of 6.25 was used to convert Kjeldahl nitrogen to protein.

<b>Treatment</b>	<b>Moisture</b>	<b>Protein</b>	<b>Oil</b>
Ctrl B	1.95 ± 0.05	8.5 ± 0.12 d	3.1 ± 0.17
B10	1.92 ± 0.03	14.2 ± 0.19 c	3.3 ± 0.15
B20	1.90 ± 0.01	16.1 ± 0.17 b	3.4 ± 0.18
B30	2.03 ± 0.07	22.1 ± 0.15a	3.2 ± 0.11

There is a linear relationship between oil levels and MESF%. ( $R^2 = 0.94$ , figure 4). As MESF fortification increased, oil levels increased in the fried tortilla chips.

Figure 5 shows that as moisture increases, oil levels in fried tortilla chips also increase.

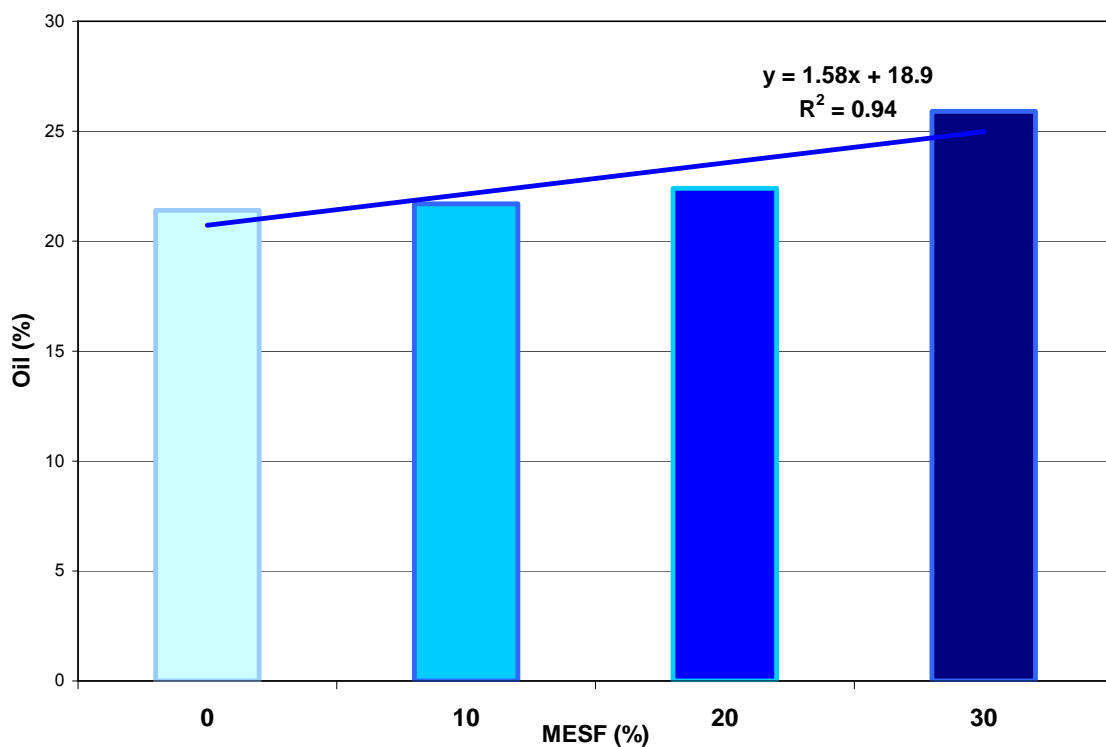
Figure 6 shows a linear relationship between oil levels and protein levels in fried tortilla chips where  $R^2 = 0.77$ . This indicates that as protein levels were increased in fried tortilla chips, oil levels also increased. This result is expected since the soy flour that was used in this experiment had 8.9% oil (d.b.).

Doughnuts containing soy protein absorb less fat during frying because the fat is prevented from penetrating into the interior (Endres 2001). This may be due to heat denaturation of the protein on the doughnut surface, which produces a barrier to fat absorption. (Endres, 2001)

Because the flour that was used in this experiment had initial levels of 8.9% oil, fried tortilla chips with higher MESF% levels (20 and 30%), did not have lower oil percentage levels than control or 10% MESF. However, it is important to notice that final oil content increased by 0.4, 3 and 4.4% when tortilla chips were fortified with 10, 20 and 30% MESF when compared to control.

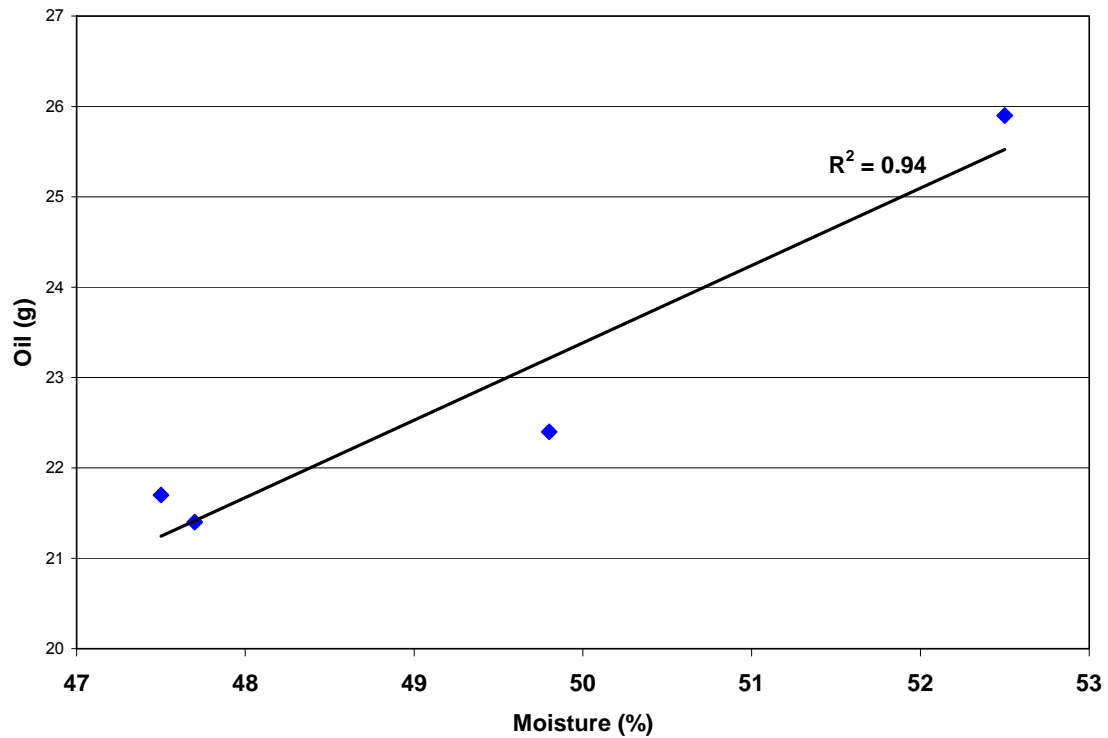
Highest level of fortification (30% MESF) provides 3.1 g/soy protein and 6.6 g/ oil per reference amount customarily consumed (RACC) (28 g/ tortilla chip serving).

An advantage of fried tortilla chips fortified with MESF is that the consumer would have more options for obtaining the recommended soy protein level/day. It would be another choice with a healthy halo to the consumer. This should also lead to more shoppers selecting organic and/or natural food.

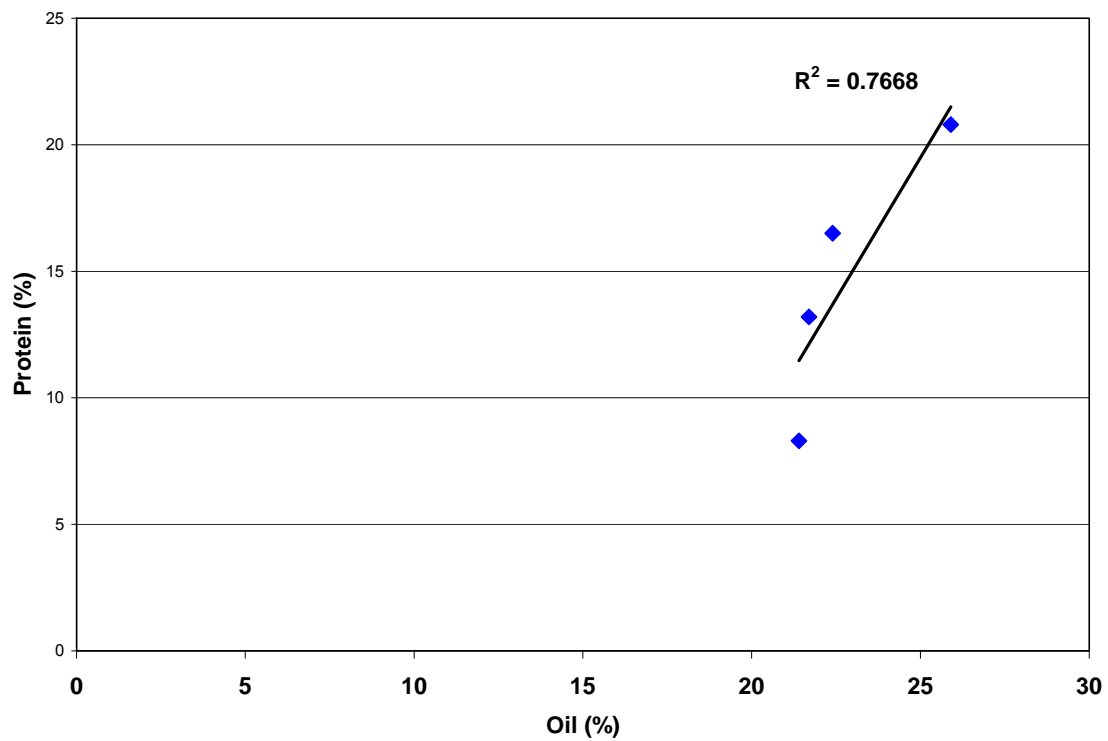


**Figure 4.** Correlation between MESF percentage added and oil levels in fried tortilla chips. MESF= mechanically expelled soy flour.





**Figure 5.** Correlation between moisture and oil levels in fried tortilla chips containing 0, 10, 20 and 30% MESF.



**Figure 6.** Correlation between oil and protein levels in fried tortilla chips containing 0, 10, 20 and 30% MESF. Factor of 6.25 was used to convert Kjeldahl nitrogen to protein.

### *Baked Tortilla Chips*

**Moisture.** Baked tortilla chips moisture ranged from 1.90-2.03% (Table 2). No significant differences were found among treatments. Drying the chips after they had been baked by the impingement oven was necessary for all treatments to obtain moisture under 3%. Tortilla chips made with specialty starches had to be dried after baking as well (Quintero-Fuentes 1997).

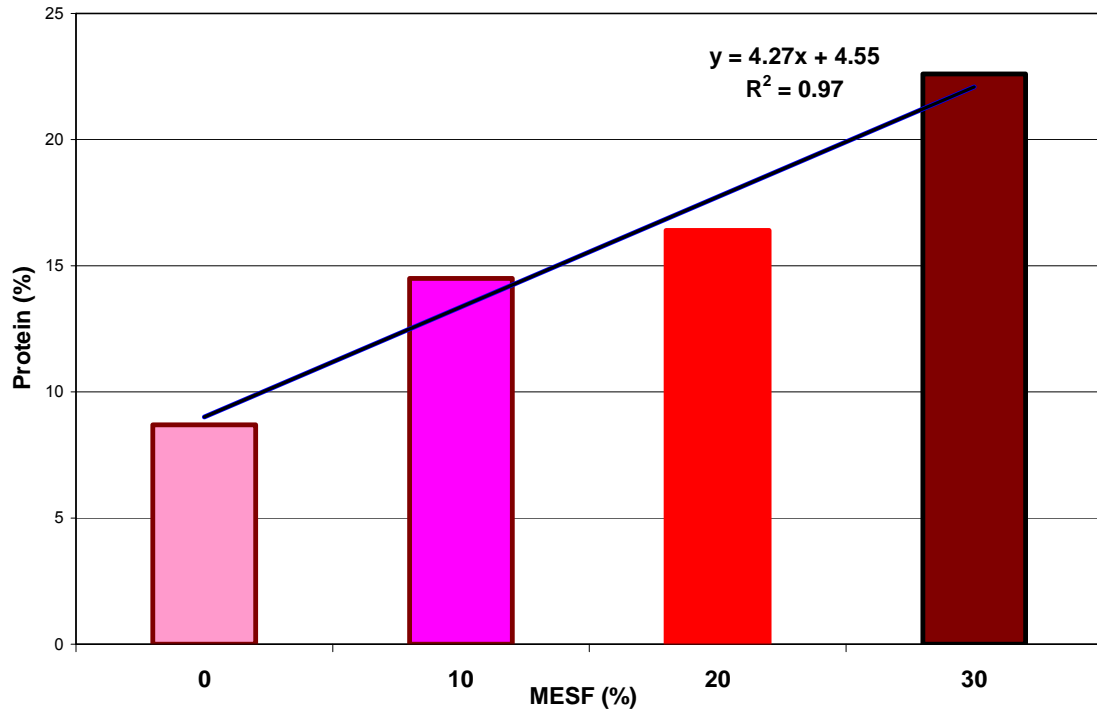
**Protein.** Protein for baked tortilla chips increased linearly as MESF levels increased. (Table 2). There are significant differences among each of the treatments. 30% MESF fortification had the highest protein level, followed by 20%, then 10% and finally 0% MESF. Figure 7 shows a strong linear relationship between MESF added and protein levels in baked tortilla chips. ( $R^2 = 0.97$ ). As soy fortification increased in baked tortilla chips, protein levels increased.

