FIBER-ENRICHED WHEAT FLOUR PRECOOKED USING EXTRUSION PROCESSING: RHEOLOGICAL, NUTRITIONAL AND SENSORY PROPERTIES

by

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Abstract

Foods with high fiber can reduce calorie uptake and provide health benefits related to chronic ailments like obesity, diabetes, cancer and cardiovascular disease. However, inclusion of fiber diminishes the final product quality and consumer acceptability of cereal products. The overall objective of this project was to produce fiber-enriched, pre-cooked wheat flours using extrusion processing in order to enhance their nutritional value, while maintaining functional and sensory properties in baked products such as cookies and tortillas. In the first part of this study, extrusion processing was utilized to pre-cook wheat flours substituted with 0, 10, 20 and 30 % wheat bran in order to enhance their rheological properties and functionality with regards to cookies and tortillas. Two extrusion conditions, low-temperature-low-shear (LTLS) and high-temperature-high-shear (HTHS) were studied for pre-cooking the flours. Results showed that for all flours, as % bran increased, RVA peak viscosity (PV), and mixograph peak time (PT_M) and peak height (PH) decreased. At all bran levels, PV and PH were significantly lower for pre-cooked flours as compared to uncooked. As the percent bran increased, the quality of cookies (weight and spread factor) and tortillas (specific volume, rollability and extensibility) deteriorated for both uncooked and pre-cooked wheat flours. In the second part of this study, effect of extrusion pre-cooking on the dietary fiber profile of wheat flour substituted with 0, 10, 20 and 30 % wheat bran was evaluated. Pre-cooking by extrusion significantly increased SDF in flours (by 22 to 59 %), although in most cases it also led to a significant decrease in TDF. Cookies and tortillas, produced from uncooked and pre-cooked flours with 0 and 20% substituted bran, were evaluated for consumer acceptability using a 9-point hedonic scale. Organoleptic properties of cookies from uncooked flour did not change significantly with increase in bran substitution from 0 to 20%. However, consumer ratings for tortillas did decrease slightly but significantly with increase in bran level. To summarize, pre-cooking of the flours using extrusion did not improve the sensory properties of cookies and tortillas, although

the products were still found acceptable by consumers and also contained higher soluble fiber.

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CHAPTER 1 - INTRODUCTION

In recent years, public awareness of the health benefits of dietary fiber has increased along with its consumption in various high-fiber food products. Numerous studies have reported that health problems linked to chronic ailments such as cardio-vascular diseases and high cholesterol (Gordon 1999; Jones 2006), colon cancer (Burkitt 1971; Gordon 1999; Decker and others 2002), diabetes and obesity (Jones 2006), and constipation (Lue and others 1991; Kantor and others 2001) can be reduced by increasing the consumption of whole-grain or fiber-enriched products. Fiber can be obtained from various sources, such as oat, wheat, rice and corn bran, soy and pea hulls, and potato peels. Properties of high-fiber ingredients vary widely. Apart from health benefits, different types of fiber provide different functionality in food products, including adding bulk, increasing viscosity, forming gels, and replacing or mimicking fats (Nelson 2001).

However, in general, fibrous ingredients have limited or poor functionalit, and it is a challenge to formulate high fiber foods with good physical and organoleptic characteristics. Previous studies have shown that incorporation of fiber into the formulation leads to deterioration in quality and consumer acceptance of baked products. For example, incorporation of oat bran, rice bran or whole wheat flour into wheat tortillas lead to poor storage stability (Friend and others 1992). Vratanina and Zabik (1978) investigated the incorporation of fiber from various sources into cookies and reported reduction in cookie spread with an increase of fiber content. Several other studies have reported similar effects of fiber incorporation on cookie spread (Sekhon and others 1997; Brennan and Samyue 2004; Inyang and Wayo 2004). Dubois (1978) reported that with the modification of both the formulation and the processing procedures, fiber incorporation into bread has been more commercially successful as compared to other food products. However, high-fiber formulations often lead to reduced loaf volume and crumb softness, and increased crumb and crust darkness (Camire 2004). Similar effects have been reported with regards to incorporation of fiber into cakes (Brockmole and Zabik 1976).

Physico-chemical modification of fiber, using high temperature and shear conditions of extrusion processing, is a possible technique for enhancing its functional properties (Fulger and Bradbury 1985; Artz and others 1990; Gualberto and others 1997; Sekhon and others 1997). This approach has been attempted to improve the functionality of corn fiber for use in cookies (Artz and others 1990) and rice bran in snack products (Sekhon and others 1997) with limited success. Extrusion treatment of fibrous ingredients has added potential of improving the nutritional quality of fiber. According to Varo and others (1983) and Artz and others (1990), extrusion cooking causes no significant changes in soluble and insoluble fiber, others (Fornal and others 1987) have reported reduced or increased fiber content (Theander and Westerlund 1987) because of extrusion cooking. Wang and Klopfenstein (1993), and other researchers (Aoe and others 1989; Ralet and others 1990) have shown significantly increased soluble dietary fiber content in extruded wheat bran. Several other studies have reported increase in total and soluble dietary fiber content in potato peels by using extrusion processing (Camire and Flint 1991; Camire and others 1997).

Very few studies have investigated the use of extrusion processing to modify the functional or/and nutritional properties of fiber-enriched flours, which is the main focus of this research. The current study focuses on utilization of extrusion technology for pre-cooking high-fiber wheat flour to increase its functionality. The main hypothesis of this research was that the thermo-mechanical treatment of bran-substituted wheat flour during extrusion would enhance its functional and nutritional properties, and lead to baked products with improved consumer acceptability. The first part of the study (Chapter 2) describes the rheological properties of wheat bran substituted flours pre-cooked using extrusion processing, and the quality parameters of cookies and tortillas made from them. Wheat flour was substituted with 0, 10, 20 and 30% wheat bran. The second part of the study (Chapter 3) describes the dietary fiber profile and sensory properties of the pre-cooked flour substituted with wheat bran. The soluble and insoluble dietary fiber contents of raw and pre-cooked flours were measured. The sensory characteristics of cookies and tortillas from uncooked and pre-cooked high-fiber flours were also evaluated.

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CHAPTER 2 - Fiber Enriched Wheat Flour, Pre-cooked Using Extrusion Processing: Functional and Rheological Properties

2.1 Abstract

Extrusion processing was utilized to pre-cook wheat flours substituted with 0, 10, 20 and 30 % wheat bran in order to enhance their rheological properties and functionality with regards to production of cookies and tortillas. Two extrusion conditions, low-temperature-low-shear (LTLS) and high-temperature-high-shear (HTHS), were studied for pre-cooking the flours. Results showed that for all flours, as % bran increased, RVA peak viscosity (PV), and mixograph peak time (PT_M) and peak height (PH) decreased. At all bran levels, PV and PH were significantly lower for pre-cooked flours as compared to uncooked. As the percent bran and storage time (4 to 16 d) increased, the quality of cookies (weight and spread factor) and tortillas (specific volume, rollability and extensibility) deteriorated for both uncooked and pre-cooked wheat flours.

Key Words: extrusion, pre-cooking, wheat bran, functional and rheological properties, cookies and tortillas.

2.2 Introduction

Obesity is a global concern and the problem is reaching epidemic proportions (McCarthy 2003; Polan 2003). It is a primary factor in a number of serious medical conditions, such as cardiovascular disease, cancer and diabetes (Mokdad and others 2005). In the U.S. alone over 127 million people are overweight, 60 million are obese, and 9 million are severely obese. This places an unnecessary burden on an already strained health system. Increased fiber consumption has been found to be important for lowering the risk of being overweight and associated with reduced body mass index, blood pressure, and fasting apo B and glucose concentrations (Jones 2006). Several studies have related consumption of dietary fiber and whole grains with a reduction in serum cholesterol, and a lower risk for coronary artery disease and certain forms of cancer (Burkitt 1971; Kantor and others 2001; Decker and others 2002). Dietary fiber has also been related to digestive health and reduction in risk of ailments such as constipation, appendicitis, and irritable bowel syndrome (Lue and others 1991; Kantor and others 2001).

Whole grains and other sources of dietary fiber, long an important part of the human diet, gained new stature in 1999 when the U.S. Food and Drug Administration authorized the following health claim: “Diets rich in whole grain foods and other plant foods and low in total fat, saturated fat, and cholesterol, may help reduce the risk of heart disease and certain cancers” (Kantor and others 2001). A recent food industry report mentioned “high-fiber” as one of the top ten functional food trends in the U.S. market (Sloan 2006). With increasing awareness of the benefits of dietary fiber, the demand for functional foods, high in fiber, is expected to continue increasing with projected growth of the fiber industry to $495 million by 2011, which would represent a more than two-fold increase over the preceding 7-year period (Sloan 2006).

There are various definitions and classifications of fiber. According to one classification, total fiber comprises dietary fiber and functional fiber (Seiz 2006). Dietary fiber consists of carbohydrates and lignins that are intrinsic and intact in plants and edible, yet resistant to digestion and absorption in the human small intestine with complete or partial fermentation in the large intestine. Functional fiber consists of isolated, non-digestible carbohydrates that have beneficial physiological effects in humans. Fiber can also be classified into soluble and insoluble fiber (Seiz, 2006). Soluble fibers such as pectins and gums are known to be effective in reducing total blood cholesterol and promoting satiety. Insoluble fibers, such as cellulose and lignin help in treating constipation and reduce the risk of colon cancer and diverticular disease. Wheat bran, which is the main fiber source for the baking industry, is mostly cellulosic. Other fiber sources such as soy hull (Seetharaman and others 1994; Seiz 2006), oat bran (Friend and others 1992; Gualberto and others 1997; Seiz 2006), citrus fruits (Seiz 2006) and rice bran (Friend and others 1992; Lima and others 2002) are also used to boost the fiber content in baked products.

Despite its nutritional benefits, incorporation of fiber in foods, especially baked products such as bread, tortillas and cookies, has been limited because of its poor functional properties and deleterious effects on the functionality of other food components. Problems like poor extensibility, reduced loaf volume and altered crumb structure are common in high-fiber baked products, because fiber disrupts the continuous visco-elastic dough matrix (Artz and others 1990; Seiz 2006; Brennan and Samyue 2004; Seguchi and others 2007). These deleterious effects depend on the bran type and its physical properties. Some studies have reported that functionality of bran from different sources can be improved by thermal processing (drum drying or jet cooking, micronising, steam cooking, auto claving) (Caprez and others 1986; Lima and others 2002; Lee and Inglett 2006). Physico-chemical modification of fiber, using high temperature and shear conditions of extrusion processing, is another possible technique for enhancing its functional properties (Fulger and Bradbury 1985; Artz and others 1990; Gualberto and others 1997; Sekhon and others 1997). This approach has been attempted to improve the functionality of corn fiber for use in cookies (Artz and others 1990) and rice bran in snack products (Sekhon and others 1997) with limited success.

