Optimization of the Sensory, Texture, Color Properties and β-Glucan Content of Waxy and Non-Waxy Barley Flour Tortillas

BY

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This dissertation submitted to the Faculty of Graduate Studies of the University of Manitoba in partial fulfillment of the requirements for the degree of ***Doctor of Philosophy***

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ABSTRACT

Barley is a rich source of β-glucan and barley products containing 0.75g of β-glucan per serving have been allowed by FDA to carry the health claim that consumption of β-glucan may reduce the risk of heart disease. The aims of this thesis were to identify hulless barley genotypes and flour blends that would make tortillas with acceptable sensory characteristics and with β-glucan content that met the requirements for the FDA health claim. For the tortilla preparation an equation to predict the dough water absorption was developed based on RVA flour slurry viscosity. Focus groups were conducted to identify factors that influenced consumers in their selection of tortillas. Two groups, one of fibre conscious consumers (FCC) and one of fibre neutral consumers (FNC) had differing selection criteria and identified different tortilla samples as most and least preferred. Descriptive analysis trained panels identified ten attributes that, for both groups, distinguished the liked from the disliked tortillas. The most important were puffiness, breakability, moisture absorption, degree of compression, flavor intensity and bitter aftertaste. The same tortillas were analyzed instrumentally for texture and color properties. Correlations $\geq$0.90 were obtained between sensory breakability and the texture curve gradient, between sensory moisture absorption and the texture analysis time to rupture, between observed puffiness and the Minolta b^* (yellowness) value, and between initial bit hardness and hand rollability. Instrumental parameters were used to set acceptability criteria for the FCC and FNC. Tortillas were formulated from straight grade flour, dusted flour from shorts and dusted flour from bran from 19 genotypes. Using a response surface mixture statistical design, 10 blends were prepared for each genotype. Optimized, acceptable formulations for the FCC were obtained from waxy barleys CDC

Candle and CDC Alamo, and non-waxy Millhouse, that contained ≥2g β-glucan per serving, and for the FNC using Millhouse and AC Hawkeye with ≥ 1.5g β-glucan per serving. Highest levels of β-glucan were possible using waxy cultivars and high levels of dusted flour from shorts.

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Snehil Dua

TABLE OF CONTENTS

ABBREVIATIONS

AACC	American Association of Cereal Chemists
BU	Barbender units
C	Celsius
DFFB	Dusted flour from bran
DFFS	Dusted flour from shorts
EDTA	Ethylenediamine tetraacetic acid
FCC	Fibre conscious consumers
FDA	Food and Drug Administration
FNC	Fibre neutral consumers
FRF	Fibre rich fraction
HA	High amylose
HDL	High density lipoproteins
LDL	low density lipoproteins
MS Excel	Microsoft Excel
NA	Normal amylose
OWA	Optimum water absorption
RSM	Response surface methodology
RVA	Rapid Visco-Analyser
RVU	Rapid Visco-Analyser units
SD	Standard deviation
SF	Soluble fibre
SGF	Straight grade flour

TDF	Total dietary fibre
TIA	Tortilla Industry Association
TTBR	Time traveled before rupture
VLA	Very low amylose
ZA	Zero amylose

LIST OF FIGURES

LIST OF TABLES

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

Barley may be a small crop on global scale, but its impact on Western Canada is large. In peak years, more than 13 million tonnes are produced across the region. Barley has primarily been used for animal feeding and malting, while food applications of barley flour in North America have been limited to pot barley and some breakfast cereals. Incorporation of barley flour into the bakery products has been restricted to minor levels due to barley's lack of functional gluten. Interest of the food industry in barley has been renewed in the past decade partly due to the development of hulless lines. The interest of food industries in barley has increased due to the presence of certain bioactive compounds in the grain including a soluble fibre, β-glucan.

β-Glucan is associated with reducing the risks of major health problems including hypercholesterolemia, cardiovascular diseases, Type II diabetes and colon cancer. The US Food and Drugs Administration (FDA 2005) has recently acknowledged some of the benefits of barley β-glucan and has allowed barley food products to carry the health claim that consumption of at least 3g barley β-glucan per day, when consumed as part of a diet low in saturated fat and cholesterol, may reduce the risk of heart disease. To be eligible to carry this health claim, a food product must provide a minimum of 0.75g of β-glucan per serving.

Nutritionally barley has an advantage over other important cereal grains including wheat and oats. It is comparable to wheat in the amount and nutritional quality of protein, in energy value, and in vitamin and mineral composition. In addition barley contains significant amount of β-glucan. Barley has a distinct advantage over oats, another good source of β-glucan, in that β-glucan is distributed throughout the entire barley kernel. Oats kernel contains this soluble fibre mostly in the outer bran layer. Thus, oat bran has found a use in food industry. After the removal of the bran, β-glucan is substantially depleted in the oats flour. In barley the β-glucan is present throughout the kernel, and even refined products such as barley flour contain significant amounts of β-glucan. Bran of barley can be used in ways similar to oat bran. However, for economic viability of the barley crop, barley flour must also be utilized.

Barley flour has been used for the preparation of tortillas in the laboratory of Dr. Nancy Ames of the Cereal Research Centre, Agriculture and Agri-food Canada, Winnipeg MB. A project was carried out in this laboratory to investigate the potential for creating new food markets for barley. After preliminary research it was observed that unique functional properties of hulless barley flour were well suited to tortilla production. Tortillas of acceptability quality have been prepared from CDC Candle. However, no research has been reported to maximize β-glucan content in barley tortillas. It was recognized that further research was needed to investigate the nutritional, sensory and processing aspects of barley tortillas in order to develop tortillas with optimum quality.

Sensory acceptability of barley tortillas may be influenced by characteristics of the flour or flour blend used in tortilla preparation. Flours from different barley genotypes and milling fractions have reportedly affected the sensory quality and/or acceptability of breads, muffins, cookies, biscuits pasta and noodles. Research is needed to determine the effects of these factors on barley tortilla quality. The purpose of this research was to evaluate the effects of genotypes and milling fractions on the sensory quality and the β-glucan content of barley tortillas.

Thus the objectives of this thesis were, 1) to develop a method to determine optimum water absorption for barley tortilla dough, 2) to identify consumer preferences and attitudes towards barley tortillas with a wide range of sensory characteristics, 3) to develop criteria of acceptability for barley tortillas based on descriptive analysis and instrumental tests, 4) to identify barley genotypes most suitable for preparation of acceptable tortillas, and 5) to optimize combinations of flour fractions that produced acceptable tortillas with high β-glucan content.

CHAPTER 2

LITERATURE REVIEW

In this chapter information has been summarized about the types, structure and composition of barley, the effects of barley on product quality and acceptability, tortillas and their important quality characteristics, methods of measurement of these characteristics and methods for determining acceptability of tortillas. Information has also been collected about the effects of major chemical components such as protein, dietary fibre and type of starch, on tortilla quality.

2.1 BARLEY

2.1.1 History and current production

Barley cultivation has been archeologically traced back to 10,000 BC to the Fertile Crescent in the Middle East (Briggs 1978). Other areas where barley was grown at an early date were Ethiopia, China and Korea (Harlan 1979). Barley was also cultivated as a cereal crop in Scandinavia during the Bronze Age, about 2000 BC (Munck 1981). Today barley is the fourth major cereal grown worldwide after wheat, corn and rice (Nilan and Ullrich 1993).

Canada is the largest producer of barley in the world, with an estimated production of 11.64 tonnes for 2006 crop year (Alberta Agriculture Food and Rural Development 2006). This is 10% of world production, compared with 5% produced by USSR. Canada is also the world's largest barley exporter. In Canada most of the barley is produced on the prairies (Alberta, Saskatchewan, Manitoba) with about half coming from Alberta alone. However, in Canada, the food market for barley for human use is very small (up to 5%), while up to 75% of the total barley production is used as feed for animals (chicken, cattle, pigs) and the remaining 20% is used in the malting and brewing industry. Development of hulless barley over the past 20 years has revived the interest of researchers in barley (Rossnagel 1999). Due to the development of hulless barley, the health benefits of barley β-glucan can more easily be incorporated to foods for human consumption. However, to incorporate hulled barley in foods hull has to be removed.

2.1.2 Classification of barley genotypes

Cultivated barley (*Hordeum vulgare*) is a diploid having seven pairs of chromosomes that control the expression of a wide range of physiological and morphological characteristics. Barley can be hulled or hulless, 2-rowed or 6-rowed, waxy, non-waxy or high amylose.

The covered or hulled barley is one in which the lemma and palea (floral parts) adhere to the caryopsis (groat) at maturity. In naked or hulless barley the hull is loose and falls off during threshing. The hulled barley is most commonly used for malting and animal feed. But for human consumption, the hull must be removed by pealing or an abrasion process, called pearling. Pearling results in the removal of aleurone layers, which contain high concentrations of essential amino acids and vitamins and thus results in the loss of nutrients. On the other hand, hulless barley does not require pearling and hence the nutrients are retained.

Either of hulled or hulless barley can be two-rowed or six-rowed. Barley has three spikelets at each rachis node and these are alternately positioned. In six rowed types all the spikelets are fertile where as in two rowed barleys only the central spikelet is fertile. Kernels from two rowed barleys tend to be symmetrical in shape, although kernel size may differ, depending upon the position of kernel on the rachis. The central kernels in six-rowed barley too, are symmetrical, but the lateral kernels are twisted due to spike attachment and crowding.

Barley is also classified based on the amylose: amylopectin ratio in the starch. Barley starch may have zero to 40% amylose. Based on the proportion of amylose in the starch, barley may be classified as waxy (0-5% amylose), non-waxy (25-27%) or high amylose (40%) barley (Bhatty 1999).

2.1.3 Kernel structure

The kernel of barley is a one-seeded fruit called a caryopsis, in which the fruit coat is adherent to the seed. Husk, pericarp, testa, aleurone layers, embryo/germ and endosperm are major tissues of barley grain.

2.1.3.1 Husk

The husk is the outermost part of hulled barley, which is 8-15% of the seed. It consists of two leaf-like structures called lemma and palea, which completely cover the grain. The husk contains significant amounts of cellulose, arabinoxylan, lignin and minerals. It also contains polyphenols. Hulless barleys have lower amounts of these components.

Two-rowed barley (plump and large kernels) has lower husk content than six-rowed barley (lean and long kernels). The color of the grain depends on the pigments in the caryopsis and palea. The caryopsis contains anthocyanin pigments and a black melanin-like compound. Anthocyanin gives red color to the pericarp and imparts blue color to the aleurone layer.

2.1.3.2 Pericarp

Pericarp comprises of 2% of the kernel weight. It is attached to the husk by a cementing layer that is significantly low in hulless barley. The pericarp is also known as fruit coat and it consists of epidermis, hypodermis, cross-cells and tube cells. It is composed mainly of cellulose, arabinoxylan, lignin, protein and other minor components (MacGregor, 1998).

2.1.3.3 Testa

This thin tissue is bonded by two lipid layers and comprises 1-3% of total kernel weight. It contains celluloses, waxes and anthocyanogens (MacGregor, 1998). It is a semi-permeable membrane, which limits the movement of solutes to interior grain and the two lipid layers limit the movement of water from the interior to the aleurone layers.

2.1.3.4 Aleurone

The aleurone layers separate the endosperm from the other grain tissues. It comprises 5-10% of total kernel weight. It consists of 3 layers of lining cells with a very rigid structure, which is hard to break down mechanically. Thiamin, riboflavin, niacin, nicotinic acid, pantothenic acid, tocotrienol and biotin are found in both the aleurone and the embryo tissues. The aleurone layer also contains arabinoxylan, β-glucan, triglycerides, protein, phytic acid/ phytate, minerals, sucrose and anthocyanogens (MacGregor, 1998).

2.1.3.5 Embryo/germ

The germ or embryo comprises 2-4 percent of the kernel weight. The major components of the germ are, lipid (13-17%), protein and free amino acids (34%), sucrose (14%), raffinose (5-10%, arabinoxylan (8-10%), ash (5-10%), cellulose and some pectin. It also contains polymers of fructose, which is known as fructans or fructo-oligosaccharides.

2.1.3.6 Endosperm

Endosperm is the plant's major storage tissue for starch and protein, where starch is embedded in a protein matrix. It is the largest tissue in the kernel, and comprises 75-80% of the kernel. It is low in ash, oil and sugars. The endosperm cell walls are mainly composed of β-glucan (70%) and remainder is arabinoxylans, glucomannans, celluloses, proteins and phenolic constituents (Jadhav et al., 1998).

2.1.4 Milling of barley

Barley can be pearled, flaked or milled into different flours for human consumption. Pearling is an abrasive process to remove the outer layers, pericarp, testa and aleurone, of the kernel.

Fractionation of barley using dry milling is important for enrichment of compounds such as β-glucan, protein and starch. Pin milling and air classification, as a dry milling process, is relatively energy efficient and requires lower capital costs than does the conventional wet milling and separation process. Air classification of a flour, obtained through pin milling or fine grinding of seeds, separates and concentrates seed constituents into flour fractions differing in particle size and composition (Young 1975). Pin milling disintegrates seeds into particles, and air classification separates them on the basis of differences in density, mass, and projected area in the direction of flow. Vasanthan and Bhatty (1995) reported that air-classification of barley through pin milling resulted not only in protein-rich, fibre-rich and β-glucan-rich fractions but also facilitated separation of large and small starch granules which were purified by a short wet-extraction procedure. Dry milling and seiving is another approach used to obtain barley fractions rich in β-glucan (Knuckles et al 1992; Temelli 1995; Yoon et al 1995). This method is more time-consuming than the air-classification, but results in higher yield of the flour.

2.1.5 Chemical composition of barley

Similar to any other cereal grain, barley contains starch, protein, non-starch polysaccharides and lipids as its major components. Carbohydrates constitute 79-87% of the grain on dry weight basis. In addition to abundance in starch, barley also contains non-starch polysaccharides, which include cellulose, β-glucan, and hemi-cellulose. The greater part of the hemicellulose in barley is arabinoxylan. The minor components include sugars, vitamins and minerals. Barley composition is influenced by both genetics factors and environmental conditions and the interactions between the two (Andersson et al., 1999). In the case of β-glucan content, several studies have demonstrated that genetics has a greater influence than environment (Stuart et al., 1988; Peterson, 1991; Miller, 1995).

It has been reported that waxy barleys, are usually higher in β-glucan and total dietary fibre than non-waxy barleys (Newman and Newman 1991; Newman and McGuire 1991). Barley has wide genetic diversity and lines can be developed to meet different nutritional and functionality requirements.

Table 2.1 Chemical composition of barley

Component		g/100g	g/100g
Starch		30-72	
	Amylose[a]		0-45
	Amylopectin[a]		60-100
Protein		9-20	
	Hordeins[b]		35-40
	Globulins[b]		20-30
	Glutelins (structural)[b]		15-25
	Albumins[b]		3-5
Non-starch polysachharides		12-38	
	Cellulose/lignin		4-6
	β-glucans		3-15
	Arabinoxylans		4-11
Lipids		2-3	
Ash		2-3	
Sugars		0.6-3.7	
Fructans		0.2-0.9	

[a]g/100g of starch
[b]g/100g of protein
(Lehtonen and Aikasalo 1987; Han and Schwarz 1996; Jadhav et al 1998; Bhatty 1999; Sustagrain 1998; Izydorczyck et al 2000)

2.1.4.1 Starch

Starch constitutes 30-72% of the barley grain on dry matter basis. Starch granules vary in shape, size and composition depending on their botanical origin (French, 1984). The large and small granules are known as A- and B-type granules, respectively. The variation in composition and structure of hulless barley starches may influence the quality of starch-containing products. Therefore, choosing starch types and control of processing conditions are very important in subsequent starch utilization. Vasanthan and Bhatty (1995) reported that granules of barley starch vary from large lenticular (<6 mm, more often 2 to 4 mm in diameter) to small spherical (10 to 30 mm but mostly in the 10 to 30 mm range). Barley starch granules exhibit the A-type X-ray pattern (Kang et al 1985), and hence exhibit the crystallinity due to amylopectin. Small granules constitute 80 to 90% of the total number of starch granules but only 10 to 15% of the total starch weight (Goering et al 1973b). Large granules constitute a small proportion (10 to 20%) of the total number of starch granules but a high proportion (85 to 90%) of the total weight of starch.

Amylose content in barley starch may vary from 0-40 % (Zheng and Bhatty 1998), which indeed is a wide range and thus offers a wide potential for food and industrial applications. Hulless genotypes of [normal (20–30% amylose), waxy (1–5% amylose), zero amylose and high amylose (30–45%)] have been developed via traditional breeding practices (Izydorczyk et al 2000).

Both waxy and high amylose genes have some effects on starch granule size distribution. Starches from waxy barleys were reported to have a greater number of starch granules per endosperm, but the granules were smaller than those of non-waxy starch (Tester and Morrison 1992). By contrast, the high amylose gene was associated with a reduction in the mean volume of A-type granules, so the proportion by volume of B-type granules was increased (McDonald et al 1991). The relative quantities by number of A-type and B-type granules were unaffected by either mutation.

In high-amylose barley starch, B-type granules are larger and A-type granules are smaller than the corresponding granules in normal barley starch (Banks et al 1973; Morrison et al 1986). Also, the small granule fraction constitutes a relatively high proportion of the total starch. Hence, the granules in high-amylose starch have a more uniform size distribution. Small granules from waxy barley starch appear to be similar in size to those in normal barley starch, but the large granules occur in small numbers and constitute a high weight fraction of the total starch (Morrison and Scot 1986). The large-granule fraction, like that of high-amylose starch, appears to have fewer granules than normal barley starch in the 20 to 30 mm range (Goering et al 1973b).

2.1.5.2 Protein

Barley contains 9-14% of protein (Table 2.1), concentrated in the endosperm (especially at the periphery) and the aleurone layer of the seed. All four major classes of protein (albumins, globulins, prolamins and glutelins) are present in barley grains, where prolamins make up the largest portion (Table 2.1). Barley prolamins are called hordeins, while for wheat the prolamins are called gliadins and for oats the prolamins are called avenins.

2.1.5.3 Dietary fibre

Barley is a good source of dietary fibre, which includes soluble and insoluble carbohydrates and also lignins. Soluble dietary fibre includes β-glucan, arabinoxylans, and fructans. β-Glucan is composed of β (1→4) and β (1→3) glycosidic linkages and is the major component in the cell walls of barley grain endosperm. It forms a viscous and sticky solution when mixed with water (Dais and Perlin 1982). Depending on the cultivar and location/environrnent, β-glucan content in barley grain was reported to vary from 3 - 6% (w/w) (Table 2.1). However new genotypes have been developed since then, and β-glucan content as high as 15% has been reported in barley (Sustagrain, ConAgra). The structures, physiochemical properties, methods of extraction and purification of β-glucan have been investigated (Woodward and Fincher 1983; Klopfenstein and Hoseney 1987; Woodward et al 1988; Bhatty 1992; Bhatty 1993; Vasanthan and Bhatty 1995; Yoon et al 1995). Primary structural features of β-glucan include glycosidic segments and glycosidic linkage profile. Glycosidic linkage profile refers to the linkage sequence; the degree of polymerization (DP) of linear β (1→4) linked cellulose percentage ratio between β (1→4) and β (1→3) linked glucosyl units. This ratio is found to range from 69:31 to 72:28 in various barley genotypes (Woodward et al 1983; Bhatty 1999; Papageorgiou et al 2005). Three or four glucose units are attached to each other by β (1→4) linkages, and are separated by β (1→3) (Macgregor and Fincher 1993). No triosyl or tetrosyl units attached to each other by β (1→3) are found anywhere in the β-glucan chain (Macgregor and Fincher 1993).

Arabinoxylan content in barley grain ranges from 4 - 7% (Table 2.1). It consists of a β-(1→4)-xylose polymer as a backbone, while some xylose units are substituted with arabinose residues (mono, di, or oligo). The degree and pattern of substitution determine the solubility and functionality of arabinoxylans. Arabinoxylan chains can be cross-linked by phenolic acid, such as ferulic acid (MacGregor 1993). Degree of linkage also affects the solubility and solution properties of arabinoxylans. They are a minor component in endosperm cell walls but a major component in the cell walls of the aleurone and outer layers (seed coat, pericarp, etc) of the kernel. Similar to β-glucan, arabinoxylan can form a viscous solution in water.

The insoluble fibre fraction is composed of cellulose, resistant starch and lignin. Cellulose is a linear β (1→4)-D-glucan polymer, which is concentrated in the outer layer of barley grain. As a dietary fibre component, resistant starch cannot be digested in the small intestine but it is fermented by microflora in the colon. There are three types of resistant starch: physically inaccessible starch, resistant starch granules and retrograded starch. Processing raw food materials can destroy the first two, but the third one may be increased.

2.1.5.4 Lipids

Lipid content of barley ranges between 2-3% (Table 2.1). Fatty acids in cereals occur in the forms of neutral lipids, glycolipids, and phospholipids. The predominant fatty acids in barley are linoleic (55%), palmitic (21%), oleic (18%) and α-linolenic (6%) acids. The lipids, mainly distributed in the aleurone and germ, exist in both free and bound form in barley and other cereal grains. Lipids that form a complex with amylose are also known as bound lipids (Morrison et al 1993).

2.1.5.5 Minerals and vitamins

Ash content of barley grains ranges between 2 - 3% (Table 2.1). The predominant minerals are phosphorus, potassium, and calcium and a small amount of magnesium, sulphur, sodium and other trace elements is also present. Up to 85% of phosphorous in cereals and legumes occurs as phytic acid (Tsao et al 1997). Phytic acid has the ability to bind minerals, such as iron, zinc, magnesium and calcium. This mitigates bioavailability of these minerals for utilization in the body.

Barley contains all isomers (a, β, γ, and δ) of tocotrienols and tocopherols, which act as antioxidants and have been reported to have cholesterol lowering effect (McIntosh and Russell 1988; Wang et al 1993a). Barley is also a source of B-complex vitamins, especially thiamine, pyridoxine, riboflavin and pantothenic acid. Although barley contains a significant amount of niacin, some of it is bound to protein, which makes it biologically unavailable.

2.1.6 Health benefits of barley

Barley is a nutritious cereal grain that offers consumers many bioactive compounds that can help improve their health. These compounds have demonstrated biological activities, such reduction of total and LDL cholesterol, post-prandial glucose and insulin levels and cancer, and cardiovascular risks (Newman et al 1989; McIntosh et al 1991; Li et al 2003; Behall et al 2004a&b).

2.1.6.1 Hypocholesterolemic effect

There have been several reports on the hypocholesterolemic effect of barley. The effect has been seen in varying degrees in chickens (Newman et al 1991; Martinez et al 1992; Newman et al 1992; Wang et al 1992; Sundberg et al 1995) in mice, rats and Syrian hamsters (Oda et al 1991; Oda et al 1992; Oda et al 1993; Jackson et al 1994; Wang et al 1997; Ranhotra et al 1998) and human subjects (Newman et al 1989; McIntosh et al 1991; Li et al 2003 Behall et al 2004a; Behall et al 2004b). The non-starch polysaccharides from plants interfere with the re-absorption of bile acids, thereby causing a reduction in serum cholesterol levels (Akiba and Matsumoto 1980; Kirby et al 1981).

A study with 25 mildly hypercholesterolemic adults demonstrated 5 and 6% reduction respectively, in the serum cholesterol levels of these adults when they were administered diets containing 3g and 6g of barley β-glucan/day for 5 weeks (Behall et al 2004a; Behall et al 2004b).

McIntosh et al (1991) reported that 10 and 13% reductions were seen in LDL-cholesterol when the consumption of 3g and 6g β-glucan diets were compared to a 0g β-glucan diet. There was no significant effect on HDL-cholesterol levels. In the same study, the effects of dry milled barley products (barley bran and barley flakes) were compared to those of wheat on 21 mildly hypercholesterolemic men, and a significant reduction in serum cholesterol and LDL-cholesterol was found. The subjects consumed test diets containing 1.5g (wheat control) or 8g β glucan per day (barley diet) for two consecutive 4-week periods in the form of bread, pasta and biscuits. The hypocholesterolemic effect of barley was attributed mainly to its water-soluble fraction of β-glucan that results in increased viscosity and lower absorption of fats and lipids in small intestine (McIntosh et al 1991).

Qureshi (1986) attributed the cholesterol reduction to tocols in barley products and showed that tocols resulted in the inhibited activity of the rate-limiting enzyme 3-hydroxy-3-methylglutaryl coenzyme A (HMG-CoA). In humans regulation of this reaction in the liver was thought to be a major factor controlling cholesterol synthesis. Qureshi et al (1991a) showed that hypercholesterolemic pigs fed on tocotrienol-rich fraction isolated from palm oil had 44% lower total serum cholesterol and 60% lower LDL-cholesterol. This effect was later confirmed in human subjects. Peterson and Qureshi (1997) reported that serum cholesterol reduction was associated with tocols in animal studies fed brewer's spent grain diets enriched in tocols that were largely free of β-glucan. However, Glore et al (1994) correlated the decrease in HMG-CoA reductase and an increase in cholesterol 7a-hydroxylase activity (an enzyme that breaks cholesterol in the synthesis of bile acids) to the presence of β-glucan. Glore et al (1994) listed the following mechanisms for the hypolipidemic effect of soluble fibre, (a) binding of bile acids that results in the reduced bile pool and serum cholesterol; (b) fermentation of SF by colonic bacteria to produce short chain fatty acids (acetate, propionate and butyrate) that may inhibit hepatic cholesterol synthesis; (c) increased break-down of LDL-cholesterol and (d) indirect effect of replacement of dietary saturated fat and cholesterol by SF. It was suggested that β-glucan lowered the HMG-CoA activity.

Some of these research studies formed the basis for assigning a health claim to barley β-glucan by FDA (FDA 2006). This claim states that soluble dietary fibre from certain barley foods can help reduce cholesterol and the risk of coronary heart disease. The health claim states that consumption of minimum of 3g of β-glucan/day will produce significant reduction in cholesterol in human beings (FDA, 2006). To make this claim, a food made from eligible barley sources must contain at least 0.75 grams of β -glucan soluble fibre per serving.

The insoluble dietary fibre (IDF) from barley was found to be more effective at preventing dimethylhydrazine induced gastrointestinal tumors than was the soluble fibre rich barley bran (McIntosh et al 1993). The hypoglycemic effects of barley have been studied as well. It has been reported that several barley products resulted in reduced glycemic index values, higher satiety ratings and lower blood glucose responses than the related wheat counterparts (Granfeldt et al 1994; Yokoyama et al 1997).

2.1.6.2 Anti-carcinogenic effect

The effects of barley have also been investigated in alleviating colon cancer. Other studies (Chen et al 1984; Cummings and Branch 1986) suggested the mechanisms that involve colonic bacterial fermentation of soluble fibres to short chain fatty acids (SCFA), such as butyric, propionic and acetic acids inhibit cholesterogenesis. Further, it was evidenced that higher concentrations of SCFA (especially butyric acid) in colon have a protective effect with regard to the colon cancer in human beings (Kruh 1982).

2.1.7 Effect of barley on food product quality and acceptability

Owing to the nutritional quality and health benefits of barley, researchers have incorporated barley in products including breads, noodles, muffins, kishk, tortillas and chapattis (Bhatty et al 1986; Knuckles et al 1997; Cavallero et al 2002; Gujral et al 2003; Izydorczyk et al 2005; Erkon et al 2006) Research studies show the effect of fully or partially replacing the wheat flour with barley components in products like noodles, pasta, muffins and bread on the product quality. Bhatty (1986) reported that incorporation of more than 10% barley flour into white pan bread seriously affected loaf volume and appearance of the bread. Berglund et al (1994) reported that cereals produced by extrusion of 100% barley had limited expansion and high bulk densities, however, when blended with 50% rice, the bulk densities were reduced by 50%, and the appearance was similar to that of the 100% rice cereal. Extrusion resulted in increased alkaline viscosity and soluble fibre content of most cereals. In another study, when 20% of the wheat flour was replaced by a β-glucan rich fraction of barley, the bread had lower loaf volume and darker color than the wheat bread (Knuckles et al 1997). This bread contained more TDF and β-glucan than the wheat flour control bread. In the same study, pasta was prepared by replacing 20 and 40% semolina with the β-glucan rich fraction from barley. The color of pasta was also darker than that of the control semolina pasta. In a study by Izydorczyk et al (2005), when a fibre-rich fraction from waxy barley replaced 25% of white wheat flour in yellow alkaline and white salted noodles, the noodles were darker in color but required ~50% less cooking time.

Acceptability of a wide range of food products prepared with different levels of barley flour has been studied (Swanson and Penfield 1988; Berglund et al 1992). Berglund (1992) determined the acceptability of a wide variety of food products in which waxy hulless barley was incorporated. Swanson and Penfield (1988) developed an acceptable formula for whole-grain bread containing 20% barley flour and 30% whole-wheat flour.

Berglund et al (1992) reported that overall acceptability of 26% barley bread was not significantly different from the control that contained 26% whole-wheat flour. In the same study, carrot spice bars when prepared from 100% whole barley flour were not significantly different from 100% all-purpose flour carrot spice bars (Berglund et.al. 1992), but noodles containing 75% barley flour had lower acceptability for texture and appearance as compared to the commercially available whole wheat flour noodles, although the flavor scores for the two noodles were similar. In the same study, the less desirable texture and appearance of the noodles were attributed to the lower gelatinization of starch in the barley noodles. These studies aimed at achieving a higher TDF and β-glucan in products that had acceptable sensory properties.

2.2 TORTILLAS

Tortillas, a staple bakery food, have been homemade and widely consumed for centuries in Mexico and Central America. The popularity of tortillas has been spreading in North America where the tortilla industry is the fastest growing segment of the baking industry (TIA 2006). Traditionally tortillas were prepared from wheat or corn.

Apart from wheat and corn, the popular grains for tortilla production, tortillas have also been prepared from sorghum, triticale, soybean flour and barley (Amaya-Guerra et al 2004; Ames et al 2004; Bedolla et al 1983; Choto et al 1985; Serna-Saldivar et al 2004). Triticale, which has better nutritional quality than wheat, is environmentally more flexible than other cereals and shows better tolerance to diseases, drought, and pests than its parental species (Darvey et al 2000) and thus was used to prepare tortillas to increase the crop utilization (Serna-Saldivar et al 2004). Soybean flour has also been added to corn flour to improve protein quality of the tortillas (Amaya-Guerra et al 2004). Tortillas have also been prepared solely from barley grain components without any additives (Ames et al 2004).

2.2.1 Methods for preparation of tortillas

There are three major processing methods used to make tortillas (Serna-Salvidar et al 1998). The hand stretched method, in which tortilla is first sheeted and then hand-stretched into its final size, has the advantage that the tortilla has a homemade appearance. However, the irregular shape of tortilla and intensive labor requirements are the disadvantages of this method. The hot press method, most commonly used for flour tortillas, involves pressing of the proofed dough with a hydraulic stamping device into the final tortilla size. The die-cut method, most commonly used for corn tortillas, involves sheeting the dough into desired thickness in a long sheet, which is then die-cut into several tortilla size discs.

2.2.2 Methods for evaluation of tortillas

For sensory quality, appearance, flavor and texture are important attributes which characterize processed food products (Schutz and Wahl 1981). The appearance of food products in general, encompasses several basic sensory attributes such as color, opacity, gloss, visual structure, visual texture and perceived flavor. Of all these visual aspects, the effect of color is the most obvious and well studied (Imram 1999). The textural properties of a food are defined as a group of physical characteristics that arise from its structural elements, that are perceived by the sense of touch, and that are related to the deformation, disintegration, and a flow of the food under a force. Sensory quality of tortillas has been evaluated with both objective and subjective techniques. According to Waniska (1999), good quality flour tortillas should be soft, opaque, and flexible without cracking when folded, light-colored and well puffed (Waniska 1999). No such criteria have been developed for the quality of barley tortillas.

2.2.2.1 Instrumental methods

The color properties of tortillas, one of the most frequently evaluated characteristics, can be evaluated objectively for brightness (L^*), redness (a^*) and yellowness (b^*) values with a Minolta reflectance colorimeter Chroma Meter™ or with a Hunterlab Digital Color Difference Meter™ (Friend et al 1993; Wang and Flores 1999; Quintinar et al 2001). The *L^*, a^* and b^* values* have been measured to determine the effects of addition of spent soymilk (Okara) on corn tortillas. These parameters have also been used to study the effects of wheat classes and milling streams and infrared baking on wheat flour tortillas (Martinez-Bustos et al 1999).

Rheological or mechanical properties of tortillas have been determined objectively with a device that records the deformation of the tortilla under applied force. The most commonly used equipment for such tests are the TA-XT2i Texture Analyser and the Instron Universal testing Machine. These deformation tests (using different probes) are usually used to determine firmness and stretchability of tortillas. The maximum force required to puncture a tortilla has been considered as a measure of firmness and tensile strength of tortilla, while, the gradient of the curve has been considered a measure of stretchability. The area under the curve before rupture of the tortilla has also been recorded for determining tortilla texture. These TA-XT2i texture analyzer parameters have been used to determine the effects of starch, starch damage, gluten and other wheat proteins, partial waxy and waxy wheat flour, bicarbonate leaveners and leavening acids, and different processing and storage conditions on wheat tortilla quality (Wang and Flores 1999; Cepeda et al 2000; Bejasano and Waniska 2001; Mao and Flores 2001; Seetharaman et al 2002; Waniska et al 2002; Guo et al 2003; Martinez-Bustos et al 2003). These texture parameters have also been used to determine the effects of addition of maize pericarp, corn lipids, lime and hydrocolloids (Arambula et al 2001; Arambula et al 2002) and the effects of processing and storage conditions (Campas-Baypoli et al 2002; Limanond et al 2002; Mendez-Albores et al 2003) on corn tortilla quality.