**Oil.** Tortilla chip oil content for baked tortilla chips ranged from 3.1 to 3.4 (d.b.) (Table 2). There were no significant differences found among treatments.

This is contradictory since the soy flour used for fortification had an initial oil level of 8.9%. This could mean that a higher number of observations with more replications are needed to account for variability and human error.

Another possibility could be that because the fat level in baked tortilla chips is lower than the fat level in fried tortilla chips, the Soxhlet method might not be the adequate method to measure oil. Estimated oil values for 10% MESF would be 3.86%, for 20% MESF would be 4.42% and for 30% MESF would be 4.98% oil on a dry basis.

Fortification with 30% MESF provides 3.9 g/soy protein and 0.9 g/ oil per RACC (28 g/serving tortilla chips). Baked tortilla chips at 30% MESF fortification offer a good alternative for consumers to increase their soy protein intake without excessive oil ingestion.



**Figure 7.** The MESF added and protein levels in baked tortilla chips. MESF= mechanically expelled soy flour. Factor of 6.25 was used to convert Kjeldahl nitrogen to protein.

## **Sensory Evaluation of Fried and Baked Tortilla Chips**

### *Consumer Panel and Sensory Ballot*

90 untrained panelists, 70% female and 30% male, aged 18-28 years old, participated in the consumer test. The panelists were recruited from several Agricultural classes at Texas A&M University. They were screened for allergies to “nuts” and they were explained the sensory procedure as described previously.

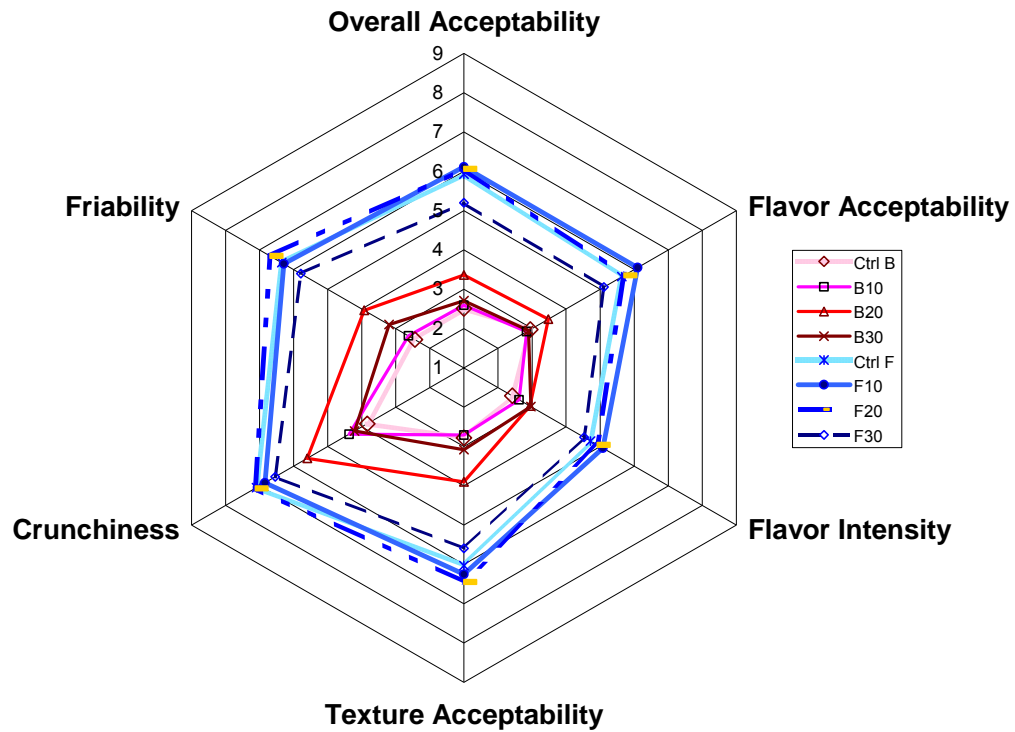
Panelists were given the definitions of crunchiness and friability to minimize judgment variability. Crunchiness was defined as when the product fractures after applying more force to break the sample than normal. Friability was defined as the ease in which a product breaks apart in the mouth. Chips with greater friability break apart into many small pieces in the mouth. In order to evaluate all attributes in the ballot, panelists were instructed to place the tortilla chip between their molar teeth and bite down evenly until the food crumbled, cracked or shattered.

A nine-point hedonic scale was chosen to measure product liking and preference. The nine-point hedonic scale is probably the most useful sensory method (Jones et al 1955). Since its development (Peryam and Haynes 1957) it has been used extensively with considerable success. Another advantage to this scale is that it is easily understood by consumers with minimal instruction.

Even though this kind of scale is great at telling us likes/dislikes of products, its disadvantage is that it can not tell us why. To overcome this shortcoming, qualitative questions were included in the ballot. Because there were many similar or identical comments from the panelists to the qualitative questions in the ballot, these qualitative comments were plotted in graphs.

A sample ballot can be seen in Appendix A.

To minimize bias, samples were given to panelists in a randomized order and panelists were not allowed to talk to one another since they were separated by booths. To ensure that there was no flavor carry-over from sample to sample, panelists were instructed to take a sip of water in between samples. The results from this sensory test can be regarded as very reliable because of the large population sample and the measures that were taken to reduce bias and variability in the test.



**Figure 8.** Sensory attributes of fried and baked tortilla chips. Values are means of 90 observations each. A nine point hedonic scale was used where 9 = like extremely, 5 = neither dislike/like and 1 = dislike extremely. For the acronym, the number indicates the percentage of MESF added. F indicates frying processing. B indicates baking processing. Ctrl = Control.



Figure 8 shows a comparison of the sensory attributes of fried and baked tortilla chips. Fried tortilla chips scored higher than baked tortilla chips for all attributes. This indicates that fried tortilla chips were preferred over baked tortilla chips for all attributes.

Figure 8 also shows that within the baked tortilla chips, 20% MESF fortification had higher scores than the rest of the treatments.

For overall acceptability, flavor acceptability, texture acceptability, crunchiness intensity, and friability there exists an interaction between processing effect and MESF% levels, where the main effect is driven by the processing method more than the MESF% level. For flavor intensity, there was not an interaction but the biggest effect was seen on processing method. This indicates that soy fortification behaved the same whether it was fried or baked.

#### *Fried Tortilla Chips*

**Quantitative data.** For overall acceptability, there were no differences found among treatments fortified with 0-20% MESF and 0 and 30%. The only significant differences were found between 10 and 30% MESF and 20 and 30% MESF. 10 and 20% MESF were the most acceptable treatments of all. Adekun et. al. (2005) suggested that partial substitution of corn flour with

soybean flour up to a level of 30% may be satisfactory in the making of kokoro, while the one with 10% soy flour substitution was preferred.

For flavor acceptability, there were no differences found among 0-20% MESF and 0, 20 and 30% MESF. The only difference was found between 10 and 30% where 10% MESF flavor was the more acceptable than 30% MESF. Payumo et al. (1982) found that 35% soy fortified rice curls were very acceptable among adults.

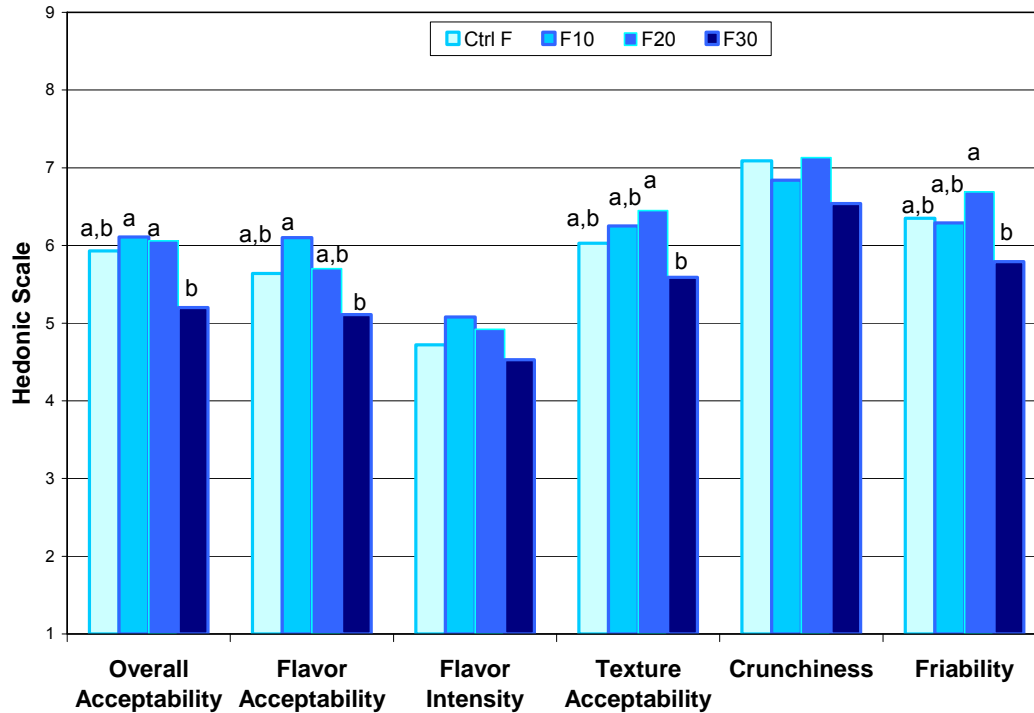
There were no differences found in flavor intensity among treatments. Also, this attribute obtained the lowest scores in the hedonic scale when compared to the other attributes. This indicates that no beany flavors were found when tortilla chips were fortified with soy flour. The LOX enzyme was deactivated successfully by the process of dry extrusion followed by pressing. In cookies, Buck et al. (1987) found that 20% of soy fortification was less strong than 20% corn gluten meal/20% soy cookies.

For texture acceptability no differences were found among treatments fortified with 0-20% MESF and 0,10 and 30%. The only significant difference was found between 20 and 30% MESF.

There were no differences among treatments in crunchiness. Of all the attributes measured in the ballot, crunchiness attribute got the highest scores of all.

For friability, the only significant differences were found between 20 and 30% MESF. 0-20% MESF and 0,10 and 30% MESF were not significantly different from one another. 20% MESF was more friable than 30% MESF.

Results can be seen in figure 9.



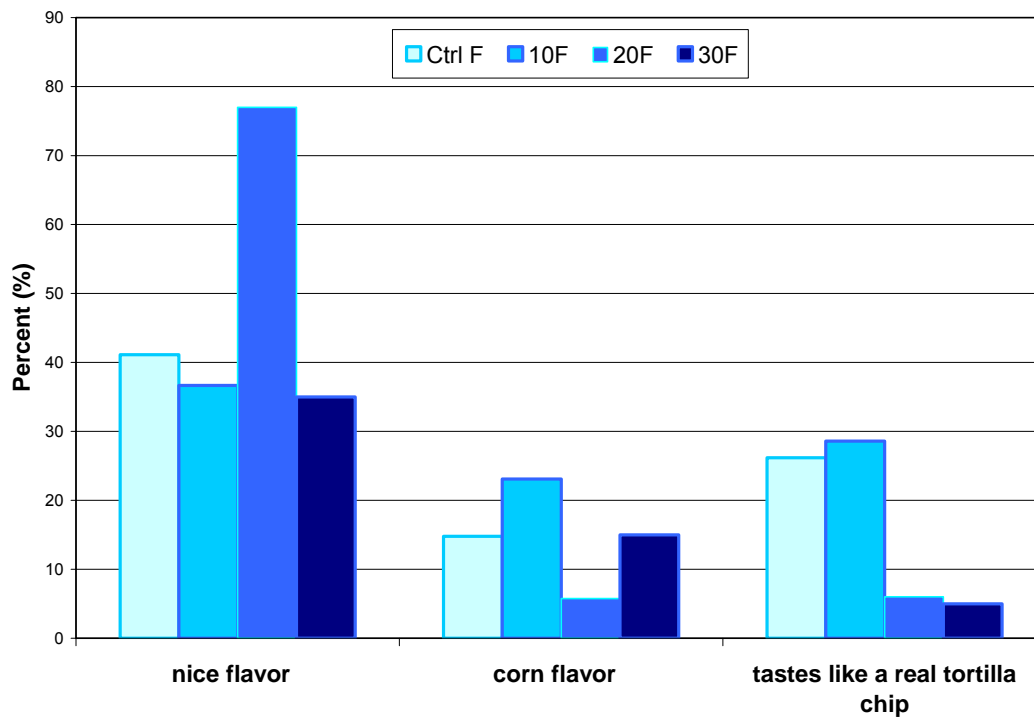
**Figure 9.** Sensory attributes of fried tortilla chips. Values are means of 90 observations each. Columns followed by the same letter are not significantly different ( $\alpha = 0.05$ ). A nine point hedonic scale was used where 9 = like extremely, 5 = neither dislike/like and 1 = dislike extremely. For the acronym, the number indicates the percentage of MESF added. F indicates frying processing. Ctrl = Control.