A slight but significant variation to the above discussed studies would be the treatment of flours enriched with high levels of fiber for the improvement of functionality of the formulation as a whole (Arambula and others 2002). The purpose of this study was to utilize extrusion processing for producing pre-cooked wheat flour substituted with high levels of wheat bran. The hypothesis was that by utilizing appropriate combinations of process parameters, the extrusion pre-cooking of fiber-enriched flour would lead to synergistic interactions between bran and other components and increase its functionality for use in baked products. Rheological properties of the pre-cooked flours and their functionality with regards to making cookies and tortillas were studied. Different extrusion processing conditions and post-extrusion drying methods (lyophilization and conventional oven drying) were also investigated.

2.3 Materials and Methods

2.3.1 Materials & formulation

Commercial hard red winter wheat flour, with moisture, protein and ash contents of 14, 11.8 and 0.5%, respectively, was obtained from Horizon Milling, LLC (Wichita, KS). The wheat flour yielded moisture, protein and ash contents of 14, 11.8 and 0.5%, respectively. Depending on the treatment, the flour was substituted with 0, 10, 20 or 30% with hard red winter wheat bran obtained from the pilot mill in the Department of Grain Science and Industry, Kansas State University. All experiments were conducted using the bran substituted wheat flour as base ingredient. The other ingredients in the cookie formulation, including sugar (90%; United Sugar Corp., Clewiston, FL), all purpose shortening (60%; ACH Food Companies Inc., Cordova, TN), dry eggs (7%; Michael Foods Egg Products, Gaylord, MN), salt (1.8%; Morton Salt, Chicago, IL), sodium bicarbonate (1.8%; Sigma Aldrich Co., St.Louis, MO) and Butter Lemon Vanilla flavor (1.0%; Mothers Murphy's Labs, Greensboro, NC) were obtained from a local grocery store. This formulation was based on the method described by Payne (1995). The other ingredients in the tortilla formulation included all purpose shortening (11%), salt (1.5%), sodium bicarbonate (1.5%), potassium sorbate (0.5%), sodium propionate (0.5%), sodium stearoyl lactate (0.5%), fumaric acid (0.2%) and cysteine (0.003%). This formulation was based on the method described by Bello and others (1991). These ingredients, except for the first two, were obtained from Sigma Aldrich Co. (St.Louis, MO). The relative amounts of all materials for both cookie and tortilla formulation were expressed in baker's percentages.

2.3.2 Flour processing

The wheat flour substituted with 0 – 30% bran was processed in a 6–zone laboratory scale twin-screw extruder (Micro 18; American Leistritz Extruder Corp., Somerville, NJ) under two different conditions - 1) barrel temperatures of 30-32-34-36-38-40˚C and screw speed of 200rpm (low-temperature-low-shear or LTLS), and 2) barrel temperatures of 30-40-50-60-70-80˚C and screw speed of 250 rpm (high-temperature-high-shear or HTHS). The extruder screw profile and barrel temperature zones are shown in Figure 2.1. Feed moisture content was maintained at 30% (wet basis) for all treatments. The target moisture was achieved by mixing the flour with water in a mixer (KSM5; Kitchen Aid, St Joseph, MI), taking the initial moisture of the flour into account. The hydrated flour was stored overnight at 4˚C for equilibration before extrusion. Specific mechanical energy (SME), an indicator of mechanical energy input into the material during extrusion, was calculated as the following.

$$SME = \frac{(L - L_0)P_r\left(\dfrac{N}{N_r}\right)}{\dot{m}} \qquad \text{(KJ/kg)}$$

where, L = motor load (%), L_0 = no-load motor load (%), P_r = rated power (2.2 kW), N= screw speed (rpm), N_r = rated screw speed (500 rpm), and $\dot{m}$ = mass flow rate (Kg/s). An average value of 5% was used for L_0.

The ribbon-like extruded product was dried by two different methods – lyophilization and oven drying. The former was performed using a Labconco FTS System Inc. (Kansas City, MO) freeze drier, while a Thelco laboratory oven (160DM; Precision Scientific, Chicago, IL) set at 60˚C was used for the later. The moisture content of the dried flour ranged between 3.9 – 7.4 % (wet basis). The dried product was ground to pass through a 0.5-mm sieve using a Thomas Wiley laboratory mill (Model 4; Arthur H. Thomas Company, Philadelphia, PA). For control studies, bran substituted in the uncooked flour was also ground using the same mill to pass through a 0.5-mm sieve.

2.3.3 Cookie preparation

The cookie dough preparation and subsequent baking was performed using a method outlined by Payne (1995) as summarized in Figure 2.2. The ingredients were mixed using a 10-qt mixer (A-200; Hobart, Troy, OH). For both uncooked and pre-cooked flours, the water addition level was 20%. A moistened scoop (#20; Vollrath®, Sheboygan, WI) was used to drop dough onto a pan covered with a liner sheet. Cookies were baked in an oven (Reed Oven Co., Kansas city, MO) at 176.6˚C (350˚F) for 13-15 min.

2.3.4 Tortilla preparation

The tortilla dough preparation, pressing and subsequent baking were performed using the standard method described by Bello and others (1991), as summarized in Figure 2.3. For uncooked flour, water addition level was 61%. For the pre-cooked flours a few modifications were made to the methodology. These included addition of 15 and 20% wheat gluten (MGP Ingredients, Atchinson, KS) to the pre-cooked LTLS and HTHS flours, respectively; mixing of ingredients at speed 1 for 1 min, and mixing time at speed 2 for 8 min; and water addition levels increasing from 61 to 81% as bran levels increased from 0 to 30%. Wheat gluten has been added previously to increase the machinability and shelf stability of high fiber tortillas (Friend and others 1992).The dough balls were hot pressed for 15 s using a Dough Pro tortilla hot press (Process Corp., Paramount, CA).The top and bottom platen temperatures of the hot press were 80.6 and 78.3˚C, respectively. The gap between the hot plates was set at "thin" (1.5 - 2.0 mm). The pressed dough was baked on griddle (Speedester, Walter & Carrell Mfg. Co., Denver, CO) for 40 sec on each side at a temperature of 173˚C.

2.3.5 Rheological properties of flour

2.3.5.1 Rapid Visco Analyser

A Rapid Visco-Analyser (RVA-3D, Newport Scientific, NSW, Australia) was used to measure the pasting properties using the AACC Approved Method 22-08. The flour sample (3.13 – 3.4 g) was added to 25.1 – 25.4 ml of water in an aluminum canister, and the RVA test was performed with a total run time of 13 min. The peak viscosity (PV) and peak time (PT_R) obtained from the pasting curve were used to infer the degree of cooking and degradation of flour during extrusion processing.

2.3.5.2 Mixograph

Dough rheological properties were measured using a Mixograph (National Mfg. Co., Lincoln, NE) as described by AACC Approved Method 54-40A. The ratio of flour and water used in the mixograph studies was calculated based on the initial flour moisture and protein content. The flour and water were mixed in a 10-g mixograph bowl for 10 min according to the standard procedure. The peak height (PH) (expressed as percentage of the scale maximum) and peak time (PT_M) obtained from the mixogram curve were used to infer the dough strength.

2.3.6 Cookie and tortilla quality parameters

2.3.6.1 Cookie Properties

The weight (w_c), diameter or width (W) and thickness (T) of cookies were determined 24 h after baking cookies as described by Payne (1995). The spread ratio defined as the W/T ratio, was also calculated.

2.3.6.2 Tortilla Physical Properties

The weight (w_T), diameter (D), and height (H) of freshly baked and cooled tortillas were measured and specific volume (V) calculated as described below.

$$V = \frac{\pi D^2 H}{4\, w_T} \qquad (m^3/g)$$

Opacity was measured subjectively using a continuous scale where 100% was completely opaque (white) and 0% was completely translucent. Water activity (a_w) was determined using a water activity meter (CX2; Decagon Devices, Inc., Pullman, WA) after blending the tortilla in a coffee grinder.

2.3.6.3 Tortilla storage studies

Tortillas were packaged in sealed plastic bags and placed at room temperature (22˚C) for storage. A previous study showed that this storage temperature corresponded with the fastest firming of flour tortillas (Kelekci and others 2003). Measurements for extensibility and rollability were conducted on tortillas stored for 4, 8, 12, and 16 days as described below (Suhendro and others 1999).

Tortilla extensibility was measured using a texture analyzer (TA.XT2; Texture Technologies Corp., Scarsdale, NY). The test was conducted on a 60 x 35-mm tortilla strip, cut from the center of the tortilla using the return-to-start option in tension mode, a trigger force of 0.05 N, and probe travel distance and speed of 10 mm and 1mm/s, respectively. The force and distance of rupture of the tortilla strip were recorded. Rollability of tortilla was evaluated using the subjective scoring method described by Friend and others (1995). A tortilla was wrapped around a wooden dowel of 1.0 cm diameter and its cracking and rollability were rated on a scale of 1-5 (1 = unrollable or worst to 5 = no cracking or best).

2.4 Experimental design and statistical analysis

The effect of drying methods (lyophilization and oven drying) was studied using only HTHS pre-cooked wheat flour without any bran substitution. Uncooked flour was used as the control. This comprised of an experiment design involving 3 treatments. The effect of bran substitution and extrusion pre-cooking on the Rheological and functional properties of wheat flour was investigated using a 4 x 3 factorial design, with four levels of bran substitution (0, 10, 20 and 30%) and three levels of extrusion processing conditions (no pre-cooking, and LTLS and HTHS extrusion pre-cooking). Flour from each treatment was partitioned into three sub-samples for all subsequent tests. RVA and Mixograph tests were duplicated for each flour sub-sample. Physical parameters of cookies and tortillas were measured from batches based on each sub-sample. Rollability measurements were duplicated for tortillas from each sub- sample. Extensibility of tortillas was measured in three replicates from each treatment. The physical and textural properties of cookies and tortillas, as well as rheological properties of the flour, were evaluated using two-way analysis of variance (ANOVA). Fisher's LSD was used for multiple mean comparisons ($\alpha = 0.05$). SAS software (version 9.1; Cary, NC) was used to conduct all statistical analyses.

2.5 Results and Discussion

2.5.1 Effect of drying methods

The rheological properties of uncooked flour and HTHS pre-cooked flour dried by lyophilization and oven drying are shown in Table 2.1.None of these flours were substituted with bran. RVA peak viscosity (PV) and peak time (PT_R) for the control (uncooked flour) were 2237 cP and 5.9 min, respectively. PV for the lyophilized and oven-dried pre-cooked flour was 34 and 48% lower, respectively, as compared to the control. The differences in PV for all three flours were significant ($P < 0.05$). PT_R for the pre-cooked flours was also lower than that for the control, although the differences were not marked. The RVA parameters provide a relative measure of starch pasting, swelling and degradation. As starch is heated in the presence of water, granules swell leading to increase in viscosity of the starch-water suspension (Atwell 2003; Brennan and Samyue 2004). Uncooked starch would take a longer time (PT_R) to reach its PV. Also intact or relatively less degraded granules would swell more, leading to a higher PV. The pasting parameters indicated that HTHS extrusion processing followed by drying and grinding led to degradation of the flours, especially the starch fraction, irrespective of the drying method. It is well known that due to substantial mechanical energy input extrusion processing not only leads to cooking or gelatinization of the starch but also ruptures the starch granules, often leading to some dextrinization (Colonna and Mercier 1983; Davidson and others 1984a, 1984b; Colonna and others 1984; Diosady and others 1985). The post-drying grinding process also probably contributed to the flour degradation. It was clear from RVA data that lyophilization led to significantly less degradation than oven drying. Very little physico-chemical changes occur during the former process because of sub-zero temperature. However, thermal processing can lead to deterioration in properties (Schweizer and Reimann 1986; Holm and others 1988) even though a relatively mild drying temperature of 60°C was employed in this study.