Rollability has also been measured instrumentally (Suhendro et al 1998) with a TA-XT2i texture analyser. In this method a custom-designed rollability dowel (1.9 cm diameter) was attached with the help of a metal chain to the texture analyzer arm of the TA-XT2i texture analyser. The force required to roll-up the tortilla was recorded and was found highly negatively correlated (r= -0.82) to the subjective tortilla rollability score. Thus, this force measurement was used as an objective predictor of tortilla rollability.

An objective bending technique has also been developed (Suhendro et al 1998) to measure the differences in uniformity, thickness and puffing of corn tortillas. A tortilla strip was bent to 40° angle using TA-XT2i texture analyser and bending modulus, peak force and bending work were recorded.

2.2.2.2 Sensory methods

Sensory methods help manufacturers, scientists and food technologists gain a clear perception of what ordinary consumers may experience. The panelists use several senses, making them more flexible than the mechanical instruments. The attributes measured by sensory panels are more realistic than those measured with instruments.

In tortillas, in addition to than color, presence of puffiness, toasted spots, opacity and the absence of cracks, have been reported to be important visual characteristics (Arambula et al 2001; Arambula et al 2002; Guo et al 2003; Pascut et al 2004a). Puffiness has been measured on a scale of 1-3 where, 1-corresponded to "no puffiness" and 3 corresponded to "complete puffiness" (Arambula et al 2001; Arambula et al 2002). Opacity of wheat flour tortillas has been measured subjectively for none to complete opacity (Cepeda et al 2000; Bajosano and Waniska 2004). A scale of 0-100%, where 0% corresponded to "completely translucent" (not white) and 100% corresponded to "completely opaque" (white) tortilla was used by Bajosano and Waniska (2004) while, a scale of 1-5, where 1= completely translucent and 5= completely opaque was used by Cepeda et al (2000).

Texture characteristics including rollability, flexibility, chewiness, moisture absorption and stickiness to teeth were reported for corn and barley tortillas (Vidal-Quintanar et al 2001; Waliszewski et al 2002; Bejosano et al 2005; Ames et al 2006). To evaluate rollability the most frequently used tortilla texture evaluation technique, a tortilla is to roll or fold the tortilla for a specific time (up to 30s) and judged the surface of the tortilla for number of cracks on a scale of 1-5 where 1 indicates several cracks and 5 indicates no cracks (Bedolla 1983; Twillman and White 1988; Torres et al 1993; Suhendro et al

1995). The higher the number of cracks, the lower is the rollability score. Rollability measurements have been used to study the effects of leavening agents (Bajesano and Waniska 2005), lime and hydrocolloids (Arambula et al 1999) and corn lipids (Arambula et al 2001) on corn tortillas and the effects of wheat classes and wheat flour streams (Wang and Flores 1999) and storage conditions (Cepeda et al 2003; Kelekci et al 2003) on wheat flour tortillas. Similarly, flexibility of flour tortillas has been evaluated by squeezing in the palm and unfolding it before checking for number of cracks on its surface (Reyes-Vega, 1998). According to this method, the higher the number of cracks, the lower the flexibility.

Descriptive analysis, a commonly used sensory method, has been used to identify, define and measure firmness, chewiness, moisture absorption and stickiness to teeth for corn, wheat and sorghum tortillas (Quintanar et al 2001; Waliszewski et al 2002). For descriptive analysis, a group of 6-12 individuals are trained to measure these attributes of a product before they measure such attributes in replicates (Meilgaard et al 1999). The training aims at reducing the differences between the scores given by the panelists. To reduce such variability between the panelists a reference sample is often included (Meilgaard et al 1999). Some sensory attributes have been measured for tortilla appearance, texture and flavor. Quintanar et al (2001) studied the effect of degermination on sensory characteristics of corn tortillas. The degermination prevented oxidation of lipids and thus improved shelf life of corn tortillas but the sensory quality of tortillas was adversely affected. The degermed tortillas were chewier and firmer ($p < 0.05$) than the tortillas made from whole corn tortilla dough. In another study, a trained panel found difference in flavor intensities of the corn tortillas fortified with okara at different levels.

It was concluded that there was significant increase in flavor intensity beyond 10% fortification with okara (Waliszewski et al 2002).

2.2.4 Consumer acceptability of tortillas

Consumer tests analyze the perception of the consumer towards the appearance of the product in terms of color, odor, taste, flavor and texture (when touching, when eating) among other properties. Tools used to determine consumer acceptability include focus group discussions, central location and home-use testing, consumer benchmarking and preference mapping.

2.2.5 Experimental designs for optimization

The classic approach for optimization is the one-variable-at-a-time techniques, which is time-consuming. Moreover, this technique does not depict the complete effects of the parameters in the process. An alternative method is response surface methodology (RSM), which is an important tool in process and product development. RSM is a collection of experimental designs and optimization techniques that enable the experimenter to determine the relationship between the response and the independent variables. RSM is typically used for mapping a response surface over particular region of interest, optimizing the response, or for selecting operating independent variables to achieve target specifications (Box and Draper 1987; Myers and Montgomery, 1995; Khuri and Cornell 1996). One of the designs used for product optimization is a mixture design.

A mixture experiment is a special type of response surface experiment in which the factors are the components of a mixture and the response is a function of the proportions of each ingredient. The mixture components cannot range in an independent way since their sum has to be equal to 100% and specific experimental matrices and mathematic models have to be used. This approach is suitable for pharmaceutical blending problems allowing investigation, with the least number of experiments, of the effects of changes in mixture composition and selection of the optimal composition for achieving the prefixed target (Myers and Montgomery 1995). Mixture experiments have been used to optimize the proportions of 2 to 4 components in both drugs and foods to give optimum stability and performance (Bodea and Leucuta 1997; Mura et al 2005; Alarcón-Valdez et al 2005).

2.2.6 Effects of major chemical components of flour on tortilla quality

Starch and protein are the two major components of barley flour. Wang and Flores (1999) have studied the effect of wheat starch and protein on the baking quality of the tortilla flour through reconstituting the flours. The major components of the flour, including proteins, starch and dietary fibre, were extracted and were combined in desired levels to reconstitute a variety of flours. It was concluded that the flour reconstitution did not fully recover the properties of original flours. Flour fractionation techniques may alter the natural bonds between protein and starch granules. The foldability of tortillas made from reconstituted flours was low (Wang and Flores 1999).

Guo et al (2000) studied the effect of amylose content of starch on tortilla properties. They observed that baked tortilla thickness was solely affected by amylose content; lower amylose flours produced thinner tortillas. They also concluded that compared to bread and noodles, amylose content was more important to tortilla whiteness. Other studies have suggested that low amylose flour dough could be responsible for poor retention of small air bubbles during and after tortilla baking and thus reduced the tortilla opacity and lightness (Seib 2000; Lee et al 2002).

2.2.7 Optimization of tortillas for sensory quality and for maximization of β-glucan content

2.2.7.1 Optimization of tortillas

Tortillas have been optimized for various reasons, but not for β-glucan content and consumer acceptability. Optimum levels of chickpea flour, lipids, hydrocolloids, resistant starch and extrusion process have been sought for optimum tortilla quality using factorial experiments (Holt et al 1992; Arambula et al 2001; Reyes-Moreno et al 2003; Rendón-Villalobos et al 2006). Holt et al (1992) studied performance characteristics of tortillas, prepared with different composite blends of wheat, cowpea and peanut flours, evaluated by mixture response surface methodology. Optimum wheat flour substitution levels were determined. Results indicated that wheat flour could be successfully replaced with up to 24% cowpea and 46% defatted peanut flours and result in tortillas with quality characteristics comparable to those from 100% wheat. Sensory evaluation indicated that beany flavor was the most limiting attribute.

2.2.5.2 Maximization of β-glucan content

Researchers have determined that the levels of β-glucan that can be incorporated in various beverages, soups, breads, cookies and breakfast cereals without any deleterious effects on the sensory quality, were different in various products (Lyly et al 2003; Lyly et al 2004; Sudha et al 2007). Lyly et al (2003) reported that the sensory and processing qualities of orange juice were affected when supplemented with 0.25-2.0% β-glucan from different types of oats. The low molecular β-glucan could be incorporated up to a level of 2% without causing significant problems in processing. However, the effects of 2% β-glucan supplementation on sensory quality were not very clear. At 1% β-glucan supplementation the flavor attributes were not different from the reference juice containing 1.3% CMC. The acceptability of these juices was not studied. It was suggested that warm beverages would be better vehicles to carry high levels of β-glucan because higher temperature resulted in lower viscosities. The same group of researchers (Lyly et al 2004) also studied the supplementation of β-glucan in a ready to eat soup. Beyond 1% supplementation with β-glucan from oats and barley, sensory properties were affected. Extensibility, thickness, and sliminess were higher for all the β-glucan supplementations beyond 1%, when compared with the reference sample (soup thickened with 0.8% starch). Tomato flavor on the other hand was suppressed with the supplementation. Consumer acceptability of these soups was not studied. Sudha et al (2007) reported that biscuits containing 2.4g of soluble fibre per 100g of biscuits prepared from barley were highly acceptable to the consumers. The serving size of biscuits, as recommended by FDA (1994), is 55g. Thus, these biscuits of acceptable quality could be eligible to carry the barley β-glucan health claim.

Hulless barley has been successfully used in unleavened foods including barley tortillas. A wide range of chemical composition of barley, that can be achieved through milling and breeding, can be utilized to optimize barley tortillas for sensory quality and to maximize β-glucan content. The results from this thesis can provide knowledge to utilize barley for tortillas that satisfy consumer expectations.

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CHAPTER 3

PREDICTION OF THE OPTIMUM WATER ABSORPTION FOR BARLEY FLOUR TORTILLA DOUGH

3.1 INTRODUCTION

Barley genotypes and their milling streams vary significantly in their chemical compositions (Aman et al 1985; Aman and Newman 1986; Henry and Brown 1987; Zheng et al 2000). The variation in chemical composition could be due to genotype effects (Aman et al 1985; Aman and Newman 1986; Zheng et al 2000), environmental effects (Bhatty 1999; Zheng et al 2000), or due to milling fractionation (Zheng et al 2000; Izydorczck et al 2005). Chemical composition can affect the water absorption of bread, noodle and tortilla dough (Sollars and Rubenthaler 1975; Park and Baik, 2002; Waniska et al 2002). When barley flour (β-glucan, 3.3%) was incorporated with wheat flour for making the Turkish flat bread, yufka, the amount of water added to form dough was reduced from the Farinograph water absorption by 1% for every 10% of barley flour substituted (Basman and Köksel, 2001). However, Izydorczyk et al (2005) reported that water in Asian noodle dough had to be increased when wheat flour was blended with a fibre-rich-fraction (FRF) of barley (β-glucan, 22%). The increase in water absorption was attributed to the β-glucan content and the porous structure of FRF. Gill et al (2000) also attributed the increased water uptake in barley flour to β-glucan. In their bread study, up to 15% of the wheat flour was replaced with barley flours, obtained from cultivars CDC Candle and Phoenix. The dough from CDC Candle was firmer and drier than that from

Phoenix at all levels of substitutions. These differences were attributed to the water-binding capacity of β-glucans which were present in higher amounts in CDC Candle flour than in Phoenix flour (Gill et al 2002).

When water absorption for wheat bread doughs is determined using a Farinograph, water is added to the flour being tested to the level that will centre the mixing curve on the 500 BU line (Legros and Castille 1972; Sollars and Rubenthaler 1975). Water absorption for wheat tortillas has also been estimated by this method, but with modification because tortillas require stiffer dough (Bello et al 1991; Suhendro et al 1995; Wang and Flores, 1999). These researchers all estimated the water absorption using a Farinograph curve centered on 750 BU (Barbender Units) as suggested by Bello et al (1991). Tortillas have also been prepared using 15% less water than the standard Farinograph water absorption (Bello et al 1991; Wang and Flores 1999; Wang and Flores 2000). Farinograph water absorption is largely determined by gluten content, and so it is suitable for wheat flours but cannot be used effectively for flours such as barley flour, that contain only trace amounts of gluten (Bhatty 1999).

Tortillas have been prepared from sorghum, barley and triticale as well as wheat and corn flours (Ames et al, 2003, Ames et al 2006; Serna-Saldivar et al 2004; Choto et al 1999). Ames et al (2006) added varying amounts of water to prepare tortillas with flours from different waxy and non-waxy barley genotypes to obtain tortilla doughs of the right consistency. When preparing non-wheat tortillas, the correct water requirement has generally been determined by dough feel (Serna-Salvidar et al, 2004). This is a subjective assessment and may vary from one experimenter to another. Moreover, this approach can be time consuming and may require a large amount of sample. A less time consuming, more objective water absorption method needs to be developed to standardize barley tortilla preparation for research studies.

It was hypothesized that barley flour water absorption would be related to the flour slurry viscosity. It was also hypothesized that for a given amount of water, higher water absorption flours would produce higher viscosity slurries, and lower water absorption flours would result in lower viscosity slurries. Therefore, the relationship between water absorption and viscosity could be the basis for predicting the optimum water absorption of barley flours for tortilla preparation.

The objectives of this study were 1) to develop a standardized, objective method to predict the optimum water absorption of barley flours for tortilla dough and 2) to determine the main component, or components, responsible for variations in water absorption among barley flours.

3.2 MATERIALS AND METHODS

3.2.1 Materials

The twenty barley samples used in this study were from the ten genotypes AC Hawkeye, CDC Alamo, CDC Candle, CDC Dawn, CDC Fibar, CDC Freedom, Condor, HB 805, Millhouse and SB 94893 grown in several environments as listed in Table 3.1.

Table 3.1. Source of Barley Flour Fractions and their Starch Types.

Genotypes	Amylose	Growing location	Growing year
AC Hawkeye	Non-waxy	Brandon	2000
AC Hawkeye	Non-waxy	Saskatoon	2000
AC Hawkeye	Non-waxy	Saskatoon	2001
CDC Alamo	Zero-amylose	Brandon	2000
CDC Alamo	Zero-amylose	Saskatoon	2001
CDC Candle	Very low amylose	Brandon	2000
CDC Candle	Very low amylose	Saskatoon	2001
CDC Dawn	Non-waxy	Brandon	2000
CDC Fibar	Zero-amylose	Brandon	2000
CDC Fibar	Zero-amylose	Saskatoon	2000
CDC Freedom	Non-waxy	Brandon	2000
Condor	Non-waxy	Brandon	2000
HB 805	Low amylose	Brandon	2000
HB 805	Low amylose	Saskatoon	2000
Millhouse	Non-waxy	Brandon	2000
Millhouse	Non-waxy	Saskatoon	2000
Millhouse	Non-waxy	Saskatoon	2001
SB 94893	High amylose	Brandon	2000
SB 94893	High amylose	Saskatoon	2000
SB 94893	High amylose	Saskatoon	2001

The cleaned kernels from these samples were milled, without tempering, in a roller mill (MLU-202 Buhler, Uzwil, Switzerland), with a 0.12-mm roller gap for the second break. The milling of each sample produced reduction and break flours, brans and shorts. The reduction and break flours were combined to give a straight grade flour (SGF), while bran and shorts were each dusted in a bran duster (Brabender Instruments Inc, NJ, US) to separate the adhering flours. Flour separated from shorts was termed dusted flour from shorts (DFFS) while that from bran was called dusted flour from bran (DFFB). Blends were prepared with varying proportions of these flours from a single barley sample at a time. The proportions in the blends varied depending on the experimental protocol.

3.2.2 Methods

Viscosity of the individual barley slurries was measured using a Rapid Visco Analyser (RVA, Newport Scientific, Australia). Flour (8g) and deionized water (20mL) were mixed manually for 30s, in the RVA canister using the disposable paddle. The slurries were sheared in the RVA (30 C) at 960 rpm for 10s and then at 160 rpm for a total time of 14 min. The final RVA viscosity was recorded and the test was replicated.

To determine the optimum water absorption (OWA) for tortilla dough, flour (5g) was placed in the RVA canister and mixed with water (30°C) for 8 min at 100 rpm. Successive trials were conducted using increasing amounts of water, starting with 65% of flour weigh. More water was used for each trial until dough feel reached the derired consistency. At the correct consistency, the dough was smooth, slightly moist and soft with no signs of cracking, and it could be mixed and sheeted well without sticking to the RVA canister or the sheeter. This dough description is a modification of that used by Bello et al (1991).

Approved Method 44-15A (AACC International 2000) was used to determine moisture content of SGF, DFFS and DFFB by oven drying for 1 hr at 130°C. Protein content (N x 5.7) of SGF, DFFS and DFFB was determined by combustion nitrogen analysis (model FP-248 Leco Dumas CAN analyzer, St. Joseph, US) calibrated with EDTA according to Approved Method 46-30 (AACC International 2000). Total starch was determined using Approved Method 76-13 (AACC International 2000). The total dietary fibre was determined by enzymatic gravimetric determination, Approved Method 32-07 (AACC International 2000) and β-glucan content of the milling fractions was determined by the rapid enzymatic procedure, Approved Method 32-23 (AACC International 2000). The flour samples used for β-glucan analyses were ground on an ultracentrifugal mill (ZM-1, Retsch GmbH & Co., Haan, Germany) with a 0.5-mm screen. Chemical composition of blends was calculated based on the amount and composition of the milling fractions included in the blend.

To determine the effect of lichenase, final RVA viscosities of slurries were measured temperature with or without treatment with 2.5U/g lichenase (EC 3.2.1.73; Megazyme Intl. Ltd., Wicklow, Ireland) at room temperature. It was hypothesized that the treatment with lichenase would breakdown the slurry viscosities if β-glucan played a role in slurry viscosities.

3.2.3 Statistical analysis

The correlation between the percentage of SGF and the RVA viscosity, and correlation and regression between final RVA viscosity and the OWA were determined using the analysis tool add-in of MS Excel (Version 5.1, 2000). The multiple stepwise regressions were performed using SAS/STAT V. 8.2 (SAS Institute, Cary, NC).

3.3 RESULTS

3.3.1 Development of optimum tortilla dough water absorption values

The first step in developing a standardized method for determining tortilla dough water absorption was to prepare a series of 11 CDC Candle blends of varying SGF and DFFS contents. Total starch, protein, β-glucan and total dietary fibre of each of the blended flours was calculated, and the flours were tested for RVA viscosity and OWA (Table

3.2). As the % DFFS increased, from 0 to 100 %, the % of β-glucan, protein and dietary fibre increased and the percent starch decreased. Both RVA viscosity and OWA also increased steadily. There were highly positive correlations between the percent DFFS and final RVA viscosity values ($r = 0.97$), and between viscosity and OWA ($r = .99$). Fig. 3.1 shows the non-linear regression of OWA on RVA viscosity. The equation for this curve is shown below:

$$Y = -0.000054X^2 + 0.1035X + 65.97 \qquad \text{......Equation 1}$$

Where, X = RVA final viscosity, and Y = OWA

Water absorption values for each Candle blend were predicted from this equation by substituting the final RVA slurry viscosities for X.

Table 3.2. RVA Final Viscosity and Optimum Water Absorption for the Blends of Straight Grade Flour and Dusted Flour From Shorts Obtained from CDC Candle (Brandon, 2000).

Straight grade flour %	Dusted flour from shorts %	Final RVA viscosity (RVU)	Chemical composition of the blended flours				Optimum water absorption (%)
			β-glucan[a]	Total starch[a]	Total Protein[a]	Total dietary fibre[a]	
100	0	62.96	3.9	66.3	16.1	13.0	72
90	10	86.42	4.3	65.5	16.2	13.6	75
80	20	120.08	4.7	64.7	16.4	14.2	78
70	30	171.34	5.0	63.9	16.5	14.9	81
60	40	199.33	5.4	63.1	16.7	15.5	84
50	50	238.42	5.8	62.3	16.8	16.1	88
40	60	284.46	6.2	61.5	17.0	16.7	92
30	70	383.34	6.6	60.7	17.1	17.3	97
20	80	428.50	7.0	59.9	17.3	18.0	101
10	90	579.00	7.4	59.1	17.4	18.6	107
0	100	694.00	7.8	58.3	17.6	19.2	112

[a]Mean values n=2, g/100g, dmb

The second step was to determine the applicability of Equation 1 for other waxy genotypes. This was tested using blends of SGF and DFFS from CDC Alamo and SB99707. RVA final viscosity values were obtained for each blend and the predicted WA was calculated. The OWA value (by dough feel) was also determined. The relationship between the predicted WA and the OWA is shown in Fig.3.2. The high correlation (r=

0.97) between these values confirmed that WA values calculated using Equation 1 could accurately predict OWA values for the waxy samples examined in this study.

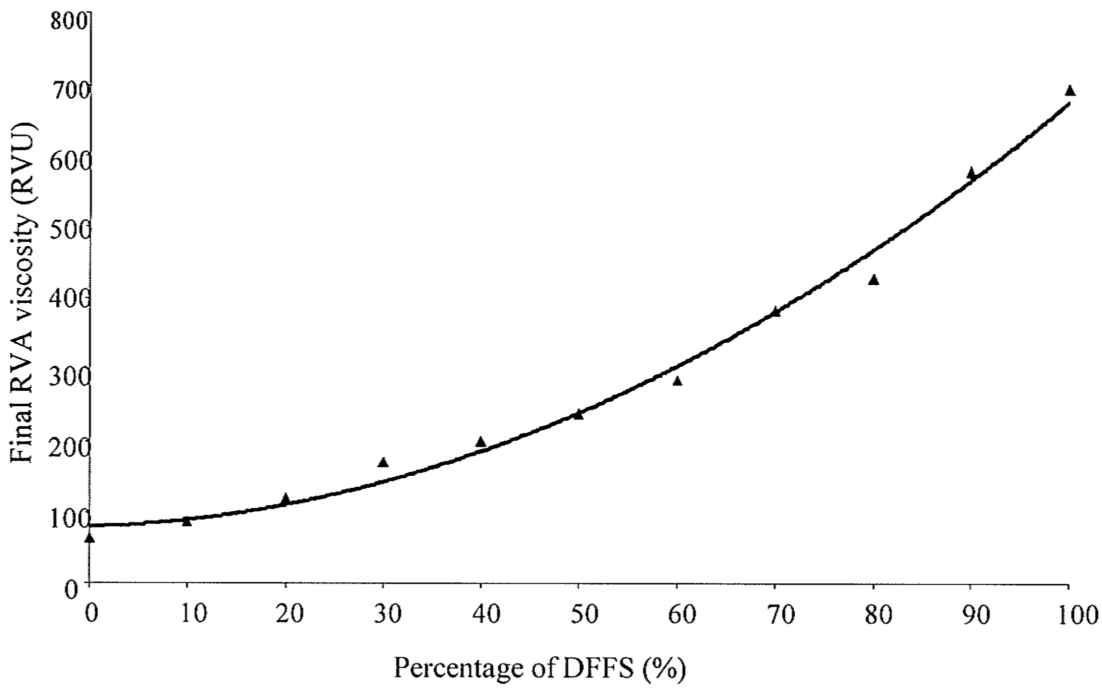

Fig. 3.1. Relationship between the final RVA viscosities of the slurries and optimum water absorption of tortilla dough for the blends of straight grade flour (SGF) and dusted flour from shorts (DFFS) obtained from CDC Candle (Brandon, 2000). The blends contained 100, 90, ..., 0% of SGF and 0, 10....100% of DFFS.

The third step was to develop an equation to predict WA for non-waxy barley genotypes. The procedure followed with CDC Candle was repeated using CDC Freedom, a non-waxy line. The data from this experiment were used to calculate Equation 2.

$Y= -0.000035X^2 +0.093X + 66.79$ ......Equation 2

Where Y = RVA final viscosity, and X = OWA

The regression curves for Equations 1 and 2, as shown in Fig.3.2., appeared identical, making it possible to use the same equation for the waxy and the non-waxy samples.

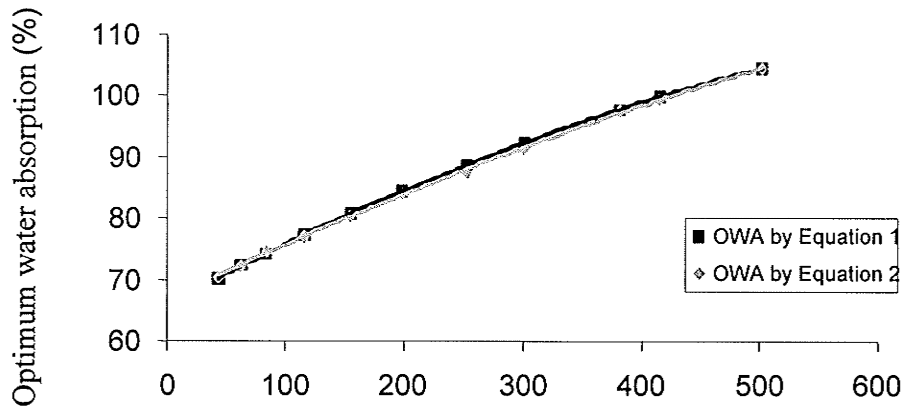

Fig. 3.2. Comparison of the two prediction equations obtained from CDC Candle (waxy) and CDC Freedom (non-waxy).

In the final step to establish a standardized method for barley tortilla dough water absorption, doughs were prepared using predicted water absorption values from a set of flours with a wide range of composition and genetic background. Ten blended flours from each of 20 barley samples, both waxy and non-waxy genotypes, formed the test set. The predicted WA was used in the preparation of tortilla doughs from each of the blends. In almost all of the 200 combinations tested the dough had the feel and handling characteristics typical of the OWA doughs. Approximately 35 samples had viscosities over 700 RVU, however, and a 3-15% reduction of water was required to prevent dough stickiness (Fig. 3.3). An indicator of excess water having been added to form the dough was that there was dough sticking to the canister after mixing.

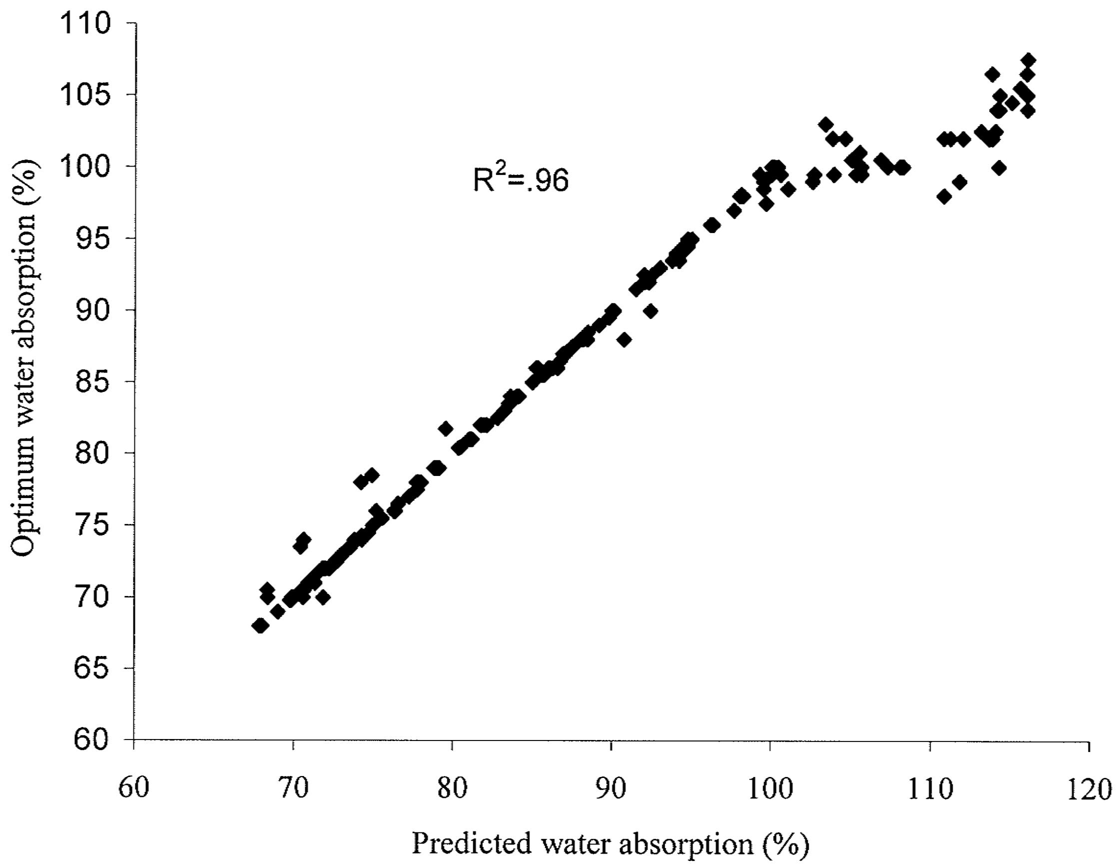

Fig. 3.3. A comparison between the predicted and optimum water absorption values for approximately 190 tortilla doughs from barley flour blends.

3.3.2 Identification of the component(s) responsible for the increase in slurry viscosity with added DDFS

As shown in Table 3.2, as the percent DFFS increased in CDC Candle flour blends, levels of protein, total dietary fibre and β-glucan, increased, and levels of starch decreased. Of the major components only the β-glucan content correlated with the viscosity ($r = 0.91$, $P<0.01$) (Fig. 3.4).

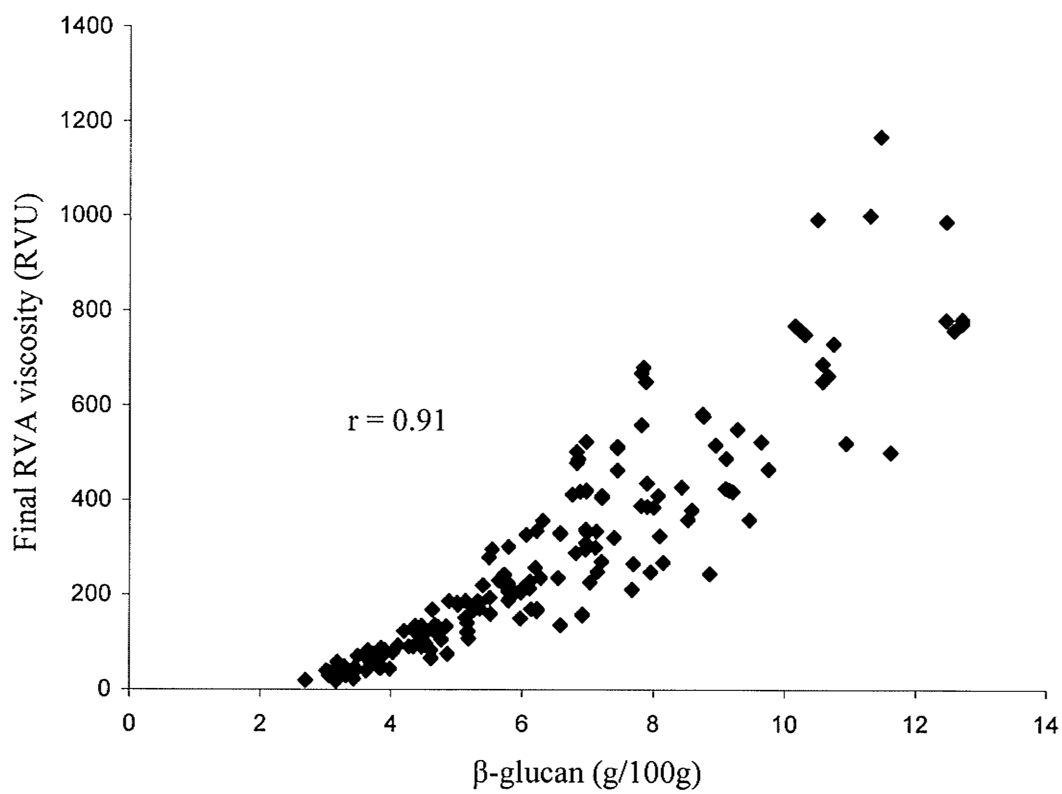

Fig. 3.4. Relation between the β-glucan contents of barley flour blends and their optimum water absorption for tortilla dough. From each of 20 barley samples, 10 different blends

of straight grade flour (0-100%), dusted flour from shorts (0-100%) and dusted flour from bran (0-10%) were obtained.

Table 3.3 Final RVA Viscosities of Slurries from Blends of SGF[a] and DFFS With or Without Lichenase Treatment.