**Qualitative data.** Panelists responded to “what did you like about the flavor of this sample?” in the following way: 77% responded “nice flavor” for the 20% MESF fortification treatment. It was followed by control with 41%, 10% MESF with 36% and finally by 30% MESF with 35%. Another answer for this question was “corn flavor” where 23% of the panelists said they liked the corn flavor for the 10% MESF, followed by 15% for 0 and 30% MESF and 5.7% for 20% MESF. These answers guide us to conclude that panelists preferred the 20% MESF fortification treatment but not due to its corn flavor. What is more interesting is that another answer for this question was “tastes like a real tortilla chip” and only 6% agreed with this comment for the 20% MESF. For this answer, 28% said that the 10%MESF level tasted like a real tortilla chip, followed by the control with 26% and 5% for 30% MESF. 20% MESF fortification level was liked the most by panelists, not for its corn flavor but for another type of flavor. Some panelists even commented on a “nut tasting” type of flavor . Results can be seen in figure 10.

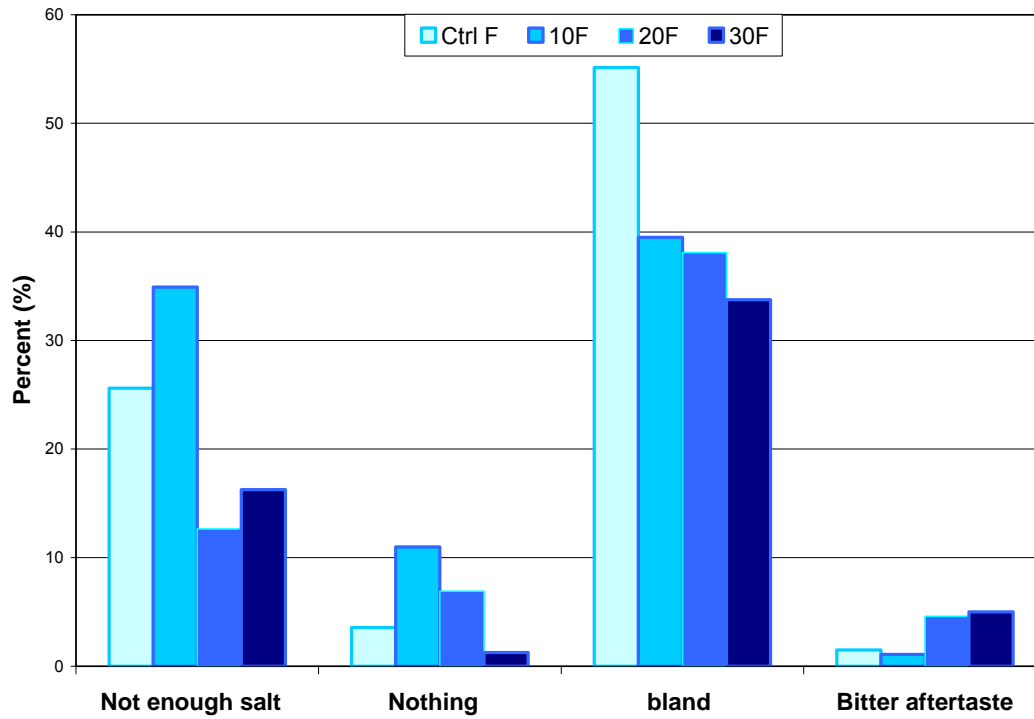
To get more information about the disliking of the flavor of each tortilla chip, panelists were asked “what did you dislike about the flavor of this sample?” Responses included “not enough salt”. This was not surprising since in order to get the true responses and not mask any off-flavors (if any) salt was not added to any of the samples. Interestingly, according to panelists, the sample that needed the less salt was 20% MESF while the one that needed most salt was

the sample with 10% MESF. 11% of the panelists said that there was nothing to dislike for the 10% MESF followed by 20% MESF with 6.5%. The sample that was the blandest was the control treatment followed by 20, 10 and 30% MESF. For bitter aftertaste, 30% MESF was the highest with 5% of the panelists responding like this. It was followed by 20% with 4.6% then by control and 10% MESF. Soy can also have a bitter after taste due to a large number of compounds like alcohols, aldehydes, ketones, furans, phenols and phosphatides. (Liu, 1999). This also proves that the dry extrusion processing followed by mechanical pressing was successful at getting rid of off-flavors and bitterness. Results can be seen in figure 11

To get more information that was not asked directly in the ballot, additional comments concerning the eating qualities of the samples were asked. Answers included good texture, too hard and too thick. For good texture, 24% of panelists chose 20% MESF followed by 10% with 17%, control with 16% and 30% with 9%. This was expected because from the quantitative data for the texture acceptability, 0-20% got the highest scores with 20% MESF being the highest, followed by 30% MESF. For "too hard", 30% was perceived as the hardest with 15%, followed by control with 10%, 10% with 3.3% and finally by 20% with 1%. An answer of "too hard" was expected because of the high scores for crunchiness in the quantitative data. About 3% of the panelists said that all samples were too thick. Results can be seen in figure 12.

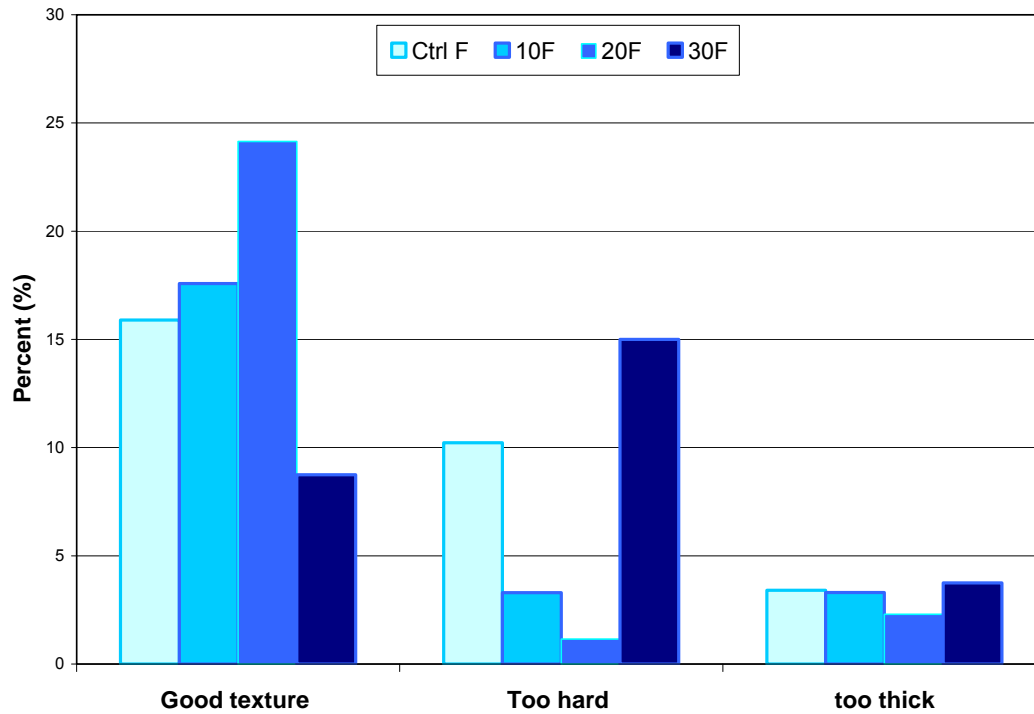


**Figure 10.** Sensory qualitative comments regarding flavor liking of fried tortilla chips. Values are averages of 90 ballots shown in percent. For the acronym, the number indicates the percentage of MESF added. F indicates frying processing. Ctrl = Control.



**Figure 11.** Sensory qualitative comments regarding flavor disliking of fried tortilla chips. Values are averages of 90 ballots shown in percent. For the acronym, the number indicates the percentage of MESF added. F indicates frying processing. Ctrl = Control.





**Figure 12.** Sensory qualitative comments regarding appearance and texture of fried tortilla chips. Values are averages of 90 ballots shown in percent. For the acronym, the number indicates the percentage of MESF added. F indicates frying processing. Ctrl = Control.

### *Baked Tortilla Chips*

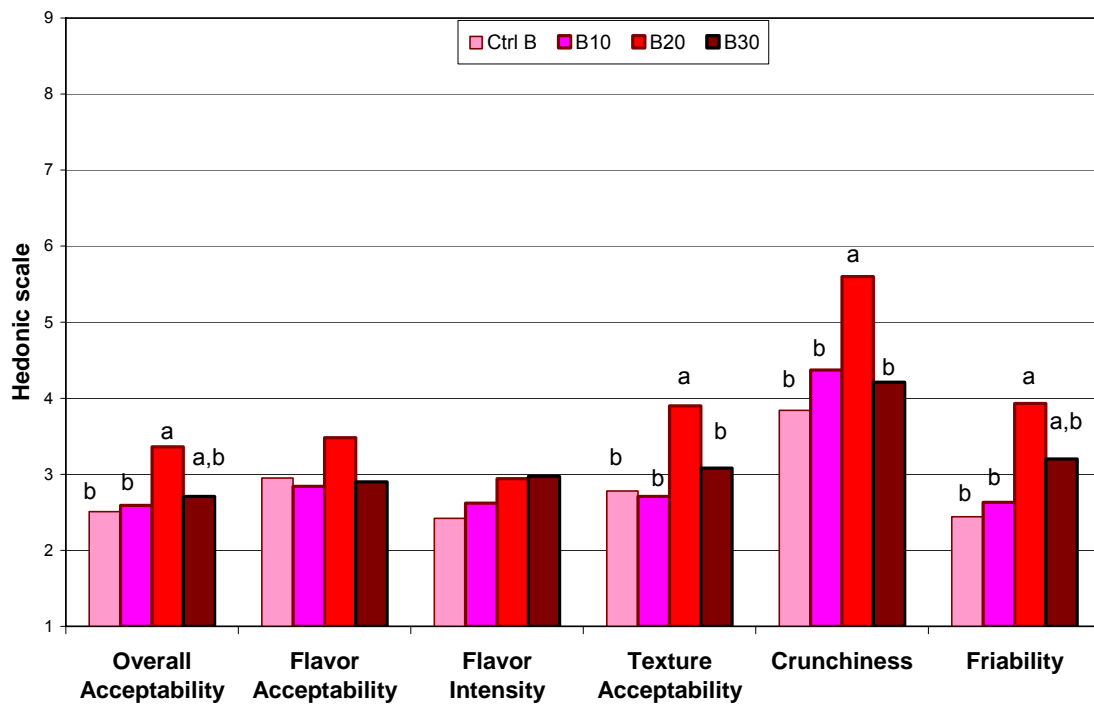
**Quantitative data.** Quantitative data included the following attributes: overall acceptability, flavor acceptability, flavor intensity, texture acceptability, crunchiness and friability.

For overall acceptability, 20 and 30% MESF scored the highest. Control and 10% MESF were the least acceptable among panelists. However, because the highest score was 3.36, this indicates that these chips were not acceptable by consumers.

There were no differences found among treatments for flavor acceptability (highest score = 3.48) and flavor intensity (highest score = 2.97). Based on these scores, these chips were not liked by consumers.

For texture acceptability and crunchiness, 20% MESF had the highest scores and was significantly different from the other treatments. There were no differences found among control, 10 and 30% MESF.

For friability, significant differences were found when 20% is compared with 0 and 10% MESF. There were no differences found between 20 and 30% MESF, where 20% had the highest score of 3.93 which indicates that overall, these chips were not friable. These results are reflected in figure 13.



**Figure 13.** Sensory attributes of baked tortilla chips. Values are means of 90 observations each. Columns followed by the same letter are not significantly different ( $\alpha = 0.05$ ). A nine point hedonic scale was used where 9 = like extremely, 5 = neither dislike/like and 1 = dislike extremely. For the acronym, the number indicates the percentage of MESF added. B indicates baking processing. Ctrl = Control.

**Qualitative data.** For baked tortilla chips, 14% of the panelists indicated they liked the corn flavor the best for the control chip. 10-30% MESF were liked the same with an average of 8% of panelists indicating this result. However, 44% of panelists indicated they did not like the control chip, followed by 30% with 33%, 10% with 23% and 20% MESF with 17%. These results were not surprising since the scores from the hedonic scale were low for all sensory attributes in the ballot. Only 10% of the panelists mentioned that the treatment with 20% MESF tasted like a real tortilla chip; 7.5% of the panelists thought that the control tasted like a real tortilla chip and less than 1% of panelists thought that tortilla chips fortified with 30% MESF tasted like real tortilla chips. 16% of panelists indicated that the sample with 10% MESF had a nice flavor, followed by 20, 10 and 30% MESF respectively. These results can be seen in figure 14.

When panelists were asked what they disliked about the flavor of the chips, 55% said the control was bland, followed by 30, 20 and 10% MESF with an average of 47%. These results were not surprising since no salt was provided to the panelists to obtain “true flavors” and avoid flavor masking. Panelists also commented that there was no salt with the chips and that samples needed salt. Salt was omitted on purpose in this study.