Mixograph peak height (PH) and peak time (PT_M) for the control were 45.4 % and 3.5 min, respectively. PH for lyophilized and oven-dried pre-cooked flours was 50 and 70% lower, respectively, as compared to the control. The differences in PH for all three flours were significant ($P < 0.05$). PT_M for both pre-cooked flours was also substantially lower (by 85%) than the control, although there was almost no difference between the oven-dried and lyophilized, flours. The mixograph parameters provide, a measure of dough water absorption, visco-elastic strength and stability or tolerance to over-mixing (Bello and others 1991; Atwell 2003). Usually, flours with good gas-holding properties and machinability for products like bread and tortillas have higher water absorption, take longer time to mix and have a better tolerance to overmixing than does poor quality flour (Atwell 2003). Most of these attributes are a function of the flour protein content and quality, but also depend on the other ingredients in the dough, for example, shortening (Bello and others 1991). PH is the height of the mixograph center curve at the highest point, and relates to water absorption and protein. PT_M is the time of mixing to reach PH or the dough development time. PH and PT_M of the mixograph curve approximately correspond to optimally developed dough. Mixograph results indicated that HTHS extrusion processing led to deterioration of protein quality, and thus poor water absorption and visco-elastic strength as compared to the control. The high thermal and mechanical energy input to the flour during extrusion, would cause denaturation of proteins, thus rendering them ineffective for dough development. It is also clear from PH data that lyophilized flour was significantly better in quality than oven-dried flour. The latter clearly led to further deterioration in protein quality, while lyophilization effectively prevents any additional physico-chemical changes.

Both RVA and mixograph data suggested that although HTHS pre-cooking led to poor flour quality and rheological properties, lyophilization was a better drying method than oven drying for the pre-cooked flour. Thus only lyophilized pre-cooked flour was used for all subsequent experiments.

2.5.2 Rheological properties of pre-cooked flour with different bran levels

The specific mechanical energy (SME) input to the flour during extrusion processing ranged from 290-300 and 300-375 kJ/kg for LTLS and HTHS conditions, respectively. This indicated that substantial mechanical energy was imparted to the flours, and HTHS process led to greater energy input, as expected. Pasting properties of uncooked (control) and pre-cooked flours with 0 – 30% bran are shown in Table 2.2-a. PT_R did not show any significant trend with respect to bran level. For all three types of flours (control, LTLS and HTHS), PV decreased as bran levels increased, with the exception of LTLS pre-cooked flour containing 20% bran. Although the general trend was not statistically significant, it was attributed to a decrease in the water-swelling starch fraction due to its replacement with bran. Another possible reason could be the interference of bran or fiber with the gelatinization or water absorption of starch granules. Similar results were observed in studies by Brennan and Samyue (2004) on biscuit flour substituted by 0 – 10% dietary fiber (RS2 starch and inulin) and Arambula and others (2002) on tortilla flour substituted with 0 – 6% corn pericarp. Extrusion pre-cooking of flour led to decrease in PV at all bran levels, except in the case of LTLS pre-cooked flour with 20% bran. These differences were statistically significant in most cases, and were attributed to starch macromolecular degradation during the extrusion process as discussed earlier. Interestingly, at lower levels, of bran substitution (0 and10%) PV was higher for HTHS pre-cooked flour as compared to that of LTLS flour. This was contrary to expectation, as the more severe temperature and shear conditions during the HTHS process were expected to cause greater starch degradation and thus lesser swelling during pasting. This anomaly could be possibly due to some kind of synergistic effect of pre-cooked fiber and starch on water binding and swelling at lower bran levels (Arambula and others 2002).

Mixograph parameters for control and pre-cooked flours with 0 - 30% bran are shown in Table 2.2-b. For the control, PH and PT_M for the control were lower by 15 - 26% and 10 – 13%, respectively, when substituted with 10 – 30% bran, with the exception of PT_M for flour with 10% bran. This was as expected because bran disrupts the continuous protein-starch matrix, negatively affects development and leads to poor visco-elastic strength. Similar results were obtained for HTHS pre-cooked flours with 10 -30% bran as compared to no bran substitution, although the dough strength appeared to improve at 30% bran level. For LTLS pre-cooked flours, dough strength deteriorated with 10% bran but was substantially higher for 20 -30% bran substitution, as compared to 0% bran. Extrusion pre-cooking at HTHS and LTLS conditions decreased PT_M of flours with the same bran level, in most cases. LTLS pre-cooking of flours also decreased the PH, but on the other hand, HTHS pre-cooking led to an increase in PH. In general, mixograph data indicated that dough development and strength were negatively affected on substitution with bran. Extrusion pre-cooking led to protein denaturation, and thus negatively affected dough development. However it appeared that pre-cooking also led to synergistic interactions between bran and with other components of the flour, resulting in improvements in the dough, especially using LTLS conditions for higher bran levels (20 – 30%) and HTHS conditions for lower bran levels (0 – 10%). Caprez and others (1986) reported an improvement in dough strength on boiling of wheat bran prior to substituting flours at 20% level. They attributed this synergistic effect to the partial gelatination of starch present in the wheat bran. However, other thermal treatments (steam cooking, autoclaving, roasting, micronising and extrusion) of wheat bran led to deterioration in dough strength at the same substitution level. Bran levels other than 20%, however, were not studied.

The pasting (RVA) and mixograph results revealed a complex relationship between degree of processing, bran substitution, and the resultant dough properties. Addition of bran led to a deterioration in dough strength, due to a reduction in the protein and starch fractions, and disruption of the continuous visco-elastic matrix. Extrusion pre-cooking led to degradation of starch and protein, but the data pointed toward some synergistic affects between bran and other flour components due to pre-cooking. This, however, needs to be investigated further.

2.5.3 Quality of cookies from pre-cooked flour with different bran levels

The quality parameters for cookies from uncooked (control) and pre-cooked flours with 0 – 30% bran are given in Table 2.3. The average weight (w_c) of baked cookies varied by 9 and 7%, respectively, for the control and HTHS pre-cooked cookies. The weight variation was much higher (up to 22%) in the case of LTLS pre-cooked flours. The methodology for cookie making employed in the study was different than the standard methodology (AACC standard methods 10-52 and 10-53). In the latter, the cookie dough is flattened and then cut with a cookie cutter, which results in more uniform cookies. In this study, however, a scoop was used to dispense the cookie dough onto the baking pan according to the method described by Payne (1995). Although care was taken to minimize variation in the volume of batter dispensed by the scoop, this departure from the standard "cookie-cutter" method could be one of the reasons for the variation in w_c.

However, it is more likely that some other factors were responsible for the variation in w_c, as a definite trend was observed for w_c with respect to the bran level. For all three types of flour (control, LTLS and HTHS), w_c increased as bran levels increased from 0 – 30%. It is possible that cookies with higher bran level retained more water after baking because of binding of water by fiber. The effect of processing on w_c also exhibited an interesting trend with control > LTLS > HTHS. This was likely due to decreased water binding as the flour fraction was more degraded with higher degree of processing. Differences in cookie weight also corresponded with water retention and variation in final moisture in the study by Artz and others (1990).

For the control flour, cookie width (W) decreased and thickness (T) increased as the bran level increased from 0 – 30%. The W/T ratio or spread (Figure 2.4) correspondingly decreased with an increase in bran. All differences in W, T and W/T were significant. A very low spread indicates poor cookie quality. The spread mechanism in cookies is a function of the total availability of water (Fuhr 1962). Any change in composition of the flour which would make it more hydrophilic tends to decrease the spread, as less water is available for dissolving the sugar, which is the main spreading ingredient. In this study, higher bran level in the control flour probably led to greater water binding as discussed earlier, resulting in reduced spread. Similar results have been obtained in previous studies on incorporation of resistant starch dietary fiber (RS) (Ranhotra and others 1991) or rice bran (0 – 15%) (Sekhon and others 1997) into cookies, and RS, inulin or potato fiber (0 – 10%) into biscuits (Brennan and Samyue 2004). For both LTLS and HTHS pre-cooked flour, the trends for W, T and spread with respect to bran levels were different than the control. In general, LTLS and HTHS flours had greater W, lower T and correspondingly higher spread (Figure 2.3), as compared to the pre-cooked flours without any bran substitution. Pre-cooking of flour under both LTLS and HTHS conditions led to a significant decrease in spread. This was attributed to lesser water retention during baking.

2.5.4 Quality of tortillas from pre-cooked flour with different bran levels

Common attributes that determine tortilla quality include opacity, height, diameter and shelf stability (Adams and Waniska 2005). Consumers generally prefer opaque, fluffy tortillas that retain their freshness and flexibility for weeks. The quality parameters of tortillas from uncooked (control) and pre-cooked flours with 0 -30% bran are shown in Table 2.4. As discussed earlier extrusion pre-cooking of flour led to poor-dough development and low visco-elastic strength. In order to make a machinable dough that was fit for baking tortillas, 15 and 20% gluten was added, respectively, to LTLS and HTHS flours, as has been done previously for high fiber tortillas (Friend and others 1992). The level of gluten addition was determined based on 'trial-and-error' for optimum dough development and tortilla quality. The quality parameters, including weight (w_T), diameter (D), height (H), opacity, specific volume (V) and water activity (A_w), did not vary substantially. Weight of the tortillas (w_T) was not affected substantially by the bran level or degree of processing of the flour, as the same amount of dough was weighed while rounding the balls. The amount of water uptake increased on addition of bran. This led to evaporation of water during baking and shrinkage of tortilla diameters, as was observed for the control and LTLS pre-cooked flour. The height of tortillas from HTHS pre-cooked was, significantly higher. In general, LTLS pre-cooked flour tortillas had greater opacity, but lower specific volume. Opacity of tortillas results from diffraction of light from the surface of air bubbles (Adams and Waniska 2005), and less number of bubbles lead to greater translucency. Results indicated that tortillas from LTLS flour probably had more air bubbles, leading to greater opacity. The A_w of all the tortillas was very high (> 0.91). The optimum A_w for preventing mold growth is usually below 0.70. This underscores the need for preservatives to enhance the shelf-life.