			Final RVA viscosity (Mean ± SD)[b]	
Sample[a]	Type of starch	β-Glucan[b] (g/100g)	Without Lichenase	With Lichenase
SB 99707 DFFS	Zero amylose	11.3	1372.7 ± 7.6	20.0 ± 0.2
Candle DFFS	Very low amylose	8.9	883.2 ± 11.3	14.5 ± 1.5
HB 805 DFFS	Low amylose	7.3	352.4 ± 2.6	14.3 ± 0.2
HB 805 SGF	Low amylose	3.4	35.7 ± 5.1	3.3 ± 0.4
Hawkeye DFFS	Non-waxy	7.0	119.3	7.2[c]
Hawkeye SGF	Non-waxy	3.7	48.6 ± 1.0	5.8 ± 0.6
SB 94893 DFFS	High Amylose	10.2	564.7 ± 2.7	24.8 ± 0.6
SB 94893 SGF	High Amylose	6.0	135.0 ± 1.7	9.3 ± 0.9
Water	Not applicable	NA	2.1 ± 0.6	-1.9 ± 0.1

[a]SGF and DFFS after the genotype names stand for straight grade flour and dusted flour from shorts, respectively.
[b]Mean and standard deviation for duplicate measurements.
[c]Viscosity value is based on single measurement due to missing the data.

The influence of the β-glucans on viscosity was studied further by treating slurries with a β-glucan hydrolyzing enzyme. Slurries of SGF and/or DDFS from five genotypes varying in amylose content were treated with lichenase (EC 3.2.1.73, Megazyme Int. Ltd., Wicklow, Ireland) using 2.5U/g of flour (db). The viscosities of the treated slurries were compared to those of their untreated controls (Table 3.3). Treatment with lichenase reduced the RVA viscosities of the treated slurries by 91 to 99 % (Table 3.3). The DFFS samples had treated viscosity values that were slightly but significantly higher than those for the SGF samples, suggesting that components of total dietary fibre other than β-glucan might exert a minor influence on viscosity. However, the β-glucan content was clearly the dominant factor affecting the viscosity of the barley slurries.

3.4 DISCUSSION

The RVA, which has traditionally been used for studying pasting properties and measuring the viscosities of starchy slurries, was used to measure viscosities of the barley flour slurries at 30 C, the temperature at which doughs are prepared for barley tortillas in this laboratory. The RVA was also used to mix the dough on a small scale (5g sample). This unique application of the RVA reduced the amount of sample required, while mixing and measuring the viscosity of the samples. The process of dough formation using RVA was similar to the regular procedure for making the dough on a large scale with respect to the type of paddle used and the speed of mixing the dough.

It has been hypothesized that the barley flour blends with higher slurry viscosity would need higher water absorption to form tortilla dough. A very strong relationship was observed between final RVA viscosities of the slurries of barley flour blends from CDC

Candle and the optimum water absorption for these blends for tortilla doughs. Thus, an equation was developed which could predict the water absorption for a barley flour/blend from the RVA slurry viscosity measured by the method described in this manuscript. However, extrapolation of the equation beyond the range of slurries tested for developing the equation, may not predict the OWA accurately.

It was important to develop another prediction equation for non-waxy samples as researchers have found differences in dough properties of low amylose and non-waxy barley and wheat flour (Gill et al 2002; Guo et al 2003). Gill et al (2002) studied the dough rheology of CDC Candle and Phoenix (very low amylose and non-waxy, respectively) flours. Water absorption of blends containing CDC Candle at all levels was higher than that of blends containing Phoenix flours. At these higher levels, CDC Candle blends also contained higher amounts of β-glucan. Guo et al (2003) studied the effect of waxy wheat starch on the dough rheology of non-waxy wheat flour doughs. They reported that higher proportion of low amylose wheat resulted in higher water absorption for bread dough. Also, the former gave smoother and less sticky dough but had poor pliability. Thus there is some evidence to suggest that amylose has an effect on water absorption and dough rheology. Also, there was a need to develop a separate prediction equation for non-waxy barley. CDC Freedom was used to develop this equation.

The prediction equation developed for CDC Freedom (Equation 2) was practically identical to the one developed with CDC Candle (Equation 1). It is possible that there could be an effect of amylose on the water absorption of barley dough, but at least in this case it did not affect the derivation of the prediction equation. Thus, Equation 1 was used for determining water absorption of about two hundred flour blends from various sources.

With the Equation 1, water absorption was predicted very accurately for the majority of the samples, where the final RVA was less than 500 RVU. However, at higher viscosities, less water than predicted was needed to achieve the correct dough feel. This was the case for about 25 samples (Fig. 3.4). Since Equation 1 was developed with samples that had maximum 700 RVU final RVA viscosities, it did not give accurate results when extrapolated beyond that point. This equation is also possible that the RVA did not measure high viscosities very accurately as the standard error increased with viscosities higher than 700 RVU.

The factor that seemed to be most responsible for higher viscosities was β-glucan. The addition of lichenase to the barley slurries resulted in a sharp decrease in viscosities. β-glucans are believed to reduce the cholesterol levels in human blood due to their ability to bind water and thus increase viscosity in the gut (Akiba and Matsumoto 1980; Kirby et al 1981). In certain yogurts β-glucans are used as thickeners due to the same property (Cargill 2006).

However, there may have been other factors contributing to the barley slurry viscosities at 30 C. DFFS slurries had low, but yet significantly higher viscosities, than did SGF slurries, but due to the collinearity between β-glucan and amylose types as well as total dietary fibre and starch in this study, it was not possible to determine the effect of these other chemical components. It can be speculated that the particle size and the porosity might have had an effect. Izydorczyk et al (2005) attributed the high viscosity of barley

FRF slurries to high β-glucan content and porous structure. Gill et al (2002) suggested that coarser fractions of milled barley absorbed more water than the finer fractions. The DFFS fractions, in our study were also fibre rich fractions, with larger particle size and lighter than the SGF. This was assessed by the determining the weight of equal volumes of SGF and DFFS. It is possible that the DFFS particles contributed to viscosity even after Lichenase treatment.

3.5 CONCLUSIONS

Barley flour slurries varied in their composition, and higher ratio of DFFS to SGF increased slurry viscosities significantly ($p<0.01$). Samples with higher slurry viscosities also had higher OWA for tortilla doughs and this formed the basis for the prediction equation to predict water absorption. This objective approach for the determination of optimum water absorption for barley tortillas appeared to be accurate, saved time, and reduced the amount of sample required for testing.

It may be possible to extend this approach to other barley products. The optimum water absorption would have to be redefined and a new regression equation computed.

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CHAPTER 4

CHARACTERISITICS OF BARLEY TORTILLAS THAT DETERMINE CONSUMER PREFERENCES: A FOCUS GROUP STUDY

4.1 INTRODUCTION

According to the latest available market figures from the Tortilla Industry Association (TIA 2006), the US tortilla market was valued at $6.1 billion in 2004. Estimates for its market size in 2006 were between $6.5 billion - $7 billion. Having cornered 32 percent of the sales for the US bread industry in 2004, tortillas trailed white bread sales by only two percent, and thus became the second most popular bread type in North America. Tortillas are traditionally prepared from cornmeal or wheat flour. Corn tortillas are becoming popular more rapidly than wheat tortillas, although wheat flour remains the leading type of tortilla in North America.

Although in North America wheat and corn tortillas dominate the market, acceptable tortillas have also been prepared from 100% triticale, sorghum or barley flours, and from blends of these cereal flours with wheat flour (Choto et al 1999; Serna-Saldivar et al 2004; Ames et al 2006). Choto et al (1999) prepared tortillas with 100% yellow maize flour, 100% sorghum flour, and blends of sorghum and yellow maize flour. The 25% sorghum flour tortillas were the most acceptable of the blended products to the consumers. Tortillas from blends of sorghum and yellow maize are commercially available in Central but not in North America. Serna-Saldivar et al (2004) reported that color, texture and flavor of tortillas prepared from 50:50 blends of triticale flour were found acceptable to a panel of 49 untrained consumers. However, to prepare a 100% triticale tortilla it was necessary to add at least 2% vital gluten to the formulation. Acceptable tortillas have also been prepared from formulations of barley milling fractions without adding flour from any other source (Ames et al 2004 and 2006).

The development of acceptable barley tortillas has potential health benefits, because barley is an excellent source of both soluble and insoluble dietary fibre. Bhatty and Rossnagel (1998) reported that soluble fibre in the form of β-glucan was present at levels of 4–6% in normal hulless barley genotypes, and at levels of 6–8% in waxy genotypes. Since then new genotypes have been developed that contain higher levels of β-glucan. One such genotype is waxy, hulless Prowashonupana (Sustagrain, ConAgra Foods) that contains 15% β-glucan. In addition β-glucan content of barley flour can be increased by milling as the β-glucan content varies across the barley kernel (Kiryluk et al 2000).

The interest in barley β-glucan has stemmed from its extensive health benefits (Klopfenstein and Hosney 1987; Lia et al 1995; Pick et al 1998). β-glucan has been shown to lower plasma cholesterol, reduce glycemic index and diminish the risk of colon cancer in human beings (McIntosh et al 1991; Newman and Newman 1991; Bhatty 1993; Kahlon and Chow 1997; Yokoyama et al 1997; Jadhav et al 1998). After evaluating the effects of barley β-glucan on cholesterol, FDA amended the health claim that foods with β-glucan, a soluble fibre, from whole oats may reduce heart disease risk when eaten as part of a diet low in saturated fat and cholesterol. FDA has now included barley in this claim and has identified several sources of barley β-glucan that are eligible for the health claim. These include whole grain barley, barley bran, barley flakes, barley grits, barley flour, barley meal, sieved barley meal and pearl barley produced from clean, sound dehulled or hulless barley using standard dry milling techniques. To qualify for the claim a product must provide at least 0.75 grams of β-glucan per serving. At least 3 grams of β-glucan daily is needed for an effect on cholesterol levels. Consumer reactions to tortillas prepared from barley flour milling fraction blends, designed to give varying levels of β-glucan and insoluble fibre, are the focus of this study.

Research studies (Knuckles et al 1997; Izydorczyk 2005) on noodles, pasta, muffins and bread have shown that product quality was affected when wheat flour was replaced by barley flour to achieve high β-glucan products. Bread made with 20% of the wheat flour replaced by a β-glucan rich fraction of barley had more TDF and β-glucan than the control bread, but lower loaf volume and a darker color (Knuckles et al 1997). In the same study, pasta prepared by replacing 20 and 40% semolina with the β-glucan rich fraction from barley had a darker color than the control pasta. When Izydorczyk et al (2005) used a fibre-rich fraction from waxy barley containing over 20% β-glucan to replace 25% white wheat flour in yellow alkaline and in white salted noodles, the noodles were darker in color and cooking time was reduced by approximately 50%. Instrumental testing indicated that noodles had acceptable texture; however, sensory testing was not carried out.

Sensory studies have also shown that addition of barley flour and other components to a food product may adversely affect the qualities of the product (Erkon et al 2006: Gujral et al 2003). A study by Cavallero et al (2002) showed the effects of barley flour on wheat bread quality. When barley flour replaced 50% of the wheat flour for making bread, crumb texture, flavor and overall acceptability scores were adversely affected. To formulate acceptable barley products it is important to consider the sensory properties of the products, and to understand the factors that influence consumer preferences.

Information on consumer attitudes and behavior can be obtained by qualitative and/or quantitative methods (Chambers and Smith 1991; Lawless and Heymam 1998). Qualitative methods have an exploratory nature. They generate oral-descriptive, non-numerical information, and are usually carried out with small groups of people. Quantitative methods are usually based on questionnaires, where the answers to different questions are generally presented in a numerical format. However, this type of method requires answers from much larger groups of people than qualitative methods to obtain statistically significant results. The number of interviews to be done in market research usually oscillates between 100 and 500 (Barrios and Costell, 2004).

Qualitative research enables one to get detailed information about consumer attitudes, opinions, perceptions, behaviors, and habits (Hashim et al 1996). One of the most frequently used qualitative tools is the focus group, which has been widely applied for product development research (Bellenger et al 1979). A focus group is a carefully planned discussion, or interview, with small groups of participants. Its main advantage is that it allows much more freedom of expression by the participants than is possible using other forms of enquiry. A focus group study can be designed and conducted in a variety of ways depending on its purpose (Stewart & Shamdasani 1990). The focus groups typically comprise six to ten people who are selected based on defined criteria. Group sessions are repeated with different people to obtain diverse viewpoints. Normally a focus group study begins with three to four groups and continues until theoretical saturation is reached, i.e. until no more new information is received (Krueger and Carey 2000).

The objectives of this focus group study were: (1) to determine if there are external factors that influence consumer preferences, (2) to identify the most and least preferred barley tortilla(s) among tortillas with a wide range of color, texture and flavor characteristics, by assessing them for appearance, texture and overall hedonic scores and (3) to document descriptors used by consumers for barley tortillas. This information will serve as a basis for future development of criteria for optimizing barley tortillas.

4.2 MATERIAL AND METHODS

4.2.1 Sample set

Four registered hulless barley cultivars (AC Hawkeye, CDC Alamo, CDC Candle and Millhouse) and one breeding line (SB 94893) grown at Saskatoon, Saskatchewan in 2001 were obtained from Dr. Brian Rossnagel, University of Saskatchewan (Table 4.1). AC Hawkeye and Millhouse contain normal levels of amylose and are considered non-waxy genotypes. CDC Alamo and Candle contain low levels of amylose and are considered waxy. SB 94893 contains high levels of amylose. Kernels were cleaned, measured for moisture and milled into flour using a lab scale Buhler roller mill (MLU-202 Buhler, Uzwil, Switzerland) with a 0.12-mm roller gap for the second break. The milling of each sample resulted in reduction and break flours, which were combined to give straight grade flour (SGF), and bran and shorts. The bran and shorts were separately dusted in a bran duster (Brabender Instruments Inc, NJ, US) to separate the adhering flours. These flours were termed dusted flour from shorts (DFFS) and dusted flour from bran (DFFB).

Approved Method 44-15A (AACC International 2000) was used to determine moisture content of SGF, DFFS and DFFB by oven drying for 1 hr at 130°C. Protein content (N x 5.7) of SGF, DFFS and DFFB was determined by combustion nitrogen analysis (model FP-248 Leco Dumas CAN analyzer, St. Joseph, US) calibrated with EDTA according to Approved Method 46-30 (AACC International 2000). Total starch was determined using Approved Method 76-13 (AACC International 2000). The total dietary fibre was determined by enzymatic gravimetric determination, Approved Method 32-07 (AACC International 2000) and β-glucan content of these milling fractions was determined by the rapid enzymatic procedure, Approved Method 32-23 (AACC International 2000).

4.2.2 Tortilla preparation

Tortillas with a wide range of sensory attributes were prepared from the five barley genotypes using blends with varying amounts of SGF, DFFS and DFFB (Table 4.1). These formulations were selected based on a preliminary study of barley tortillas using a wide range of blends. Doughs were prepared by mixing the flour (100g) and water in a GRL 200 Mixer (Muzeen and Blythe Ltd, MB, Canada) at low speed (mark 2) for 1.5 min and then at high speed (mark 6) for an additional 3.5 min. The optimum amount of water for the dough was determined using the RVA prediction method (Chapter 3). When mixed, the dough was rested at room temperature in an airtight container for 10 min and then divided into 9 equal sized portions. Dough portions were flattened in a dough sheeter and moulder (National Manufacturing Co., Nebraska, US) to a thickness of 1.32

mm or 1.20 mm, and then die-cut into discs with a 17.5 round cutter. Two discs at a time were baked on a counter top tortilla grill (32N 24X24 BE&SCO Inc, San Antonio, US) at 254 ± 5C and were flipped twice to obtain a fully cooked product.

To determine the cooking times for different barley samples, tortillas prepared from the different barley flour formulations were each cooked for 60, 70, 80...120s. These tortillas were visually examined for the absence of translucent spots (indicator of uncooked areas) and dark brown toasted spots (indicator of over cooked areas). The cooking time was considered optimum when the translucent spots were the minimum and dark brown toasted spots were absent. Based on these preliminary tests, the cooking times are shown in Table 4.2.

The cooked tortillas were cooled at room temperature on wire racks for 1.5 min, were sealed in vacuum bags and were stored at -40°C for up to 7 days. Tortillas were thawed for one hour before each session and were presented to the focus group members in individual Ziploc bags, which were coded with three digit random numbers. The packaging mimicked see-through retail packaging. Table 4.1 shows barley flour formulations with their chemical composition and tortilla processing specifications.

Table 4.1 Barley Flour Blend Proportions and Tortilla Cooking Specifications for Seven Tortilla Formulations.

			Blend proportions			Cooking specifications	
Sample[a]	Source	Starch type	SGF[b] (g)	DFFS[c] (g)	DFFB[d] (g)	Water absorption (%)	Cook time[e] (s:s:s)
ZA 24	CDC Alamo	Waxy	24.3	66.2	9.5	91.5	25:50:25
ZA 94	CDC Alamo	Waxy	93.9	0.0	6.1	73.8	15:30:15
VLA 20	CDC Candle	Waxy	20.5	69.5	10.0	90.1	25:50:25
NA29	Millhouse	Non-waxy	29.3	62.4	8.3	80.5	20:40:20
NA 36	AC Hawkeye	Non-waxy	36.0	62.9	1.2	80.1	20:40:20
NA 87	AC Hawkeye	Non-waxy	87.2	6.2	6.6	71.1	15:30:15
HA 2	SB 94893	High-amylose	1.5	93.5	5.0	106.1	30:60:30

[a]The alpha part indicates amount of amylose in starch and are abbreviated as, ZA: Zero Amylose, VLA: Very low amylose, NA: Non-waxy and HA: High Amylose. The numeric part indicates the proportion of straight grade flour in the formulation.
[b]SGF- Straight grade flour
[c]DFFS- Dusted flour from shorts
[d]DFFB- Dusted flour from bran
[e]Cooking times are for side1: side2: side1 so that both the sides are cooked for equal amount of time

4.2.3 Focus Groups

4.2.3.1 Participant recruitment

A total of 26 participants were recruited from staff at the Winnipeg Cereal Research Centre, Agriculture and Agri-Food Canada, and from students and staff at the University of Manitoba. Only those who consumed tortillas at least biweekly were asked to participate in the focus groups. These participants were asked to sign an ethics consent form, which included their agreement to have the discussion recorded, and they also completed a questionnaire giving their frequency of tortilla consumption, and the type of tortilla they preferred (Appendix I). When the panelists were recruited barley tortilla acceptability was given as the topic to be discussed, but the specific goals of the study were not mentioned. Four men and 22 women, age18 to 50 years, participated.

4.2.3.2 Focus group arrangements and protocol

Focus group meetings were held in a sensory discussion room of the George Weston Sensory and Food Research Laboratory, Department of Human Nutritional Sciences, University of Manitoba, Winnipeg. Participants and the moderator were comfortably seated around a table with sufficient space for individual sample trays to be placed in front of each participant. The interviews were recorded and later transcribed and analyzed. The focus group sessions followed a protocol based on a semi-structured interview guide (Table 4.2), which was developed in accordance with established guidelines and designed to identify the beliefs and attitudes of the participants (Brug et al, 1995). After the moderator and the participants introduced themselves, the moderator explained the objective of the task and then facilitated group discussions. The moderator also controlled the audio equipment and took notes. Participants were advised that there were no right or wrong responses to the question and were asked to express their honest thoughts, opinions, and beliefs. The arrangements facilitated participant interaction, eye contact and free flow of discussion. Each session was held under similar conditions and lasted approximately 90 min. Beverages and snacks were available to participants at the end of each session.

Before the participants were given the prepared samples they were asked to explain the considerations that led them to make purchasing decisions. After this discussion each participant received the same set of tortillas, presented in the same order on a tray that also held bowls of mild salsa, grated cheddar cheese, chopped tomatoes and lettuce. Knives, cutting sheet, aluminum foil-lined wax paper sheets (5" x 5"), water and toothpicks were also provided (Figure 4.1).

Panelists were asked to score the tortillas for appearance on a 9-point hedonic scale before the tortilla was removed from its packaging. The ratings were then discussed for each tortilla. Texture was the next characteristic that was scored and discussed. To evaluate texture during handling, each participant rolled a tortilla, with any or all of the condiments provided, in aluminum-foil-lined-waxed paper as demonstrated by the moderator. The tortilla was cut into half with one half for testing later was placed and sealed in the Ziploc bag to prevent moisture loss. The other half was used to evaluate texture while biting, chewing and swallowing it. The half tortilla set aside for tasting was then used to assess flavor and to evaluate overall.

Fig. 4.1 Individual presentation of samples to the focus group participants.

Table 4.2. Interview Guide Used to Guide Focus Group Discussions.

Interview Guide
Introduction and general questions
What types of tortillas do you consume and why?
What do you look for in a tortilla when you purchase a tortilla?
How do you judge a tortilla from a package?
Tortilla color and appearance
Just looking at the tortilla from outside the package what do you think about the appearance of the tortilla?
Is there anything you like or dislike about this tortilla?
Please score all the tortillas for their appearance on the 9-point hedonic scale of acceptability
Tortilla texture
Demonstration of salad, salsa and cheese filling, rolling and cutting of the tortilla
What is your opinion about the texture of the tortilla while handling it?
While consuming the tortilla please evaluate the tortilla texture
What do you like and/or dislike about this tortilla?
Please score all the tortillas for their texture on the 9-point hedonic scale of acceptability.
Tortilla flavor
What kinds of flavors are tasted in this sample?
Is it a pleasant flavor or an unpleasant one?
Is there any after taste noticed
Overall
Which of the barley tortilla did you like the best and why?
Which of the barley tortilla did you like the least and why?

4.2.4 Statistical analysis

The mean appearance, texture and overall hedonic score and mean ± SD were calculated using the analysis tool of Microsoft Excel (Version 5.1, 2000).

4.3 RESULTS

As a result of the initial questionnaires and the preliminary discussions the participants were categorized into two groups. One group, which will be called the fibre conscious consumers (FCC) consisting of 11 participants, purchased high fibre, whole-wheat tortillas. They also read labels to determine tortilla fibre content. The other group, which will be called the fibre neutral consumers (FNC), consisting of 15 participants, purchased all-purpose wheat flour tortillas and did not look for product fibre content. The FCC group ranged in age from 18-39, while the FNC ranged from 18 to 50 with the majority over 38 years of age. Results will initially be presented for the two groups separately.

Mean scores for appearance, texture, and overall quality of the seven samples were calculated for the FCC group and for the FNC group and are shown in (Table 4.3). Flavor was not scored, although taste and odor characteristics were discussed, and were factors in the overall evaluation.

Table 4.3. Focus Group Participants' Hedonic Scores[ab] for Appearance, Texture and Overall Quality of Barley Tortillas.

Sample	Appearance		Texture		Overall	
	FCC	FNC	FCC	FNC	FCC	FNC
ZA 24	6.1 ± 1.6	3.8 ± 2.6	7.7 ± 0.5	3.1 ± 1.7	7.1 ± 0.7	2.9 ± 1.2
ZA 94	5.0 ± 2.7	4.4 ±2.5	6.4 ± 1.5	3.5 ± 1.7	5.6 ± 1.3	3.9 ± 2.7
VLA 20	7.2 ± 1.5	4.4 ± 2.1	8.3 ± 1.0	4.2 ± 2.1	8.1 ± 0.7	4.6 ± 2.1
NA 36	7.0 ± 0.7	7.1 ± 0.6	6.2 ± 2.8	6.8 ± 1.8	6.0 ± 2.5	6.3 ± 2.3
NA 87	6.8 ± 2.7	7.4 ± 0.9	5.0 ± 0.7	7.3 ± 1.7	4.4 ± 0.5	6.8 ± 2.1
NA 29	8.4 ± 0.5	7.8 ± 1.1	7.8 ± 0.8	6.6 ± 0.7	8.0 ± 1.0	7.2 ± 1.5
HA 2	3.3 ± 1.4	2.4 ± 2.2	3.1 ± 1.8	2.6 ± 1.8	2.7 ± 1.5	3.2 ± 2.7

[a]Mean ± standard deviation

[b]Based on 9-point hedonic scale (1= dislike extremely; 5= neither like nor dislike and 9= like extremely).

4.3.1 Tortilla evaluation by the fibre conscious consumers

The FCC preferred two of the tortilla formulations, the VLA 20 and NA 29, and gave them the highest scores both overall and for texture. For appearance they gave NA 29 the highest score, while VLA 20 was given a score similar to NA 36 and NA 87. The two formulations, VLA 20 and NA 29, which were well liked by the participants who favored higher fibre, were therefore identified as possible benchmarks. During the focus group discussion the participants explained their choices in greater detail and provided information about their criteria for selection (Table 4.4 - 4.6).

Appearance scores were influenced by color, brightness and extent of toasted areas on the tortilla surface. The FCC liked tortillas that were dark in color but were "bright", had several toasted spots and lacked translucent areas (Table 4.4). The darker tortillas were favored over the whiter tortillas because the dark color was considered an indicator of a whole grain product and also a healthier choice. The FCC liked the tortillas that had reddish or brown tints, but did not like the ones that were described as having a gray color, which they termed “dull”. The presence of puffed and toasted spots was considered desirable, and samples with insufficient spots were termed “too flat”. Translucent areas, evident on ZA 24 and ZA 94, were thought to indicate uncooked dough and were therefore thought to be undesirable.

FCC referred to flavor of some samples as having “mild toasted or nutty” notes (NA 29, VLA 20 and ZA 24), as listed in Table 4.5. These tortillas were preferred to the ones that lacked flavor (NA 36 and NA 87) which were termed “too bland”. The FCC also had some tolerance for bitter aftertaste. The VLA 20 sample was considered to have only mild bitter aftertaste but for a number of other samples the bitter aftertaste was stronger and was objectionable (ZA 24, ZA 94 and HA 02).

Table 4.4 Attributes of Tortillas with High and Low Appearance Acceptability Amongst Fibre Conscious Consumer (FCC)

Appearance of preferred barley tortillas			Sample[a]	Appearance of least preferred barley tortillas	
Sample[a]	Color	Textural appearance		Color	Textural appearance
NA 29	Slightly dark color giving a high fibre appearance was highly desirable. Bright	Very soft and light in weight and puffed and layered tortilla with sufficient toasted spots.	HA 02	Color not too dark but very dull	No toasted spots, coarse, too "branny" too hard, dry and crumbly appearance.
VLA 20	Dark but somewhat bright	Pliable and soft tortillas with enough toasted spots	ZA 94	Red and dark color. Not very bright.	Oily, moist, raw look and absence of toasted spots. Too thin to hold the salad.

[a]The alpha part indicates amount of amylose in starch and are abbreviated as, ZA: Zero Amylose, VLA: Very low amylose, NA: Non-waxy and HA: High Amylose. The numeric part indicates the proportion of straight grade flour in the formulation.

Table 4.5 Flavor Attributes of Tortillas with High and Low Overall Acceptability Amongst Fibre Conscious Consumer (FCC).

Flavor of preferred barley tortillas			Sample[a]	Flavor of least preferred barley tortillas	
Sample[a]	Bitterness	Other flavors		Bitterness	Other flavors
NA 29	No bitterness at any stage of eating.	Slight toasted or nutty pleasant flavor	HA 02	Very strong bitter aftertaste.	Strong highly unpleasant raw bran-like flavor
VLA 20	Only slight bitter after taste	Pleasant toasted nutty flavor	NA 87	No bitter after taste	Too bland and tasteless

[a]The alpha part indicates amount of amylose in starch and are abbreviated as, ZA: Zero Amylose, VLA: Very low amylose, NA: Non-waxy and HA: High Amylose. The numeric part indicates the proportion of straight grade flour in the formulation.

Texture was evaluated at two stages, first while the tortilla was being handled and then while it was being eaten. VLA 20 was considered to have the most desirable texture, but NA 29 was also well liked by FCC (Table 4.3). A good tortilla with good handling properties was judged to be one that was soft, flexible and rolled easily without cracking (VLA 20 and NA 29). The tortillas that cracked or chipped off while rolling (NA 36, NA 87 and HA 02) were considered less desirable, and were often described as being hard and inflexible (Table 4.6). According to FCC, a tortilla that would chip off or crack was not fresh enough, and also was incapable of holding the ingredients when used as a wrap.

Textural eating properties of importance were agreed by FCC group to be stretchiness, chewiness and moistness. As reported in table 4.6, they liked the tortillas that stretched when bitten (VLA 20, NA 29, ZA 24, ZA 94) rather than those crumbled (NA 36, NA 87 and HA 02). One of the participants commented, "I like a tortilla that stretches slightly while biting rather than just crumbling when I bite into it". The soft, flexible tortillas were also said to be easy to chew as compared to the harder tortillas, which required more effort to eat. FCC liked the tortillas that were slightly chewy and moist (VLA 20, ZA 24, and ZA 94). However, sample ZA 94, which was hard and moist with some stickiness to teeth, was not liked and was called "rubbery".

Table 4.6 Attributes of Tortillas with High and Low Texture Acceptability Amongst Fibre Conscious Consumer (FCC)

Texture of highly preferred barley tortillas			Texture of least preferred barley tortillas		
Sample[a]	Handling	Eating	Sample[a]	Handling	Eating
VLA 20	Very pliable, rolled very easily without any signs of cracking.	Very soft, easy to chew, with right amount of chewiness and moistness. Not sticky to teeth. Stretchability while biting prevented crumbling	HA 02	Lacked flexibility, very difficult to roll and broke in all cases on rolling. Folded rather than rolled.	Hard to bite into, chew and swallow. Very dry and very coarse in mouth
NA 29	Rolled without any signs of cracking. It was very easy to roll and was very pliable.	Right amount of chewiness and did not require extra work to chew. Not rubbery and did not leave the mouth very dry. Stretchability while biting prevented crumbling.	NA 87	It was difficult to roll and to keep it rolled. Felt less pliable and had dry ends.	Hard to bite in, too chewy, too much work to chew, and high stickiness to teeth.
ZA 24	Rolled without any signs of cracking and with great ease.	Right amount of moistness in mouth and not very doughy feel. Stretchability while biting prevented crumbling.			

[a]The alpha part indicates amount of amylose in starch and are abbreviated as, ZA: Zero Amylose, VLA: Very low amylose, NA: Non-waxy and HA: High Amylose. The numeric part indicates the proportion of straight grade flour in the formulation.

4.3.2 Tortilla evaluation by the fibre neutral consumers

Three formulations received similar scores (Table 4.3) for appearance, texture and overall liking from the FNC (NA 29, NA 36 and NA 87). These tortillas were considered similar to plain wheat flour tortillas. Since FNC did not seek high fibre products, and usually consumed plain wheat flour tortillas, they liked barley tortillas that had similar characteristics. An ideal tortilla, as described by this group, was one that was white and bright, with several toasted spots, rolled well, was easy to bite and chew, had a floury mouthfeel, lacked any distinctive flavor and had no bitterness (Tables 4.7 - 4.9).

Appearance scores by FNC for tortillas that were white and bright (NA 29, NA 36 and NA 87) were higher than the scores for tortillas those were dark or dull (ZA 24, ZA 94, VLA 20 and HA 02), as listed in Table 4.7. FNC liked the tortillas that were puffed and had several toasted areas (NA 29, NA 36 and NA 87) rather than those that were flat and dense with few or no toasted areas (VLA 20, ZA 24 and ZA 94). The absence of translucence was considered highly desirable (NA 36, NA 87 and NA 29). Tortillas with some translucent sections (ZA 24, ZA 94 and VLA 20) were considered undercooked and doughy in appearance. These participants refused to compromise on appearance. One of them commented, "I do not care how much fibre there is or how healthy the tortilla is, I like my tortilla white, bright and fluffy."

Table 4.7. Attributes of Tortillas with High and Low Appearance Acceptability Amongst Fibre Neutral Consumer (FNC)

Appearance of preferred barley tortillas			Appearance of least preferred barley tortillas		
Sample[a]	Color	Textural appearance	Sample[a]	Color	Textural appearance
NA 29	Quite white and bright	Very soft and light in weight and more puffed and layered tortilla with enough toasted spots	HA 02	Color not too dark but very dull	No toasted spots, coarse, too "branny" too hard, dry and crumbly appearance.
NA 87	Bright and white in appearance.	Similar to wheat flour tortillas. Highly puffed with enough toasted spots. Fluffiness was similar to wheat flour tortillas.	ZA 24	Bright golden but dark appearance	Heavy, rubbery, granular appearance.
NA 36	Bright and white in appearance.	Similar to wheat flour tortillas. Highly puffed with enough toasted spots. Fluffiness was similar to wheat flour tortillas.	ZA 94	Red and dark color.	Oily, moist, raw look and absence of toasted spots. Too thin to hold the salad.
			VLA 20	Bright but too dark in color	Many but not enough toasted spots

[a]The alpha part indicates amount of amylose in starch and are abbreviated as, ZA: Zero Amylose, VLA: Very low amylose, NA: Non-waxy and HA: High Amylose. The numeric part indicates the proportion of straight grade flour in the blend.

Flavor of any kind was considered undesirable by FNC (Table 4.8). They all agreed with a participant who said, "When I eat a tortilla I like to taste only the filling and not the tortilla. For me tortilla should be inert." The most preferred flavor characteristics were agreed to be those of N36 and N87, which lacked any detectable flavor or bitterness at any stage of eating. The FNC noticed some nutty flavor in NA 29, which they agreed, was not an objectionable flavor, but they would have preferred no flavor at all. One participant commented, "I think I won't mind eating this tortilla as there is no bitterness, but I wish there was no flavor either."