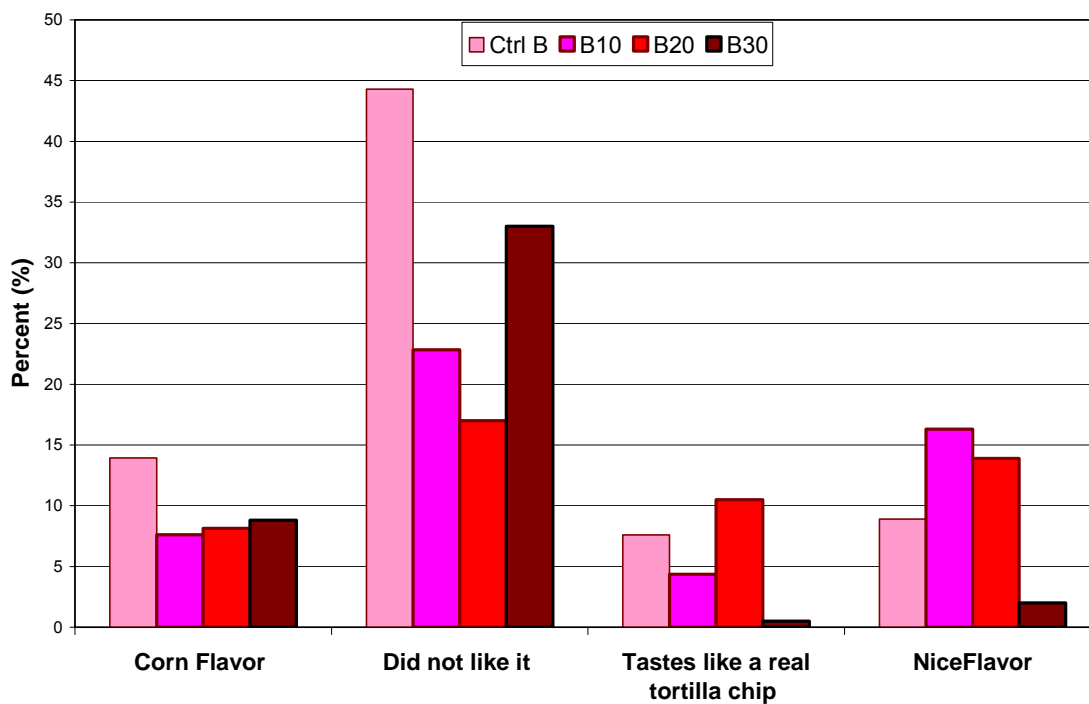
44% of the panelists said control treatment was stale, followed by 10% MESF with 38%, 30% and 20% MESF with an average of 18%. The baking process

and the omission of salt could have played a role in this response from the panelists. From these results, soy fortification may play a role in decreasing stale perception in panelists. Further research is needed to prove this statement.

32% of panelists perceived a burnt taste for the 30% MESF treatment. This was not seen for the other treatments where an average 5% of panelists indicated a burnt taste.

Aftertaste was another response from panelists (Figure 15). Aftertaste seemed to increase as MESF% fortification increased. However, aftertaste percentage was low with the highest being 14.3% for the 30% MESF. Because no focus groups were conducted, no conclusion can be made in regards to the nature of this aftertaste. These results can be seen in figure 15.

Additional comments included tough, hard and too thick. More than 40% of panelists considered the control sample as tough, followed by 10, 30% MESF with an average of 20%, where 20% was perceived as the least tough with 10% of panelists indicating this.

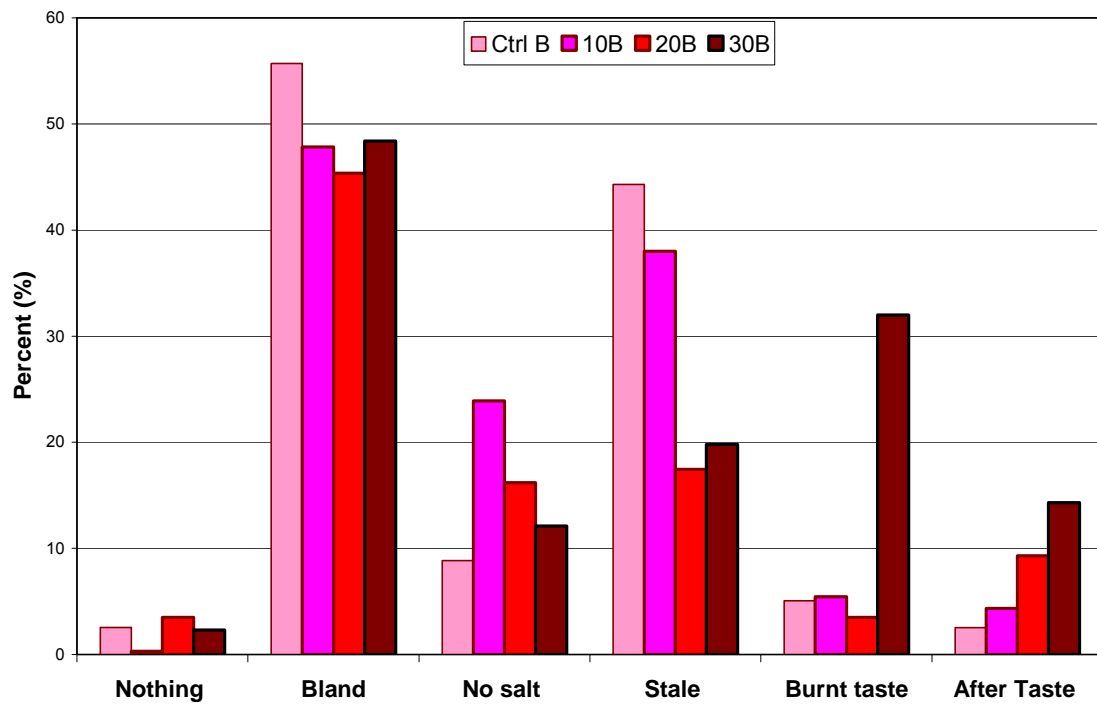


**Figure 14.** Sensory qualitative comments regarding flavor liking of baked tortilla chips. Values are averages of 90 ballots shown in percent. For the acronym, the number indicates the percentage of MESF added. B indicates baking processing. Ctrl = Control.

This is not surprising since stale comments were also included when panelists were asked about what they disliked about the flavor and they also follow the same pattern as the tough comments. (Figure 16)

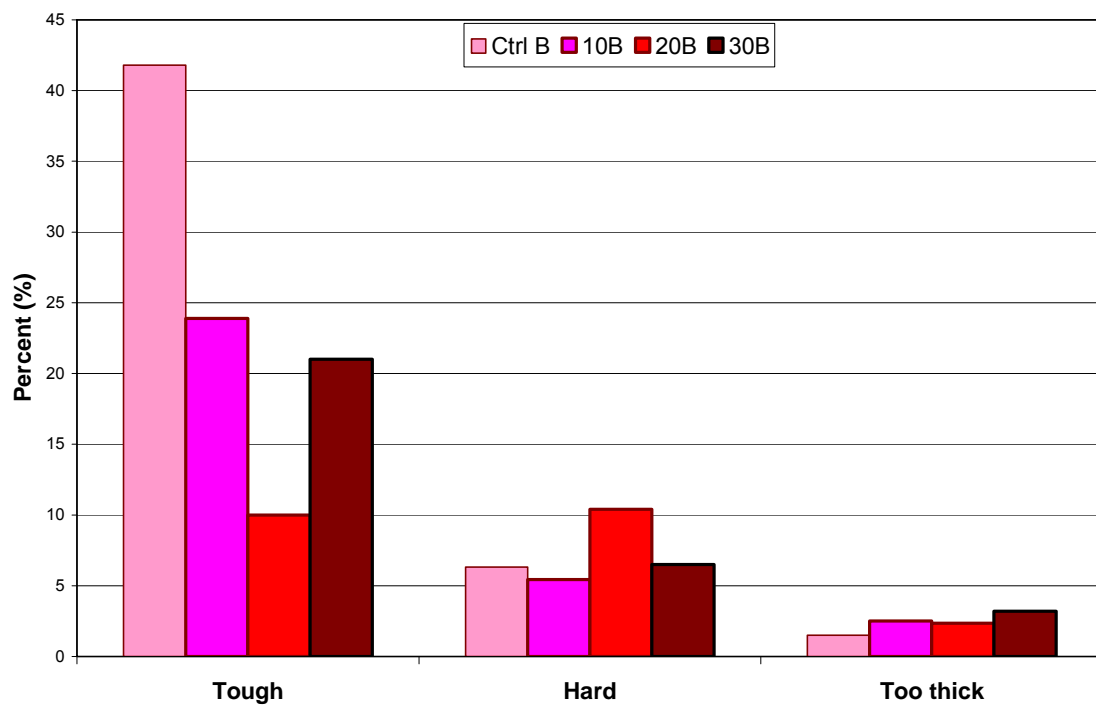
10% of panelists thought the 20% MESF sample was the hardest, equally followed by the rest of the samples with an average of 5%. Because this is a low percent of panelists indicating this attribute, baked tortilla chips are not considered as being hard in this study.

Only 1.5-3.2% of panelists perceived these samples to be thick which are a little bit lower percentages when compared to the fried chips.



**Figure 15.** Sensory qualitative comments regarding flavor disliking of baked tortilla chips. Values are averages of 90 ballots shown in percent. For the acronym, the number indicates the percentage of MESF added. B indicates baking processing. Ctrl = Control.





**Figure 16.** Sensory qualitative comments regarding appearance and texture of baked tortilla chips. Values are averages of 90 ballots shown in percent. For the acronym, the number indicates the percentage of MESF added. B indicates baking processing. Ctrl = Control.

## **Properties of Fried and Baked Tortilla Chips**

### *Thickness*

Figure 17 shows fried tortilla chips were thicker than baked tortilla chips. This result is not surprising because fried tortilla chips had blisters whereas baked tortilla chips did not. Baked tortilla chips were flat. There was not an interaction between MESF fortification and processing method. The processing method was the factor that drove these differences. This means that the addition of MESF in tortilla chips did not affect thickness, unlike what was observed with frying and baking.

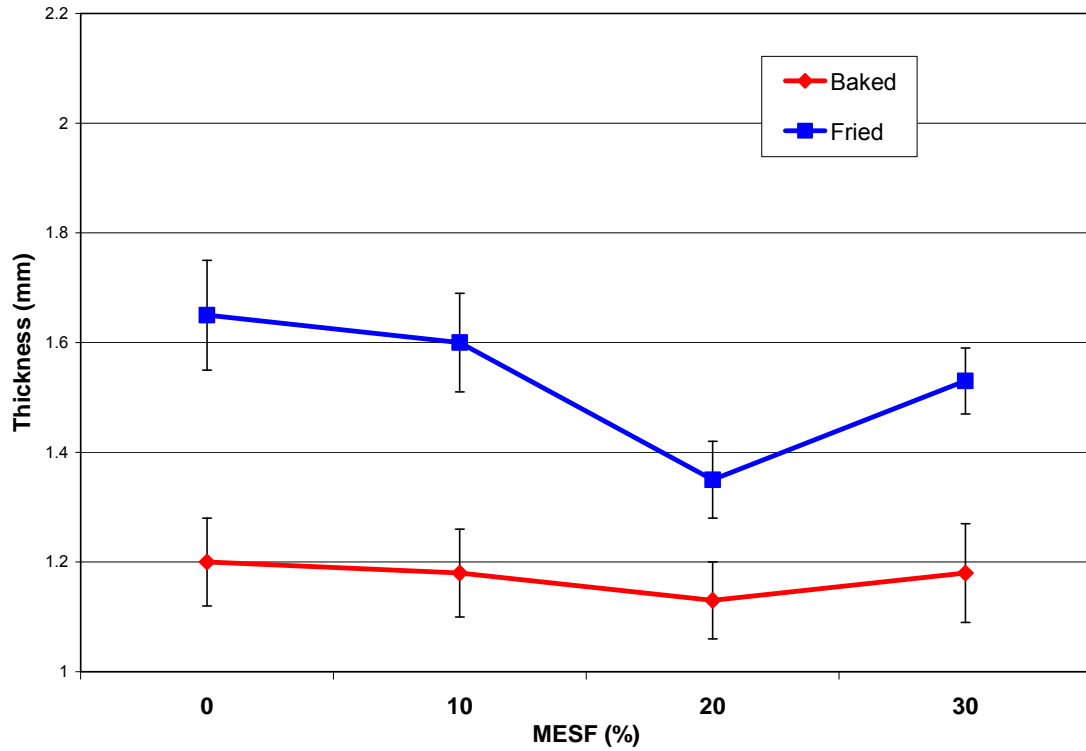
### *Fried Tortilla Chips*

There were no significant differences among control, 10 and 30% MESF treatments. Figure 18 shows 20% MESF was the least thick of all treatments. Because frying was the most significant factor for the difference between baked and fried chips, this difference is not due to the amount of MESF that was added to chips. It is important to mention that tortilla chips were fried for different amounts of time. Control was fried for 1 min and 10 seconds, 10% MESF was fried for 55 seconds, and 20 and 30% MESF tortilla chips were fried for 50 seconds. The frying adjustments were made to prevent burnt and overcooked chips. Tortilla chips require a coarse particle size and low moisture content in the formulation to promote crispness in chips after frying. The small particle size