Figures 2.5, 2.6 and 2.7 show the results from storage studies for the tortillas. In general, for all three flour types (control, LTLS and HTHS), rollability decreased with increasing bran levels and storage time (4 -16 d) (Figure 2.5). Rollability of tortillas from control (Figure 2.5-a) and LTLS flours (Figure 2.5-b) was similar, but rollability of tortillas from HTHS flours (Figure 2.5-c) was significantly lower. Tortilla extensibility, as measured by force and distance for rupture, is shown in figures 2.6 and 2.7. In general, force for rupture was higher and rupture distance shorter for tortillas from flours substituted with 10 – 30% bran, indicating a decrease in extensibility. Extensibility also decreased with increases in storage time from 4 to 16 d. Pre-cooking of flours by extrusion lowered their extensibility. Good tortillas are characterized as soft, extensible and flexible when fresh. The texture becomes firmer, less extensible and less rollable when the tortillas are stored at room temperature for a prolonged period of time. The loss of freshness and increased firmness in tortillas with increasing storage time were due to retrogradation of starch, as has been observed in previous studies (Seetharaman and others 1994; Adams and Waniska 2005). Decreases in rollability and extensibility with the addition of bran were caused by poor dough development as discussed earlier, and also reported by previous studies (Seetharaman and others 1994). Extrusion pre-cooking did not lead to any substantial improvement in tortilla quality or shelf stability.

2.6 Conclusion

The rheological properties of wheat flour substituted with 0 – 30% wheat bran were investigated. Extrusion processing was utilized for pre-cooking the fiber-enriched flours, in order to improve their functional properties with regard to cookie and tortilla production. Results indicated complex inter-relationships between bran level, processing condition, and the rheological and functional properties of the flours. With some modifications to the methodology employed in the current study, extrusion cooking has the potential to improve dough development of flours substituted with high levels of bran, although current results indicate that quality of cookies and tortillas from pre-cooked flour were either similar or inferior to those from uncooked flour. Future work should focus on extrusion pre-cooking of just the bran for improving its functionality.

2.7 Acknowledgements

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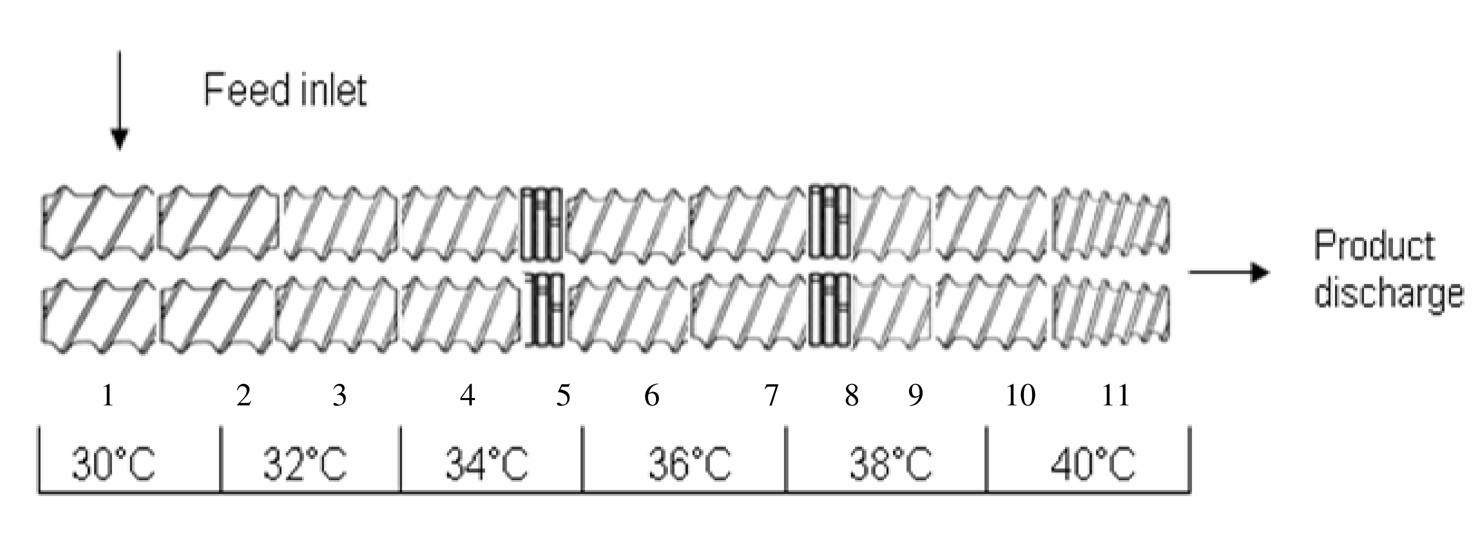
Figures

Figure 2.1 Schematic diagram for extruder screw profile[1] and barrel temperatures[2].



SE GFA				KB	SE GFA		KB	SE GFA		
2-30-60	2-30-60	2-20-60	2-15-60	4-4-20-30F	2-15-60	2-10-30	4-4-20-30F	2-15-60	2-15-30	2-10-60
1	2	3	4	5	6	7	8	9	10	11

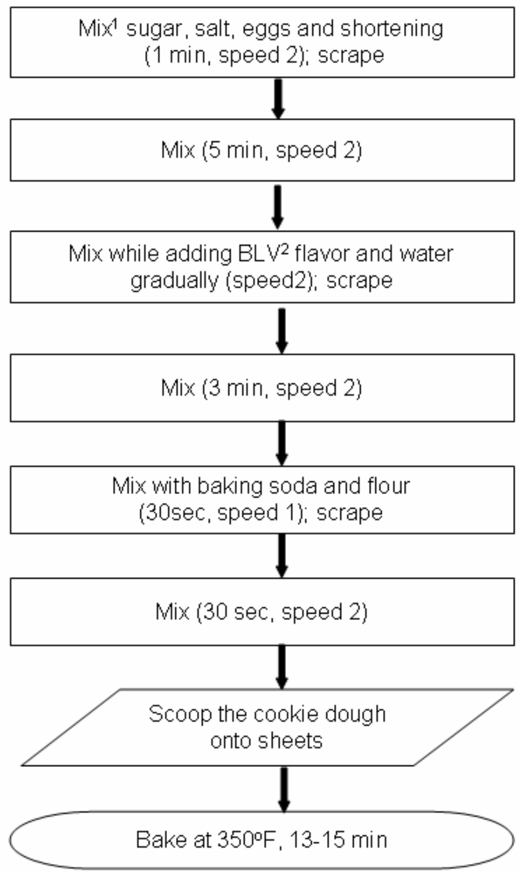
SE=screw element
Letters:
G- Co-rotating
F - conveying
A- free meshing
Numbers:
1st –number of flights
2nd - length of flight (mm)
3rd – total element length

KB = kneading blocks
Letters:
F- Forward
R- Reverse
Numbers:
1st- number of blocks
2nd- length of blocks (mm)
3rd- total element length (mm)
4th-angle of blocks

[1]All screws are double flighted with pitch progressively decreasing from feed to discharge ends.

[2]LTLS process temperatures (shown above) were 30-32-34-36-38-40˚C and HTHS process temperatures were 30-40-50-60-70-80˚C.

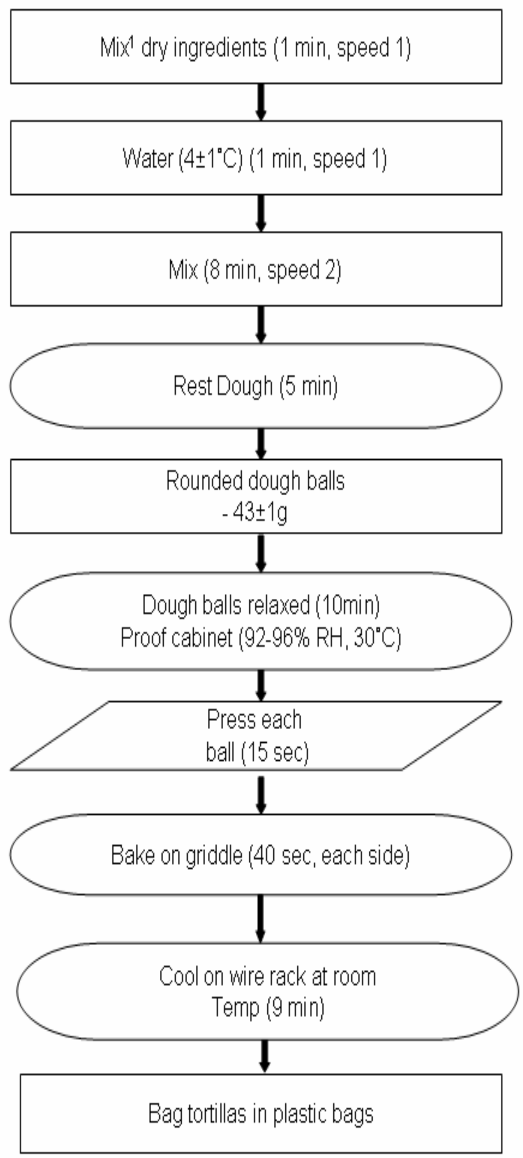
Figure 2.2 Schematic of the cookie making method.



[1]Mixer had speed settings from 1-3

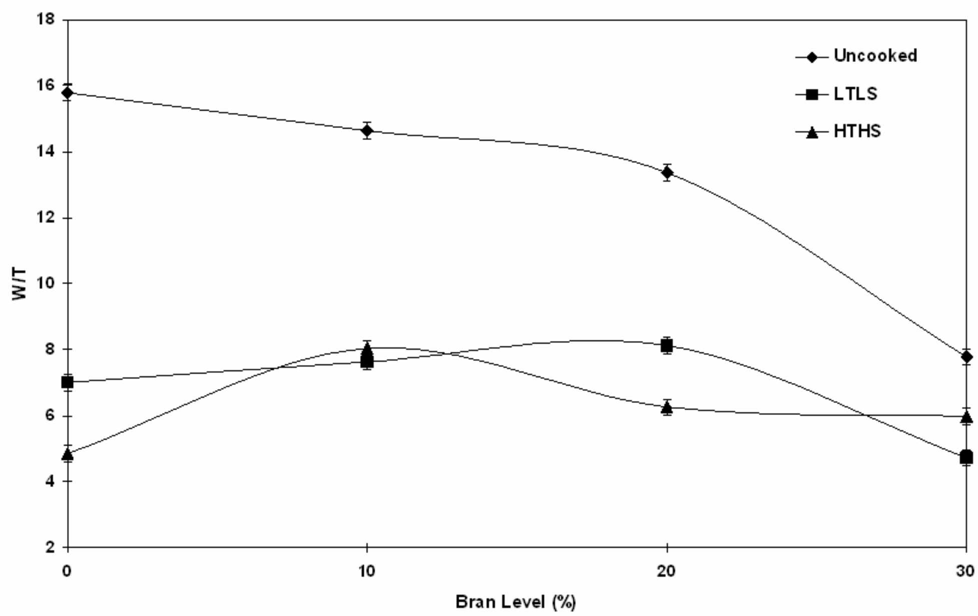
[2]BLV = Butter Lemon Vanilla

Figure 2.3 Schematic of tortilla making method.