When texture was evaluated by FNC, handling properties were considered less important than the eating properties (Table 4.9). However, the FNC preferred the tortillas that rolled well without cracking or chipping off (VLA 20, ZA 24 and NA 29), but rated NA 87 as a moderately liked tortilla, even though it cracked slightly while it was being rolled.

The type of characteristics present in NA 29, NA 36 and NA 87 tortillas were preferred. These tortillas that did not stretch too much as they were bitten, or require too much chewing when eaten and did not stick to the teeth, were preferred. One of the participants commented, "I like my tortilla to break when I bite into it." The tortillas (ZA 24, ZA 94 and VLA 20) that were moist, too chewy and sticking to teeth were termed as gummy and doughy and were disliked. These participants had no tolerance for any level of stickiness to teeth. They liked the tortillas to leave a dry floury mouthfeel (NA 29, NA 36 and NA 87), which reminded them of the mouthfeel of a plain wheat flour tortilla.

Table 4.8. Flavor Attributes of Tortillas with High and Low Overall Acceptability Amongst Fibre Neutral Consumer (FNC)

Flavor of preferred barley tortillas				Flavor of least preferred barley tortillas	
Sample[a]	Bitterness	Other flavors	Sample[a]	Bitterness	Other flavors
NA 36	No bitterness or bitter after taste.	Bland	HA 02	Very strong bitter taste and aftertaste.	Strong highly unpleasant raw bran-like flavor
NA 84	No bitter aftertaste.	Bland	ZA 24	Strong bitter after taste	Very strong flavor
NA 29	No bitterness at stage of eating.	Slight flavor, not liked			

[a]The alpha part indicates amount of amylose in starch and are abbreviated as, ZA: Zero Amylose, VLA: Very low amylose, NA: Non-waxy and HA: High Amylose. The numeric part indicates the proportion of straight grade flour in the blend.

Table 4.9. Attributes of Tortillas with High and Low Texture Acceptability Amongst Fibre Neutral Consumer (FNC)

Texture of highly preferred barley tortillas				Texture of least preferred barley tortillas	
Sample[a]	Handling	Eating	Sample[a]	Handling	Eating
NA 36	Rollability was acceptable but there were some cracks	It had floury mouth feel similar to that of an all-purpose wheat flour tortilla. Did not require stretching while biting. Did not stick to and was not rubbery.	HA 02	Lacked flexibility, very difficult to roll and broke in all cases on rolling. Folded rather than rolled.	Hard to bite into, chew and swallow. Very dry and very coarse in mouth
NA 87	Rolling was slightly difficult with some cracks.	It had floury mouth feel similar to that of an all-purpose wheat flour tortilla. Did not require stretching while biting. Did not stick too much to teeth and was not rubbery.	ZA 24	Rolled without any signs of cracking and with great ease. Felt rubbery while rolling.	Right amount of moistness in mouth and not very doughy feel. Too chewy and required a lot of work to eat and was rubbery, gummy, damp and gluey.
NA 29	Rolled without any signs of cracking as the participants had expected. It was very easy to roll and was very pliable.	Those who liked wheat flour or corn tortillas liked it for right amount of chewiness and did not require extra work to chew. Not rubbery and did not leave the mouth very dry.	ZA 94	Soft, easy to roll, but doesn't stay rolled.	Easy to bite but hard to chew. Doughy. Very rubbery, gummy and too moist.

[a]The alpha part indicates amount of amylose in starch and are abbreviated as, ZA: Zero Amylose, VLA: Very low amylose, NA: Non-waxy and HA: High Amylose. The numeric part indicates the proportion of straight grade flour in the blend.

4.3.3 Comparison between the tortilla preferences of FCC and FNC

The focus group participants were clearly divided into those who preferred healthier products and those who did not care about the health aspect of the product. The focus group participants who were not interested in the fibre content wanted tortillas which were white and bright with several toasted spots. This group put emphasis on the appearance characteristics. The participants that considered fibre important in a healthy diet appreciated a darker, but not gray appearing product. Both groups wanted the tortillas to roll easily without cracking, although for those not interested in fibre content, rollability seemed less critical than the appearance to their selection criteria. Those preferring higher fibre considered ease of rolling to be a major criterion. The non-fibre group liked tortillas that had a floury, dry mouthfeel, whereas the group that gave importance to fibre content liked tortillas those were more moist and chewy. Those who liked white floury tortillas also preferred them to have no bitterness and flavor, to simply serve as a carrier for the filling used, while those who liked the darker, chewier tortillas said that some flavor, especially the toasted nutty notes, was quite well liked and low levels of bitterness were acceptable.

4.4 DISCUSSION

Appearance preferences for FCC and FNC differed with respect to color and toasted spots preferences. Stauffer (2003) reported that brown rice and whole wheat are preferred over their white, refined varieties by health conscious consumers as they are aware that the white color of cereal-based products is achieved using refined and nutrient-depleted ingredients. Izydorczyk et al (2005) indicated darker noodles containing β-glucan rich barley fraction would be especially appealing to health conscious consumers. Similar results were reported in a study where the hyperfibrinigenaemic men and women gave higher acceptability scores for appearance texture and taste of high-fibre muffins than did the other individuals (Scholtz and Bosman, 2005).

The texture preferences for barley tortillas were different for FCC and FNC. There are reports that indicate that health conscious consumers accept a wider range of texture characteristics as compared to the consumers that are not health conscious (Stauffer, 2005). Our study also suggests this, but in addition, it was interesting to note that FCC and FNC preferred different characteristics of barley tortilla texture. FCC were not too concerned about stickiness to teeth and gumminess. On the other hand, FNC preferred tortillas that did not stretch when bitten into and were not sticky to teeth or gummy or rubbery in texture. FCC preferred tortillas with moist mouth feel while FNC preferred tortillas with floury mouth feel. These differences might be due to the usual consumption of different types of tortillas by the two groups. FCC consumed whole wheat/whole grain tortillas and thus were accustomed to consuming tortillas with moist and somewhat gummy mouth feel while the FCC consumed white flour tortillas and thus were accustomed to a floury mouth feel. Consumers are more likely to enjoy food similar to the foods they regularly consume (Puumalainen et al 2002).

The flavor of barley tortillas was not scored but it was discussed by the consumers. FCC liked a certain degree of nutty, toasted flavor and tolerated some degree of bitter aftertaste but FNC liked their tortillas without any distinct flavor or bitterness at any stage of eating. There is a lack of studies on consumer acceptability of barley flavors in food products.

These preferences expressed by FCC and FNC clearly differentiated the tortillas into two groups on the basis of their genotypes and chemical composition. One group was represented by the tortillas prepared with blends obtained from waxy genotypes (VLA 20, ZA 24 and ZA 94). Waxy tortillas were darker, moister, stickier (to teeth), had fewer toasted spots than the non-waxy tortillas, and had nutty flavor with bitter aftertaste. The second group was represented by the tortillas prepared with blends obtained from non-waxy genotypes (NA 29, NA 36 and NA 87). These tortillas were white, dry and floury in the mouth, did not stick to teeth, had several toasted spots, and had no distinct flavor or bitterness at any stage of eating. These results are in accordance with other studies that have reported that flour from waxy barley or wheat led to darker products that did not crack or break easily and were dense (Guo et al 2003; Friend et al 1993; Cepeda et al 2000). Wheat tortillas, when wheat flour was replaced with waxy barley flour, were reported to be darker, with less apparent puffiness and opacity (Guo et al 2003). Opacity may indicate puffiness as small air bubbles dispersed in tortillas diffract light to give an opaque appearance (Friend et al 1993; Cepeda et al 2000). In another study (Bhattacharya et al 2002) waxy flour substitution in wheat flour bread led to smaller loaves due to the retention of smaller or fewer air bubbles. Also, the crumb color was less white in bread containing 30% waxy flour (Bhattacharya et al 2002). Barley tortillas from waxy barley rolled easily and were less dry in the mouth than the tortillas from high amylose barley (Ames et al 2006) and tortillas prepared solely from grain components of hulless waxy barley (CDC Candle) were liked moderately or very much by the majority of consumers.

Through focus group discussions in the present study, which tested a variety of barley tortillas, it was clear that consumers were divided in their preferences for different barley tortillas based on their very differing attitudes towards the value of fibre in their diets, and its relation to good health. Out of 26 consumers 11 were more health conscious than the remaining 15. Such segmentation of the market based on attitudes and behaviors of the consumers is termed psychographic segmentation (Lesser and Hughes 1986). Market segmentation based on health awareness has been observed and found useful in various food markets (Ruiu 2006 and Sanjuan et al 2003). All the four men in our study belonged to the fibre neutral group, while women were divided between the two groups of FCC and FNC. Studies suggest that women are more health conscious than men (Ruiu 2006).

Due to different expectations, the definition of an ideal barley tortilla may be different for FCC and FNC. Waniska (1999) documented that an ideal wheat flour tortilla should be soft, elastic, light, fluffy and easy to roll. Consumers' expectations for a barley tortilla may be different as these tortillas are prepared without the addition of shortening leavening and curing agent, and a different method is used for their preparation. The definition, which defined an optimum wheat tortilla, may hold true for barley tortillas for FNC but must be modified for FCC. The preferences of barley tortillas for FCC were based on the nutrition aspects of the tortillas while for FNC, the sensory qualities alone were important. Our results indicated that the two consumer groups, FCC and FNC emphasized different sensory characteristics in their selection of barley tortillas.

Starch type affected acceptability of barley tortillas. For FCC, two of the three best-liked tortillas were from waxy samples (VLA 20 and ZA 24). On the other hand, for the FNC group, the best-liked tortillas were from non-waxy samples (NA 29, NA 36 and NA 87). Consumers in other studies have also found differences between waxy and non-waxy barley samples with respect to their effect on product acceptability. Berglund et al (1994) studied the effect of two waxy hulless barleys (Wanubet and Apollo) and non-waxy hulless barley on the appearance, texture and overall acceptability of extruded crisp cereals. In their study, substitution (50%) of rice flour with waxy barley increased the color acceptability score while substitution (50%) with non-waxy barley had no effect on color acceptability. The sensory color score correlated positively ($r=0.90$, $p\leq0.05$) with "a-value" that is, the redness of cereal color. The tenderness acceptability scores were lower while crispness acceptability scores were higher for extruded cereals that contained waxy and non-waxy barley. Flavor acceptability scores were not affected by barley substitution (Berglund et al 1994). However our study shows that some of flavor from waxy genotypes was liked by FCC but not by FNC and the absence of these flavors in tortillas from non-waxy genotypes was liked by FNC but not by FCC. Thus, it seems that starch type might also have effects on flavor acceptability of barley tortillas. The waxy samples were also high in β-glucan, which has been reported to contribute flavors and off-flavors to soup (Lyly et al 2004). Effects of starch type and β-glucan content on the acceptability of appearance, texture and flavors might be more pronounced in this study in comparison to other studies probably because this study dealt with a wide range of genotypes and barley flour blends. Also, the use of focus groups provided detailed information in this study.

Barley tortillas can be a good vehicle for carrying beneficial health effects of barley to consumers because they can be prepared exclusively from barley grain components and are acceptable to consumers. Literature shows that barley and barley components adversely affect the sensory quality of most food products tested when added in large proportions (Berglund et al 1994; Basman and Koksel 1999; Brochetti and Penfield 1989; Dhingra and Jood 2004). Ragaee and Abdel-Aal (2006) reported that the overall for acceptability scores of the pita bread, cookies and cake prepared by substitution (15, 30 and 30%, respectively) with barley whole meal were similar to the scores of the wheat flour controls for these products. The higher substitution levels were not tested for acceptability because the instrumental evaluations indicated poor texture qualities. These studies (Berglund et al 1994; Basman and Koksel 1999; Brochetti and Penfield 1989; Dhingra and Jood 2004) indicated that there was a significant deviation in color preferences of the product with addition of barley flour. In a consumer study, bread crust texture score, which was related to the crust smoothness or roughness, decreased with the increased substitution (up to 20%) of barley flour for wheat flour with (Dhingra and Jood 2004).

4.5 CONCLUSIONS

This study revealed that consumers' attitudes were influenced by their concern or lack of it, for the presence of high fibre in the tortillas. Health consciousness segmented participants into two groups and affected their attitudes towards the barley tortillas. The health conscious consumers (FCC) believed that whole grain products were healthier choices than the refined grain products because of their higher fibre contents. They thus preferred darker tortillas to whiter ones. They also had more tolerance for other texture and flavor characteristics that differed from those of a regular wheat tortilla. The consumers who were apparently less health conscious (FNC) based their preference criteria solely on sensory properties of these tortillas and did not like characteristics different from a regular wheat tortilla even if it was nutritionally superior.

Most and least preferred tortillas identified by FCC and FNC were different for these consumer groups. These differences were explained during discussions that led to the identification of critical descriptors for acceptability. It can be concluded that the wide range of barley genotypes and blending of milling fractions can provide tortillas that are liked by both fibre conscious and fibre neutral groups. However, there is a need for information that shows the effects of barley on the sensory qualities of products in addition to breads. Further work will be done to measure for measuring the important attributes of tortillas by instrumental and sensory descriptive analysis to further define the factors that were critical to consumer acceptance.

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CHAPTER 5

DEVELOPING CRITERIA FOR OPTIMIZATION OF BARLEY TORTILLAS THROUGH DESCRIPTIVE ANALYSIS AND INSTRUMENTAL TESTS

5.1 INTRODUCTION

Cereals and cereal products have been investigated for functional components that include, but are not limited to, insoluble fibre, soluble fibre (β-glucan and arabinoxylans), resistant starch, phytates and phenols (Wood et al 1994; Velioglu et al 1998; Bhatty 1999). There is an increased interest in development of foods with health benefits beyond a basic nutrition function (Hugget and Schliter 1996). β-Glucan, a primary soluble fibre component of barley and oats, is the most extensively studied cereal component, which has exhibited hypocholesterolemic effects (Klopfenstein and Hoseney 1987; Newman et al 1992; Wang et al 1992; Kahlon et al 1993; Wang et al 1997; Wood and Beer 1998).

Barley is an excellent source of both β-glucan and insoluble dietary fibre. β-Glucan, a soluble fibre was reported by Bhatty (1999) to be present at levels of 3-8% in barley, however, new genotypes have been developed since that contain higher levels of β-glucan. One of these is Prowashonupana (Sustagrain ConAgra Foods), which contains 15% β-glucan. The variation in the β-glucan has been attributed not only to genetics (Aman et al 1985; Aman and Newman 1986; Zheng et al 2000), but also to environment (Bhatty 1999; Zheng et al 2000), and to milling fractionation (Zheng et al 2000; Izydorczyk et al 2005). A milling fraction from barley grain which contained as much as

25% β-glucan was identified by Izydorczyk et al (2005). Thus, a wide range of β-glucan content can exist in barley flours.

The variation in the amounts of fibre and β-glucan can affect the sensory quality of barley tortillas. Sensory properties are a critical factor in food product acceptability. Even if a food meets its nutritional requirements, it is unlikely to be accepted by the consumers if they do not like the appearance, mouthfeel or flavor of the product (Frewer et al 1998).

Tortillas, if acceptable to consumers, can become a vehicle for carrying the health benefits of barley, as these can be prepared from barley grain components without blending with any other grain (Ames et al 2004; Ames et al 2006) and can contribute a significant amount of β-glucan to consumers' diets. To prepare tortillas acceptable to consumers it is essential to understand consumers' attitudes and behavior towards these tortillas.

A focus group study was conducted previously to identify the barley tortilla characteristics that were critical to consumer choices. It was concluded that consumers formed two distinct groups based on their attitude to fibre and its importance for a healthy diet. One group, the fibre conscious consumers (FCC), preferred tortillas with some flavor and chewiness, and accepted tortillas of darker color and with some bitter aftertaste. The other group, the fibre neutral consumers (FNC), preferred whiter tortillas that had no flavor or bitter aftertaste. As the criteria used by FCC and FNC for characterizing an ideal tortilla for FCC and FNC were different, the two groups selected different barley tortillas as the ones they liked best. In the present study, tortillas were characterized separately for consumers who selected tortillas based on perceived fibre content, and for those who selected tortillas that had no flavor and little color and resembled white flour tortillas.

To differentiate and quantify the appearance, texture and flavor attributes of tortillas, both instrumental and descriptive analysis methods have previously been used (Bello et al 1991; Campus-Baypoli et al 1999; Quintanar et al 2001; Waliszewski et al 2002; Waniska et al 2002; Guo et al 2003; Amaya-Guerra et al 2004; Serna-Saldivar et al 2004; Bejosano et al 2005). Instrumental methods are generally less time consuming, more objective and reproducible than the descriptive analysis. Descriptive methods, on the other hand, can measure attributes that cannot be measured instrumentally and are more likely to represent the attributes that are practically more important such as bitterness, flavor intensity, stickiness to teeth, chewiness and moisture absorption.

Instrumental tests are commonly used for testing texture and appearance. Texture techniques include, but are not limited to, measurement of firmness, stretchability, tensile strength, and bending, using equipment such as the TA-XT2i texture analyzer and the Instron Universal Testing Machine. Suhendro et al (1997) developed an objective rollability measurement, which was conducted using the TA-XT2i. The color of tortillas, one of the most frequently evaluated characteristics, is commonly evaluated objectively for brightness (L^*), redness (a^*) and yellowness (b^*) values with a reflectance colorimeter such as a Minolta Chroma Meter™ or a Hunterlab Digital Color Difference MeterTM (Friend et al 1993; Quintinar et al 2001; Wang et al 2002).

Descriptive analysis methods, which depend on trained sensory panels to determine the sensory properties of foods, are designed to translate qualitative information into numerical data by applying a statistically valid experimental design and controlled testing conditions (Stone et al 1974; Hunter and McEwan 1998). According to Jellinek (1985), sensory analysis of food relies upon evaluation by our senses (odor, taste, vision, tactile etc). Only by applying exact scientific testing methods can reproducible results be obtained and analyzed statistically (Jellinek 1985). The human participants can differentiate between, and test, only a limited number of samples and a limited number of attributes at a time, due to fatigue, inconsistency and limited memory (Daget et al 1984; Rizvik et al 1992; Martin et al 2000). A major limitation of descriptive analysis methods is that these methods are suitable only for a small sample set. Thus, descriptive analysis studies generally include no more than 10 samples (Quintanar et al 2001; Waliszewski et al 2002) and this method is time consuming and expensive.

However, a major strength of descriptive analysis is its ability to allow relationships between sensory properties and instrumental or consumer preference measurements to be determined (Murray et al 2001). Knowledge of "desired composition" allows for product optimization, and validated models using descriptive sensory and relevant instrumental and/or preference measures are increasingly being applied within the food industry (Wang et al 1996; Desrochers et al 2002; Brown et al 2003; Lee and Resurreccion 2006).

Several research groups have studied the effects of different treatments on tortilla appearance, texture and flavor (Quintanar et al 2001; Waliszewski et al 2003; Bejosano et al 2005). Quintanar et al (2001) reported that the degermination of nixtamal prevented oxidation of lipids and thus improved shelf life of corn tortillas, but the sensory quality of the tortillas was also affected. The degermed tortillas were chewier and firmer than the tortillas made from whole nixtamal. In another study, a trained panel found differences in flavor intensities of corn tortillas fortified with okara at different levels. It was concluded that there was a significant increase in flavor intensity beyond 10% fortification with okara (Waliszewski et al 2002).

The purpose of the present research was to identify the sensory attributes important for acceptability of tortillas for the two types of consumers identified through the earlier focus group study, and to determine the levels of the attributes that formed the criteria of acceptability. Thus, the first objective was to establish a trained descriptive analysis panel to identify the sensory attributes critical for tortilla acceptability. The second objective was to have this panel evaluate these attributes for the selected set of tortillas. The third objective was to compare the mean attribute scores for the six tortilla formulations, and to determine a range that represented acceptability of the attribute for each type of consumer, those wanting high fibre products and those who were concerned primarily with eating characteristics only. The fourth objective was to measure color and texture properties of the tortillas using a colorimeter and texture analyzer, and to correlate these results with panel attribute scores. The fifth objective was to identify the acceptable region for the instrumental measurements that corresponded to the acceptability region for each of the sensory attributes for the two types of consumers.

5.2 MATERIALS AND METHODS

5.2.1 Materials

Hulless food barley samples from four registered cultivars (AC Hawkeye, CDC Alamo, CDC Candle and Millhouse) and from one breeding line (SB 94893) were grown and harvested at Saskatoon, Saskatchewan in 2001 and were obtained from the Crop Development Centre, University of Saskatchewan, Saskatoon, Canada. Amongst these AC Hawkeye (six-rowed) and Millhouse (two-rowed) were non-waxy, CDC Alamo (two-rowed, spring) and CDC Candle (two-rowed) were waxy, and SB 94893 (two-rowed) was a high amylose genotype.

The barley samples were milled (without tempering) in a roller mill (MLU-202, Buhler, Uzwil, Switzerland) with a 0.12-mm roller gap for the second break. The milling of each sample resulted in reduction and break flours, brans and shorts. The reduction and break flours were combined to get straight grade flour (SGF) while bran and shorts were separately dusted in bran duster (Brabender Instruments Inc, NJ, US) to separate the adhering flours. The flour separated from shorts was termed dusted flour from shorts (DFFS) while that from bran was called dusted flour from bran (DFFB).

5.2.2 Milling fraction characterization

Approved Method 44-15A (AACC International 2000) was used to determine moisture content of SGF, DFFS and DFFB by oven drying for 1 hr at 130°C. Protein content (N x 5.7) of SGF, DFFS and DFFB was determined by combustion nitrogen analysis (model FP-248 Leco Dumas CAN analyzer, St. Joseph, US) calibrated with EDTA according to

Approved Method 46-30 (AACC International 2000). Total starch was determined using Approved Method 76-13 (AACC International 2000). The total dietary fibre was determined by enzymatic gravimetric determination, Approved Method 32-07 (AACC International 2000) and β-glucan content of these milling fractions was determined by the rapid enzymatic procedure, Approved Method 32-23 (AACC International 2000). Starch was extracted and analyzed for amylose content by potentiometric titration as described by Schoch (1964), except that lipids were removed before assay by extraction with a 3:1 (v/v) mixture of n-propanol and water at 100C (Morrison and Coventry 1985).

5.2.3 Sample preparation

Blends of SGF, DFFS and DFFS for each of the five genotypes were prepared from the formulations shown in Table 5.1. These formulations were based on a preliminary study, and they represented tortillas with a wide range of attributes. The samples were named after the starch type and proportion of straight grade flour in the blend. The different starch types were zero amylose (ZA) 0 amylose/100g of starch, very low amylose (VLA), 5g amylose/100g of starch, non-waxy (NA), approximately 25g amylose/100g of starch and high amylose (HA), 40g amylose/100g of starch. The zero and very low amylose genotypes are often described as waxy. The numeric part of the sample name indicates the proportion of SGF. Tortillas were prepared by the die-cut method explained in Chapter 3 and were packaged in freezer–proof wrapping and stored at -40°C for up to 7 days. Tortillas for each testing session were selected according to an incomplete randomized block design. They were presented to the panelists in individual ziploc bags labeled with three digit random numbers. Sample order was randomized for each panelist.

Table 5.1. Formulation and Cooking Times of Barley Tortillas and Dietary Fibre Composition of the Formulations.

Formulation[a]	Genotype	Starch type	Blend properties[b]					Processing conditions	
			Flour fraction (% basis)			Fibre composition			
			SGF (%)	DFFS (%)	DFFB (%)	TDF (g/100g)	β-Glucan (g/100g)[b]	Water[d] (g)	Cooking time[e] (s: s: s)
HA 02	SB 94893	High amylose	1.52	93.48	5.00	21.4	9.0	106.14	30:60:30
NA 29	Millhouse	Non-waxy	29.31	62.37	8.31	13.2	4.8	80.47	20:40:20
NA 36	AC Hawkeye	Non-waxy	95	62.86	1.18	12.9	4.7	80.07	20:40:20
NA 87	AC Hawkeye	Non- waxy	87.21	6.24	6.55	8.3	3.4	71.13	15:30:15
VLA 20	CDC Candle	Waxy	20.51	69.49	10.00	16.8	6.9	90.06	25:50:25
ZA 24	CDC Alamo	Waxy	24.29	66.19	9.52	18.1	8.0	91.47	25:50:25

[a] The names have been based on the starch type of the genotype and the proportion of straight grade flour (SGF) in the formulation. HA stands for high amylose, NA for non-waxy or non-waxy, ZA for zero amylose waxy and VLA for very low amylose waxy.
[b]Mean, n=2, dmb of barley flour formulation
[c]SGF, DFFS and DFFB stand for straight grade flour, dusted flour from shorts and dusted flour from bran.
[d]As is moisture basis.

[e] Cooking time on first side: second side: first side, respectively.

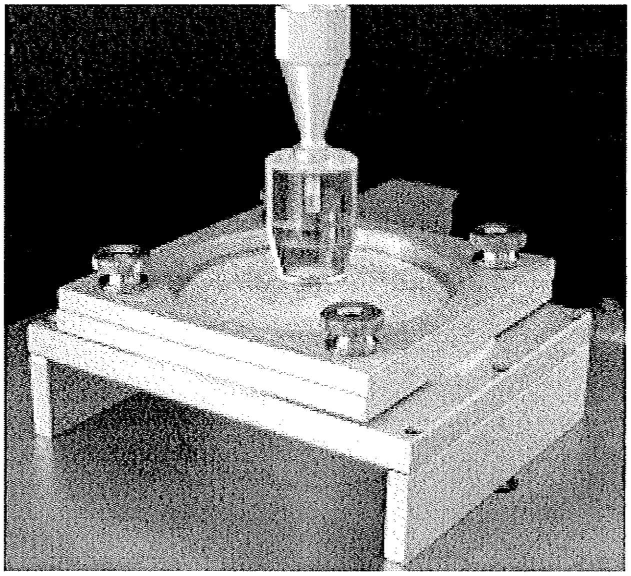
5.2.4 Instrumental testing

The tortillas were stored at room temperature for 24 hours before the texture was evaluated instrumentally. Thickness was measured using Vernier callipers at four different points at 1cm from the edge on each tortilla. A colorimeter (Minolta handheld Chroma Meter, CR-310 Minolta Corp., Ramsey, N.J., US) was used to measure the color of the samples. Values for L^* = darkness/lightness (0 = black, 100 = white), a^* ($-a^*$ = greenness and $+a^*$ = redness), and b^* ($-b^*$ = blueness, $+b^*$ = yellowness) were recorded.

A trained technician measured tortilla rollability by wrapping a tortilla firmly around a 1cm diameter dowel and holding the tortilla in place for 30 seconds. The tortilla was then evaluated for cracks and breaking using a discrete scale with values from 1 (broke immediately, impossible to roll) to 5 (no cracks or breakage)

Texture measurements were made using a TA-XT2i Texture Analyzer (Texture Technologies Corp., Scarsdale, NY, US) equipped with a ¾" rounded end probe (TA-108). The probe travel distance was set at 35 mm after contact with the tortilla. This ensured stretching of the tortilla to the point of puncture. The speed of the probe during the test was set at 1mm/s and the post-test speed at 5mm/s, and a load cell of 5 kg was used. A force/deformation curve was recorded for each tortilla (Fig. 5.1), and the peak force, distance traveled before rupture, area under curve, and the modulus of the gradient were determined.

a)



TA-XT2i Texture Analyser

b)

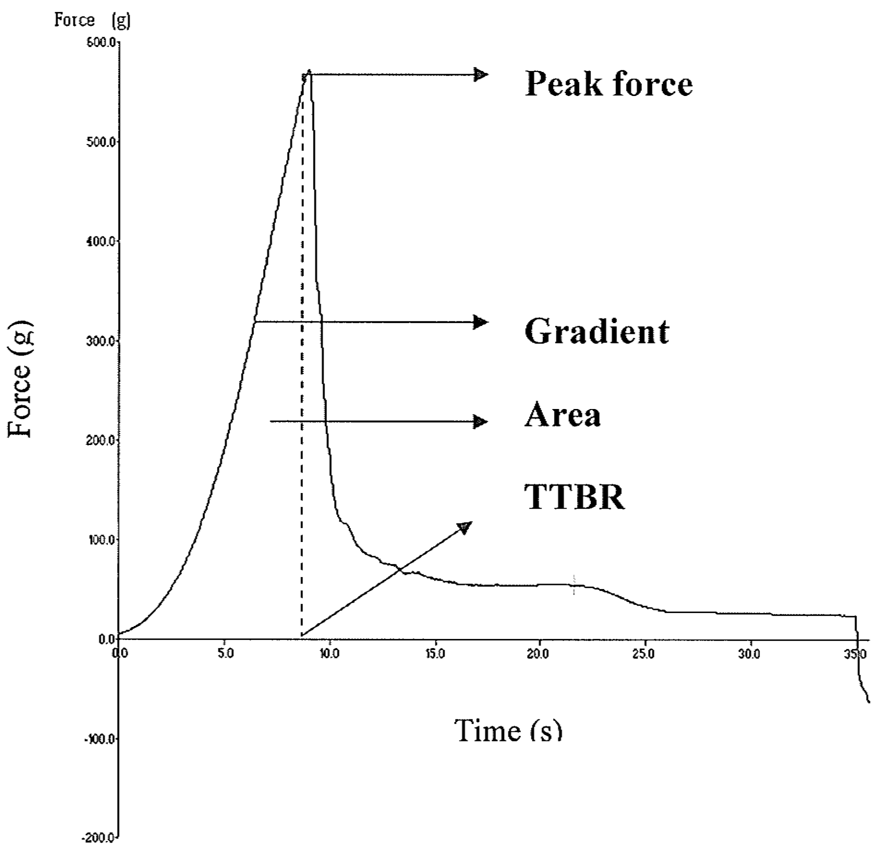


Fig. 5.1 Instrumental measurement of texture attributes using TA-XT2i. a) Mounting the tortilla on TA-XT2i. b) An example of the force/deformation curve for barley tortilla tested on TA-XT2i.

5.2.5 Sensory profiling

Sensory profiling was carried out in the George Weston Ltd. Sensory and Food Research Laboratory of the Department of Human Nutritional Sciences, University of Manitoba, and Winnipeg, MB, which fulfils the requirements of the ISO standards (ISO 1985; 1986). The seven panelists, recruited from Agriculture and Agri-Food Canada and the University of Manitoba were trained in sensory testing of barley tortillas and their evaluation abilities were routinely checked throughout the trials. Samples were presented to the panelists in four sessions, with each one presented twice. They were presented according to a randomized block design.

Training took place over four weeks in 11 sessions beginning with the development of a lexicon to comprehensively and accurately describe tortilla attributes. During the training the panelists were exposed to tortillas with characteristics typical of the products to be tested.

The panel was trained to use a common frame of reference to define these attributes and their intensities in the samples by exposing the panel members to a range of tortillas. Barley tortillas prepared from CDC Candle (60% extraction) was selected as a reference, defined as, "the background information and reference points that assessors mentally refer to when evaluating products" (Munoz and Civille 1998). Attribute intensities were rated on a continuous 15cm line scale anchored at each end, the left end of the scale corresponding to the lowest intensity (value 0) and the right end to the highest intensity (value 15) of the attribute. The reference intensities for each attribute were located on the line scale.

At each testing session, the panelists received three coded samples and an internal reference sample. Food products represented the lowest and highest values on the 15 cm scales, for each attribute. Water, soda crackers and toothpicks were also provided. One full tortilla of each type being tested was given to each panelist. They were instructed to evaluate the appearance (puffiness) of whole tortilla first, and then cut the tortilla vertically and then horizontally into 4 quarters (using a stencil). The quarters were used to evaluate, the remaining attributes.

5.2.6 Statistical analysis

The data were analyzed by analysis of variance (ANOVA) and means compared using Duncan's test ($p \leq 0.05$). SAS statistical software version 9 (SAS Institute Inc, Cary, NC, US) was used. Replicated results are reported as means. Differences were considered highly significant at $p \leq 0.01$ and significant at $p \leq 0.05$. Multiple correlations and simple linear regressions between the instrumental and sensory profile texture attributes were conducted using Microsoft Excel (Version 5.1, 2002).

5.3 RESULTS

5.3.1 Descriptive analysis- attribute identification of barley tortillas

The descriptive analysis panel which was established and trained as described earlier, discussed and identified attribute descriptors. The attributes selected for inclusion on the final ballot were based on a consensus procedure. For the descriptive analysis the selected attributes were puffiness, flavor intensity, bitter after-taste, ease of rolling, breakability, hardness on initial bite, degree of compression, chewiness, moisture absorption and stickiness to teeth. Attribute definition, testing techniques and endpoint anchors for appearance are listed in Tables 5.2 and for texture are listed in Table 5.3. The panelists evaluated the attributes in the order listed.

Two appearance characteristics, color and the extent of raised or puffy surface areas, were considered important by the focus group participants. However, color properties were measured entirely by colorimeter. Puffiness was defined as the proportion of the tortilla covered by air pockets, and the higher the area covered, the greater the puffiness score (Fig. 5.2).

Two assessments of flavor were included on the ballot. The first, flavor intensity, was a measure of the intensity of the roasted and nutty notes, and was judged during mastication of the sample. The second, bitterness aftertaste, was judged after the sample had been swallowed.