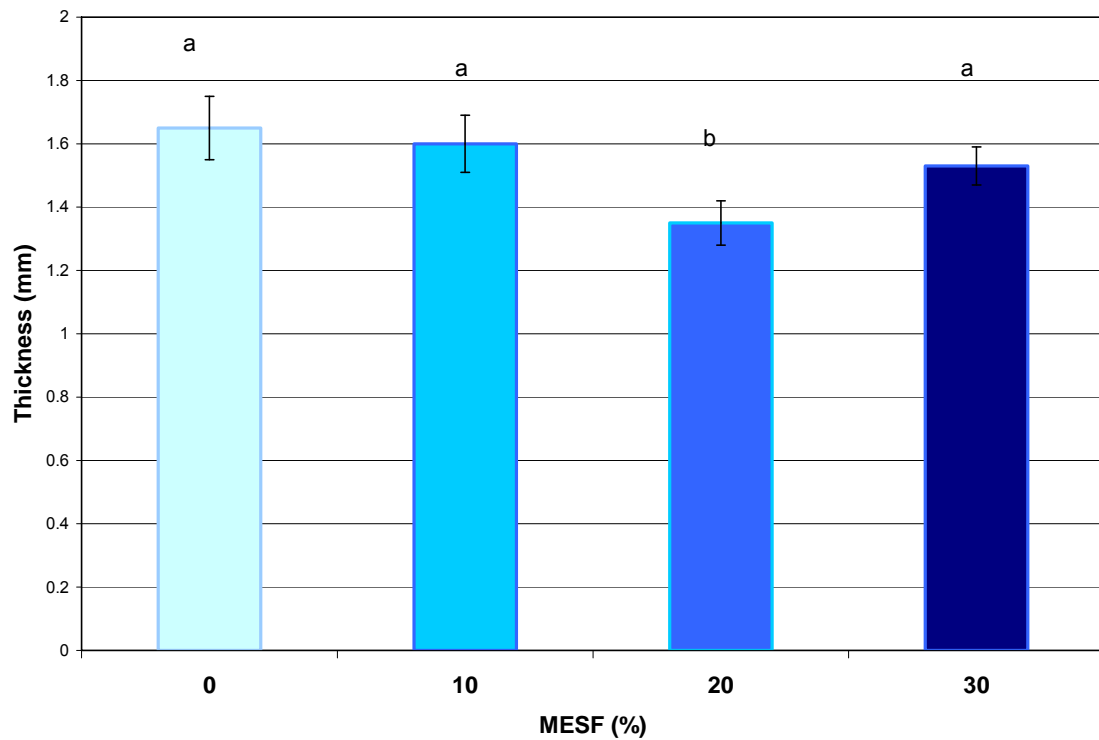
will absorb more water and will produce cohesiveness, plasticity, smoothness and a homogenous film will be formed. This film will entrap steam during frying and will cause the expansion that forms pillows or blisters. On the other hand, the large particles disrupt the dough network, reduce blistering, reduce oil uptake and will produce crispness in tortilla chips. In this study, a coarse masa flour was used to produce the tortilla chips. Minimal blisters or pillows were seen when tortilla chips were fried, however they were not as flat as baked tortilla chips.

#### *Baked Tortilla Chips*

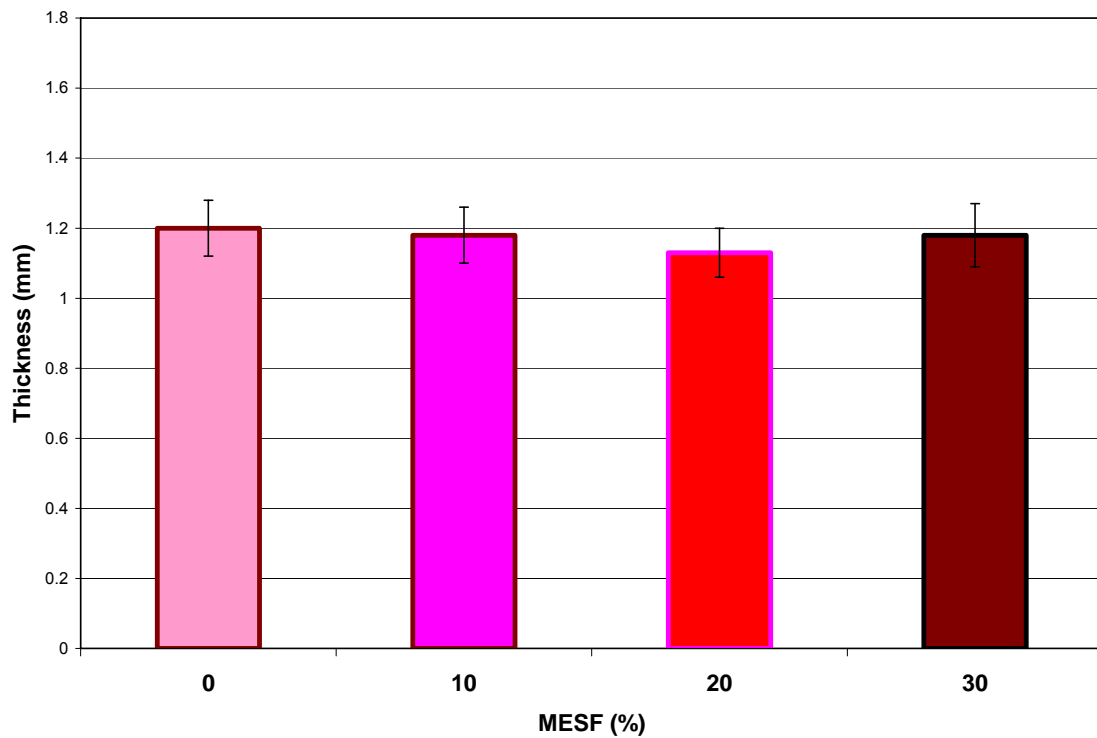
No significant differences were found among treatments as seen in figure 19. This was expected since these chips were flat and there was no cause for variation since the fortification of MESF did not have an effect on thickness.



**Figure 17.** Thickness comparison of fried and baked tortilla chips containing 0, 10, 20 and 30% of MESF. Values are means 3 replications, 10 observations each. MESF = mechanically expelled soy flour.



**Figure 18.** Thickness of fried tortilla chips containing 0, 10, 20 and 30% of MESF. Values are means of 3 replications, 10 observations each. Columns followed by the same letter are not significantly different ( $\alpha=0.05$ ). MESF = mechanically expelled soy flour.



**Figure 19.** Thickness of baked tortilla chips containing 0, 10, 20 and 30% of MESF. Values are means of 3 replications, 10 observations each. Columns followed by the same letter are not significantly different ( $\alpha=0.05$ ). MESF = mechanically expelled soy flour.

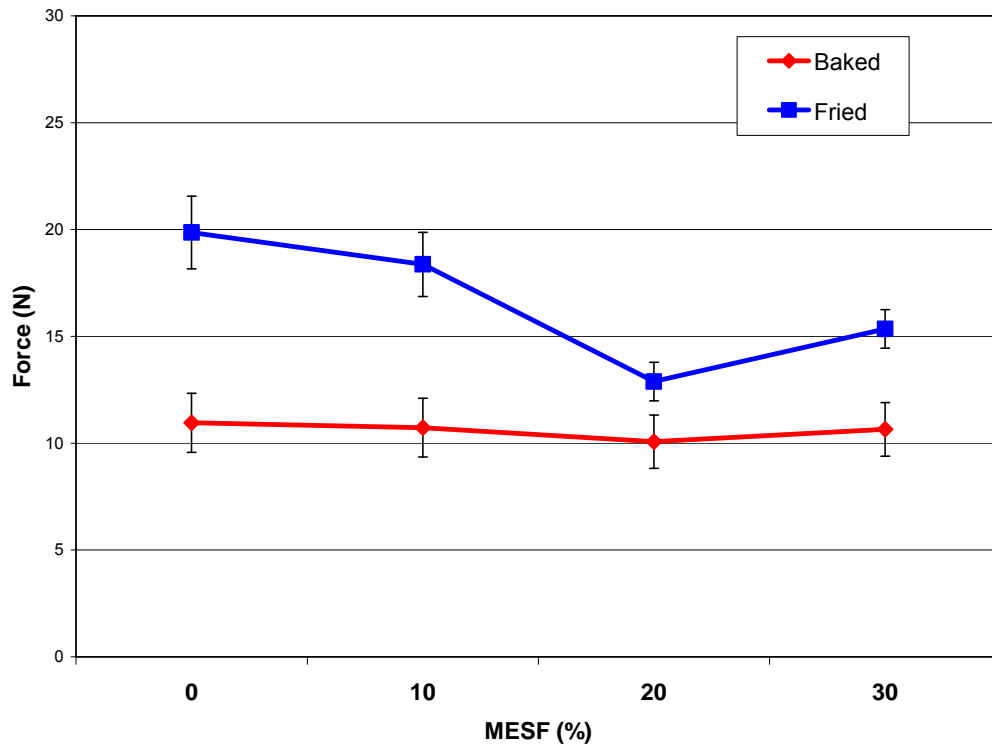
## *Texture*

**Fracturability test.** Figures 20 and 21 show the comparison of force between fried and baked tortilla chips. Overall, fried tortilla chips had higher force and work than baked tortilla chips. These results were expected since fried tortilla chips were thicker than baked tortilla chips. The thicker the tortilla chip, the more force and work it will take to break it. An interaction was seen between processing method vs. MESF levels with processing method driving the main effect for force and work texture measurements. Differences in texture were mainly caused by frying and/or baking more so than the MESF fortification.

A typical fracturability curve is shown in figure 22. The first peak force indicates the maximum breaking force of the sample. The series of minor fractures that appear after the initial fracture indicate that the chip sample was composed of various layers.

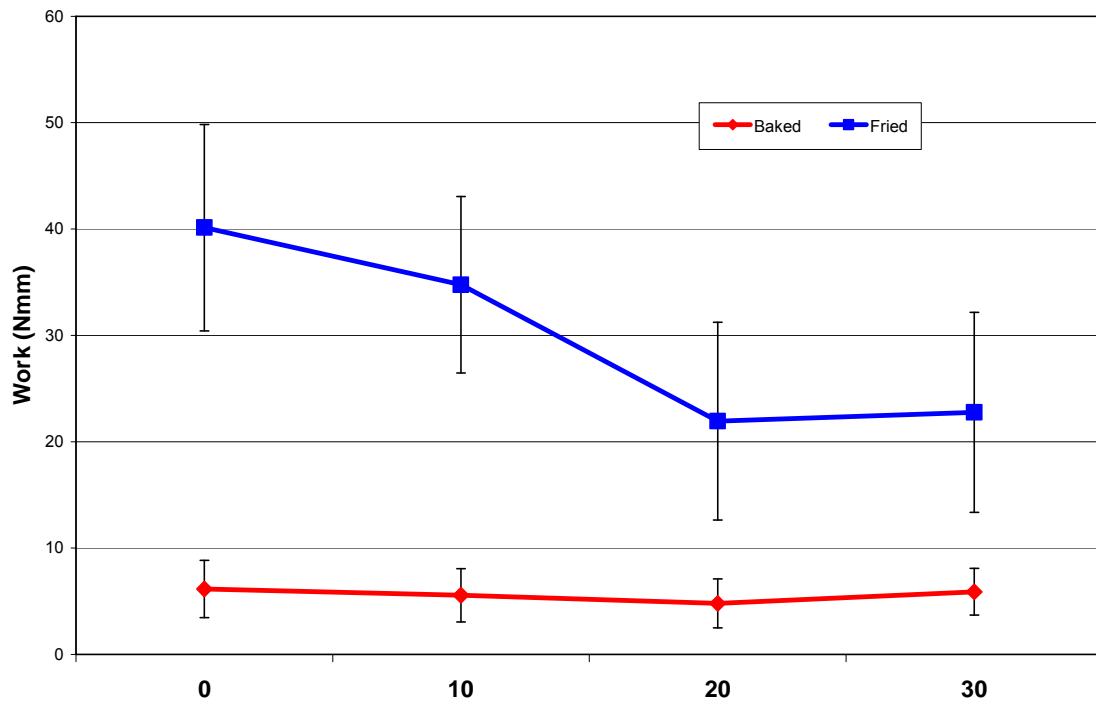
Soy caused expansion in both products (McDonough 2006). There was more natural expansion in the fried product than in the baked product as seen in figure 23 (McDonough 2006). This result was expected because when water is “trapped” under extreme heat, it tries to quickly escape and so it forms channels and creates more expansion (McDonough 2006). MESF created more air cells and therefore more expansion. (McDonough 2006). Soy behaves in this way in most products by creating a more foamy structure in products that have been

fortified with soy flour. Soy should be softer and easier to break in both processes (McDonough 2006).