[1]Mixer had settings from 1-3

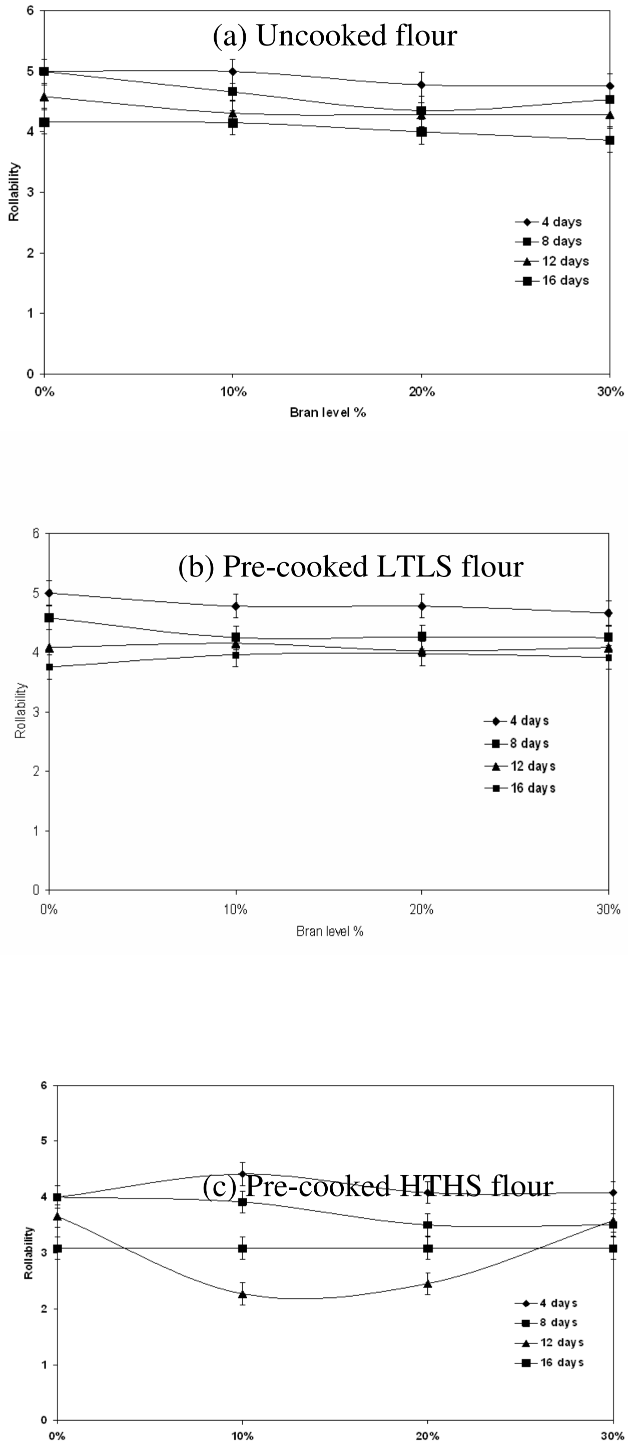
Figure 2.4 Spread (W/T ratio) of cookies from uncooked and pre-cooked wheat flours with 0 – 30% wheat bran.



[1]Y error bars denote the least significant difference, n = 3

[2]HTHS = high-temperature-high-shear extrusion processing conditions and LTLS = low-temperature-low shear extrusion processing conditions

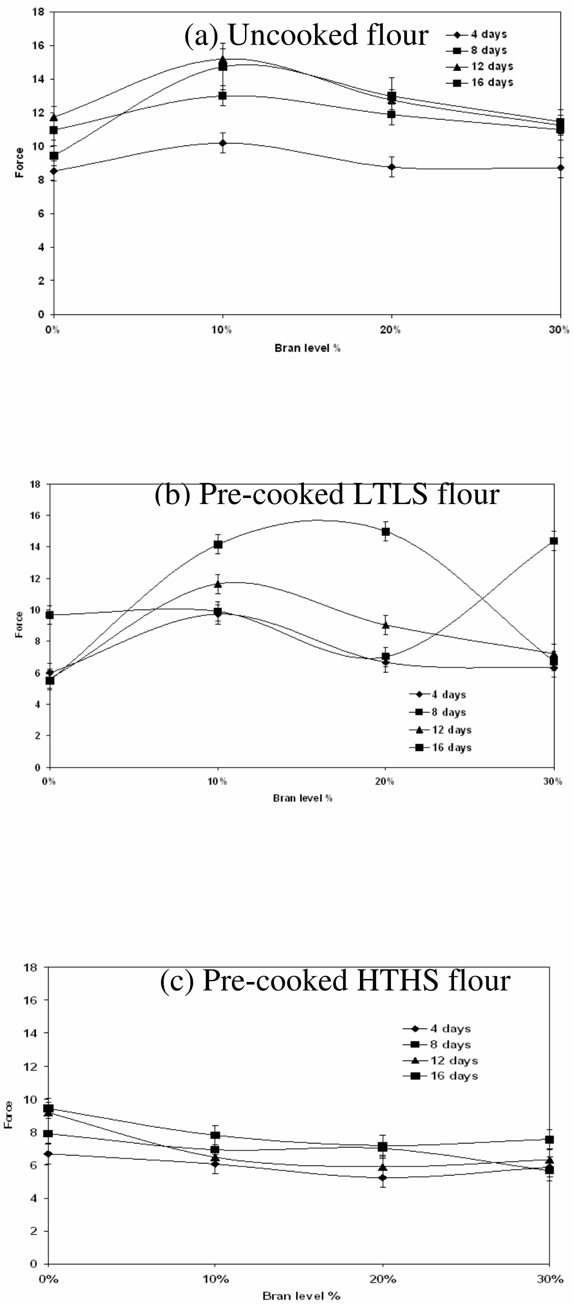
Figure 2.5 Rollability of tortillas[1] from (a) uncooked flour, (b) LTLS pre-cooked flour[2] and (c) HTHS pre-cooked flour, after storage for 4, 8, 12, and 16 d.



[1]Y error bars denote the least significant difference, n = 3

[2]HTHS = high-temperature-high-shear extrusion processing conditions and LTLS = low-temperature-low shear extrusion processing conditions

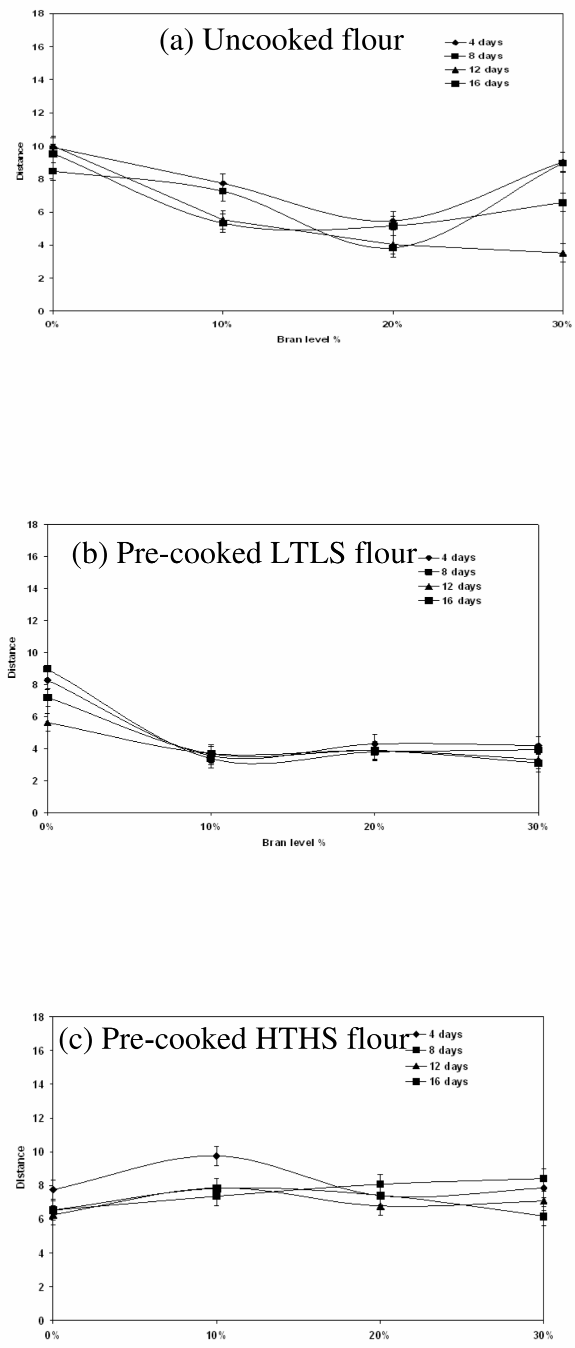
Figure 2.6 Extensibility (force) data for tortillas from (a) uncooked flour, (b) LTLS pre-cooked flour and (c) HTHS pre-cooked flour, after storage for 4, 8, 12, and 16 d.



[1]Y error bars denote the least significant difference, n = 3

[2]HTHS = high-temperature-high-shear extrusion processing conditions and LTLS = low-temperature-low shear extrusion processing conditions

Figure 2.7 Extensibility (distance) data for tortillas from (a) uncooked flour, (b) LTLS pre-cooked flour and (c) HTHS pre-cooked flour, after storage for 4, 8, 12, and 16 d.



[1]Y error bars denote the least significant difference, n = 3

[2]HTHS = high-temperature-high-shear extrusion processing conditions and LTLS = low-temperature-low shear extrusion processing conditions

Table 2.1 Rheological properties[1] of uncooked flour and HTHS[2] pre-cooked flour[3] prepared by oven drying and lyophilization.

Flour type	RVA peak visc (cP)	RVA peak time (min)	Mixograph peak height (%)	Mixograph peak time (min)
Uncooked	2237[a]	5.92[a]	45.4[a]	3.5[a]
Lyophilized HTHS	1480[b]	5.5[b]	22.9[b]	0.5[b]
Oven dried HTHS	1160[c]	5.8[a]	13.8[c]	0.5[b]

[1]Mean, n = 3; Means with same superscript in the same column are not significantly different ($p < 0.05$)

[2] High-temperature-high-shear extrusion processing conditions

[3]All flours had 0% bran substitution

Table 2.2 Rheological data[1] for uncooked and pre-cooked[2] wheat flour with 0 - 30% bran substitution –using (a) rapid visco analyzer (RVA) and (b) mixograph.