Handling properties included were ease of rolling, and the extent of cracking and/or breaking. Eating texture was evaluated using five parameters: hardness and degree of compression both measured on initial bite; chewiness and moisture absorption, measured during mastication of the sample; and stickiness to teeth which was assessed after the sample was swallowed.

Low High

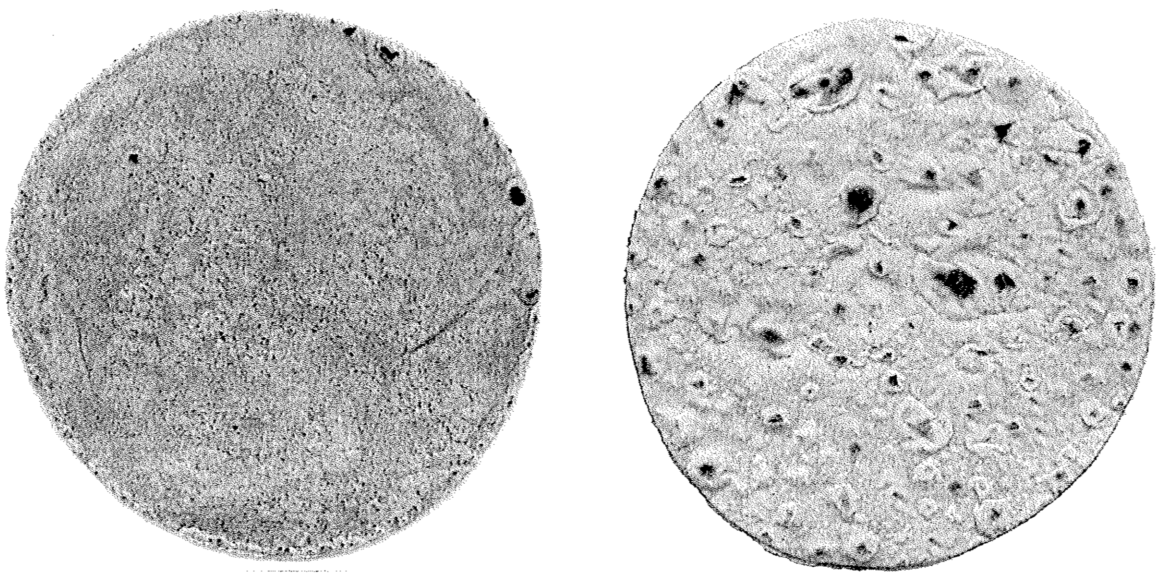


Fig. 5.2 Low and high end points for puffiness

Table 5.2. The Attributes, Definitions, Evaluation Techniques for Evaluating and the Endpoints of Texture Attributes.

Attribute	Definition	Technique	End points
Hardness	The amount of force it takes to bite through the sample.	Place the sample between the front teeth and bite straight through the sample quickly. Evaluate the force required to penetrate the sample.	Low: White bread crumb High: crisp flat bread
Degree of compression	The degree to which the sample compresses.	Place the sample between the front teeth and bite straight through the sample quickly. Determine the degree to which the sample compresses.	Low: Corn tortilla High: White bread crumb
Chewiness	The number of chews required to break up sample before swallowing.	While the sample is placed between the molars apply constant force and chew at a rate of chews per second. Determine the number of chews required to prepare the sample for swallowing.	Low: White bread crumb High: Starburst candy
Moisture absorption	Amount of moisture absorbed by the sample after mastication.	Chew the sample 10 times and evaluate the amount of saliva absorbed by the sample.	Low: Licorice High: Soda cracker
Stickiness to teeth	The amount of sample that sticks to all the surfaces of the teeth.	After the sample has been swallowed evaluate the amount of sample that sticks to all the surfaces of the teeth	Low: Carrot High: Starburst candy

Table 5.3. The Attributes, Definitions, Techniques for Evaluating and the Endpoints of Appearance, Flavor and Handling Attributes.

Attribute	Definition	Technique	End points
Appearance			
Puffiness	The proportion of the tortilla covered by the air pockets. Higher the proportion of air pockets more is the puffiness.	On the backside of the tortilla, check for the proportion of air pockets that can be seen. Evaluate the puffiness on 15 cm line scale.	Low: "Low picture"* High: "High picture"(Fig 5.2)
Flavor			
Flavor intensity	The total amount of flavor tasted while chewing the sample.	Evaluate the amount of flavor tasted while chewing and score flavor intensity of the samples on the 15 cm line scale.	Low: plain pasta High: Bran cereal
Bitter aftertaste	The bitterness felt in the mouth after swallowing the sample.	10 sec after swallowing the sample evaluate the amount of bitterness felt in the mouth and score the bitter after taste of the samples on the 15 cm line scale.	Low: White bread crumb High: Caffeine solution (0.05 %)
Handling properties			
Ease of Rolling	The ability of the sample to be rolled tightly.	Roll the sample tightly; cut edges together until completely rolled. Evaluate the ability of the sample to be completely rolled.	Low: Corn tortilla High: Uncooked tortilla from CDC Alamo
Breakability	The amount of cracking and breaking on rolling the sample tightly.	Roll the sample tightly; cut edges together until completely rolled. Evaluate the amount of cracking/ breaking when rolled completely.	Low: Undercooked tortilla from CDC Alamo High: Corn tortilla

Table 5.4. Sensory Attribute Mean Scores[a,b] For Six Formulations Of Barley Tortillas.

Attribute	High amylose sample	Non-waxy samples			Waxy samples		Range
	HA 02	NA 29	NA 36	NA 87	ZA 24	VLA 20	
Puffiness	2.9^{c}	9.5^{b}	10.1^{b}	12.1^{a}	2.3^{c}	8.5^{b}	2.3 - 12.1
Flavor intensity	6.3^{b}	4.3^{b}	4.7^{b}	4.4^{b}	8.1^{a}	5.2^{b}	4.3 - 8.1
Bitter aftertaste	7.0^{a}	4.4^{c}	5.0^{bc}	4.1^{c}	6.5^{ab}	4.5^{c}	4.1 - 7.0
Breakability	11.9^{a}	3.7^{b}	4.7^{b}	6.0^{b}	1.3^{c}	1.4^{c}	1.3 - 11.9
Ease of rolling	4.7^{d}	11.2^{b}	10.5^{b}	8.8^{c}	13.3^{a}	12.8^{a}	4.7 - 13.3
Hardness on initial bite	7.7^{ab}	6.2^{bc}	7.5^{ab}	8.6^{a}	4.4^{d}	4.9^{cd}	4.4 - 8.6
Degree of compression	4.7^{c}	8.1^{b}	8.9^{b}	9.2^{b}	11.2^{a}	9.7^{ab}	4.7 - 11.2
Chewiness	6.5^{ab}	7.3^{ab}	8.0^{a}	8.4^{a}	5.6^{b}	6.9^{ab}	5.6 - 8.4
Moisture absorption	10.0^{a}	7.1^{b}	6.2^{b}	7.1^{bc}	3.0^{d}	3.8^{cd}	3.0 - 10.0
Stickiness to teeth	6.6^{ab}	5.5^{b}	5.7^{ab}	6.1^{ab}	7.7^{a}	7.5^{ab}	5.5 - 7.5

[a]Mean score measurements based on a 15cm line scale, n=7, replicates = 2.
[b]Means in the same column with the same superscript were not significantly different ($p \leq 0.05$).

5.3.2 Evaluation of the tortillas and comparison of attribute scores

The attribute mean scores for the six barley formulations are presented in Table 5.4. There were significant differences among the six formulations for all of the attributes. The greatest differences were observed in the intensities of puffiness (2.3-12.1), breakability (1.3-11.9), ease of rolling (4.7-13.3), degree of compression (4.7-11.2) and moisture absorption (3-10). These properties therefore distinguished most effectively among the samples.

It may be possible to screen for the most important sensory properties using fewer attributes than the ten tested. Scores of hardness on initial bite, chewiness and stickiness to teeth, differed significantly among the samples but showed narrow ranges and were correlated to other sensory attributes as shown in Table 5.5. Hardness on initial bite was moderately correlated to breakability ($r = 0.69$) and ease of rolling ($r = 0.70$). Chewiness was highly correlated with puffiness ($r = 0.92$). Flavor intensity was correlated with stickiness to teeth ($r = 0.78$). In addition, breakability and ease of rolling corresponded to each other ($r = -1.00$). Thus, puffiness, breakability, stickiness to teeth, bitter aftertaste, degree of compression and moisture absorption sufficiently represented the variability of sensory attributes in these samples.

5.3.3 Effects of chemical composition of barley tortillas on the sensory quality of tortillas

Composition of the formulations affected the sensory quality of the barley tortillas (Fig. 5.3). Puffiness was negatively related to TDF ($r = -0.89$) and breakability was related negatively to β-glucan. Amylose content in the formulations affected breakability (r = 0.82), hardness on initial bite (r = 0.92) and moisture absorption (r = 0.94). For the set of tortillas evaluated in this study, it appeared that some of the sensory perceptions were largely deformed by the fibre components.

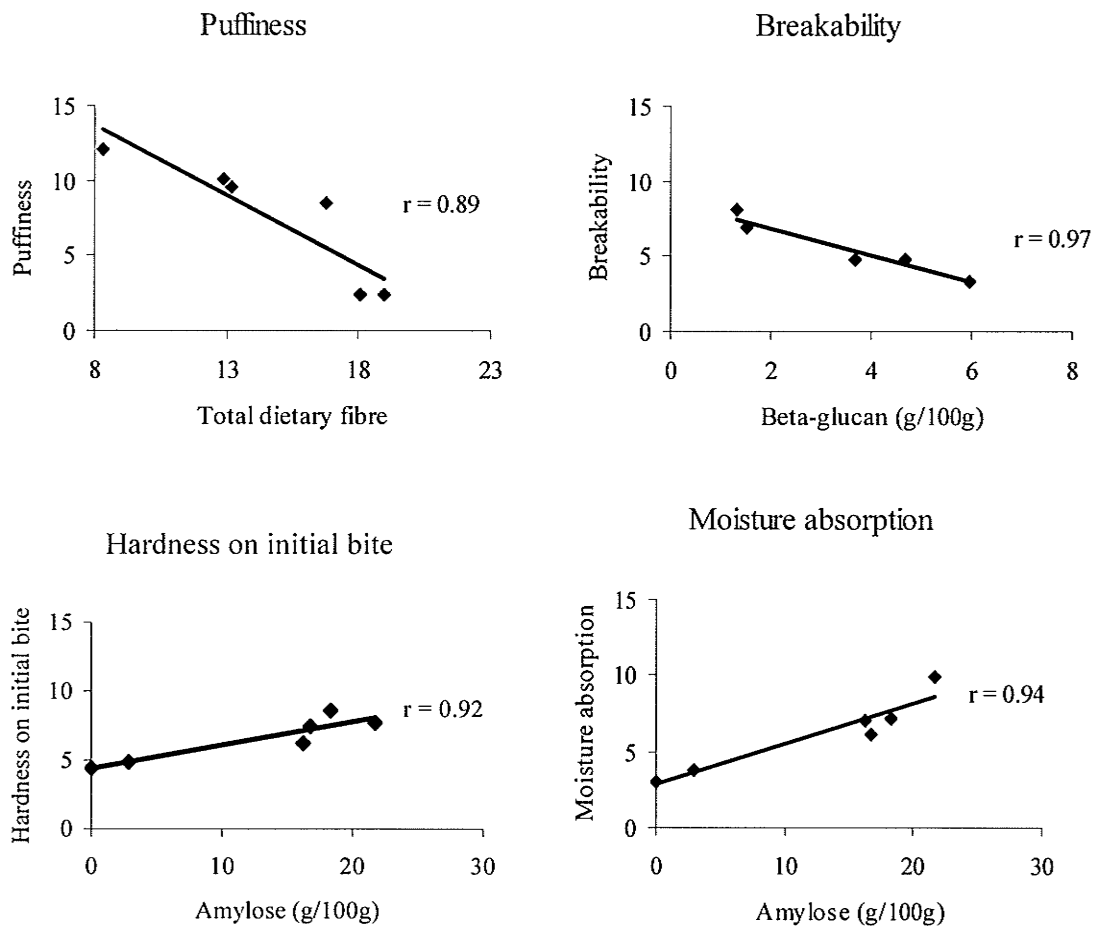


Fig. 5.3 Effects of chemical components on the sensory quality of tortillas. A) TDF vs. puffiness, b) β-glucan vs. breakability, c) amylose vs. hardness on initial bite and d) amylose vs. moisture absorption.

The effect of amylose level is also shown in Table 5.5, where the waxy samples (VLA 20 and ZA 24) had the least breakability and moisture absorption while they had the highest ease of rolling. Non-waxy samples (NA 29, NA 36 and NA 87) had lower breakability and moisture absorption than the high amylose HA 02.

5.3.4 Sensory qualities of the most preferred tortillas

In the previous focus group study (Chapter 4) fibre conscious consumers (FCC) and fibre neutral consumers (FNC) indicated their preferences for barley tortillas. Sensory attribute intensities of the acceptable tortillas were used as the guidelines for setting limits for acceptability criteria for FCC and FNC (Fig. 5.4). FCC preferred VLA 20 and NA 29. The trained panel scores for these two samples were similar in puffiness, flavor intensity, bitter aftertaste, hardness on initial bite, degree of compression chewiness, and stickiness to teeth. Although these samples were significantly different ($p \leq 0.05$) with respect to breakability, ease of rolling and moisture absorption, their scores also helped define the acceptable regions for the three characteristics (Fig. 5.5). Thus, from the intensities of the most preferred tortillas, an acceptable range of scores could be estimated. An acceptable tortilla for FCC was estimated to have scores of $\geq$ 8.5 puffiness, $\geq$11.2 ease of rolling, $\leq$ 3.7 breakability, $\leq$ 6.2 hardness, and $\leq$ 7.3 chewiness, $\leq$ 7.5 stickiness to teeth, $\leq$ 7.1 moisture absorption, and $\leq$ 5.2 flavor intensity.

FNC preferred three tortillas (NA 29, NA 87 and NA 36) for their appearance, texture and flavor attributes. The trained panel results showed that these tortillas were not significantly different (Fig. 5.4) with respect to flavor intensity, bitter after taste, breakability, degree of compression, chewiness, moisture absorption and stickiness to teeth. They differed with respect to puffiness, ease of rolling and hardness on initial bite.

However, all the appearance, texture and flavor attributes were helpful in defining the acceptable score range for these attributes, which were puffiness ≥ 9.5, flavor intensity ≤ 4.7, bitter aftertaste ≤ 5.0, ease of rolling ≥ 8.8, breakability ≤ 6.0, hardness on initial bite ≤ 8.6, degree of compression ≤ 9.2, moisture absorption between 6.2 and 7.1 (inclusive) and stickiness to teeth ≤ 6.1 (Fig. 5.4).

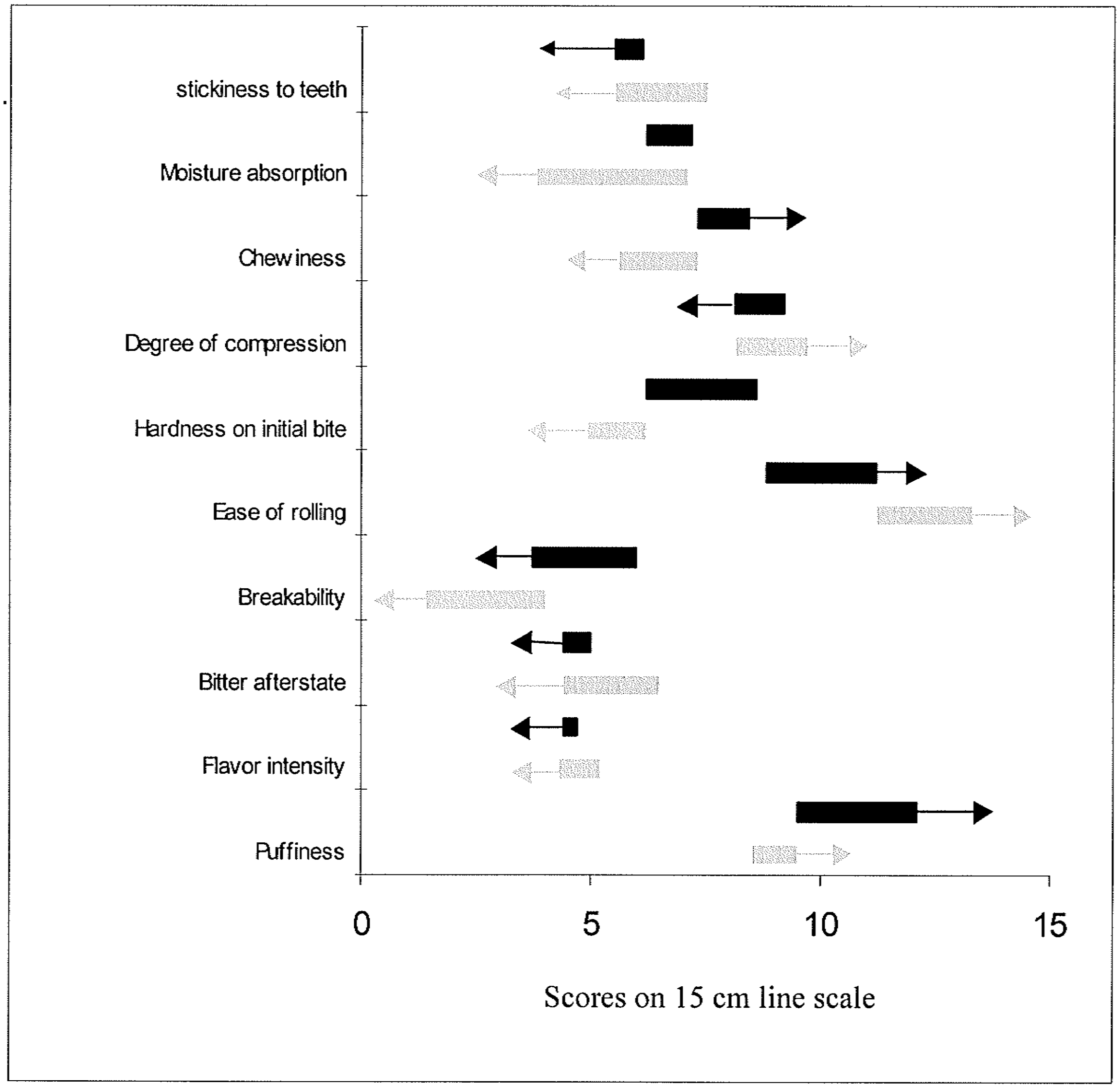


Fig. 5.4 Acceptability limits of sensory attributes of barley tortillas for FCC and FNC. The bars show the range of scores and the arrows indicate the direction of preferences.

Table 5.5 Correlations[a] Among the Sensory Attributes of Barley Tortillas Determined by Descriptive Analysis.

	Puffiness	Bitter aftertaste	Flavor intensity	Breakability	Ease of rolling	Degree of compression	Chewiness	Hardness	Moisture absorption	Stickiness to teeth
Puffiness	1.00									
Bitter aftertaste	**-0.93**	1.00								
Flavor intensity	**-0.89**	0.71	1.00							
Breakability	-0.24	0.58	-0.10	1.00						
Ease of roll	0.18	-0.53	0.15	**-1.00**	1.00					
Degree of compression	0.23	-0.54	0.20	**-0.92**	**0.90**	1.00				
Chewiness	**0.92**	-0.73	**-0.91**	0.13	-0.19	-0.07	1.00			
Hardness	0.42	-0.08	-0.57	0.73	-0.77	-0.56	0.73	1.00		
Moisture absorption	0.01	0.34	-0.37	**0.93**	**-0.94**	**-0.93**	0.33	0.80	1.00	
Stickiness to teeth	-0.61	0.42	0.78	-0.33	0.34	0.38	-0.75	-0.70	-0.60	1.00

[a]Values in bold indicate significant correlations ($p \leq 0.01$)

5.3.5 Instrumental measurements and prediction of sensory acceptability

Sensory evaluation provided information about aspects of barley tortillas that could not be measured instrumentally. However, some texture and color attributes could be evaluated by texture testing instruments and colorimeters. When a large number of products need to be tested, instrumental tests can be chosen accessed for their ability to provide rapid and efficient measurements of characteristics. The instrumental parameters that were most highly correlated with the sensory attributes were identified and used as the predictors of sensory properties.

5.3.5.1 Instrumental measurements of barley tortilla appearance and texture

Barley tortillas varied in their appearance and textural attributes as measured instrumentally (Table 5.6). Color measurements of tortillas showed a wide range of L^*- (62.3-77.7), a^*- (2.4-7.8) and b^*- (19.1-24.2) values. Texture parameters also showed a wide range for rollability (2.3-5.0), gradient (68.0-107.7) and time traveled before rupture (TTBR) (6.6-13.1). There was, however less variability seen for peak force and area under curve for the barley tortillas.

Starch characteristics might have had an effect on the appearance and texture parameters. The tortillas prepared with waxy genotypes (VLA 20 and ZA 24) had lower L^* and a^* values than did the tortillas prepared with non-waxy genotypes. These tortillas also had higher rollability (4.7-5.0) and TTBR and lower gradient than did the tortillas prepared with non-waxy samples.

Table 5.6. Means[a] of Instrumental Measurements[b] of Barley Tortillas.

Sample	Thick-ness (mm)	*L*-value*	*a*-value*	*b*-value*	Roll-ability	Gradient (g/s)	TTBR[c] (s)	Area (gs)
HA 02	1.5[b]	66.5[c]	3.9[b]	22.5[c]	2.3[a]	107.7[c]	6.6[a]	3806[c]
NA 29	1.7[c]	70.0[d]	3.0[b]	20.7[b]	3.5[b]	70.1[a]	8.9[b]	
NA 36	1.6[c]	73.4[e]	3.2[b]	20.9[b]	3.2[b]	80.0[b]	9.4[b]	3046[b]
NA87	1.7[c]	77.7[f]	2.4[a]	19.1[a]	2.8[b]	81.7[b]	9.0[b]	3002[b]
VLA 20	1.4[b]	65.0[b]	4.9[c]	21.4[b]	4.7[c]	69.8[a]	11.3[c]	2690[a]
ZA 24	1.2[a]	62.3[a]	7.8[d]	24.2[d]	5.0[c]	68.0[a]	13.1[d]	3714[c]
Range	1.2 - 1.7	62.3 – 77.7	2.4 – 7.8	19.1 – 24.2	2.3 – 5.0	68.0 – 107.7	6.6 – 13.1	2690 - 3806

[a]Means of instrumental parameters, replicates = 3.
[b]Means in the same column with the same superscript were not significantly different ($p \leq 0.05$).
[c]TTBR- Time traveled before rupture

5.3.5.2 Identification of predictors

Correlations between sensory attribute scores and instrumentally determined values are shown in Table 5.7. Puffiness, measured by descriptive analysis, was negatively and significantly correlated ($r= -0.93$, $p \leq 0.05$) with the *b**-value of barley tortillas. Since these parameters did not have a direct cause-effect relationship, the linear regression between puffiness and the *b**-value ($R^2= 0.86$) could be used for prediction of puffiness in this set of sample but not for explaining the effect of *b**-value on puffiness.

The breakability correlated positively ($r= 0.97$) with the gradient while ease of rollability correlated negatively ($r= -0.96$) with the gradient. The regressions of breakability and ease of rollability against gradient indicate that 94% of breakability and 91% of ease of rollability could be explained by gradient. Therefore the regression coefficients were also used to predict the values of sensory attributes.

Strong correlations were also found between the tortilla texture while masticating the sample and texture measurements with texture analyzer (TA-XT2i). There were high correlations of degree of compression (r= 0.92), hardness on initial bite (r= -0.81) and moisture absorption (r= -0.98) with TTBR. Linear regressions indicated that TTBR explained 85% of the variability in the degree of compression and 97% of the variability in moisture absorption. There seemed to be no strong predictors for chewiness and stickiness to teeth.

Indirect relationships were seen between instrumentally measured color attributes and sensory flavor attributes resulting in a strong positive correlation between flavor intensity and *b*-value*. A linear regression between *b*-value* and flavor intensity could be used for predicting the flavor intensity but not for explaining the effect of *b*-value* on flavor intensity.

5.3.5.3 Translation of the sensory criteria for barley tortillas into the instrumental measurements

Levels of sensory attributes that were critical for barley tortilla acceptability to FCC and FNC were replaced by the predicted instrumental measures using the regression equations. Criteria developed for FCC and FNC in terms of instrumental measurements were: for FCC, the acceptable barley tortilla will have L^**-value* ≥ 63.5, b^**-value* ≤ 22.5, gradient ≤ 76 g/s, time ≥ 9.2 and a^**-value* ≤ 6.5, and for FNC the acceptable barley tortilla will have L^**-value* ≥ 69.0, b^**-value* ≤ 20.6, gradient ≤ 84 g/s, time before rupture ≥ 8.9s and a-value ≤ 3.4.

Table 5.7 Correlations[a] between the Sensory Attribute Scores and the Instrumental Measurements

Instrumental parameter[b]	Sensory attribute									
	Puffiness	Bitter aftertaste	Flavor intensity	Breakability	Ease of rolling	Degree of compression	Chewiness	Hardness on initial bite	Moisture absorption	Stickiness to teeth
Gradient	-0.33	0.65	0.01	**0.97**	**-0.96**	**-0.88**	0.04	0.66	**0.85**	-0.18
Area	-0.86	0.88	0.76	0.47	-0.42	-0.38	-0.65	-0.03	0.32	0.20
TTBR	-0.12	-0.23	0.50	**-0.88**	**0.88**	**0.92**	-0.43	-0.81	**-0.98**	0.65
Peak force	-0.73	0.74	0.72	0.46	-0.44	-0.19	-0.48	0.10	0.17	0.25
Rollability	-0.11	-0.25	0.38	**-0.88**	**0.88**	0.79	-0.47	**-0.93**	**-0.93**	0.54
L-value*	0.82	-0.61	-0.78	0.19	-0.22	-0.10	**0.95**	0.83	0.42	-0.77
a-value*	-0.73	0.44	**0.92**	-0.43	0.46	0.49	-0.88	-0.82	-0.69	**0.86**
b-value*	**-0.93**	0.72	**0.94**	-0.04	0.07	0.10	**-0.96**	-0.67	-0.34	0.69

[a]Values in bold indicate significant correlations ($p \leq 0.01$)

[b]TTBR is time traveled before rupture, and *L**, *a**, and *b**-values are brightness, redness and yellowness value of the tortilla

5.4 DISCUSSION

Appearance, texture and flavor attributes similar to those identified in this study have been reported in flour and corn tortillas (Bejosano et al 2005; Reyes-Vega et al 1998; Waliszewski et al 2002; Quintanar-Vidal et al 2001). Puffiness in tortillas and similar products has been cited as an important quality factor (Milan Carrillo et al 2006, Shahzadi et al 2005) but has not been measured through descriptive analysis. Waniska et al (2002) reported that opacity, a property similar to puffiness, was correlated positively with amylose content in wheat tortillas where amylose content ranged between 14.3-17.7 g/100g. They also reported that the opacity decreased with addition of barley flour and was lower for formulations containing higher amounts of β-glucan. In the present study, puffiness was negatively related to TDF which, included β-glucan. There was an effect of amylose on puffiness but it was not a linear relationship. Puffiness was the highest in non-waxy samples and the least in zero and high amylose samples.

Ease of rolling and breakability have been very often measured subjectively by trained panels or objectively with instruments (Bejosano et al 2005, Waliszewski et al 2000) to determine the effects of amylose, gluten, milling fractions, barley β-glucan and storage among other factors. In wheat tortillas it was reported that rollability increased with higher gluten protein and lower amylose content (Waniska et al 2002; Pascut et al 2003). In the present study the effect of protein was not observed because barley contains only trace amounts of gluten. Other sensory attributes reported include fracturability, chewiness, stickiness and moisture absorption, which have been considered important for determining the effect of storage on textural attributes of tortillas (Bejosano et al 2005).

Toasted flavor and bitter aftertaste were the only flavor attributes identified by the panelists. Bitterness and bitter aftertaste have been reported in corn tortillas (Quintinar-Vidal et al 2001). Basman and Koksel (1999) reported that addition of barley flour to wheat flour for Balsama bread, did not affect the taste and aroma of the bread. This might be due to the fact that only one barley genotype was tested which was non-waxy and low in β-glucan (3.34%) and the proportion of barley flour fraction was only up to 40%. In the present study, bitter aftertaste was more pronounced for high amylose and waxy samples that contained high proportions of DFFS.

Barley tortilla acceptability criteria confirmed and quantified the differences between the tortilla preferences of FCC and FNC. There are reports that indicate that health conscious consumers accept a wider range of texture characteristics as compared to the consumers that are not health conscious (Stauffer 2005). Separate criteria for acceptability of strawberry gels and peach nectars have been suggested for consumers with different preferences (Damasio et al 1999; Costell et al 2000). Peach nectars were rated by consumers and were tested by trained panelists for several flavor and texture attributes (Costell et al 2000). Consumers were sub-grouped into four segments by factor analysis based on the preferences for texture and flavor attributes.

Descriptive analysis was utilized to set criteria for acceptable tortilla quality by quantifying the intensities of the critical sensory attributes of these tortillas. A similar relationship between consumer acceptability and sensory attribute scores was utilized by Hough et al (2002) to determine the shelf life of powdered milk. The attribute intensities of acid, caramel, cooked flavor, dark color, studied the sensory descriptors, acid, caramel, cooked flavor, dark color and oxidized flavor were monitored over time. The attribute intensities were measured at the stage when consumer acceptability declined, were set as the criteria for shelf-stability. Consumer acceptability has also been used for quality control of sausage texture and flavor and beef tenderness (Huffman et al 1996; Hough et al 2002; Dingstad et al 2005).

Appearance attributes could be predicted by color parameters (L^*, a^* & b^*-*values*). The color attributes were measured instrumentally and were not measured through descriptive analysis due to the accurate prediction of color properties by instrumentally measured parameters. The b^*-*value* was a strong but indirect predictor of puffiness.

Direct and indirect predictors were identified for the texture attributes of barley tortillas. Breakability and ease of rolling could be predicted by the gradient value as measured with the TA-XT2i texture analyzer. The gradient is the amount of force per unit time required by the probe to stretch the tortilla. Other studies have reported this as elasticity, which was negatively related to rollability (Bello et al 1991). High correlation between stickiness to teeth and a^*-*value* (redness) infers that there may be an indirect relationship between the occurrences these two parameters. Similar co-occurrence of these two parameters has been reported in whole grain and high-fibre wheat tortillas (Seetharaman et al 1994).

Indirect predictors for flavor attributes were identified by correlating flavor with color parameters. Flavor intensity was highly correlated to b^*-*value* which is in accordance with other studies that suggest that high fibre tortillas are darker and have more flavor (Seetharaman et al 1999). Bitterness was not predicted because it correlated weakly with

*L** (r = -0.61) and *b**-values (r = 0.72). This might have been due to a narrow range of bitter aftertaste found in the barley tortillas tested for this study. Other studies have shown that tortillas with darker color have higher bitterness (Friend et al 1992; Seetharaman et al 1994).

5.5 CONCLUSIONS

Criteria were developed on the basis of both sensory and instrumental measurements for optimum tortillas as identified by different groups of consumers. Important instrumental parameters that could predict sensory attributes were, *L*, a* & b*-values*, gradient and time before rupture on the texture analyzer curve. These predictors could be used to screen barley tortillas for sensory quality and acceptability, without the need to conduct sensory analysis. This study also indicates that the tortilla quality may be more dependent on amylose and β-glucan content than on other chemical components, there is a need to determine the effects of these other components on barley tortilla quality.

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CHAPTER 6

BARLEY FORMULATIONS OPTIMIZED FOR CONSUMER ACCEPTABILITY AND HIGH β-GLUCAN CONTENT

6.1 INTRODUCTION

Health benefits of β-glucan have been confirmed through the human nutritional studies (Klopfenstein and Hosney 1987; Lia et al 1995; Pick et al 1998). The benefit of β-glucan has been shown to be in lowering plasma cholesterol, reducing glycemic index and diminishing the risk of colon cancer in human beings (McIntosh et al 1991; Newman and Newman 1991; Bhatty 1993; Kahlon and Chow 1997; Yokoyama et al 1997; Jadhav et al 1998).

FDA has recognized the benefits of barley β-glucan and thus has allowed barley food products to carry the health claim that the consumption of at least 3g barley β-glucan per day when consumed as part of a diet low in saturated fat and cholesterol, may reduce the risk of heart disease (FDA 2005). A food product must provide a minimum of 0.75g of β-glucan per serving to be eligible to carry this health claim. The FDA has identified several sources of barley β-glucan soluble fibre that are eligible for the health claim. These include whole grain barley, barley bran, barley flakes, barley grits, barley flour, barley meal, sieved barley meal and pearl barley produced from clean and sound dehulled or hulless barley using standard dry milling techniques. Oat flakes available in market provide a maximum of 1g of β-glucan per serving of 30g of the cereal (Quakers 2004). A food product containing higher levels of β-glucan might prove more useful to the consumers.