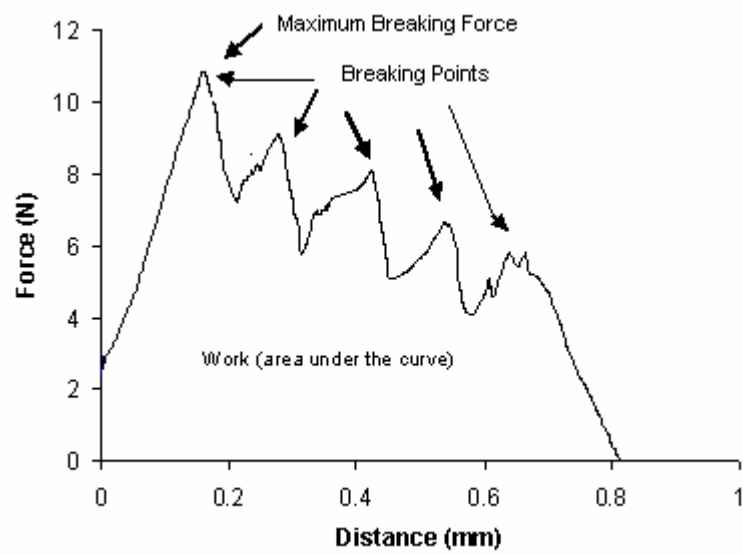


**Figure 20.** Force comparison of fried and baked tortilla chips containing 0, 10, 20 and 30% MESF. Values are means 3 replications, 80 observations each. MESF= mechanically expelled soy flour.

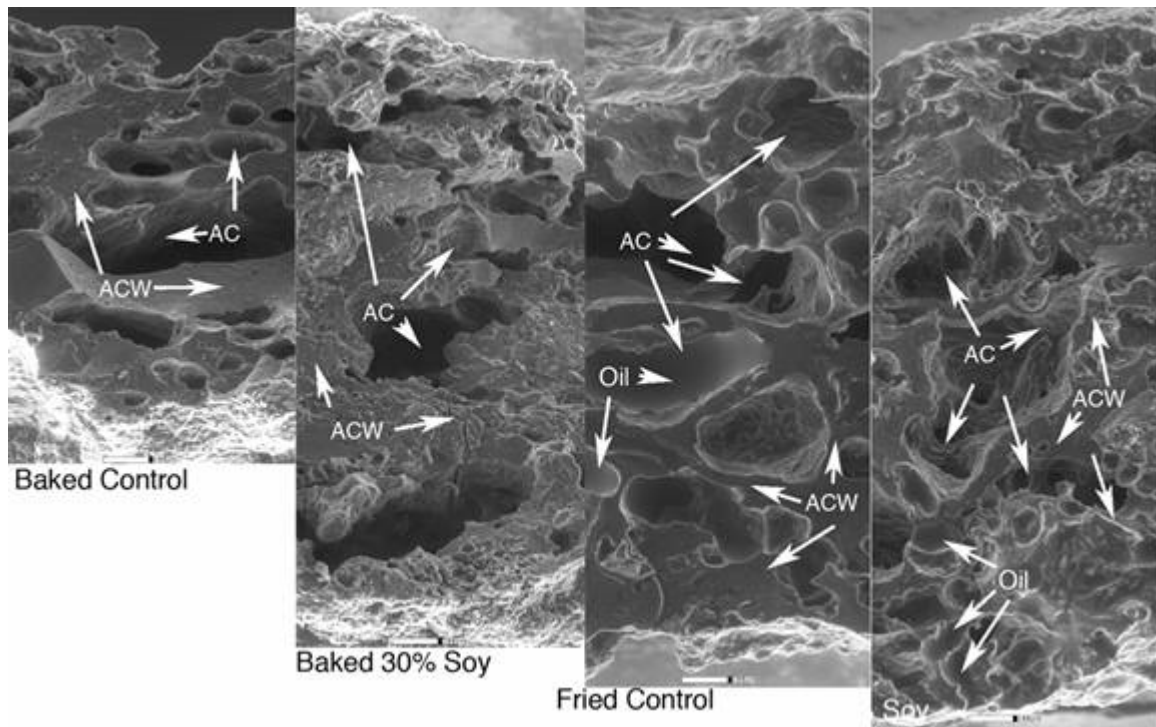




**Figure 21.** Work values of fried and baked tortilla chips containing 0, 10, 20 and 30% MESF. Values are means 3 replications, 80 observations each. MESF= mechanically expelled soy flour.



**Figure 22.** Typical fracturability curve of a tortilla chip.

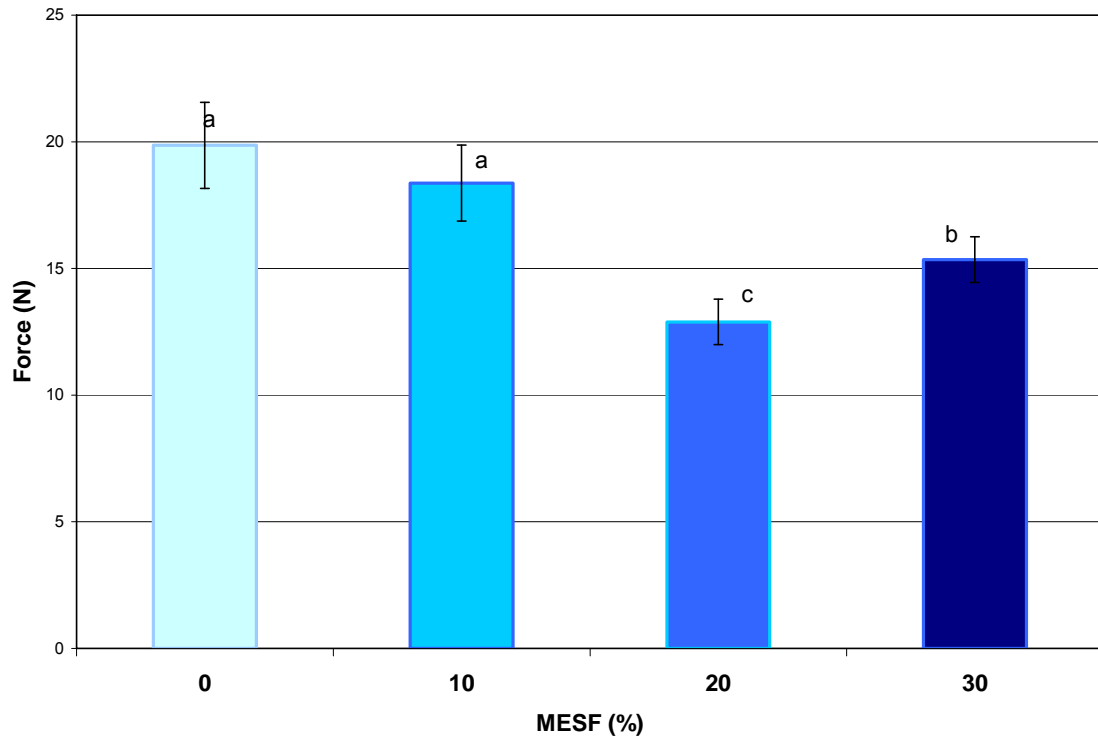


**Figure 23.** ESEM of control and 30% MESF baked and fried tortilla chips.

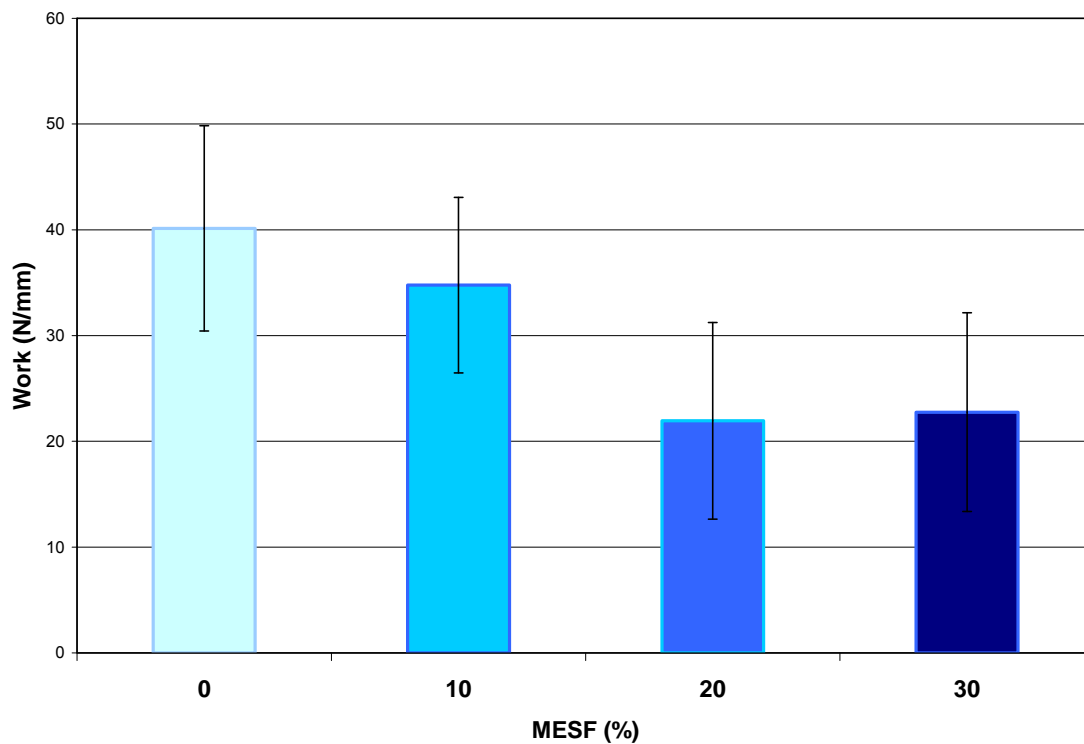
## Fried Tortilla Chips

**Fracturability test.** Significant differences were found between 20% MESF and 30% MESF, 20% MESF and 0 and 10% MESF and 30% MESF and 0 and 10% MESF. As MESF fortification increased, force and work values decreased. This result was expected since soy caused expansion in the chips. There were more air cells and more expansion as MESF increased. Because of a foamy structure created by MESF, chips with higher levels of MESF were softer. (Figure 24 and Figure 25).

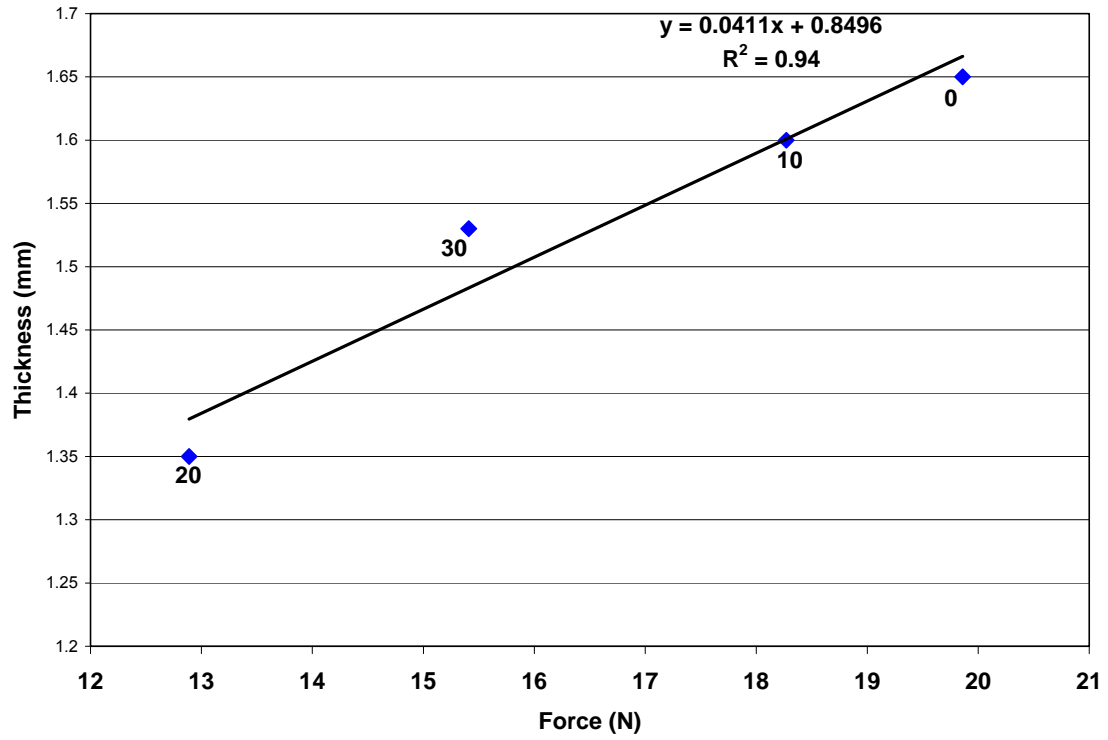
Thickness also played a role in the texture of fried tortilla chips. Figure 26 shows a direct relationship between thickness and force in fried tortilla chips. ( $R^2 = 0.94$ ).



**Figure 24.** Force of fried tortilla chips containing 0, 10, 20 and 30% MESF. Values are means of 3 replications, 80 observations each. Columns followed by the same letter are not significantly different ( $\alpha= 0.05$ ). MESF = mechanically expelled soy flour.