(a)

Flour type	Bran level (%)	Peak Visc (cP)	Peak Time (min)
Uncooked	0	1059^{b}	4.9^{h}
	10	998^{bc}	5.0^{g}
	20	935^{bc}	5.2^{e}
	30	930^{bc}	5.1^{f}
LTLS pre-cooked	0	786^{d}	5.3^{d}
	10	783^{d}	5.3^{d}
	20	1231^{a}	5.3^{d}
	30	709^{cd}	5.2^{e}
HTHS pre-cooked	0	982^{bc}	5.6^{a}
	10	894^{cd}	5.4^{c}
	20	601^{e}	5.5^{b}
	30	527^{e}	5.6^{a}

[1]Mean, n = 3; Means with same superscript in the same column are not significantly different ($P < 0.05$)

[2] HTHS = high-temperature-high-shear extrusion processing conditions and LTLS = low-temperature-low shear extrusion processing conditions

(b)

Flour type	Bran level(%)	Peak Height (%)	Peak time (min)
Uncooked	0	44.6^{b}	4.1^{bcd}
	10	37.9^{bc}	5.2^{abcd}
	20	$33.2c^{cd}$	3.7^{cde}
	30	34.4^{cd}	3.6^{def}
LTLS precooked	0	26.8^{d}	0.8^{h}
	10	16.2^{e}	0.7^{h}
	20	31.3^{cd}	6.0^{a}
	30	36.5^{bc}	1.0^{gh}
HTHS Pre-cooked	0	66.1^{a}	5.8^{ab}
	10	66.6^{a}	4.9^{abcd}
	20	44.0^{b}	1.8^{fgh}
	30	61.6^{a}	2.2^{efgh}

[1]Mean, n = 3; Means with same superscript in the same column are not significantly different ($P < 0.05$)

[2] HTHS = high-temperature-high-shear extrusion processing conditions and LTLS = low-temperature-low shear extrusion processing conditions

Table 2.3 Quality parameters[1] of cookies from uncooked and pre-cooked[2] wheat flour with 0 – 30% bran substitution.

Flour type	Bran level (%)	Weight (g)	Width (cm)	Thickness (mm)
Uncooked	0	49.8[e]	11.0[a]	0.7[f]
	10	52.7[c]	10.9[b]	0.7[f]
	20	53.9[b]	10.4[c]	0.7[f]
	30	54.5[a]	9.3[f]	1.2[e]
LTLS pre-cooked	0	42.0[h]	8.8[j]	1.3[d]
	10	42.4[g]	9.0[i]	1.2[e]
	20	49.9[e]	9.8[e]	1.2[e]
	30	51.1[d]	8.0[l]	1.7[b]
HTHS pre-cooked	0	41.0[i]	8.7[k]	1.8[a]
	10	41.1[i]	10.1[d]	1.2[e]
	20	43.8[f]	9.2[g]	1.5[c]
	30	42.5[g]	9.1[h]	1.5[c]

[1]Mean, n = 3; Means with same superscript in the same column are not significantly different ($P < 0.05$)

[2] HTHS = high-temperature-high-shear extrusion processing conditions and LTLS = low-temperature-low shear extrusion processing conditions

Table 2.4 . Quality parameters[1] of tortillas from uncooked and pre-cooked[2] wheat flour with 0 – 30% bran substitution.

Flour type	Bran level (%)	Weight (g)	Diameter (cm)	Height (mm)	Opacity (%)	Sp.Vol (m^3/g)	Aw
Uncooked	0	37.7^{c}	18.1^{a}	1.5^{e}	76.3^{b}	1.01^{b}	0.91^{f}
	10	38.4^{b}	14.4^{i}	2.2^{a}	73.4^{d}	0.94^{e}	0.93^{d}
	20	38.7^{a}	15.3^{d}	1.9^{c}	76.2^{b}	0.95^{d}	0.94^{c}
	30	38.7^{a}	15.6^{c}	1.9^{c}	72.4^{e}	0.95^{d}	0.95^{b}
LTLS Pre-cooked	0	37.6^{cd}	16.4^{b}	1.7^{d}	71.5^{f}	0.95^{d}	0.92^{e}
	10	36.6^{f}	14.3^{j}	2.0^{b}	77.4^{a}	0.88^{f}	0.94^{c}
	20	37.2^{e}	14.4^{i}	1.9^{c}	76.0^{b}	0.87^{g}	0.97^{a}
	30	36.3^{g}	15.3^{d}	1.7^{d}	77.8^{a}	0.87^{g}	0.95^{b}
HTHS Pre-cooked	0	38.4^{b}	14.6^{h}	2.2^{a}	74.2^{c}	0.95^{d}	0.94^{c}
	10	37.6^{cd}	14.9^{g}	2.2^{a}	74.1^{cd}	1.02^{a}	0.95^{b}
	20	37.4^{de}	15.1^{f}	2.0^{b}	74.8^{c}	1.01^{b}	0.94^{c}
	30	37.4^{de}	15.2^{e}	2.0^{b}	72.2^{ef}	0.99^{c}	0.93^{d}

[1]Mean, n = 3; Means with same superscript in the same column are not significantly different ($P \leq 0.05$)

[2] HTHS = high-temperature-high-shear extrusion processing conditions and LTLS = low-temperature-low shear extrusion processing condition

CHAPTER 3 - Fiber-Enriched Wheat Flour Pre-cooked Using Extrusion: Nutritional and Sensory Characteristics

3.1 Abstract

Effect of pre-cooking by extrusion processing on the dietary fiber profile of wheat flour substituted with 0, 10, 20 and 30 % wheat bran was evaluated. Depending on the level of bran, total dietary fiber (TDF) and soluble dietary fiber (SDF) in uncooked flours ranged from 4.3 to 19.5 % and 1.5 to 2.6 %, respectively. Pre-cooking by extrusion significantly increased SDF in flours (by 22 to 59 %), although in most cases it also led to a significant decrease in TDF. Cookies and tortillas, produced from uncooked and pre-cooked flours with 0 and 20% substituted bran, were evaluated for consumer acceptability using a 9-point hedonic scale. With a few exceptions, all cookies had scores ranging from 6 to 7 (“like slightly” to “like moderately”) for each attribute, including overall acceptability, appearance, texture, crumbliness and flavor. Tortillas were rated for the same attributes except for crumbliness, which was replaced with chewiness. In most cases, tortilla scores ranged from 5 to 7 (“neither like nor dislike” to “like moderately”). Organoleptic properties of cookies from uncooked flour did not change significantly with increase in bran substitution from 0 to 20%. However, consumer ratings for tortillas did decrease slightly but significantly with increase in bran level. Pre-cooking of the flours using extrusion did not improve the sensory properties of cookies and tortillas, although the products were still found acceptable by consumers and also contained higher soluble fiber.

Keywords: Extrusion, wheat bran, dietary fiber, sensory properties, cookies, tortillas

3.2Introduction

In recent years, dietary fiber has received increased amount of attention. Several studies have related consumption of dietary fiber and whole grains with reduction in chronic ailments like high serum cholesterol, and cardiovascular disease (Anderson and others 1991; Gordon 1999; Jones 2006), certain forms of cancer (Burkitt and Trowell 1975; Whitehead and others 1986; Gordon 1999; Decker and others 2002) and constipation (Lue and others 1991; Kantor and others 2001). In 2001, the Food and Nutrition Board of the Institute of Medicine estabilished a recommendation for total dietary fiber intake of 38 and 25 g per day for adult men and women, respectively (IOM, 2002).

There are various definitions of fiber (Englyst and others 1995). According to the American Association of Cereal Chemists, dietary fiber is the edible parts of the plants or analogous carbohydrates that are resistant to digestion and absorption in the human small intestine with complete or partial fermentation in the large intestine and functional fiber (Seiz 2006). Dietary fiber can be divided into soluble (SDF) and insoluble dietary fiber (IDF). Both SDF and IDF are associated with several health benefits. Soluble fibers such as pectins and gums are known to be effective in reducing total blood cholesterol and promoting satiety. Insoluble fibers, such as cellulose and lignin help in treating constipation and reduce the risk of colon cancer and diverticular disease (Mongeau 1984; Best 1987; Lue and others 1991; Seiz 2006).

Whole wheat flour and wheat bran are two of the most commonly used and important sources of dietary fiber for the cereal based foods industry. Wheat bran is rich in insoluble fiber and to some extent water-soluble fiber as well. It comprises of crude fiber (10%), pentosans (26.5%), cellulose (21.4%), starch (7.51%), total sugar (5.04%), sucrose (2.98%), and reducing sugars (4.42%) (Pomeranz 1988). Other fiber sources of fiber such as soy hull (Seetharaman and others 1994; Seiz 2006), oat bran (Gualberto and others 1997; Seiz 2006), corn bran (Artz and others 1990a, 1990b), rice bran (Lima and others 2002) and citrus fruits (Seiz 2006) are also used to boost the fiber content in cereal products.

Many cereal-based foods, such as expanded snacks from corn (Artz and others 1990b), breakfast cereals from wheat, oat and barley (Wang and Klopfenstein 1993; Berglund 1994), and baked products such as cookies, bread, crackers and tortillas (Ranhotra and others 1990; Seetharaman and others 1994) are good carriers of dietary fiber (Dreher 1987). However, incorporation of fiber deteriorates the quality characteristics (such as expansion, loaf volume, spread and texture) of these products (Dreher 1995). Some studies have attempted to improve the functionality of fiber-based ingredients by thermal treatment. Various types of thermal treatments such as drum drying (Lima and others 2002), jet cooking (Lee and others 2006), autoclaving, roasting, micronising (Caprez and others 1986), mechanical treatments such as fine-milling (Galliard and Gallagher 1988), and thermo-mechanical treatments such as extrusion cooking (Caprez and others 1986; Camire and others 1997) have been attempted for modifying the properties of fibrous ingredients such as wheat bran, rice bran and corn fiber with some success.

The thermo-mechanical nature of extrusion cooking has the added potential of improving the nutritional quality of fiber. Several researchers (Aoe and others 1989; Ralet and others 1990; Wang and Klopfenstein 1993) have shown significant increase in SDF content in extruded wheat bran. Some studies have also reported increase in TDF and SDF content of potato peels by using extrusion processing (Camire and Flint 1991; Camire and others 1997). Contradictory results have been reported as well (Asp and Bjorck 1989). According to Varo and others (1983) and Artz and others (1990b), extrusion cooking causes no significant changes in soluble and insoluble fiber, while reduction in fiber content has also been reported (Fornal and others 1987) because of extrusion cooking. When extruding flours or whole formulations, the effect on nutritional properties of other components also needs to be considered. For example, although extrusion has been shown to increase the total dietary fiber content of wheat flour (Theander and Westerlund 1987), it negatively affects the nutritional value of proteins due to Maillard reactions and also leads to loss of heat-labile vitamins (Singh and others, 2007).

Apart from functional and nutritional improvements due to thermal/ mechanical treatment of fiber based ingredients, the sensory characteristics of the final product could also be positively affected. A previous study by our research group described the modification of wheat bran - enriched flour by extrusion cooking with the goal of improved functionality in making tortillas and cookies (chapter 2). The current study focuses on determining the effect of extrusion cooking on dietary fiber profile of flour enriched with wheat bran. The consumer acceptability of cookies and tortillas made with the pre-cooked flours was also studied.