High levels of β-glucan can be achieved in barley flour by breeding high β-glucan genotypes and by milling fractionation. A new cultivar, Prowashonupana (Sustagrain, ConAgra Foods) has been bred that contains 15% β-glucan. Through milling fractionation β-glucan as high as 25% has been achieved in a waxy barley fraction. Such flours and other milling fractions that contain high levels of β-glucan can be utilized for product development to achieve high levels of the soluble fibre in these products.

Achieving this high level of β-glucan in food products may be challenging due to adverse effects of barley incorporation on sensory quality of certain products (Erkan et al 2006, Gujral et al 2003). In a study (Kim et al 2004) that examined the effect of barley bran on sugar-snap cookies and muffins, 10, 20 and 30% bran substitution led to lower acceptability scores in each case. In another study (Cavallero et al 2002) the substitution of 50% of enriched wheat flour with barley flour in bread resulted in lower hedonic scores for crumb texture, flavor and overall acceptability. Thus, high levels of substitution with barley flour may not be suitable for making leavened food products like bread and muffins.

However, the sensory quality of unleavened products like unleavened tortillas, noodles and pasta has not been adversely affected by barley incorporation. In a study on chapatti, unleavened flat bread prepared with wheat flour, positive effects of barley flour on extensibility and shelf-stability in terms of texture of the chapatti were reported (Gujral and Gaur 2005). Izydorczyk et al (2005) found that a fibre-rich-fraction from a waxy barley improved the texture and cooking quality of Asian noodles. Ames et al (2006) reported that barley tortillas, prepared with a CDC Candle flour blend, were highly acceptable to the consumers when compared with a commercially prepared wheat flour tortilla. In the same study, chemical composition of the formulations and the texture and color of tortillas prepared from 17 genotypes showed a large variation. However, the acceptability of tortillas prepared with other genotypes (CDC Alamo, CDC Fibar and SB 94893) that contained higher β-glucan content than CDC Candle, was not tested. It was important to identify genotypes and their flour blends that could be used to maximize β-glucan content in barley tortillas with acceptable sensory quality. A need of such a balance between functional ingredient and sensory quality of a product has been expressed (Cleary 2006).

The classic approach for optimization is the one-variable-at-a-time techniques, which is time-consuming and does not depict the complete effects of the parameters in the process. A more efficient method is response surface methodology (RSM), which is an important tool in process and product development. RSM is a collection of experimental designs and optimization techniques that enable the experimenter to determine the relationship between the response and the independent variables. RSM is typically used for mapping a response surface over particular region of interest, for optimizing the response, or for selecting operating independent variables to achieve target specifications (Box and Draper 1987; Khuri and Cornell 1996; Myers and Montgomery 1995). One of the designs used for product optimization is a mixture design.

A mixture experiment is a special type of response surface experiment in which the factors are the components of a mixture and the response is a function of the proportions of each ingredient. The mixture components cannot range in an independent way since their sum has to be equal to 100%, and specific experimental matrices and mathematic models have to be used. These designs have been used to optimize the proportions of 2 to 4 components in drugs to give optimum stability and performance (Bodea and Leucuta 1997; Mura et al 2005). This approach is suitable for pharmaceutical blending problems allowing investigation, with the least number of experiments, of the effects of changes in mixture composition and selection of the optimal composition for achieving the prefixed target (Myers 1995). It has also been used for formulating food products (Alarcón-Valdez et al 2005)

To carry out the optimization for barley tortillas, criteria of desired tortilla quality based on instrumental testing were defined in previous studies (Chapter 4 and Chapter 5). These criteria were developed using focus groups to identify acceptable tortillas, descriptive analysis to measure the critical sensory attributes of acceptable tortillas and physical tests to measure the texture and color of barley tortilla. Two distinct types of consumers, fibre conscious consumers (FCC) and fibre neutral consumers (FNC), were identified and the criteria of acceptability were different for these two groups. Critical sensory attributes for FCC were high ease of rolling, low breakability, and low hardness on initial bite; while those for FNC were bright and light color, and high puffiness. The instrumental limits that formed the criteria for the two groups were rollability (measured subjectively by a trained technician), L^* a, and b^* values (measured with Minolta Chroma Meter), gradient and time traveled before rupture (measured with TA-XT2i texture analyzer tortilla rig.

These criteria were applied to a range of barley genotypes and their milling fractions to 1) screen barley genotypes and formulations for acceptable barley tortillas, and 2) to maximize β-glucan content of acceptable barley tortillas.

6.2 MATERIALS AND METHODS

6.2.1 Materials

Nine samples of hulless barley were selected from an initial set containing 20 genotypes grown at Brandon MB in 2000, and obtained from Dr. Mario Therrien of the Brandon Research Centre of Agriculture and Agri-food Canada (Appendix II). Ten additional samples grown in Saskatoon SK, in 2000 and 2001, were obtained from Dr. Brian Rossnagel of the University of Saskatchewan. Among all the samples, three were grown in all the three environments and were AC Hawkeye, Millhouse and SB 94893. The remaining seven samples were grown in one or two environments. The complete set of samples with yields of flour milling fractions is listed in Table 6.1. Grains were cleaned, milled and dusted as explained in Chapter 5 to yield straight grade flour (SGF), dusted flour from shorts (DFFS), and dusted flour from bran (DFFB).

6.2.2 Milling fraction characterization

Approved Method 44-15A (AACC International 2000) was used to determine moisture content of SGF, DFFS and DFFB by oven drying for 1 hr at 130°C. Protein content (N x 5.7) of SGF, DFFS and DFFB was determined by combustion nitrogen analysis (model FP-248 Leco Dumas CAN analyzer, St. Joseph, US) calibrated with EDTA according to Approved Method 46-30 (AACC International 2000). Total starch was determined using

Approved Method 76-13 (AACC International 2000). The total dietary fibre was determined by enzymatic gravimetric determination, Approved Method 32-07 (AACC International 2000) and β-glucan content of these milling fractions was determined by the rapid enzymatic procedure, Approved Method 32-23 (AACC International 2000). Starch from the whole grain was extracted and analyzed for amylose content by Potentiometric Titration as described by Schoch (1964), except that lipids were removed before assay by extraction with a 3:1 (v/v) mixture of n-propanol and water at 100C (Morrison and Coventry 1985). The amount of moisture, crude protein, total starch, total dietary fibre, β-glucan and amylose in the blends of SGF, DFFS and DFFB were calculated from the amounts of these components in these flour fractions.

6.2.3 Tortilla preparation

Tortillas were prepared by the die-cut method described in the descriptive analysis study (Chapter 5). The cooking times of this large number (190) of tortilla formulations were estimated from a pre-test. Tortillas from a set of formulations that represented a wide range of chemical compositions, were cooked for 60, 70, 80 ...120s and were checked for undercooked translucent areas and over cooked burnt areas. Cooking times at which the tortillas lacked any undercooked or over cooked areas were selected as the ideal time of cooking. There was a relationship between these cooking times and the water absorption of the respective dough for preparing tortillas. Tortillas prepared from dough with higher optimum water absorption required longer time to cook. This relationship was used to estimate the cooking time of the test samples for this study.

The amount of β-glucan/serving has been calculated based on the moisture content of these tortillas and on the β-glucan content of the flour formulation used for preparing the tortilla (Appendix III b & c). The moisture content of the tortillas was determined and these values were used to calculate the dry matter content. The β-glucan content of the blends was used to calculate β-glucan in the tortillas. These calculated β-glucan/serving values were used as another variable for optimization, and the Design Expert (Version 6.0.10, Stat-Ease Inc., Minneapolis, US) was used to estimate the β-glucan/serving of tortillas for the acceptable formulations.

Design Expert (Version 6.0.10, Stat-Ease Inc., Minneapolis, US) was used to estimate the highest amount of β-glucan that could be achieved within the acceptable region for each barley sample. After the recognition of an acceptable region based on the appearance and texture acceptability criteria developed, an additional criterion was applied i.e. to "Maximize" the β-glucan content. The Design expert (Version 6.0.10, Stat-Ease Inc., Minneapolis, US) generated a list of 1-3 formulations that could contain highest amount of β-glucan, within the acceptable region from each barley sample and one formulation with the highest β-glucan from each of the barley samples capable of producing acceptable tortillas and these are reported.

Table 6.1 Yields (g/100g) of Flour Fractions[a], SGF, DFFS and DFFB from 19 Waxy, Non-Waxy, Low-Amylose and High-Amylose Hulless Barley

Genotype	Amylose content of starch (g/100g)	Location/year	Milling fractions (g/100g) SGF	DFFS	DFFB
AC Hawkeye	26	Brandon/2000	56.9	31.8	1.6
AC Hawkeye	26	Saskatchewan/2000	58.7	31.1	1.8
AC Hawkeye	27	Saskatchewan/2001	43.8	24.8	2.1
CDC Alamo	0	Saskatchewan/2001	34.4	22.8	3.4
CDC Candle	5	Brandon/2000	42.9	25.0	3.0
CDC Candle	5	Saskatchewan/2001	45.1	20.1	3.3
CDC Dawn	26	Brandon/2000	58.2	33.5	2.5
CDC Fibar	0	Brandon/2000	37.3	25.1	4.8
CDC Fibar	0	Saskatchewan/2000	35.6	32.4	4.7
CDC Freedom	26	Brandon/2000	52.8	31.1	2.2
Condor	26	Brandon/2000	49.2	30.9	2.7
HB 805	16	Brandon/2000	48.9	28.4	2.6
HB 805	16	Saskatchewan/2000	50.9	34.3	2.4
Millhouse	26	Brandon/2000	58.5	27.3	2.2
Millhouse	26	Saskatchewan/2000	53.2	32.4	2.2
Millhouse	26	Saskatchewan/2001	44.5	19.4	2.5
SB 94893	40	Brandon/2000	42.5	27.7	4.9
SB 94893	40	Saskatchewan/2000	40.5	29.5	2.8
SB 94893	40	Saskatchewan/2001	31.0	14.0	3.0

[a]SGF, DFFS and DFFB stand for straight grade flour, dusted flour from shorts and dusted flour from bran, respectively.

6.2.4 Instrumental testing of tortilla texture and color

After they were cooked, the tortillas were stored at room temperature for 24 hours before their texture was evaluated instrumentally. Thickness was measured using Vernier callipers at four different points at 1cm from the edge on each tortilla. A colorimeter (Minolta handheld Chroma Meter, CR-310 Minolta Corp., N.J, US) was used to measure the color properties of the samples. Values for $L*$ = darkness/lightness (0 = black, 100 =

white), a^* ($-a^*$ = greenness and $+a^*$ = redness), and b^* ($-b^*$ = blueness, $+b^*$ = yellowness) were recorded.

A trained technician measured tortilla rollability by wrapping a tortilla firmly around a 1cm diameter dowel and holding the tortilla in place for 30 seconds. The tortilla was then evaluated for cracks and breaking using a discrete scale with values from 1 (broke immediately, impossible to roll) to 5 (no cracks or breakage)

Texture measurements were made using a TA-XT2i Texture Analyser (Texture Technologies Corp., Scarsdale, US) equipped with a ¾" rounded end probe (TA-108). The probe travel distance was set at 35 mm after contact with the tortilla. This ensured stretching of the tortilla to the point of puncture. The speed of the probe during the test was set at 1mm/s and the post-test speed at 5mm/s, and the load cell of 5 kg was used. A force/deformation curve was recorded for each tortilla, and the peak force, distance traveled before puncture, area under curve, and modulus of the gradient were determined from the curve as shown in Fig. 4.1. The tests were run in triplicate

6.2.5 Experimental design

In a mixture design, values of the factors cannot be chosen arbitrarily, because for each formulation these values must add up to 100 (Snee 1971). In a design so constrained, use of a simplex lattice design has been recommended (Huisman et al 1984). Since this study involved three factors, SGF, DFFS and DFFB, all possible formulations can be graphically represented by the interior and the boundaries of an equilateral triangle using simplex lattice design, where each component ranges from 0-100%. In this study, the level of DFFB was limited to 0-10%, therefore, the area of interest, shown as shaded area in Fig.6.1, is an irregular polyhedron. The true value of the response can be represented as a distance orthogonal to factor space (vector). The only design available in this case was a D-optimal design (Lewis and Chariot 1991). Using Design Expert (Version 6.0.10, Stat-Ease Inc., Minneapolis, US) statistical software, formulation points chosen from a candidate point set were spread throughout the design region. Six points (model points) were selected for the model and were augmented by four points to provide for estimates of pure error by replication, and four points for determining the lack of fit (Table 6.2). This design was used to screen the formulations from each barley sample by applying the acceptability criteria for the two consumer groups, using numerical and graphical tools of optimization from Design Expert (Version 6.0.10, Stat-Ease Inc., Minneapolis, US). The models for each response variable were evaluated for significance, lack of fit, R^2, and for normality and outliers, before optimization.

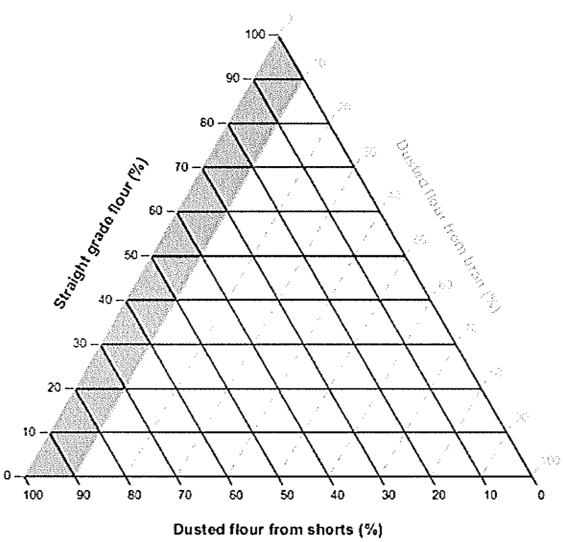


Fig. 6.1 Area of interest is shown in yellow color where SGF and DFFS ranged between 0-100 %, while DFFB ranged between 0-10% of the formulation.

6.2.6 Statistical analysis

One-way ANOVAs and linear and non-linear regressions were conducted with Design Expert (Version 6.0.10, Stat-Ease Inc., Minneapolis, US) statistical software.

Table 6.2. D-Optimal Design Point Formulations for Optimization of barley Tortillas

Design points[a]	SGF (%)	DFFS (%)	DFFB (%)
1	90	0	10
2	0	90	10
3	50	50	0
4	0	95	5
5	0	100	0
6	100	0	0
7	68.75	23.75	7.5
8	23.75	68.75	7.5
9	45	45	10
10	73.75	23.75	2.5

[a] Design points 1,2,5 and 6 were replicated. The run order was decided randomly using the Design Expert™.

6.3 RESULTS

6.3.1 Screening of the formulations for acceptable barley tortillas

The optimization procedure identified the formulations that met the instrumental criteria for acceptability based on instrumental measurements. These criteria differed for the two groups of consumers identified in the focus group study (Chapter 4). The acceptability ranges for each of the differing variables for each type of consumer are given in Table 6.3. The response criteria for a particular consumer group were combined by superimposing the contour plots of each response variable (Fig 6.2 a-d) and were applied for each barley sample separately for FCC and FNC to identify the regions where all criteria of acceptability were met.

Table 6.3. Consumer Acceptability Criteria of Barley Tortillas.

Predictor variable	FCC	FNC
L^*	≥ 63.5	≥ 70.0
a^*	≤ 6.5	≤ 3.4
b^*	≤ 22.5	≤ 20.7
Rollability	≥ 3.5	≥ 2.5
Gradient (g/s)	≤ 76.0	≤ 84.0
TTBR (s)	≥ 9.2	≥ 8.9

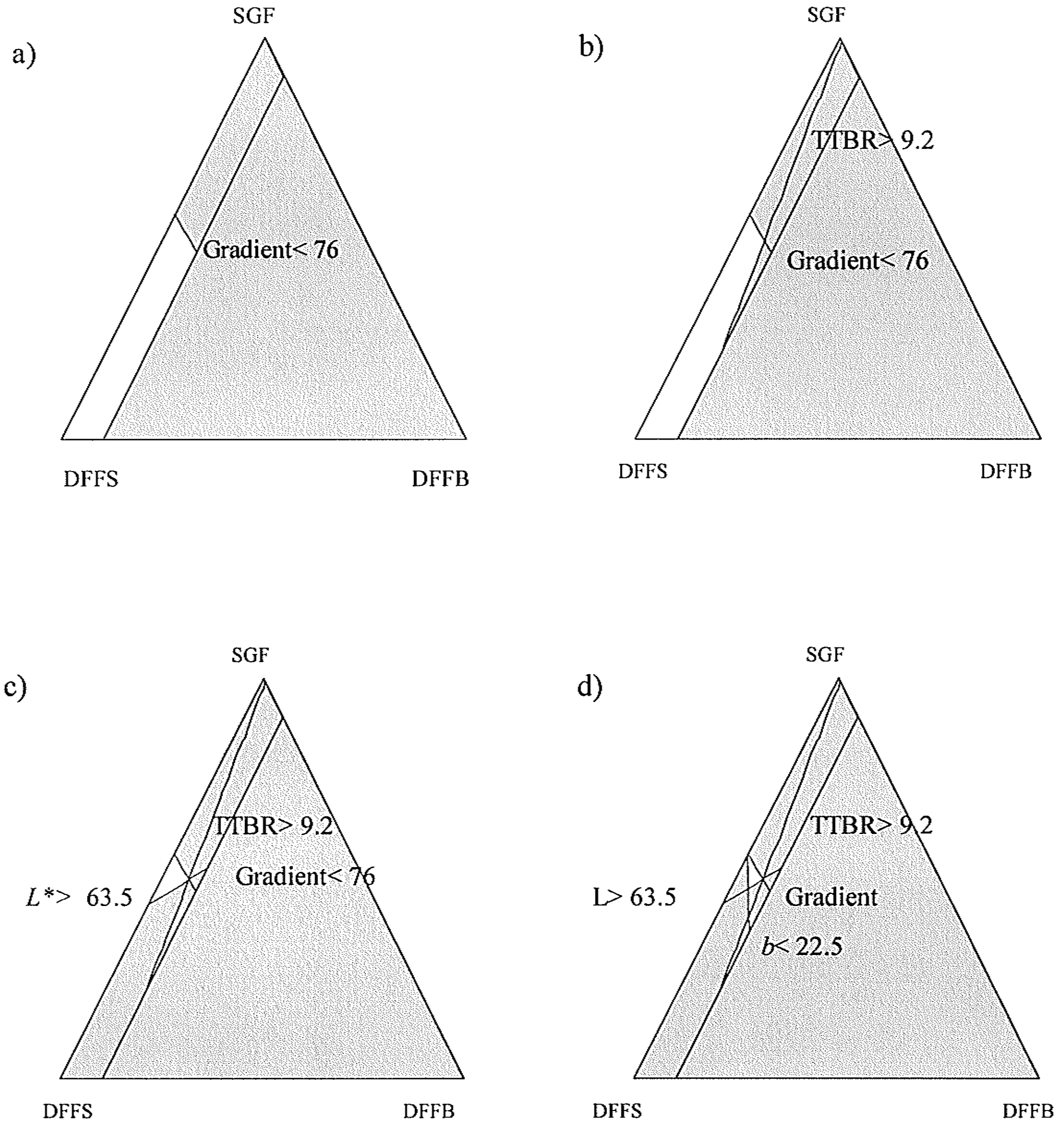


Fig. 6.2. Stepwise graphical presentation of the application of FCC acceptability criteria for CDC Candle, Brandon, 2000 (as an example), showing the process of overlaying the response variable limits of yellow areas indicate the combinations of SGF, DFFS and DFFB that fall within the limits for the gradient alone (a), the gradient and TTBR (b), gradient, TTBR and *L*-value* (c), and gradient, TTBR *L**- and *b* values* (d).

Formulations that would produce tortillas of acceptable quality are shown in (Fig. 6.3 a-f) for FCC and in (Fig. 6.4 a-d) for FNC. For FCC acceptable tortillas could be made from both waxy (CDC Alamo S01, CDC Candle B00, Candle S01) and non-waxy barleys (AC Hawkeye S01, Millhouse S00, Millhouse S01).

As can be seen from Fig. 6.3 (a-f), different combinations were possible for FCC from waxy genotypes (CDC Alamo S01, CDC Candle B00 and CDC Candle S01) and from non-waxy genotypes (AC Hawkeye S01, Millhouse S00 and Millhouse S01). From CDC Alamo S01, tortillas prepared with 10% SGF had lower gradient and higher TTBR than those prepared with 45% SGF, however, both were acceptable to FCC. From CDC Candle, tortillas prepared with 0% SGF had higher rollability and TTBR, and lower gradient than those prepared with 80% SGF, however, both were acceptable to FCC. Texture parameters limited the acceptable areas for FCC. Rollability, TTBR and gradient were the main limiting factors for FCC in non-waxy samples while only gradient was the limiting factor in waxy samples.

For FNC, acceptable tortillas could be prepared from only non-waxy barleys (AC Hawkeye S00, AC Hawkeye S01, Millhouse S00 and Millhouse S01). For FNC higher amounts of SGF were required to prepare acceptable tortillas from AC Hawkeye S00, Millhouse S00 and AC Hawkeye S01. Millhouse S01 and Millhouse S00 allowed only a narrow range of SGF and DFFS proportions, thus, acceptable tortillas prepared with all the possible formulations had similar properties. Appearance parameters limited the areas for FNC. For FNC, L^*, a^* and b^* *values* were the most limiting factors. Higher L^*, and lower a* and b* values were sought which could be achieved through higher levels of SGF.

No acceptable region was identified from AC Hawkeye B00, CDC Fibar B00, CDC Fibar S00, CDC Dawn B00, CDC Freedom B00, Condor B00, HB 805 B00, SB 94893 B00, SB 94893 S00 or SB 94893 B00 for either of the two consumer groups.

a(1)

a(2)

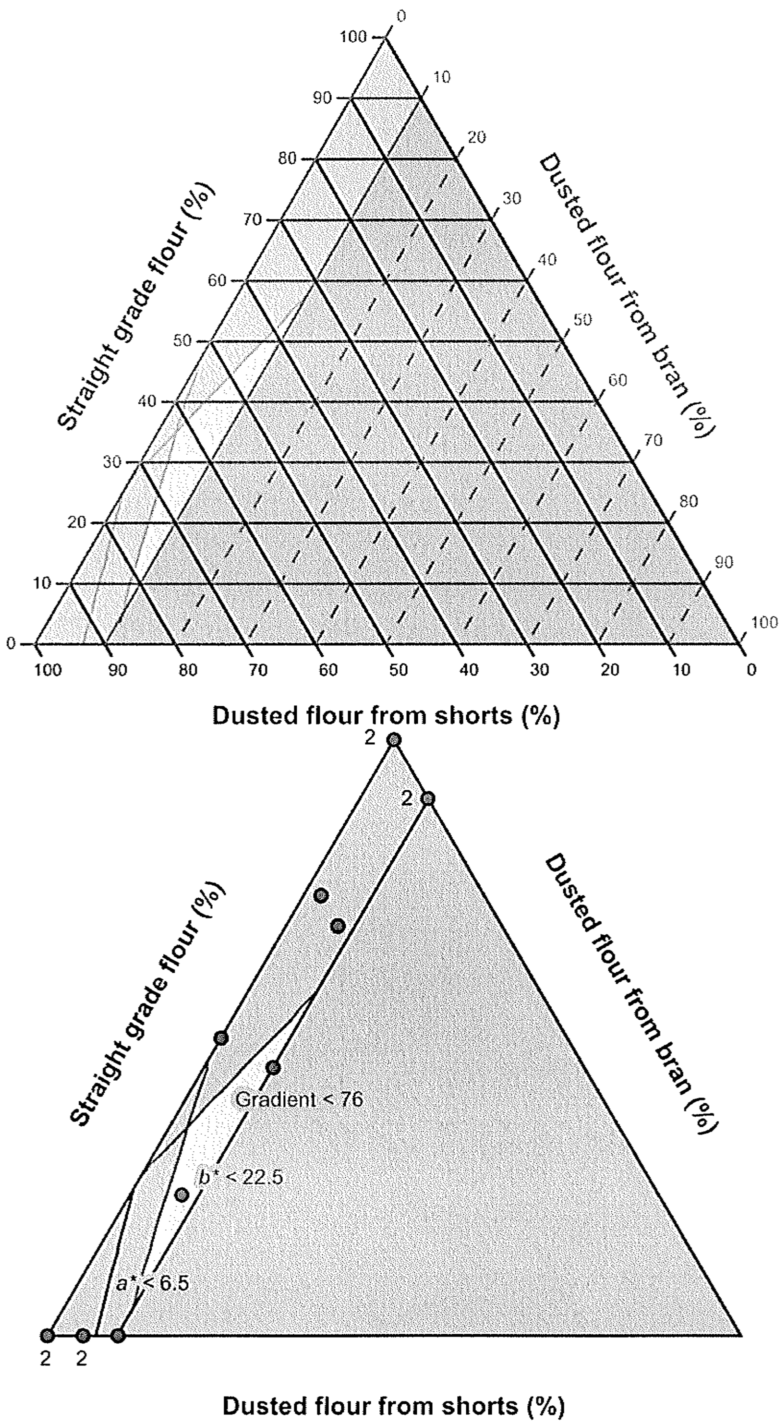
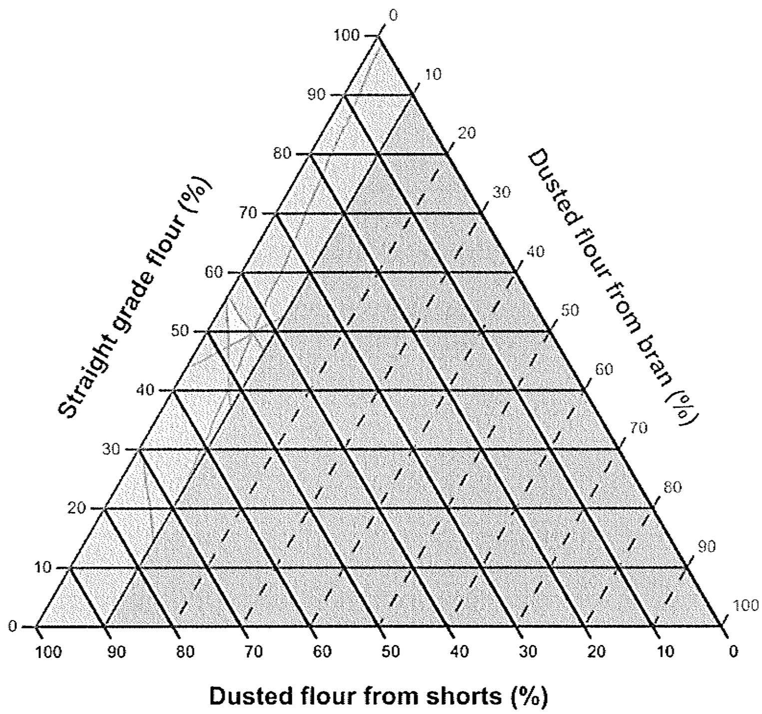


Fig 6.3 (a) Acceptable areas (yellow) of tortilla formulations of SGF, DFFS and DFFB for FCC in Alamo S00. a(1) with grids to show formulations, and a(2) to show the criteria levels.

b(1)



b(2)

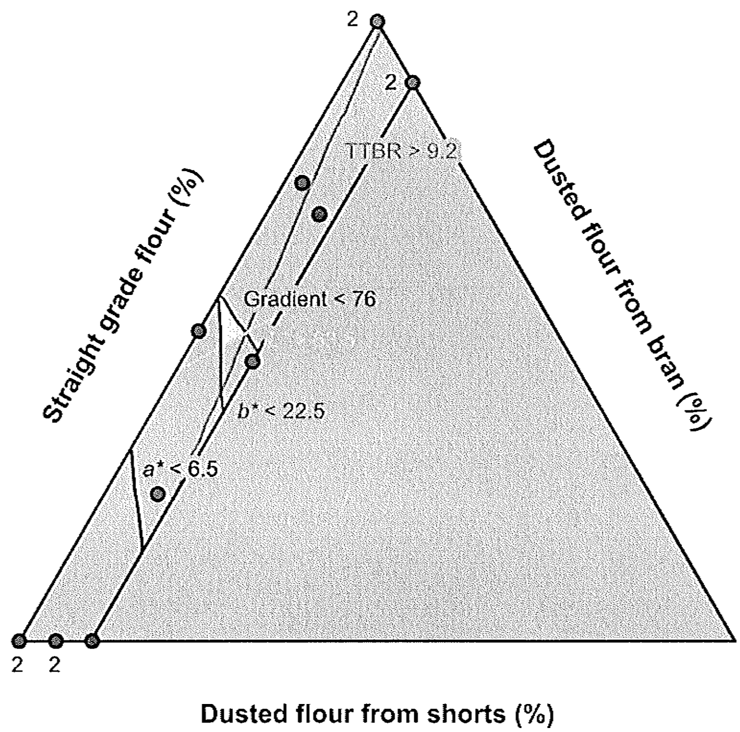
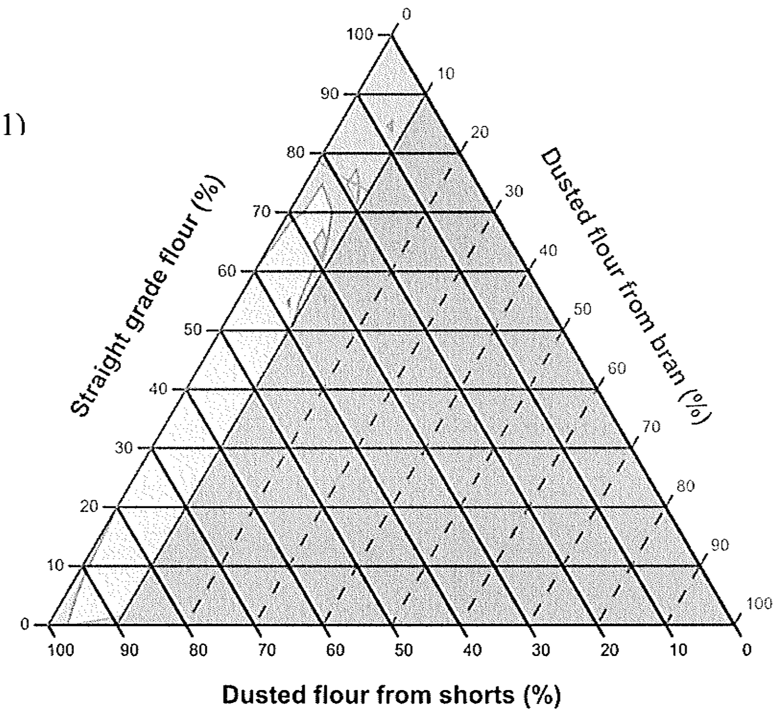


Fig 6.3 (b) Acceptable areas (yellow) of tortilla formulations of SGF, DFFS and DFFB for FCC in Candle B00. b(1) with grids to show formulations, and b(2) to show the criteria levels.

c(1)



c(2)

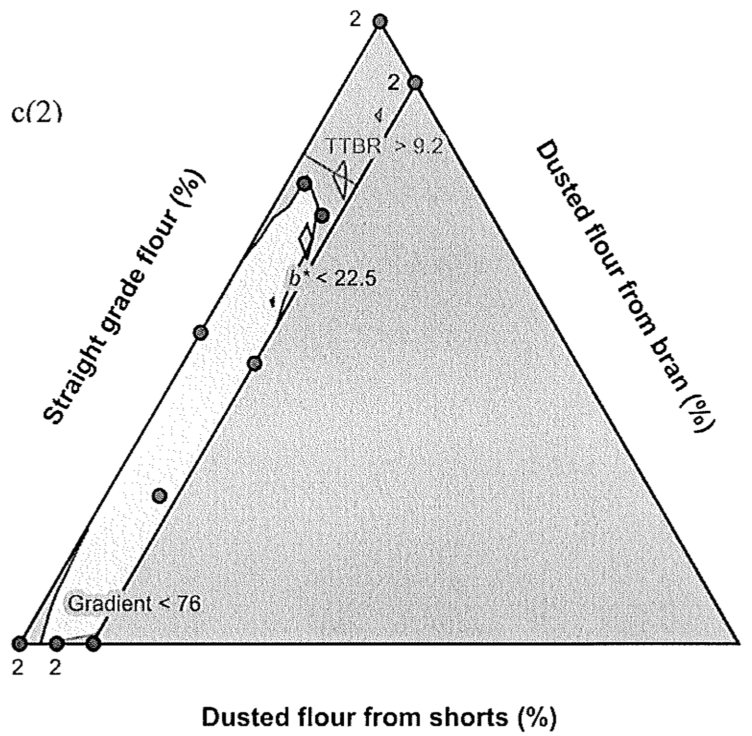
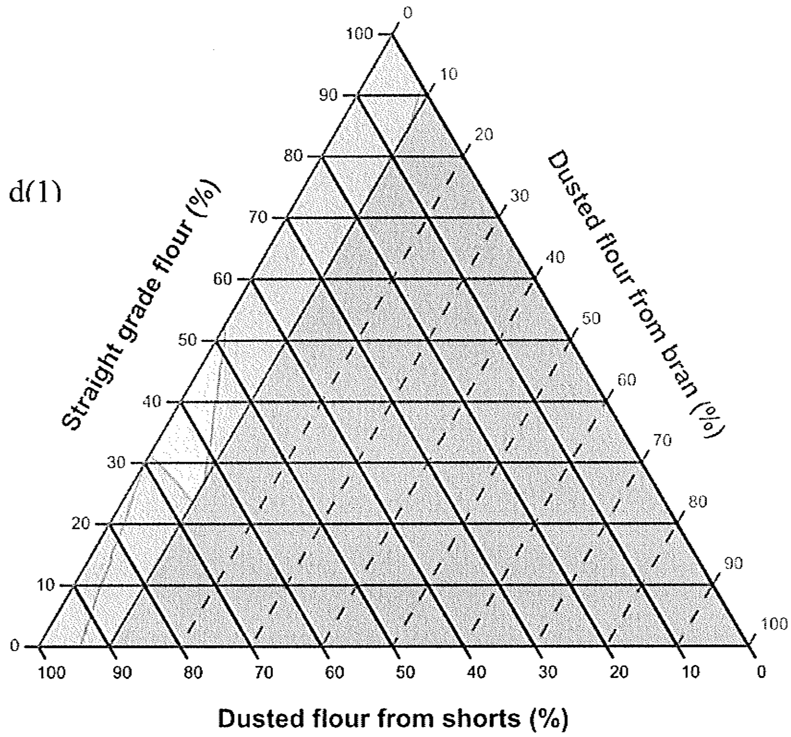


Fig 6.3 (c) Acceptable areas (yellow) of tortilla formulations of SGF, DFFS and DFFB for FCC in Candle S01. c(1) with grids to show formulations, and c(2) to show the criteria levels.