**Figure 25.** Work of fried tortilla chips containing 0, 10, 20 and 30% MESF. Values are means of 3 replications, 80 observations each. Columns followed by the same letter are not significantly different ( $\alpha= 0.05$ ). MESF = mechanically expelled soy flour.



**Figure 26.** Correlation between force and thickness of fried tortilla chips containing 0, 10, 20 and 30% MESF.

**Table 3.** Breakage susceptibility data from tortilla chips with 0, 10, 20 and 30% MESF added. Values are means of 4 replicates, 3 observations each. Values represent the percent by weight of broken chips from 10 whole chips. Columns followed by the same letter are not significantly different ( $\alpha= 0.05$ ). For the acronym, the number indicates the percentage of MESF added, Ctrl= Control, F= Fried.

Treatment	Large pieces <sup>1</sup>	Small <sup>2</sup>	Fines <sup>3</sup>
CF	99.3 ± 0.2	0.5 ± 0.1	0.2 ± 0.1 b
10F	99.2 ± 0.3	0.5 ± 0.3	0.3 ± 0.1 b
20F	98.7 ± 0.5	0.2 ± 0.3	1.1 ± 0.1 a
30F	99.4 ± 0.2	0.1 ± 0.4	0.5 ± 0.3 b

<sup>1</sup> Large pieces are 95-100% the size of an unbroken chip

<sup>2</sup> Small pieces are 5-50% the size of an unbroken chip

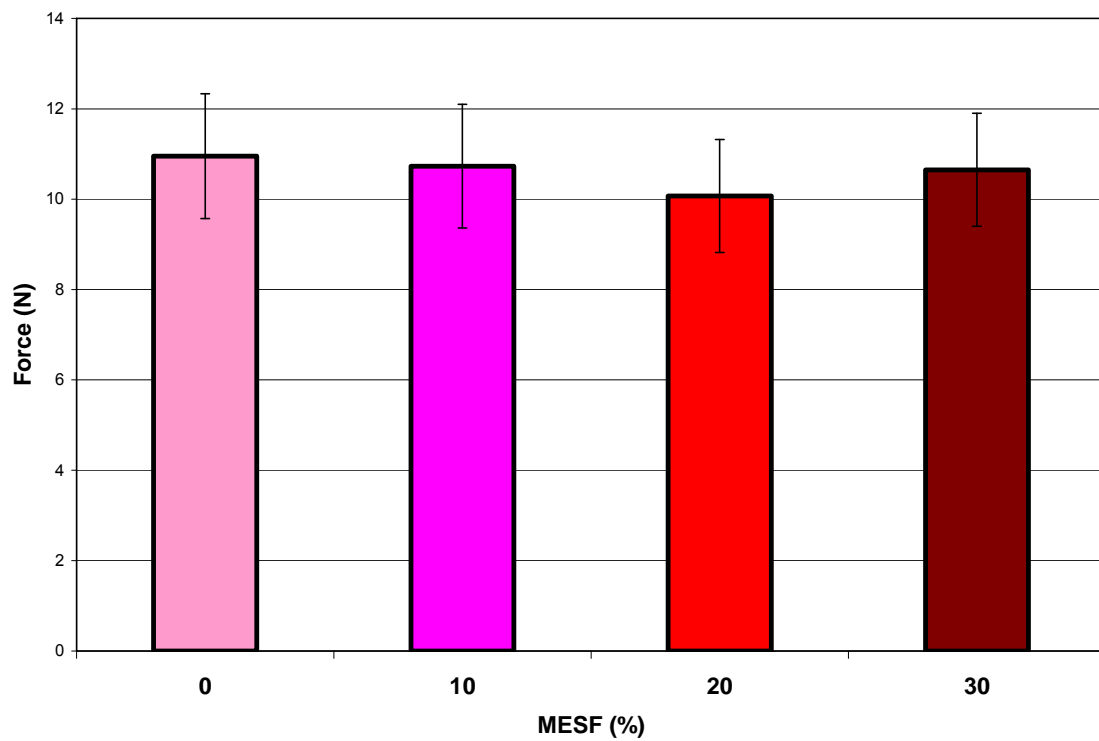
<sup>3</sup> Fines are less than 5% the size of an unbroken chip



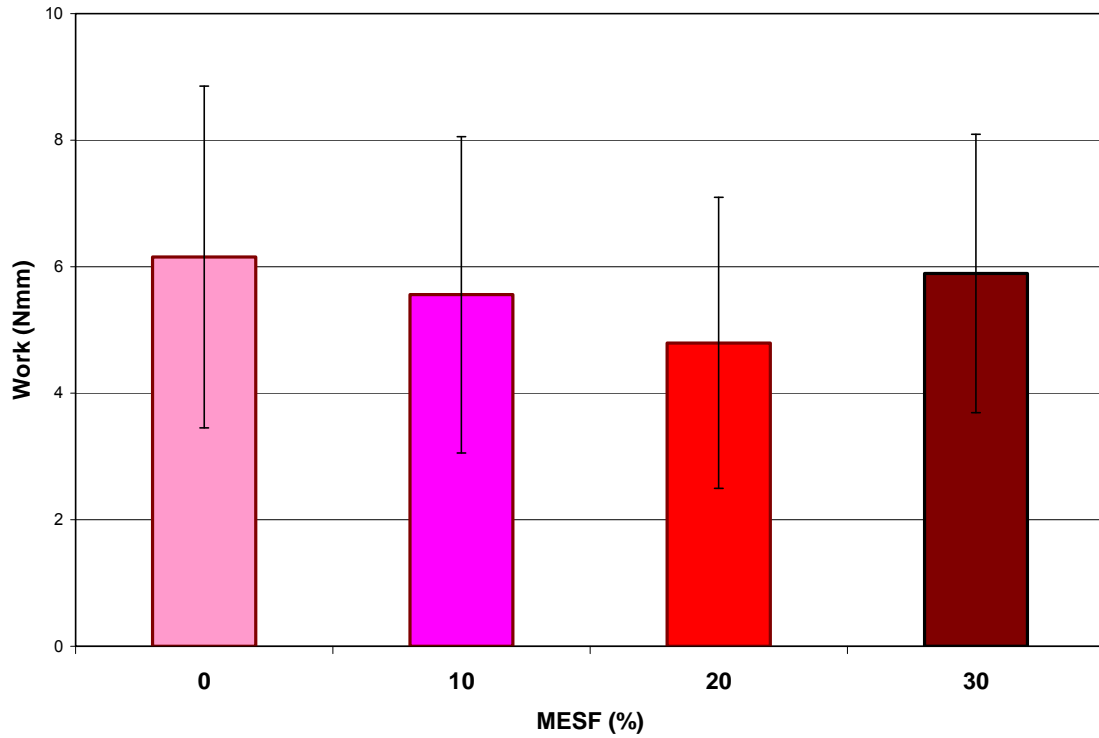
**Breakage susceptibility test.** The breakage susceptibility test for fried tortilla chips can be seen in table 3. Treatment with 20% MESF resulted in more fines than the rest of the treatments. This result is not surprising because when this result is compared to the texture analyzer, 20% MESF required a lower force to break than the rest of the treatments. No significant differences were found among treatments in the amounts of large and small pieces produced. Overall, these chips were very resistant and did not break. This means that during transportation and handling, minimal breakage if none could be expected. Because these chips are thick, they are less likely to break as well.

#### *Baked Tortilla Chips*

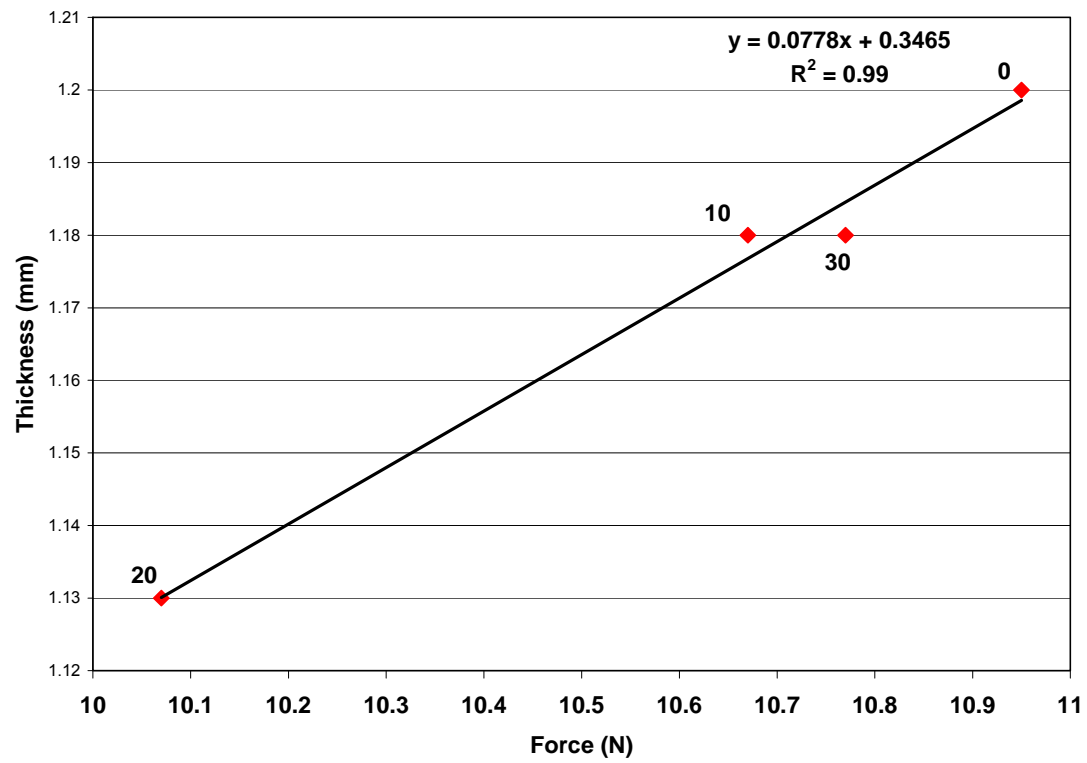
**Fracturability test.** There were no significant differences found among treatments for the force and work of baked tortilla chips as seen in figures 27 and 28. The method that was used to analyze the texture may have been the reason for these results. This indicates that the texture analyzer was not sensitive enough to detect any differences. Lower values for force and work were expected due to the foamy structure that soy creates in products, as seen with the fried tortilla chips. Even though there were no significant differences seen in thickness values for these chips, figure 29 indicates that there is a linear relationship between thickness and force values. As thickness increases, force increases as well. However, this is a non-significant value.



**Figure 27.** Force of baked tortilla chips containing 0, 10, 20 and 30% MESF. Values are means of 3 replications, 80 observations each. Columns followed by the same letter are not significantly different ( $\alpha= 0.05$ ). MESF = mechanically expelled soy flour.



**Figure 28.** Work of baked tortilla chips containing 0, 10, 20 and 30% MESF. Values are means of 3 replications, 80 observations each. Columns with the same letter are not significantly different ( $\alpha= 0.05$ ). MESF = mechanically expelled soy flour.



**Figure 29.** Correlation between force and thickness of baked tortilla chips containing 0, 10, 20 and 30% MESF.

**Table 4.** Breakage susceptibility data from tortilla chips with 0, 10, 20 and 30% MESF added. Values are means of 4 replicates, 3 observations each. Values represent the percent by weight of broken chips from 10 whole chips Columns followed by the same letter are not significantly different ( $\alpha= 0.05$ ). For the acronym, the number indicates the percentage of MESF added, Ctrl= Control, B= Baked

Treatment	Large pieces <sup>1</sup>	Small <sup>2</sup>	Fines <sup>3</sup>
CB	98 ± 0.1	1.0 ± 0.4	1.0 ± 0.2
10B	98.2 ± 0.4	1.3 ± 0.2	0.5 ± 0.5
20B	98.3 ± 0.3	1.4 ± 0.2	0.3 ± 0.7
30B	97.9 ± 0.5	1.1 ± 0.1	1.0 ± 0.1

<sup>1</sup> Large pieces are 95-100% the size of an unbroken chip

<sup>2</sup> Small pieces are 5-50% the size of an unbroken chip

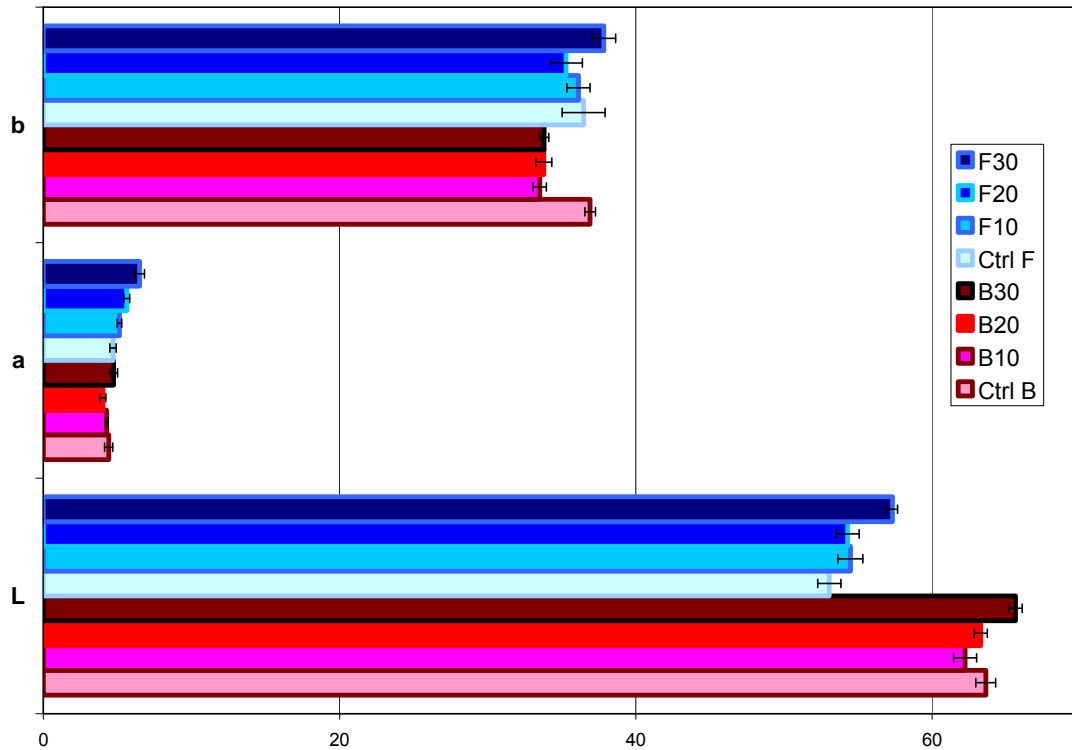
<sup>3</sup> Fines are less than 5% the size of an unbroken chip

***Breakage susceptibility test.*** Table 4 shows the results for baked tortilla chips breakage susceptibility which was measured by a tumbler. No differences were found in the percentage of large, small or fines produced by the treatments. These results were expected since the texture analyzer results showed no differences either. Also, since these chips are thick, they are expected to be firm and resistant to breakage during transportation and handling.