3.3 Materials and Methods

3.3.1 Flour processing

Commercial hard red winter, with moisture, protein and ash contents of 14, 11.8 and 0.5%, respectively, was obtained from Horizon Milling, LLC (Wichita, KS). The flour was substituted with 0, 10, 20 and 30% hard red winter wheat bran obtained from the pilot mill in the Department of Grain Science and Industry, Kansas State University. The wheat flour substituted with 0 – 30% bran was processed in a laboratory scale American Leistritz Micro 18 twin-screw extruder (American Leistritz Extruder Corp., Somerville, NJ) with barrel temperatures of 30-32-34-36-38-40˚C and screw speed of 200 rpm. The extruder screw profile and barrel temperature zones are shown in Figure 2.1 (LTLS conditions). Feed moisture content was maintained at 30% (wet basis) for all treatments. The target moisture was achieved by mixing the flour with water in a KSM5 Kitchen Aid (St Joseph, MI) mixer, taking the initial moisture of the flour into account. The hydrated flour was stored overnight at 4˚C for equilibration before extrusion. The ribbon-like extruded product was dried using a Labconco FTS System Inc. (Kansas City, MO) freeze drier. The moisture content of the dried flour ranged between 3.9 – 7.4 % (wet basis). The dried product was ground to pass through a 0.5-mm sieve using a Thomas Wiley Model 4 laboratory mill (Arthur H. Thomas Company, Philadelphia, PA). For control studies, uncooked flour was also substituted with 0-30% bran that was ground using the same mill to pass through a 0.5-mm sieve.

3.3.2 Dietary fiber analysis

Megazyme thermostable α-amylase (E-BLAAM), protease (E-BSPRT) and amyloglucosidase (E-AMGDF) were obtained from Megazyme International Ireland Ltd (County Wicklow, Ireland). Ethanol (95%) and acetone were obtained from chemical stores at Kansas State University, Manhattan, KS. Standard solutions such as MES-TRIS buffer solution, ethanol (78%) and HCL solution (0.561 N) were prepared to analyze the total dietary fiber, soluble dietary fiber and insoluble dietary fiber content. MES-TRIS buffer solution, 0.05 M was obtained by dissolving 19.52 g 2(N-morpholino) ethanesulfonic acid (MES) (M 8250, Sigma-Aldrich, St. Louis, MO) and 14.2 g tris (hydroxymethyl) aminomethane (TRIS) (T1503, Sigma-Aldrich) in 1.7 L deionised water, adjusted to pH to 8.2 with 6.0 **N** NaOH and diluted with water to 2 L. Ethanol, 78% concentration was obtained by diluting 1-of 95% ethanol with 207 mL water. Similarly, HCL solution (0.561 N) was obtained by adding 93.5 mL of 6 **N** HCL to approximately 700 mL of water in a volumetric flask, and diluting the resultant solution to 1-L with water.

Total, soluble and insoluble dietary fiber contents of wheat bran, uncooked flour and pre-cooked flour substituted with 0, 10, 20 and 30% bran were determined using the AACC Approved Method 32-21 (AACC 2000) with slight modifications. One gram of sample and 40 mL MES-TRIS buffer solution was added in 600 mL beaker. The sample was subjected to enzymatic digestion by adding 50 µL of heat-stable α-amylase in a water bath (95 - 100˚C) and shaken continuously. After 35 m, the sample was removed from water bath and 100 µL of protease was added, followed by incubation in the water bath at 60˚C with continuous stirring. After another 30 min, the sample was removed from water bath and 5 mL of 0.56 N HCL was added to adjust the pH to 4.1 – 4.8. A 200 µL amyloglucosidase solution was added to the sample again followed by incubation in the water bath at 60˚C for 30 m with continuous stirring. The enzyme digested solution was filtered through a celite-containing crucible and the residue was washed twice with 10 mL of water at 70˚C. The residue was then washed with 10 mL of 95% ethanol and acetone, and dried for overnight in 103˚C oven. The weight of the dried residue gave the insoluble dietary fiber (IDF) content. Filtrate from the crucible and water washings were precipitated with four volumes of 95% ethanol at 60˚C for soluble dietary fiber (SDF) determination. The precipitate was filtered, washed with 78%, 95% ethanol and acetone, and then dried over night. The weight of this dried residue gave the SDF content. The total dietary fiber (TDF) content of the sample was obtained from the sum of IDF and SDF values (Berglund and others 1994). IDF, SDF and TDF for uncooked wheat flour with 10 – 30% bran were calculated from the corresponding data for wheat bran and uncooked flour with 0% bran.

3.3.3 Cookie preparation

Cookies were prepared using uncooked and pre-cooked wheat flour with 0 and 20% bran as the base ingredient. The other ingredients in the cookie formulation, included sugar (90%; United Sugar Corp., Clewiston, FL), all purpose shortening (60%; ACH Food Companies Inc., Cordova, TN), dry eggs (7%; Michael Foods Egg Products, Gaylord, MN), salt (1.8%; Morton Salt, Chicago, IL), sodium bicarbonate (1.8%; Sigma Aldrich Co., St.Louis, MO) and Butter Lemon Vanilla flavor (1.0%; Mothers Murphy's Labs, Greensboro, NC). The relative amounts of all materials for the cookie formulation were expressed as baker's percentages. The formulation and the procedures for cookie dough preparation and subsequent baking as described in chapter 2 (Figure 2.2) were adapted from Payne (1995).

3.3.4 Tortilla preparation

Tortillas were also prepared using uncooked and pre-cooked wheat flour with 0 and 20% bran as the base ingredient. The other ingredients in the tortilla formulation included all purpose shortening (11%), salt (1.5%), sodium bicarbonate (1.5%), potassium sorbate (0.5%), sodium propionate (0.5%), sodium stearoyl lactate (0.5%), fumaric acid (0.2%) and cysteine (0.003%). These ingredients, except for the first two, were obtained from Sigma Aldrich Co. (St.Louis, MO). The relative amounts of all materials for tortilla formulation were expressed as baker's percentages. The tortilla formulation, and procedures for dough preparation, pressing and subsequent baking as summarized in chapter 2 (Figure 2.3) were adopted from the standard method described by Bello and others (1991). For pre-cooked flours, a few modifications were made to the methodology. These included addition of 15% wheat gluten (MGP Ingredients, Atchinson, KS) and water addition level changing from 65 to 71% as bran levels increased from 0 to 30%.

3.3.5 Color

A hand held chroma-meter (Model CR-210, Minolta, Japan) calibrated with standard white plate (Model CR-210, Minolta, Japan; Y = 94.5, x = 0.3129, and y = 0.3199) was used to measure the lightness (L), redness (a), and yellowness (b) color value of the test cookies and tortillas. The dimension 'L' represents lightness with 100 for white and 0 for black, 'a' indicates redness when positive and greenness when negative, and 'b' represents yellowness when positive and blueness when negative. Color readings were taken from the center of each cookie and tortilla.

3.3.6 Consumer acceptability

The consumer acceptability study was reviewed and approved by the Institutional Review Board of Kansas State University (Manhattan, KS). A consumer panel consisting of 78 subjects (53 females and 25 males) was recruited to rate cookies and tortillas on their overall acceptability and other attributes. All panelists were cookie and tortilla consumers and were provided with free ice-cream coupons as an incentive to participate. Participants were screened for critical conditions such as pregnancy and allergies to wheat. Background information for each panelist, including gender, frequency of consumption of high-fiber products, awareness of health benefits of such products and willingness to incorporate them in their daily diet was recorded. A 9-point hedonic scale (1 = "dislike extremely", 5 = "neither like nor dislike", 9 = "like extremely") was used to evaluate the products (Lawless and Heymann 1998). Cookies were rated for overall acceptability, appearance, texture/mouthfeel, crumbliness, and flavor. Tortillas were rated for overall acceptability, appearance, texture/mouthfeel, chewiness, and flavor. The cookies and tortillas were prepared 1 – 3 d prior to testing and stored at room temperature in sealed plastic bags. All the samples were randomized using 3-digit codes. The order of the treatments served to the consumers was also random, although cookies were served first and then tortillas. Drinking water and unsalted crackers were used to cleanse the mouth between the samples. Prior to serving, each tortilla was sprinkled with 25g of shredded Colby & Pepper Jack cheese (Kraft Foods, Northfield, IL) and heated for 25 s in a microwave oven (Model MA-1572M, Gold Star, Korea). Panelist were provided with quarter sections of tortilla sample thus prepared. The consumer acceptability data was collected using a computerized data collection system, Compusense® (Version 4.6; Compusense Inc., Guelph, Ontario, Canada).

3.4 Experimental design and statistical analysis

The effect of bran substitution and extrusion pre-cooking on the dietary fiber profile of wheat flour was investigated using a 4 x 2 complete factorial design, with 4 levels of bran substitution (0, 10, 20, and 30%) and 2 levels of processing (no pre-cooking, and LTLS extrusion pre-cooking). The IDF and SDF contents measured for wheat bran, uncooked flour with 0% bran and all the pre-cooked flours were averages from triplicate tests. Color values were averaged based on 6 samples from each treatment. Consumer acceptability tests were conducted on cookies and tortillas prepared from uncooked and pre-cooked flours with 0 and 20% bran levels only. Data were analyzed using general linear models procedure (PROC GLM) in SAS® (Version 9.1.3; SAS Institute, Cary, N.C.). Analysis of Variance (ANOVA) was performed on all data. Fisher's least square difference (LSD) was used as a post-hoc mean separation technique for treatments when ANOVA indicated significant differences among the samples. The consumer ranking data was analyzed by Friedman's chi-square test (Lawless and Heymann 1998). All statistical analyses were performed at a 5% level of significance.

3.5 Results and Discussion

3.5.1 Effect of extrusion processing on dietary fiber content

The total, insoluble, and soluble dietary fiber contents of the uncooked and pre-cooked flours are shown in Table 3.1. The insoluble dietary fiber (IDF) and soluble dietary fiber (SDF) contents of wheat bran were 43.03 and 4.62%, respectively. IDF and SDF of the uncooked flour without bran substitution were 2.7 and 1.5%, respectively. Ranhotra and others (1990) reported similar dietary fiber profiles for wheat bran (41.93%

IDF and 2.10% SDF) and wheat flour (1.42% IDF and 1.09% SDF). The dietary fiber profile of uncooked flours with 10, 20 and 30% bran were calculated based on IDF and SDF data for bran and unsubstituted, uncooked flour. For pre-cooked flours, the IDF, SDF and TDF increased significantly as bran substitution increased from 0 to 30%, as expected. Extrusion pre-cooking increased SDF by 22 - 59% and decreased IDF by 33 - 41%, respectively, depending on the bran level. These results indicated that the thermo-mechanical treatment undergone by the wheat flour and bran during extrusion led to conversion of the IDF to SDF, leading to an increase in the latter. However, the TDF of pre-cooked flours was up to 30% lower as compared to that for uncooked flours with the same bran level. This implied that a portion of both SDF and IDF were probably being converted to sugars due to extrusion treatment, leading to a decrease in TDF. Similar changes in the dietary fiber profile of various extruded products have been reported by numerous studies. SDF increased due to extrusion processing of wheat flour (Siljestrom and others 1986; Wang and Klopfenstein 1993), barley (Berglund and others 1994), sugar beet fiber with corn meal (Lue and others 1991), wheat bran (Caprez and others 1986; Aoe and others 1989; Ralet and others 1990; Wang and others 1993; Gualberto and others 1997), soy fiber (Qian and Ding 1996), and potato peels (Camire and Flint 1991; Camire and others 1997). The increase in SDF was usually at the expense of IDF due to fragmentation or other type of thermo-mechanical decomposition of cellulose and lignin that are major components of insoluble fiber. These above studies have reported conflicting results with regards to TDF, which either remain unchanged (Siljestrom and others 1986), decreased (Lue and others 1991), or even increased (Camire and Flint 1991; Camire and others 1997) in some cases. Increase in TDF due to extrusion was attributed to formation of resistant.