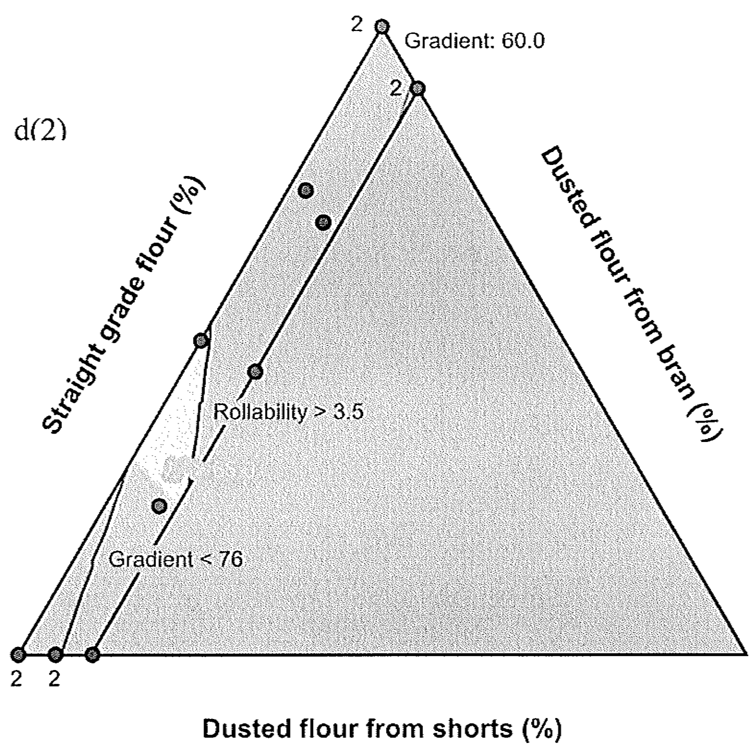
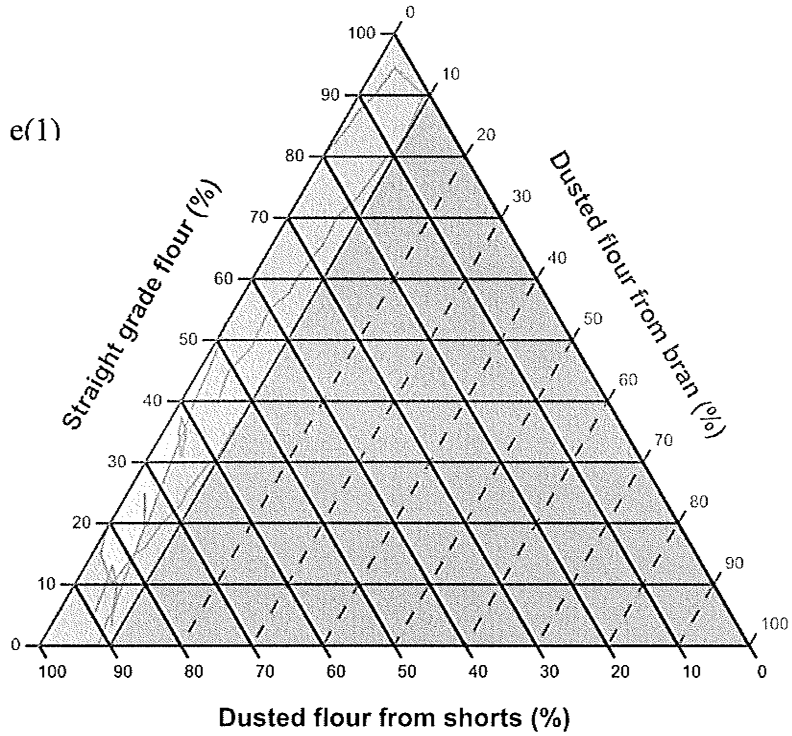


Fig 6.3 (d) Acceptable areas (yellow) of tortilla formulations of SGF, DFFS and DFFB for FCC in Millhouse S00. d(1) with grids to show formulations, and d(2) to show the criteria levels.

e(1)



e(2)

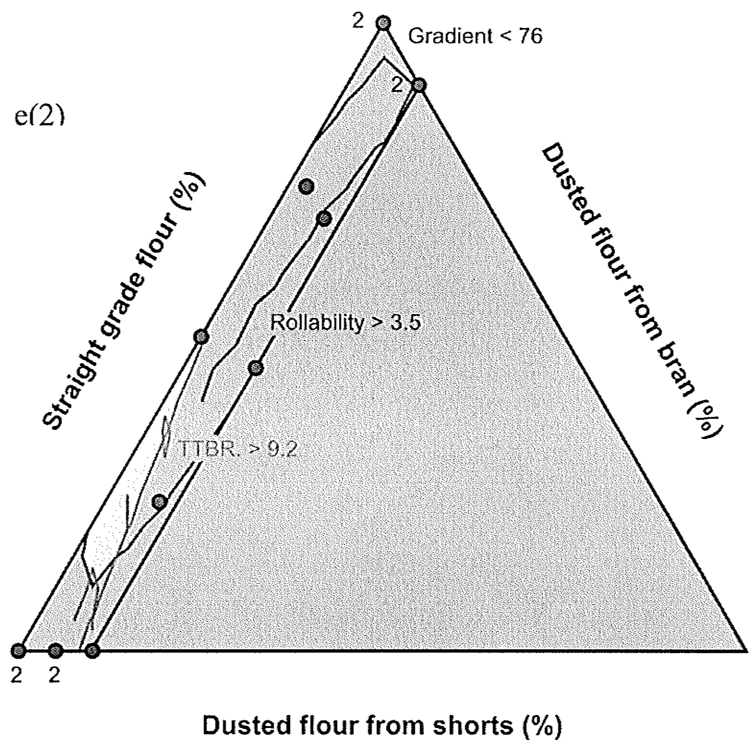
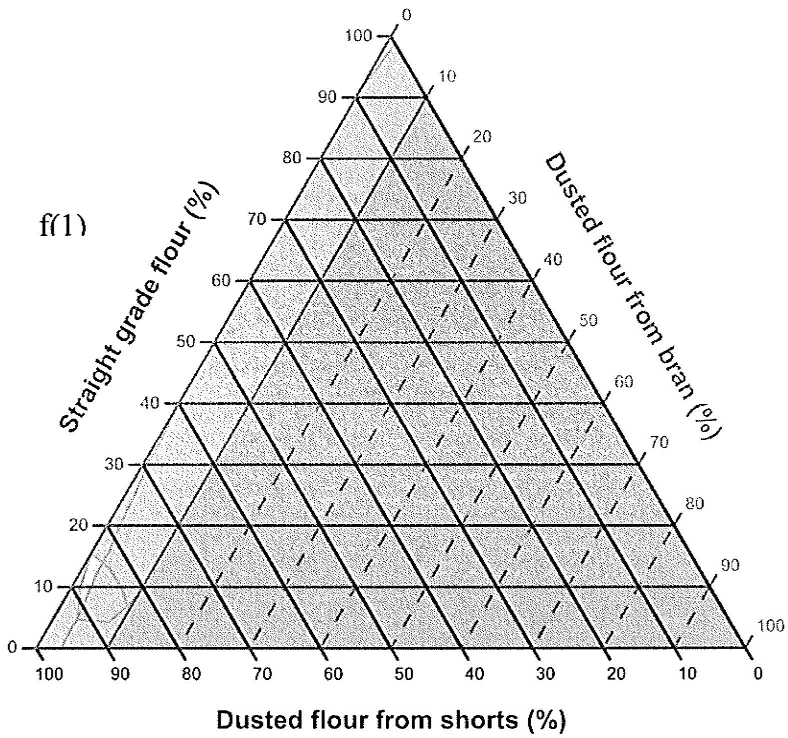


Fig 6.3 (e) Acceptable areas (yellow) of tortilla formulations of SGF, DFFS and DFFB for FCC in Hawkeye S01. e(1) with grids to show formulations, and e(2) to show the criteria levels.

f(1)



f(2)

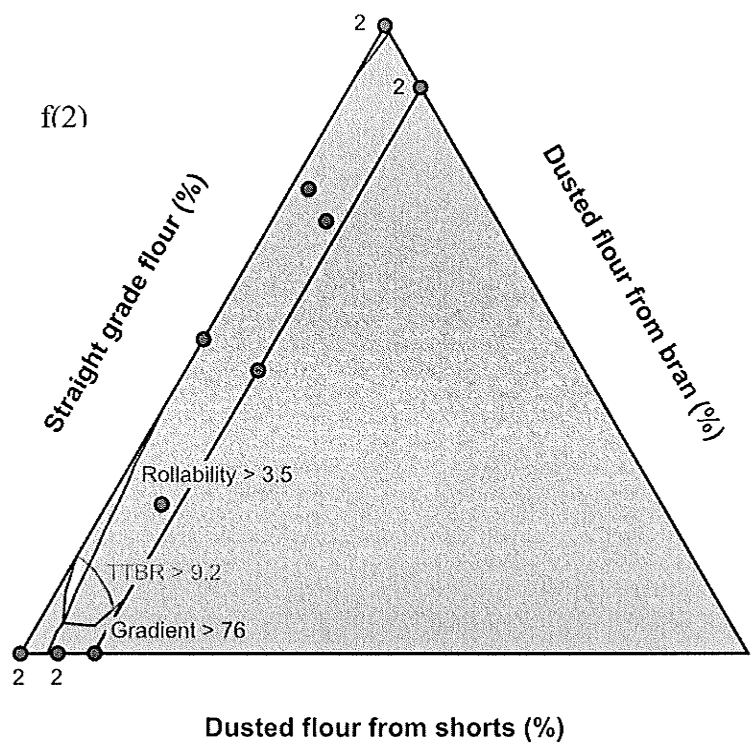


Fig 6.3 (f) Acceptable areas (yellow) of tortilla formulations of SGF, DFFS and DFFB for FCC in Millhouse S01, f(1) with grids to show formulations, and f(2) to show the criteria levels.

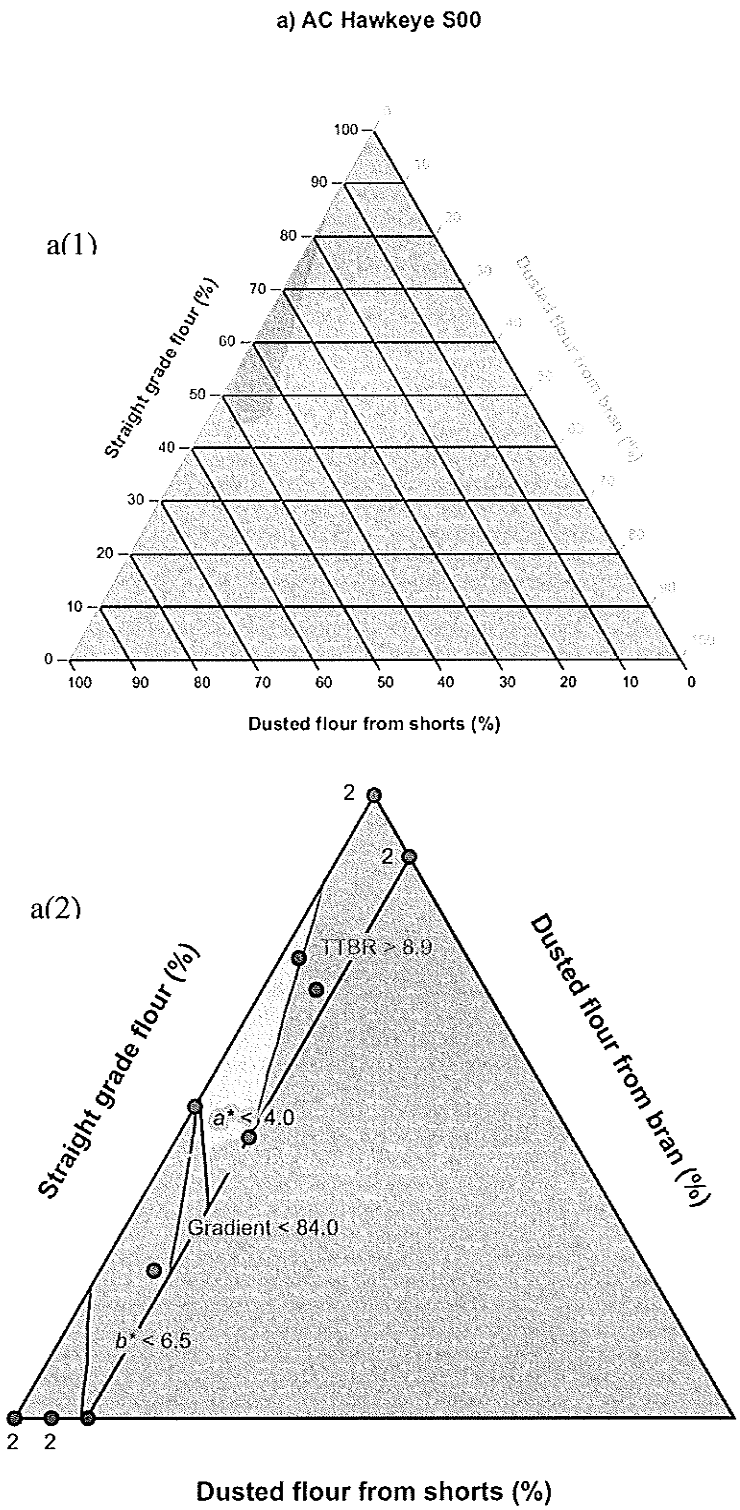
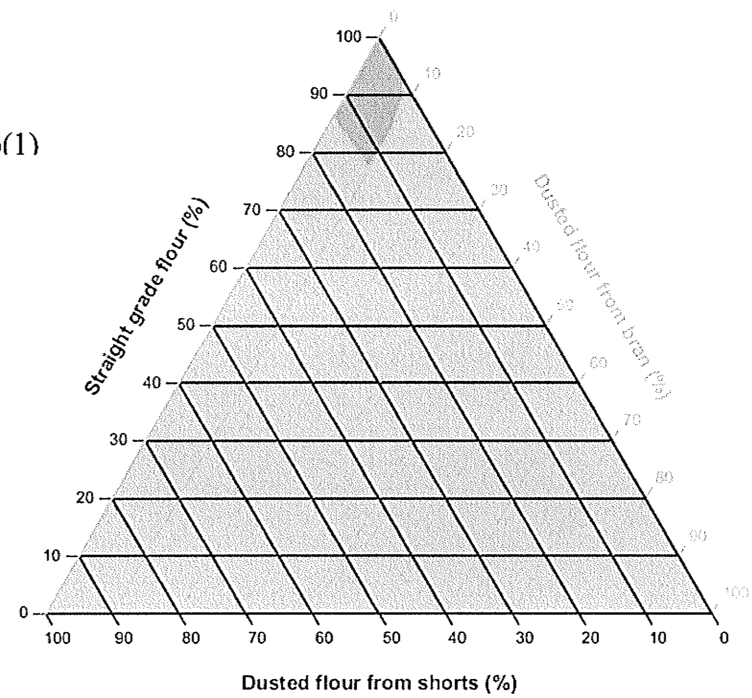


Fig 6.4 (a) Acceptable areas (yellow) of tortilla formulations of SGF, DFFS and DFFB for FCC in Hawkeye S00. a(1) with grids to show formulations, and a(2) to show the criteria levels.

b) Millhouse S00

b(1)



b(2)

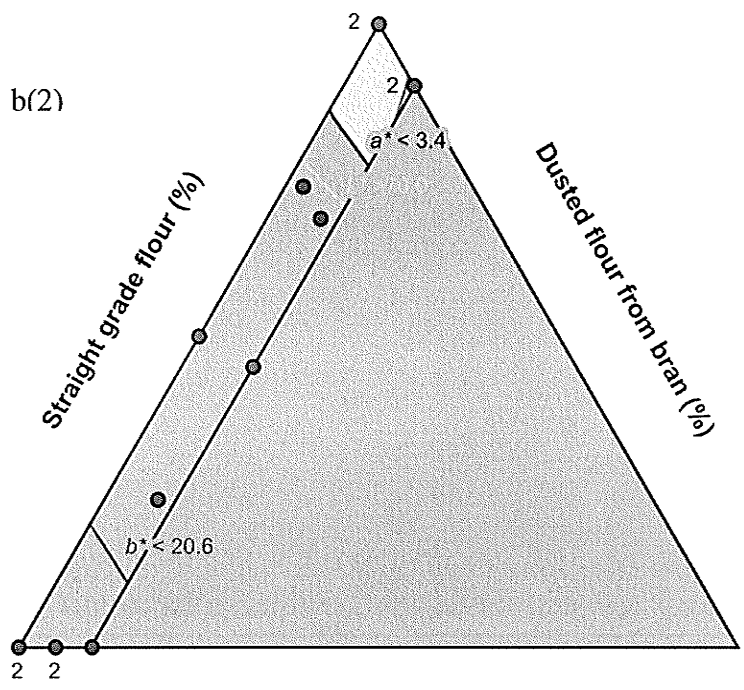


Fig 6.4 (b) Acceptable areas (yellow) of tortilla formulations of SGF, DFFS and DFFB for FCC in Millhouse S00. b(1) with grids to show formulations, and b(2) to show the criteria levels.

c) AC Hawkeye S01

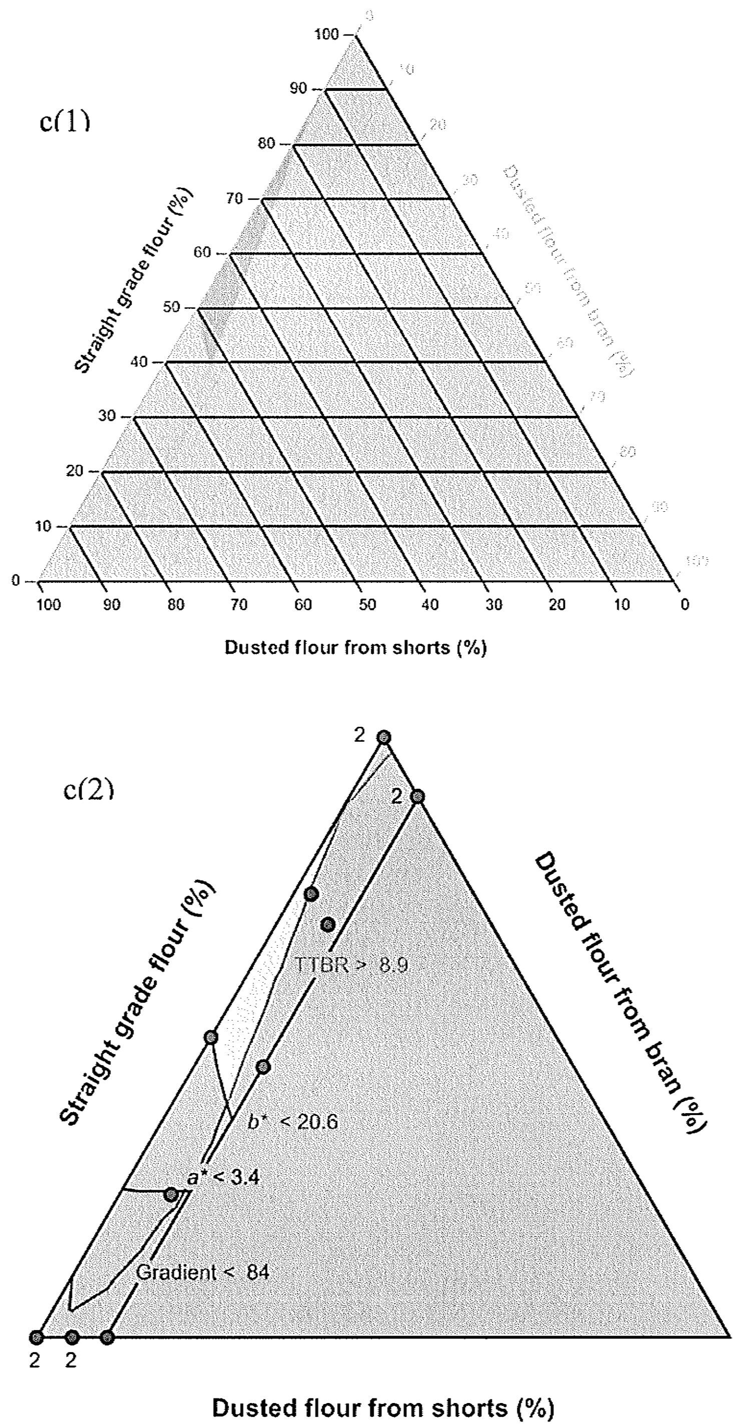
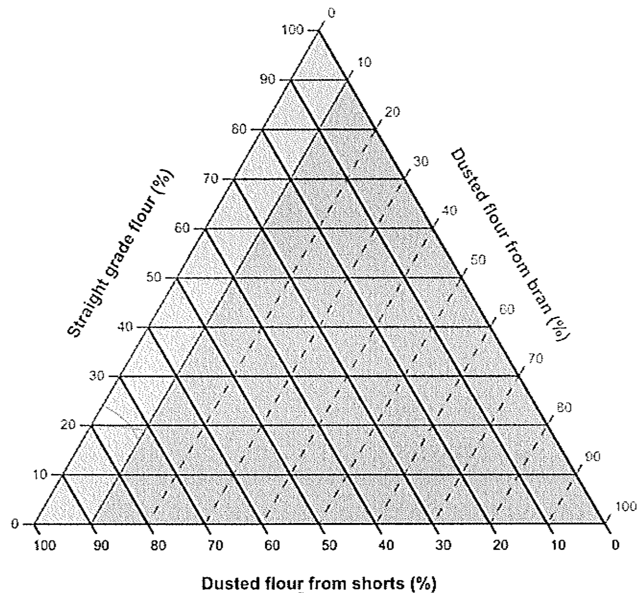


Fig 6.4 (c) Acceptable areas (yellow) of tortilla formulations of SGF, DFFS and DFFB for FCC in Millhouse S00. c(1) with grids to show formulations, and c(2) to show the criteria levels.

d(2)



d(2)

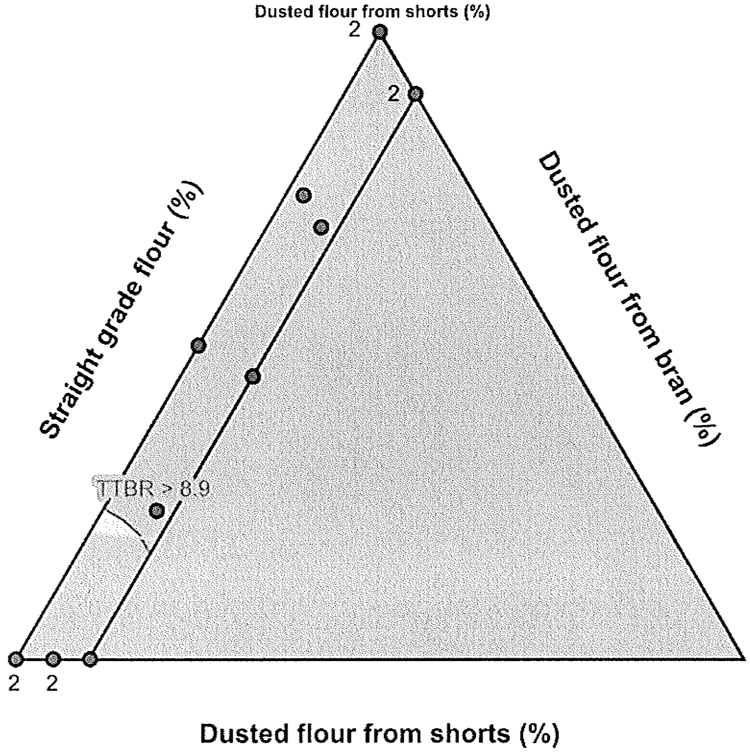


Fig 6.4 (d) Acceptable areas (yellow) of tortilla formulations of SGF, DFFS and DFFB for FCC in Millhouse S00. d(1) with grids to show formulations, and d(2) to show the criteria levels.

6.3.2 Maximization of β glucan in acceptable tortilla formulations

To carry a barley β-glucan health claim, a minimum of 0.75g of β-glucan must come from one serving of a barley product (FDA, 2005). The reference amount of serving size for a tortilla is 55g (FDA 1994). For both FCC and FNC a number of acceptable barley tortilla formulations would be eligible for the health claim. Formulations that met the criteria of acceptability for each barley sample were analyzed further to determine their β-glucan content, and the formulation that gave the highest content was identified with Design Expert. Levels of β-glucan twice or more than those required for a health claim could be reached for all of the samples (Table 6.4). Higher amounts of β-glucan in the formulations for acceptable barley tortillas could be achieved for FCC. The daily β-glucan requirement, as stated by FDA health claim, could be met for FCC with two serving of acceptable tortillas made with formulations from CDC Candle B00, AC Hawkeye S00, AC Hawkeye S01, Millhouse S00, Alamo S01, CDC Candle S01 and Millhouse S01. FOR FNC this requirement of β-glucan could be met with two servings of tortillas made with formulations from AC Hawkeye S00, AC Hawkeye S01, Millhouse S00, and Millhouse S01.

When β-glucan in an acceptable region was maximized, Design Expert selected higher proportions of DFFS and DFFB. For FCC, the highest level of β-glucan/serving (3.1g) could be achieved with a formulation from CDC Alamo (DFFS = 97%, DFFB = 3%). For FNC, highest β-glucan (1.8g) was achieved from a formulation from AC Hawkeye S00 (SGF = 51.2%, DFFS = 48.5%, DFFB = 0.2%).

Table. 6.4. Composition and β-Glucan Contents of Formulations Maximized for β-Glucan for the FCC and FNC.

	Using FCC criteria				Using FNC criteria			
	Milling fraction proportion[b] (g/100g)			β-Glucan	Milling fraction proportion[b] (g/100g)			β-Glucan
Sample[a]	SGF	DFFS	DFFB	(g/serving[c])	SGF	DFFS	DFFB	(g/serving[c])
CDC Candle B00	47.5	48.2	4.3	2.1			NA[d]	
AC Hawkeye S00			NA[d]		51.2	48.5	0.3	1.8
Millhouse S00	50.7	49.3	1.7	2.3	77.1	13.0	10.0	1.4
AC Hawkeye S01	8.9	88.1	3.0	1.8	39.1	53.2	7.8	1.6
CDC Alamo S01	3.7	86.3	10.0	3.2			NA[d]	
CDC Candle S01	0.3	95.5	4.3	2.5			NA[d]	
Millhouse S01	4.2	92.7	3.2	1.9	23.9	76.1	0.0	1.7

[a]Sample names are comprised of two parts; the first is the name of the genotype and second identifies the environment where B stands for Brandon, and S for Saskatoon, 00 for 2000 and 01 for 2001.
[b]SGF, DFFS and DFFB stand for straight grade flour, dusted flour from shorts and dusted flour from bran, respectively.
[c]Calculations were based on a tortilla-serving size of 55g
[d]Acceptable formulations were not possible.

6.3.3 Maximization of the proportion of SGF in flour blend

For maximum utilization of the major milling fraction SGF higher proportions of SGF were sought while, sensory acceptability criteria and health claim requirements were met. Formulations for both FCC and FNC were identified in acceptable regions that provided at least 0.75g β-glucan/serving of tortilla (Table 6.5). Adequate amounts of SGF (50-90%) could be utilized for most of the samples except Millhouse B00 and Millhouse S01 for FCC.

Table 6.5 Composition and β-Glucan Contents of Formulations Maximized for Straight Grade Flour (SGF)

	Using FCC Criteria				Using FNC Criteria			
	Milling fraction proportion (g/100g)[b]			β-Glucan	Composition of the blend			β-Glucan
Sample[a]	SGF	DFFS	DFFB	(g/serving[c])	SGF	DFFS	DFFB	(g/serving[c])
CDC Candle B00	55.82	44.18	0.0	2.0	NA[d]			
AC Hawkeye S00	NA[d]				86.6	13.4	0.0	1.4
Millhouse S00	52.9	47.1	0.0	1.7	100.0	0.0	0.0	1.2
AC Hawkeye S01	45.1	54.9	0.0	1.5	88.9	11.1	0.0	1.1
CDC Alamo S01	47.2	46.3	6.5	2.5	NA[d]			
CDC Candle S01	76.0	20.2	3.9	1.5	NA[d]			
Millhouse S01	15.5	84.5	0.0	1.8	24.4	75.6	0.0	1.7

[a]Sample names are comprised of two parts the first is the name of the genotype and the second identifies the environment where B stands for Brandon, S for Saskatoon, 00 for 2000 and 01 for 2001.

[b]SGF, DFFS and DFFB stand for straight grade flour, dusted flour from shorts and dusted flour from bran, respectively.

[c]Calculations were based on a tortilla serving size of 55g.

[d]Acceptable formulations were not available.

6.3.4 Factors affecting the characteristics of the flour blends

The variations in characteristics of flour blends, and their effects on barley tortilla sensory and nutritional quality could have resulted from the differences in genotypes environmental factors, milling composition, or from combinations of these factors. The data is shown in Appendix III a, b, c and d. Barley genotypes varied in the total starch (53-68 g/100g), total protein (14.5-16.4g/100g), β-glucan (4.3-10.3 g/100g) and amylose (0-40g/100g of total starch) contents. An inverse relationship between starch and protein ($r= -0.94$) was observed in the sample set. Genotypes had differing starch compositions, which were 0-5g amylose/100g of starch (waxy), 25-27g amylose/100g of starch (non-waxy), 16g amylose/100g of starch (low amylose) and 40g amylose/100g of starch (high amylose). Chemical compositions of milling fractions, SGF, DFFS, and DFFB, were also affected by the starch-type of the genotypes. The SGF had higher amount of starch, but lowest amount of protein, TDF and β-glucan ($p \leq 0.05$) than the other fractions except in the case of high amylose SB 94893 (Brandon 2000). DFFB had higher starch content than DFFS in waxy samples, but in non-waxy, low amylose and high amylose samples DFFS had higher starch than DFFB.

Within each environment starch type had similar effects on the chemical composition of the barley samples. Waxy genotypes (CDC Alamo, CDC Candle and CDC Fibar) and high amylose (SB 94893) genotypes contained significantly higher amount of β-glucan, TDF and total protein than the non-waxy genotypes (AC Hawkeye, CDC Dawn, CDC Freedom, Condor, and Millhouse). Amount of total starch were higher for non-waxy samples than for waxy samples ($p \leq 0.05$).

Due to an unequal and insufficient number of barley genotypes grown in the three environments tested, the effect of environment on the chemical composition of the samples could not be determined. Thus, the effects of starch-type and milling on these components were studied separately for each location.

6.3.4 Effects of flour blends on tortilla quality

Blending had an effect on the color of barley tortillas and has been shown in Appendix VI. Brightness (*L*-value*) increased, redness (*a*-value*) and yellowness (*b*-value*) decreased with higher SGF in the tortilla formulation. Gradient was affected by milling fraction and starch type with an interaction between the effects of the two factors. Increasing proportions of SGF resulted in higher gradients in waxy samples. On the other hand, increasing proportions of SGF resulted in lower gradient for non-waxy samples.

Blending also affected the instrumentally measured texture parameters of barley tortillas. Instrumentally measured rollability increased with DFFS in all genotypes and was highest for waxy samples and the least for high amylose sample. It also increased with increasing proportions of DFFS. Time traveled before rupture (TTBR) seemed be affected by milling fraction. Increasing proportions of SGF and decreasing proportions of DFFS led to a decrease in TTBR irrespective of genotype. The effects of increasing DFFB on these texture and color parameters were inconsistent between genotypes and followed no recognizable pattern.