### *Color*

Color for baked and fried tortilla chips is seen in figure 30. There was an interaction seen between processing method and MESF fortification for L, a and b values. There were differences within each processing type at different levels of MESF, but those differences depend on whether chips were baked or fried. Overall, baked chips are lighter in color than fried chips because L values were higher for baked chips.

Figure 31 shows the appearance of baked and fried tortilla chips.



**Figure 30.** Color of fried and baked tortilla chips containing 0, 10, 20 and 30% MESF. L\* indicates lightness, a\* indicates hue on a green (-) to red (+) axis, and b\* indicates hue on a blue (-) to yellow (+) axis. Values are means of 2 replications, 10 observations each. For the acronym, the number indicates the percentage of MESF added. F indicates frying processing. B indicates baking process. Ctrl = Control.



**Figure 31.** Appearance of baked and fried tortilla chips containing 0, 10, 20 and 30% MESF.



### *Fried Tortilla Chips*

To avoid excessive browning, frying times had to be adjusted. Overall, the higher the soy fortification, the lower the frying time it required. (1 min 10 seconds for control vs 50 seconds for 20 and 30% MESF). These frying times were successful in maintaining the moisture of tortilla chips less than 3%.

Fortification of 30% MESF produced the lightest tortilla chips among fried treatments. This was expected as to the human eye, MESF is lighter in color than DMF.

Redness or “a” values increased with increasing levels of MESF. Similar results were found by Buck et al. (1987) where 30% soy flour (hexane extracted from ADM) fortification in bread had higher “a” values than control (wheat bread). Similar results were found by the same authors in extruded puffs made with corn grits where redness values increased with the addition of soy. However, redness is not noticeable and neither one of the panelists could see it or mentioned it either. All treatments were significantly different from each other as seen in figure 32.

Tortilla chips fortified with 30% MESF had higher b (yellow) values than 10 and 20% MESF and equal values to control chips. This indicates that within chips

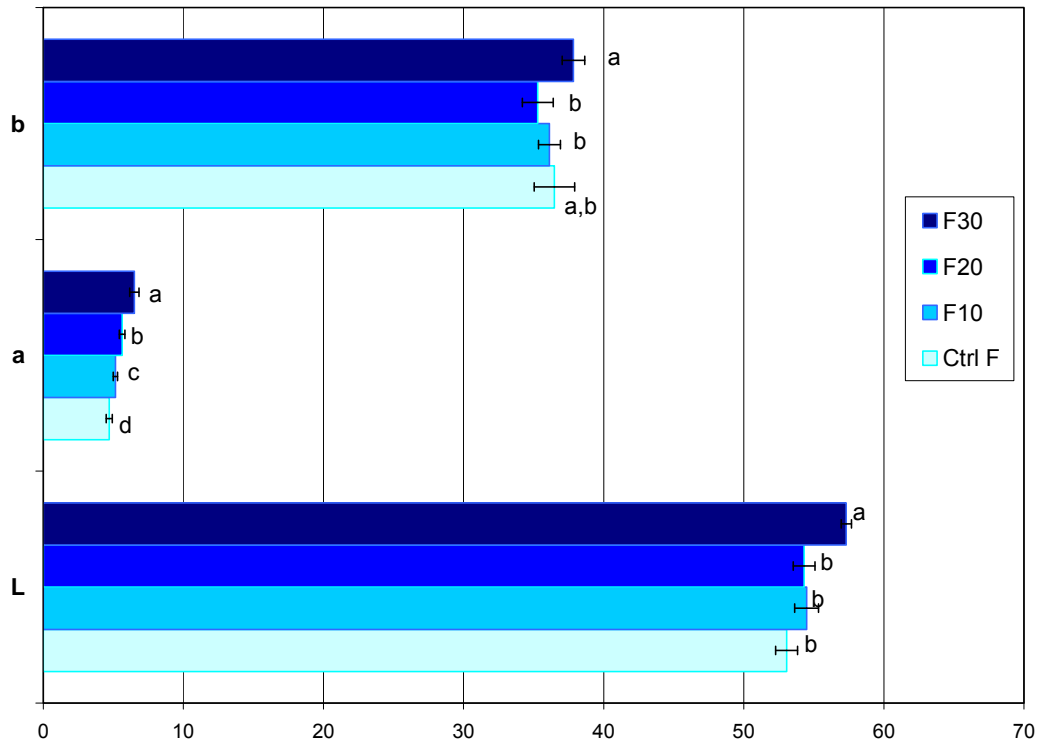
fortified with MESF, increasing levels of MESF will yield higher b values. Control, 0 and 10% MESF had the same yellowness levels.

### *Baked Tortilla Chips*

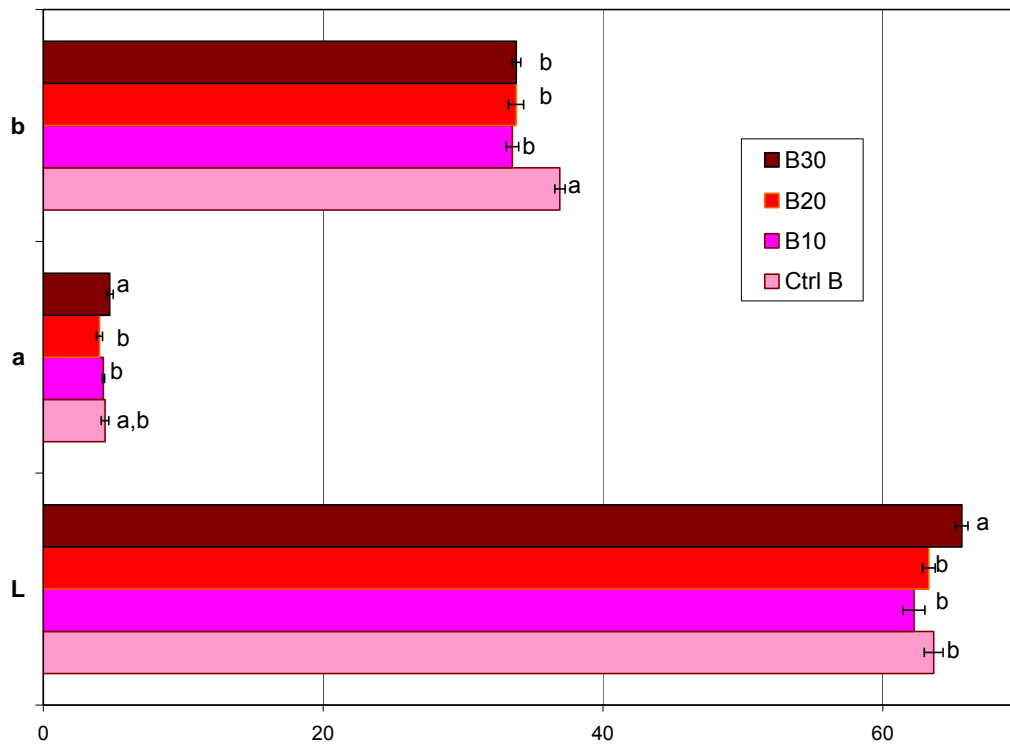
As with fried tortilla chips, increasing levels of MESF produced lighter tortilla chips. (Figure 33).

Redness values were the same among treatments except for 30% when compared to 10 and 20% MESF, 30% MESF had higher “a” values but the same as control. Similar results were found by Buck et al. (1987).

Yellowness was the same for all chips fortified with MESF. Values for 10, 20 and 30% MESF were lower than control. Buck et al (1987) found similar results in extruded puffs made with corn grits where yellowness values decreased slightly with the addition of soy. Control had the highest yellow (b) values possibly due to the inherent yellow color of corn.



**Figure 32.** Color of fried tortilla chips containing 0, 10, 20 and 30% MESH. L\* indicates lightness, a\* indicates hue on a green (-) to red (+) axis, and b\* indicates hue on a blue (-) to yellow (+) axis. Values are means of 2 replications, 10 observations each. For the acronym, the number indicates the percentage of MESH added. F indicates frying processing. Ctrl = Control.



**Figure 33.** Color of baked tortilla chips containing 0, 10, 20 and 30% MESH. L\* indicates lightness, a\* indicates hue on a green (-) to red (+) axis, and b\* indicates hue on a blue (-) to yellow (+) axis. Values are means of 2 replications, 10 observations each. For the acronym, the number indicates the percentage of MESH added. B indicates baking processing. Ctrl = Control.

## SUMMARY AND CONCLUSIONS

Dry extrusion followed by mechanical pressing proved to be successful in the production of mechanically expelled soy flour as the lipoxygenase enzyme activity was most likely inactivated, acceptable protein dispersibility was obtained and good oil extraction (8.9% d.b. oil in the flour) was obtained.

The fortification of baked and fried tortilla chips with mechanically expelled soy flour (MESF) impacted tortilla chip structure, organoleptic properties and fracturability. Frying had a bigger effect in texture and flavor than MESF.

Increasing the percentage of MESF in tortilla chips improves the nutritional value, but some loss of acceptability occurs when tortilla chips are baked. Fried tortilla chips had higher sensory scores on a 9-point hedonic scale than baked tortilla chips. Panelists liked fried chips better than baked and among the fried ones, 20% MESF was liked the best. Sensory scores suggest that 20% MESF fortification would be a good level of soy protein fortification.

Fried tortilla chips had higher force and work values than baked ones. The texture analyzer was not sensitive enough to measure differences in baked tortilla chips. ESEM showed that soy caused expansion in both products, where

fried tortilla chips had more expansion than in the baked ones. A direct correlation between thickness and force was found indicating that thicker tortilla chips had higher force values. Soy impacted the force values of fried chips where 20% MESF had the lowest values among treatments because soy created more air cells in the product. There was an indirect correlation found between final oil content in chips and force values, where as oil increased, force values decreased due to the fact that the starting oil content of the flour was 6.7% oil.

Frying had a higher impact in color than MESF and baking. Frying caused chips to be darker in color than baked ones. Sensory scores did not indicate a negative appearance of chips.

The widespread popularity of tortilla chips from kids to adults makes these products a good option for soy protein fortification. These products can serve as suitable vehicles for improving nutrient intake without compromising flavor. Snacks such as tortilla chips provide an avenue for introducing soy to consumers who normally resist trying any unfamiliar foods. It is possible to supplement corn flour with cost effective soybean flour that is rich in protein.

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## APPENDIX A

### SENSORY BALLOT

SAMPLE NUMBER \_\_\_\_\_

1. Indicate by placing a mark in the box your **OVERALL LIKE/DISLIKE** of this sample.

<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Dislike Extremely			Neither Like nor Dislike					Like Extremely

2. Indicate by placing a mark in the box your **OVERALL LIKE/DISLIKE** for the **FLAVOR** of this sample.

<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Dislike Extremely			Neither Like nor Dislike					Like Extremely

3. Indicate by placing a mark in the box how you feel about the **INTENSITY OF THE FLAVOR** of this sample.

<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
None or Extremely Bland								Extremely Intense

4. What did you **LIKE** about the **FLAVOR** of this sample?

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5. What did you **DISLIKE** about the **FLAVOR** of this sample?

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## VITA

Monica De La Torre Pineda received her Bachelor of Science degree in nutritional sciences from Texas A&M University in 2001. She entered the food science and technology program at Texas A&M University in January 2002, and received her Master of Science degree in May 2007.

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