3.5.2 Color

The color parameters (L, a and b) for the experimental cookies and tortillas are shown in Table 3.2. Cookies and tortillas made from pre-cooked flours were significantly darker than those made from uncooked flours. Also, increase in bran level from 0 to 20% led to significant increase in the darkness of both products. In most cases, cookies and tortillas from pre-cooked flours were more redder (a value) and yellower (b value) in color than the products from uncooked flours. The change in redness was more pronounced than in yellowness. Increase in bran level from 0 to 20%, however, led to a much greater increase in redness and decrease in yellowness. Most differences in 'a' and 'b' values were statistically significant. Overall results indicated that both pre-cooking and increased bran level in flour led to cookies and tortillas that were substantially darker and redder in appearance. The wheat bran had a reddish brown color, thus higher levels of wheat bran substitution led to darker products. Also extrusion cooking probably might lead to Maillard browning reactions causing darker color for the pre-cooked flours and their products. Similar reasons were attributed for change in color in cookies and tortillas substituted with corn (Artz and others 1990a; Seetharaman and others 1994; Soto-Mendivil and Vidal-Quintanar 2000) or wheat bran (Jeltema and others 1983).

3.5.3 Consumer acceptability

3.5.3.1Cookies

Table 3.3 shows the consumer acceptability ratings for various sensory attributes of cookies. ANOVA results indicated that overall acceptability, appearance and flavor were significantly affected by the treatments, while texture and crumbliness were not significantly affected. Previous studies have shown that addition of fibrous ingredients such as corn, rice, oat and wheat bran to the formulation beyond a certain level (6 - 20%) decreases the organoleptic characteristics of cookies and biscuits (Vratanina and others 1978; Artz and others 1990a; Sekhon and others 1997; Soto-Mendivil and Vidal-Quintanar 200l; Haque and others 2002). However, chemical or physical treatment of fiber prior to their addition into the formulation could improve the sensory properties of the final product (Galdeano and others 2006). This was attributed to the destructuring and improvement of hydration properties of the fiber due to the pre-treatment. Our study indicated mixed results with regards to effects of bran level and pre-treatment on consumer acceptability of cookies. Increase in bran level from 0 to 20% did not significantly affect any of the attributes of cookies from uncooked flour, however, for pre-cooked flour similar increase in bran level decreased the overall acceptability, appearance and flavor. The decrease in appearance ratings corresponded with the color measurements discussed earlier which indicated that higher bran levels led to darker and redder products. Pre-cooking of flour with 0% bran did not significantly affects any attributes, while pre-cooking of flour with 20% bran significantly lowered the overall acceptability and flavor of the cookies. Cookies made from uncooked flour without any bran substitution received the highest mean hedonic scores for all the five attributes. However, cookies from all four treatments were acceptable to consumers, receiving hedonic scores ranging from 6 to 7 ("like slightly" to "like moderately") for all attributes with the exception of cookies made from pre-cooked flour with 20% bran that had crumbliness and flavor ratings slightly below 6. The ranking results mirrored the consumer attribute ratings and showed that all the cookies were preferred equally with no significant differences ($P < 0.05$).

In general, male ($N = 25$) consumers had higher overall acceptability scores than female ($N = 53$) consumers for all treatments except the pre-cooked flour cookies with 20% bran substitution. Both female and male consumers who were frequent consumers (more than once a week) gave higher scores to the cookies from pre-cooked flours. Out of 78 panelists, 76 were aware of health benefits linked to fiber-enriched products and were willing to use them in their daily diet.

3.5.3.2 Tortillas

Table 3.4 shows the consumer acceptability ratings for various sensory attributes of tortillas. ANOVA results indicated that all the attributes (overall acceptability, appearance, texture, chewiness and flavor) were significantly affected by the treatments. Just like cookies, previous studies on tortillas have shown that addition of fibrous ingredients from sources such as corn, oat, pea, soy and sugar beet to the formulation beyond a certain level (12 - 25%) decreases the sensory properties (Seetharaman and others 1994; Soto-Mendvil and Vidal-Quintanar 200l). Dreher (1995) also reported adverse effects of bran inclusion on tortilla sensory characteristics, such as appearance, texture, and chewiness. Our study indicated mixed results with regards to effects of bran substitution and extrusion pre-treatment on consumer acceptability of tortillas. Increase in bran level from 0 to 20% in uncooked flour significantly reduced the overall acceptability and all other attributes for tortillas except for chewiness. However, for tortillas made from pre-cooked flour, similar increase in bran level did not significantly affect overall acceptability, texture and chewiness. Pre-cooking of flour with 0% bran led to decrease in most of the attributes, while pre-cooking of flour with 20% bran did not significantly improve any of the attributes except for chewiness. Along with other attributes, appearance played a major role in determining the overall acceptability. The color measurements discussed earlier underscored this point, as darkness and redness increased with pre-cooking or increase in bran level. Similar to cookies, the tortillas made from uncooked flour without any bran substitution received the highest mean hedonic scores for all the five attributes. However, tortillas from all four treatments were acceptable to consumers, receiving hedonic scores ranging from 5 to 7 ("neither like nor dislike" to "like moderately") for most attributes.

The ranking results indicated that the tortillas from uncooked flour with 0% bran were liked the most, while tortillas from pre-cooked flour with 20% bran were the least liked. Most rankings were significantly different ($P < 0.05$). Male consumers had higher overall acceptability scores than female consumers for all the treatments. Both female and male panelists who consumed tortillas frequently gave higher acceptability scores for all the treatments.

3.6 Conclusion

Cookies and tortillas, prepared from uncooked and extrusion pre-cooked flours with 0 or 20% wheat bran substitution, were found to be acceptable (scores ranging between 5 and 7 on a 9-point hedonic scale) by consumers. With 20% bran substitution, up to 2.24 and 2.75 g of total dietary fiber, and 0.54 and 0.66 g of soluble fiber could be provided per serving of the cookies and tortillas, respectively. Organoleptic properties of the products made from uncooked flour substituted with 20% bran were similar or poorer than those from flour with no bran substitution. Pre-cooking of flour using extrusion processing did not improve the consumer acceptability of cookies and tortillas, however, it did improve their nutritional profile by increasing the soluble dietary fiber significantly.

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Tables

Table 3.1 Dietary fiber content[1] of uncooked and pre-cooked wheat flours with 0 - 30% bran.

	Uncooked flour[2]			Pre-cooked flour		
Bran level (%)	IDF[3] (%)	SDF[3] (%)	TDF[3] (%)	IDF (%)	SDF (%)	TDF (%)
0	2.7	1.5	4.2	1.7[d]	2.6[c]	4.3[d]
10	7.5	1.8	9.3	5.0[c]	2.2[d]	7.2[c]
20	12.4	2.2	14.6	8.2[b]	3.5[b]	11.7[b]
30	16.9	2.6	19.5	9.9[a]	3.7[a]	13.6[a]

[1]Mean, n = 3; Means with same superscript in the same column are significantly different ($P < 0.05$). All percentages are on dry weight basis.

[2]IDF, SDF and TDF for uncooked wheat flour with 10 – 30% bran were calculated using data from wheat bran (43.0% IDF and 4.6% SDF) and uncooked flour with 0% bran substitution.

[3]IDF = insoluble dietary fiber; SDF = soluble dietary fiber; TDF = total dietary fiber

Table 3.2 Color values[1] for (a) cookies and (b) tortillas from uncooked and pre-cooked wheat flour with 0 and 20% bran.

Flour type	Bran level (%)	(a) Color - Cookies		
		L	a	b
U[2]	0	77.0[a]	1.2[c]	25.3[a]
P[3]	0	71.3[b]	0.6[d]	21.9[b]
U	20	61.5[c]	5.4[b]	20.2[c]
P	20	58.7[d]	5.8[a]	21.1[b]

Flour type	Bran level (%)	(b) Color - Tortillas		
		L	a	b
U[2]	0	72.7[a]	0.4[d]	18.8[b]
P[3]	0	68[b]	1.3[c]	21.5[a]
U	20	61.4[c]	3.8[b]	15.6[d]
P	20	53.3[d]	5.5[a]	16.8[c]

[1]Mean, n = 6; Means with same superscript in the same column are significantly different (P < 0.05)

[2]U = uncooked flour

[3]P = pre-cooked flour

Table 3.3 Consumer acceptability (9-point hedonic scale) results[1] for cookies from uncooked and pre-cooked flours with 0 and 20% bran.

Flour type	Bran level (%)	Overall	Appearance	Texture	Crumbliness	Flavor
U[2]	0	6.7[a]	7.0[ab]	6.4[a]	6.1[a]	6.3[a]
P[3]	0	6.7[a]	6.7[bc]	6.5[a]	6.1[a]	6.4[a]
U	20	6.9[a]	7.2[a]	6.4[a]	6.2[a]	6.8[a]
P	20	6.0[b]	6.4[c]	6.3[a]	5.9[a]	5.7[b]

[1]Mean, n =78; Means with same superscript in the same column significantly different ($P < 0.05$)

[2]U = Uncooked flour

[3]P = Pre-cooked flour

Table 3.4 Consumer acceptability (9-point hedonic scale) results[1] for tortillas from uncooked and pre-cooked flours with 0 and 20% bran.

Flour type	Bran level (%)	Overall	Appearance	Texture	Chewiness	Flavor
U[2]	0	7.0[a]	7.2[a]	6.8[a]	6.5[a]	6.8[a]
P[3]	0	6.3[b]	6.4[b]	6.1[b]	5.9[bc]	6.3[ab]
U	20	6.0[b]	5.2[c]	6.0[b]	6.0[ab]	6.0[bc]
P	20	5.8[b]	4.8[c]	5.6[b]	5.5[c]	5.8[c]

[1]Mean, n =78; Means with same superscript in the same column are significantly different ($P < 0.05$)

[2]U = uncooked flour

[3]P = pre-cooked flour