6.4 DISCUSSION

The purpose of this study was to identify formulations that had both acceptable sensory quality and high β-glucan content in barley tortillas. Variation in β-glucan content and tortilla characteristics were achieved through varying the proportions of SGF, DFFS and DFFB for each genotype.. DFFS and DFFB contained higher amounts not only of β-glucan but also of TDF and protein, but a lower amount of starch than the corresponding grain. These results are in accordance with other published work (Kiryluk et al 2000; Izydorczyk et al 2003). The heterogeneous composition of barley (Zheng et al 2000) allowed fractionation into products enriched in various constituents, especially β-glucan (Izydorczyk et al 2003). Kiryluk et al (2000) milled barley in a wheat roller mill to achieve a fraction named fine-grain grit that contained ~ 50, 72, 55 and 24% more β-glucan, TDF, ash, and protein, respectively, than the original dehulled barley.

The milling method utilized in this study allowed the experimentation with a wide variety of flours for optimizing barley tortillas. DFFS is an important fraction because its yield is similar to that of SGF. The barley shorts are comprised mainly of the endosperm cell walls unlike the wheat shorts, which are comprised primarily of bran. Thus, this fraction contained high amounts of soluble fibre and starch without a higher concentration of insoluble fibre.

The use of Design Expert for optimizing the proportions of flour fractions allowed estimation of various tortilla characteristics of all possible combinations of SGF (0-100%), DFFS (0-100%) and DFFB (0-10) without actually testing all these combinations. This approach was beneficial in exploring these formulations for meeting different criteria of acceptability, β-glucan content and SGF proportions, and can be utilized for optimizing various parameters including the chemical components.

6.5 CONCLUSIONS

Optimization can be used to apply the criteria of acceptability for screening barley genotypes and formulations to achieve the desired sensory and nutritional quality. Waxy barley can be utilized for fibre conscious consumers for preparing tortillas of acceptable quality which can deliver the daily requirement of β-glucan from a single serving. Higher amounts of β-glucan could be achieved in acceptable tortillas for FCC than for FNC. FCC might be the target population for the barley tortillas because these consumers constantly look for high fibre products in the market. Barley tortillas could not only be another choice, but also be a better choice for these consumers.

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CHAPTER 7

CONCLUSIONS

- An accurate, simple, timesaving and objective method was successfully developed and utilized for predicting water absorption of tortilla prepared in this study. Water absorption for non-wheat dough is generally determined by trial and error method, which is not only subjective, but also time consuming. A prediction equation was generated for optimum water absorption (OWA) for barley tortilla dough, based on the relationship between Rapid Visco Analyzer (RVA) viscosities of barley flour slurries and OWA of the doughs. This equation could accurately predict OWA for barley tortilla dough when the slurry RVA viscosity was less than 700 RVU.
- Focus group consumers could be segmented into two groups over their preferences for barley tortillas. There were the health conscious consumers who wanted high fibre products, and the consumers whose preferences were based solely on the sensory quality. The first group, fibre conscious consumers (FCC), preferred darker, more fibrous tortillas than the second group. This group, the fibre neutral consumers (FNC), preferred light floury tortillas. Different barley tortillas were acceptable to FCC and FNC, which indicated that they had a different outlook for an acceptable tortilla. The focus group study here identified differences in not only color preferences but also in texture and flavor preferences between FCC and FNC. This study identified that for barley tortillas there were two separate definitions to describe ideal tortillas one for FCC and one for FNC.

- FCC preferred VLA 20 (waxy) and NA 29 (non-waxy) tortillas the most and described these tortillas as dark in color, soft, easily to roll, moist in the mouth and contained some nutty and toasty flavor. FNC preferred NA 29, NA 36 and NA 87 and described these tortillas as white and bright, well puffed, not sticky to teeth, dry floury mouth feel and contained no to slight flavor and no bitterness at any stage of eating.
- Six tortillas evaluated by the descriptive analysis panel were significantly different from each other with respect to the ten sensory attributes tested. The widest range was measured for the intensities of puffiness, breakability, ease of rolling, degree of compression, and moisture absorption.
- The texture and color of tortillas were also tested instrumentally to determine relationship between sensory attributes and textural parameters. Significant correlations occured between sensory attributes and instrumental parameters of texture and color of the tortillas. There were negative relationships between gradient and ease of rolling, *b*-values* (yellowness) and puffiness, rollability and hardness on initial bite, and time traveled before rupture (TTBR) and moisture absorption; while, positive correlations were found between gradient and rollability, *a*-value* (redness) and stickiness to teeth, *a*-value* and flavor intensity.
- These relationships were used to determine predictors for sensory attributes. The important predictors were gradient for breakability and ease of rolling, *b*-value* of color for puffiness, a*-value for stickiness to teeth, rollability for hardness on initial bite, and TTBR for moisture absorption. Criteria of acceptable tortillas

could be defined for FCC and FNC in terms of *L**, *a**, and *b*-values* of color, TTBR, gradient and rollability.

- Optimization with response surface methodology was successfully used to screen barley genotypes and formulations for acceptability and high β-glucan content of the tortillas. When these criteria were applied to screen nineteen barley samples, both waxy and non-waxy barley genotypes were selected for FCC but only non-waxy genotypes were selected for FNC that met the acceptability criteria. For FCC higher proportions of dusted flour from shorts (DFFS) could be used from both waxy and non-waxy tortillas, while for FNC, high proportions of straight grade flour (SGF) were required to prepare acceptable tortillas.
- Barley tortillas have the potential to carry sufficient β-glucan to be eligible to carry the β-glucan health claim, and be acceptable to both FCC and FNC. For FCC, a serving of tortilla could provide as much as 3g of β-glucan, which would be sufficient to meet a day's requirement as suggested by FDA (2005). Several acceptable formulations could provide 1.5g of β-glucan from one serving for both FCC and FNC. Two 55g tortillas would then provide 3g β-glucan per day as needed to have a heart benefit.
- Barley tortillas, which are prepared from barley flour and water only, without any additives, might attract consumers who prefer to avoid additives. Wheat flour tortillas contain shortening, sodium propionate, sodium bicarbonate, potassium sorbate, sodium stearoyl lactylate and fumaric acid.

RECOMMENDATIONS FOR FUTURE RESEARCH

- The present study indicated that the chemical components of barley flours may have significant effects on the tortilla quality. These effects shoul further be studied further. It may also be possible to optimize the levels of these chemical components for tortilla texture and color. Such studies could also provide some useful information to the barley breeders for developing genotypes with desired chemical composition.
- The non-waxy tortillas were preferred more for their appearance than for their texture. The present study concluded that the dusted flour from shorts (DFFS) improved rollability, in each barley sample and that the waxy samples had better rollability than the non-waxy samples. It may be possible to blend the DFFS from waxy samples with the straight grade flour (SGF) of non-waxy samples to formulate tortillas that have appearance and texture attributes acceptable to all consumers.
- DFFS from barley could be tested for its effect on staling of corn tortillas, which causes poor rollability. DFFS has been shown to improve rollability, and could. be tested using DFFS from waxy genotypes at different levels to study the effect of this milling fraction on corn tortilla texture during storage.
- Barley flour could be used in combination with oats to form high β-glucan products such as a cereal bar. In oats the β-glucan is located in the outer layers of the grain while in barley a significant amount of β-glucan is present in the endosperm. Thus products may be developed from combinations of oat bran and barley flour such that the resultant product would have very high levels of β-glucan.

Appendix I

Questionnaire - Consumer Study - Barley Tortillas

Panelist No.____

Please answer the following questions by placing a check (✓) where appropriate.

1. Age
   a. 18-29_______
   b. 30-39_______
   c. 40-49_______
   d. 50-59 _______
   e 60 and over _______

2. How often do you generally eat tortillas/wraps/burritos/soft tacos? **Check one only**.
   a. two to three times a week ________
   b at least once a week ________
   c. at least twice a month ________
   e. other _____ please explain ____________________________________

3. What brand and type (e.g. corn, plain wheat, whole wheat, sun dried tomato, etc.) do you normally eat?

   Brand: _______________________Type:________________________________

4. When do you generally eat this type of product?
   a. lunch________
   b. dinner ________
   c. other _______ Please explain _____________________________

Thank you for completing this questionnaire. All information will remain strictly confidential.

Appendix II Detailed Data[a] for Selection of Samples[b] for the Study

Table IIa Carbohydrate and Protein Content of Wholemeal[a] from Barley Samples Selected for Optimization for Year 2000.

Sample	Environment[c]	Amylose (g/100g of starch)	β-glucan (g/100g)	Total starch (g/100g)	Protein (g/100g)
AC Hawkeye	B 00	26.6	4.3	68.9	12.5
AC Hawkeye	S 00	25.2	5.0	66.2	11.6
CDC Alamo	B 00	0.0	8.5	59.3	15.2
CDC Candle	B 00	5.0	6.7	63.3	16.3
CDC Dawn	B 00	25.9	4.5	62.5	14.0
CDC Freedom	B 00	27.6	5.1	66.1	13.2
Condor	B 00	26.4	5.6	65.3	14.7
HB 109	B 00	26.9	4.5	66.2	13.3
HB 109	S 00	26.6	5.0	68.3	12.5
HB 805	B 00	16.0	6.3	63.6	14.1
HB 805	S 00	16.0	5.4	63.9	13.3
Hokuto Hadaka	B 00	26.6	4.9	56.3	17.9
SB 94893	B 00	39.6	9.2	53.0	17.3
SB 94894	S 00	39.9	8.9	59.0	16.3
CDC Fibar	B 00	0.0	10.3	55.2	15.3
CDC Fibar	S 00	0.0	10.9	53.3	14.6
Shina Waju	B 00	2.4	6.8	56.3	15.7

[a]The values are calculated from the milling data and the chemical composition of the milling fractions.
[b]Samples for Saskatoon 2001 were selected from this list.
[c]B00 and S00 stand for Brandon, 2000 and Saskatoon, 2000, respectively.

Appendix III Characterization of Flours Used for Optimization of Barley Tortillas

Table IIIa. Protein and Carbohydrate Composition of SGF, DFFS and DFFB from Non-Waxy Barley Samples Used for Tortilla Formulations.

		Protein[c]			β-glucan[c]			Total starch[c]			TDF[c,d]		
Sample[a]	Fraction[b]	Mean	±	SD	Mean	±	SD	Mean	±	SD	Mean	±	SD
AC Hawkeye B00	SGF	12.3	±	0.0	3.2	±	0.0	74.2	±	0.5	9.4	±	0.1
	DFFS	15.8	±	0.0	5.8	±	0.1	60.2	±	0.1	19.7	±	0.2
	DFFB	16.3	±	0.0	5.8	±	0.1	51.7	±	0.6	24.7	±	0.2
AC Hawkeye S00	SGF	11.8	±	0.0	3.7	±	0.0	70.5	±	0.4	10.2	±	0.2
	DFFS	14.1	±	0.0	7.0	±	0.0	58.9	±	0.3	19.9	±	0.1
	DFFB	15.4	±	0.1	7.2	±	0.1	53.9	±	0.5	26.4	±	0.2
AC Hawkeye S01	SGF	10.5	±	0.0	3.0	±	0.0	72.3	±	1.5	7.0	±	0.2
	DFFS	12.3	±	0.1	5.7	±	0.0	60.1	±	0.1	16.2	±	0.1
	DFFB	15.0	±	0.0	5.4	±	0.0	54.5		0.3	18.1	±	0.1
CDC Dawn B00	SGF	14.2	±	0.0	3.3	±	0.0	70.4	±	0.6	10.2	±	0.3
	DFFS	18.5	±	0.1	6.5	±	0.0	50.1	±	0.8	22.9	±	0.3
	DFFB	17.5	±	0.0	5.8	±	0.1	44.9	±	0.3	27.1	±	0.1
CDC Freedom B00	SGF	12.0	±	0.0	3.4	±	0.0	72.1	±	0.6	9.6	±	0.4
	DFFS	13.8	±	0.1	6.8	±	0.1	56.7	±	0.3	19.6	±	0.2
	DFFB	16.7	±	0.1	7.3	±	0.1	56.3	±	2.9	23.1	±	0.1
Condor B00	SGF	13.9	±	0.0	3.2	±	0.1	71.3	±	0.6	11.9	±	0.3
	DFFS	17.9	±	0.0	7.8	±	0.0	57.0	±	0.7	20.4	±	0.1
	DFFB	19.1	±	0.0	8.4	±	0.1	51.8	±	0.9	24.0	±	0.1
HB 109 B00	SGF	13.4	±	0.1	3.0	±	0.0	71.5	±	0.7	9.7	±	0.3
	DFFS	17.0	±	0.0	6.2	±	0.1	55.8	±	1.1	19.3	±	0.2
	DFFB	16.0	±	0.8	7.2	±	0.0	53.3	±	0.2	23.5	±	0.2
HB 109 S00	SGF	12.5	±	0.1	3.3	±	0.0	73.1	±	0.6	8.8	±	0.1
	DFFS	15.4	±	0.3	7.0	±	0.0	61.1	±	0.6	19.2	±	0.0
	DFFB	16.7	±	0.0	7.3	±	0.1	57.1	±	1.1	24.6	±	0.1
HB 109 S01	SGF	11.1	±	0.0	2.7	±	0.1	70.2	±	1.2	7.1	±	0.2
	DFFS	15.9	±	0.1	5.7	±	0.1	57.6	±	0.5	15.5	±	0.2
	DFFB	15.3	±	0.0	5.9	±	0.1	56.3	±	1.0	16.7	±	0.2

[a]Environments in which the samples were grown follow the names of genotypes, where, B00, S00 and S01 stand for Brandon, 2000, Saskatchewan 2000 and Saskatchewan, 2001, respectively
[b]SGF, DFFS and DFFB stand for straight grade flour, dusted flour from shorts and dusted flour from bran, respectively.
[c]Values are on dry basis, g/100g and n=2,
[d]TDF stands for total dietary fibre.

Table IIIb. Protein and Carbohydrate Composition of SGF, DFFS and DFFB from Waxy Barley Samples Used for Tortilla Formulations.

Sample[a]	Fraction[b]	Protein[c] Mean ± SD	β-glucan[c] Mean ± SD	Total starch[c] Mean ± SD	TDF[c,d] Mean ± SD
CDC Alamo B00	SGF	16.2 ± 0.0	5.7 ± 0.0	63.0 ± 0.4	14.0 ± 0.2
	DFFS	17.1 ± 0.0	9.7 ± 0.1	54.7 ± 0.9	21.4 ± 0.3
	DFFB	17.7 ± 0.0	11.2 ± 0.0	53.6 ± 0.0	21.6 ± 0.1
CDC Alamo S01	SGF	15.9 ± 0.1	4.9 ± 0.0	58.8 ± 0.7	11.7 ± 0.2
	DFFS	12.9 ± 0.0	9.2 ± 0.3	50.4 ± 0.5	20.8 ± 0.2
	DFFB	15.4 ± 0.0	8.1 ± 0.2	56.2 ± 0.5	15.5 ± 0.3
CDC Candle B00	SGF	16.1 ± 0.1	3.9 ± 0.0	66.3 ± 1.2	13.0 ± 0.1
	DFFS	17.6 ± 0.4	7.8 ± 0.3	58.3 ± 0.8	19.2 ± 0.3
	DFFB	15.3 ± 0.1	9.7 ± 0.0	62.3 ± 0.6	22.2 ± 0.1
CDC Candle S01	SGF	13.5 ± 0.1	3.6 ± 0.0	65.8 ± 1.9	9.6 ± 0.2
	DFFS	14.7 ± 0.0	8.0 ± 0.1	53.9 ± 2.6	19.4 ± 0.2
	DFFB	13.0 ± 0.0	6.1 ± 0.1	62.9 ± 0.5	12.8 ± 0.1
CDC Fibar B00	SGF	17.9 ± 0.0	6.9 ± 0.0	58.7 ± 0.4	18.2 ± 0.3
	DFFS	17.5 ± 0.0	11.3 ± 0.2	51.2 ± 0.4	23.7 ± 0.1
	DFFB	16.4 ± 0.0	14.5 ± 0.2	56.1 ± 0.2	26.0 ± 0.2
CDC Fibar S00	SGF	16.8 ± 0.1	5.3 ± 0.1	59.6 ± 0.7	16.0 ± 0.3
	DFFS	16.9 ± 0.0	12.5 ± 0.0	46.1 ± 0.3	24.0 ± 0.2
	DFFB	15.2 ± 0.0	14.9 ± 0.6	50.0. ± 2.1	26.8 ± 0.2

[d]Environments in which the samples were grown follow the names of genotypes, where, B00, S00 and S01 stand for Brandon, 2000, Saskatchewan 2000 and Saskatchewan, 2001, respectively.
[b]SGF, DFFS and DFFB stand for straight grade flour, dusted flour from shorts and dusted flour from bran, respectively.
[c]Values are on dry basis, g/100g and n=2.
[d]TDF stands for total dietary fibre.

Table IIIc. Protein and Carbohydrate Composition of SGF, DFFS and DFFB From Low-Amylose Barley Samples Used for Tortilla Formulations.

		Protein[c]	β-glucan[c]	Total starch[c]	TDF[c,d]
Sample[a]	Fraction[b]	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD
HB 805 B00	SGF	13.8 ± 0.0	3.8 ± 0.0	71.4 ± 2.1	10.5 ± 0.1
	DFFS	17.0 ± 0.0	7.0 ± 0.1	55.9 ± 0.4	19.3 ± 0.2
	DFFB	15.7 ± 0.0	11.7 ± 0.1		24.5 ± 0.2
HB 805 S00	SGF	13.1 ± 0.0	3.4 ± 0.2	67.5 ± 0.6	10.5 ± 0.1
	DFFS	15.4 ± 0.1	7.3 ± 0.1	59.2 0.0	19.3 ± 0.2
	DFFB	16..06 ± 0.0	8.6 ± 0.0	54.5 0.8	24.5 ± 0.2

[a]Environments in which the samples were grown follow the names of genotypes, where, B00, S00 and S01 stand for Brandon, 2000, Saskatchewan 2000 and Saskatchewan, 2001, respectively.
[b]SGF, DFFS and DFFB stand for straight grade flour, dusted flour from shorts and dusted flour from bran, respectively.
[c]Values are on dry basis, g/100g and n=2.
[d]TDF stands for total dietary fibre.

Table IIId. Protein and Carbohydrate Composition of SGF, DFFS and DFFB from High-Amylose Barley Samples Used for Tortilla Formulations.

		Protein[c]	β-glucan[c]	Total starch[c]	TDF[c,d]
Sample[a]	Fraction[b]	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD
SB 94893 B00	SGF	20.2 ± 0.0	6.6 ± 0.1	52.2 ± 0.3	19.2 ± 0.4
	DFFS	18.4 ± 0.1	10.6 ± 0.0	54.4 ± 2.3	23.4 ± 0.2
	DFFB	17.8 ± 0.0	12.2 ± 0.0	52.3 ± 0.1	25.3 ± 0.1
SB 94893 S00	SGF	16.9 ± 0.0	6.0 ± 0.1	61.5 ± 0.4	17.2 ± 0.2
	DFFS	17.3 ± 0.1	10.2 ± 0.1	56.0 ± 0.8	24.8 ± 0.1
	DFFB	16.3 ± 0.1	11.7 ± 0.2	55.7 ± 1.0	25.5 ± 0.1
SB 94893 S01	SGF	15.5 ± 0.1	5.2 ± 0.2	58.1 ± 0.9	16.4 ± 0.2
	DFFS	15.7 ± 0.1	8.8 ± 0.2	50.4 ± 0.2	20.7 ± 0.3
	DFFB	16.0 ± 0.0	8.6 ± 0.0	53.4 ± 0.6	19.1 ± 0.1

[a]Environments in which the samples were grown follow the names of genotypes, where, B00, S00 and S01 stand for Brandon, 2000, Saskatchewan 2000 and Saskatchewan, 2001, respectively.
[b]SGF, DFFS and DFFB stand for straight grade flour, dusted flour from shorts and dusted flour from bran, respectively.
[c]Values are on dry basis, g/100g and n=2.
[d]TDF stands for total dietary fibre.

Appendix IV Tortilla Moisture, Thickness, Color and Texture Parameters Measured Instrumentally

Genotype	Design point	SGF	DFFS	DFFB	Moisture	Gradient	Distance traveled	Area under peak	Peak Force	Roll-ability	Thick-ness	Color		
		g	g	g	%	g/s	mm	g mm	g		mm	L	a	b
AC Hawkeye B00	1	90	0	10	36.2	71.7	8.3	1910	614	2.0	1.61	70.0	3.5	19.8
	2	0	90	10	34.0	119.7	9.8	4143	1138	4.0	1.40	62.0	5.7	22.5
	3	50	50	0	37.2	82.2	8.8	2197	639	4.0	1.59	67.0	4.6	21.4
	4	0	95	5	34.8	111.7	9.7	3606	973	4.0	1.36	64.1	5.0	22.0
	5	0	100	0	37.7	110.2	10.3	3472	992	4.0	1.48	63.7	5.6	22.7
	6	100	0	0	37.8	70.9	8.4	1932	574	3.5	1.51	70.6	3.8	21.0
	7	68.75	23.75	7.5	34.2	98.7	8.7	2473	764	3.0	1.59	68.5	4.0	20.5
	8	23.75	68.75	7.5	33.7	98.9	8.9	2602	776	3.5	1.42	65.5	4.9	21.5
	9	45	45	10	36.2	100.0	8.1	2170	714	4.5	1.37	64.9	4.5	21.2
	10	73.75	23.75	2.5	37.4	70.6	8.4	1795	557	3.5	1.61	69.8	3.9	20.4
	11	0	100	0	36.2	113.4	10.7	3599	982	4.5	1.45	63.8	5.4	22.1
	12	100	0	0	36.9	73.4	8.4	1548	512	2.5	1.61	71.6	3.5	19.9
	13	0	90	10	35.4	116.2	9.1	3499	1017	4.5	1.46	63.2	5.5	22.5
	14	90	0	10	36.7	76.1	8.2	2404	749	3.5	1.62	70.4	3.6	19.7
AC Hawkeye S00	1	90	0	10	37.3	75.4	8.0	1993	666	3.0	1.49	74.0	3.1	18.6
	2	0	90	10	37.1	80.8	9.6	2608	813	3.5	1.52	64.7	2.7	17.6
	3	50	50	0	38.3	75.2	9.0	2695	805	3.0	1.44	69.5	4.0	19.9
	4	0	95	5	35.9	91.4	9.8	4724	1291	3.5	1.35	64.7	5.1	21.7
	5	0	100	0	36.6	103.6	10.6	6302	1579	3.5	1.33	64.3	5.2	21.3
	6	100	0	0	37.0	73.3	8.8	2212	677	3.0	1.49	74.7	2.9	18.9
	7	68.75	23.75	7.5	37.1	76.5	8.5	2265	710	3.0	1.51	72.0	3.5	18.3
	8	23.75	68.75	7.5	35.8	94.4	9.9	3396	1025	3.5	1.36	67.1	4.6	21.5
	9	45	45	10	36.0	80.3	8.9	2819	873	3.0	1.44	69.5	3.9	19.3
	10	73.75	23.75	2.5	37.5	68.9	8.6	2280	711	3.5	1.51	72.0	3.5	18.2
	11	0	100	0	33.9	101.0	10.9	4483	1242	4.0	1.32	66.1	4.8	21.0
	12	100	0	0	37.9	72.3	8.9	2311	718	3.0	1.54	74.9	3.0	18.7
	13	0	90	10	37.8	80.5	9.7	3338	937	3.5	1.38	64.3	5.3	22.0
	14	90	0	10	37.3	75.8	8.3	2319	740	3.0	1.54	71.4	3.7	19.5

Genotype	Design point	SGF g	DFFS g	DFFB g	Moisture %	Gradient g/s	Distance traveled mm	Area under peak g mm	Peak Force g	Roll-ability	Thick-ness mm	Color L	a	b
AC Hawkeye S01	1	90	0	10	37.1	76.7	8.5	2761	798	3.0	1.70	77.7	2.5	19.2
	2	0	90	10	39.5	88.6	8.9	3145	882	3.0	1.56	73.0	3.6	22.4
	3	50	50	0	40.1	76.4	9.2	2621	703	3.5	1.66	73.0	3.3	20.9
	4	0	95	5	38.7	87.1	9.3	3446	903	3.5	1.50	70.4	3.7	21.5
	5	0	100	0	39.8	79.5	9.9	3548	885	4.0	1.55	72.0	3.4	21.7
	6	100	0	0	36.6	87.1	8.9	3351	912	2.5	1.69	79.3	2.1	18.7
	7	68.75	23.75	7.5	37.2	67.6	8.9	2517	695	3.0	1.72	76.2	2.8	20.4
	8	23.75	68.75	7.5	38.2	71.9	9.1	2857	743	4.0	1.56	72.2	3.5	21.1
	9	45	45	10	38.7	75.0	8.8	2726	751	4.5	1.66	73.7	2.9	19.8
	10	73.75	23.75	2.5	38.7	65.0	8.7	2440	683	3.0	1.69	76.7	2.5	20.2
	11	0	100	0	39.1	80.1	9.4	2918	795	4.0	1.54	69.8	4.0	22.3
	12	100	0	0	38.7	80.3	8.8	2211	702	3.5	1.74	78.8	2.2	19.2
	13	0	90	10	37.2	89.3	9.2	3444	936	4.0	1.56	70.5	3.9	21.6
	14	90	0	10	36.4	88.2	9.0	2447	775	3.5	1.77	78.5	2.3	18.3
CDC Alamo S01	1	90	0	10	34.7	84.0	7.2	2717	896	5.0	1.45	67.0	5.6	20.60
	2	0	90	10	37.0	65.4	8.8	3393	919	5.0	1.38	63.3	6.9	23.10
	3	50	50	0	34.9	93.6	8.0	3466	1064	5.0	1.41	64.4	6.5	23.20
	4	0	95	5	36.3	63.6	7.9	2675	780	5.0	1.37	64.5	6.5	22.50
	5	0	100	0	37.2	66.4	8.0	2387	670	5.0	1.37	63.8	6.4	22.20
	6	100	0	0	35.2	94.3	7.9	3462	1061	5.0	1.48	66.5	5.5	21.20
	7	68.75	23.75	7.5	35.7	66.6	7.6	2638	812	5.0	1.45	65.2	6.4	22.30
	8	23.75	68.75	7.5	37.3	68.8	7.7	2752	838	5.0	1.44	65.3	5.9	22.00
	9	45	45	10	35.5	80.3	7.6	2962	912	5.0	1.46	66.1	6.2	22.30
	10	73.75	23.75	2.5	37.1	87.6	7.6	3038	967	5.0	1.43	64.8	6.7	22.50
	11	0	100	0	34.1	65.6	7.8	2653	721	5.0	1.34	63.5	6.7	23.70
	12	100	0	0	34.6	91.6	7.9	3530	1121	5.0	1.49	65.6	5.6	21.50
	13	0	90	10	36.9	60.2	8.6	3147	859	5.0	1.38	65.2	6.0	22.40
	14	90	0	10	34.2	85.6	7.8	3400	1090	5.0	1.46	68.9	4.8	20.60

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Genotype	Design point	SGF g	DFFS g	DFFB g	Moisture %	Gradient g/s	Distance traveled mm	Area under peak g mm	Peak Force g	Roll-ability	Thick-ness mm	Color L	a	b
CDC Candle B00	1	90	0	10	34.6	92.2	8.7	2889	825	4.5	1.40	64.0	5.2	21.0
	2	0	90	10	38.6	60.6	9.3	2063	590	4.0	1.21	59.2	7.3	24.0
	3	50	50	0	35.1	83.4	9.6	2917	806	4.0	1.28	65.1	5.3	22.2
	4	0	95	5	39.8	59.9	10.0	2432	588	4.0	1.25	60.2	6.5	23.6
	5	0	100	0	37.0	51.0	11.4	2006	519	4.0	1.17	59.4	7.7	25.2
	6	100	0	0	31.2	95.3	9.2	3078	861	4.5	1.25	69.3	4.0	20.1
	7	68.75	23.75	7.5	37.8	74.2	9.2	2421	695	3.5	1.31	64.8	5.0	21.4
	8	23.75	68.75	7.5	36.7	70.1	9.8	2766	706	4.0	1.23	62.1	5.7	22.7
	9	45	45	10	36.8	79.2	8.3	1718	466	4.0	1.26	62.7	6.1	22.6
	10	73.75	23.75	2.5	37.1	70.6	8.8	1969	552	4.0	1.27	61.3	6.5	22.1
	11	0	100	0	36.9	56.2	11.1	2389	605	4.0	1.12	60.9	6.9	23.0
	12	100	0	0	35.1	94.1	9.7	3262	917	4.0	1.35	68.2	6.2	22.9
	13	0	90	10	37.4	61.5	9.6	2379	620	4.5	1.24	59.2	7.2	23.8
	14	90	0	10	34.3	90.3	8.2	4463	1113	4.5	1.33	70.0	3.9	20.4
CDC Candle S01	1	90	0	10	37.3	100.9	6.7	1770	612	3.5	1.49	69.3	4.1	22.0
	2	0	90	10	40.7	70.1	8.5	2308	597	5.0	1.31	64.2	4.7	22.2
	3	50	50	0	40.6	77.9	7.2	1824	558	5.0	1.42	68.6	3.8	21.5
	4	0	95	5	41.9	74.8	8.6	2258	620	5.0	1.34	64.3	4.4	21.3
	5	0	100	0	42.1	80.0	8.4	2442	671	4.5	1.38	63.5	4.9	22.1
	6	100	0	0	37.8	96.7	7.4	2032	645	4.0	1.55	71.9	3.3	21.6
	7	68.75	23.75	7.5	41.7	63.5	9.7	2128	551	4.5	1.37	66.4	5.3	24.3
	8	23.75	68.75	7.5	41.8	77.7	8.1	2294	632	4.5	1.43	67.3	4.8	21.8
	9	45	45	10	39.6	72.7	8.0	2134	585	4.0	1.47	65.6	5.0	22.4
	10	73.75	23.75	2.5	40.4	71.0	7.8	1926	550	4.5	1.51	69.2	3.9	21.2
	11	0	100	0	41.3	79.3	8.5	2392	671	4.5	1.35	61.2	5.7	23.6
	12	100	0	0	36.6	94.4	6.7	1896	639	4.0	1.47	72.7	3.6	22.7
	13	0	90	10	41.2	73.6	8.5	2248	577	5.0	1.39	63.7	5.1	23.3
	14	90	0	10	37.1	100.6	6.8	2044	684	3.0	1.55	72.1	3.4	20.7

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Genotype	Design point	SGF	DFFS	DFFB	Moisture	Gradient	Distance traveled	Area under peak	Peak Force	Roll-ability	Thick-ness	Color		
		g	g	g	%	g/s	mm	g mm	g		mm	L	a	b
CDC Dawn B00	1	90	0	10	35.49	61.6	9.5	1822	523	4.5	1.44	63.0	4.8	21.5
	2	0	90	10	35.46	102.8	10.7	4101	999	3.5	1.33	59.3	5.8	23.4
	3	50	50	0	35.71	78.1	8.7	2035	602	4.5	1.47	62.1	5.3	23.0
	4	0	95	5	36.79	127.8	10.6	4982	1228	4.5	1.54	57.9	5.8	22.2
	5	0	100	0	37.12	124.6	10.1	4468	1135	5.0	1.49	58.9	5.5	22.1
	6	100	0	0	36.50	82.5	8.7	1960	552	4.0	1.57	65.3	4.4	21.3
	7	68.75	23.75	7.5	32.42	107.9	9.5	3948	1022	4.5	1.55	62.0	4.8	21.7
	8	23.75	68.75	7.5	35.19	88.7	9.5	2856	760	5.0	1.36	60.8	5.3	22.0
	9	45	45	10	36.53	74.1	9.0	1718	525	3.0	1.59	60.0	5.1	20.7
	10	73.75	23.75	2.5	34.88	87.1	9.8	3430	851	3.5	1.38	63.9	4.7	21.3
	11	0	100	0	35.87	159.2	9.8	7713	1725	4.5	1.52	57.4	5.6	22.2
	12	100	0	0	37.41	70.4	8.8	1849	547	3.0	1.68	63.6	4.9	22.0
	13	0	90	10	35.22	119.0	10.8	4876	1175	3.5	1.45	58.1	5.8	22.0
	14	90	0	10	34.30	64.0	9.4	2042	548	3.5	1.45	63.1	5.0	21.7
CDC Fibar B00	1	90	0	10	37.7	68.4	9.2	2768	634	4.0	1.39	52.5	7.8	22.7
	2	0	90	10	36.0	75.1	8.5	2701	691	4.5	1.32	58.7	6.8	23.0
	3	50	50	0	40.7	74.2	9.0	2684	668	5.0	1.34	55.8	7.1	23.0
	4	0	95	5	37.0	86.5	8.8	3036	762	5.0	1.34	59.6	6.5	22.1
	5	0	100	0	40.6	91.7	8.2	2213	588	5.0	1.25	58.4	7.4	23.9
	6	100	0	0	35.9	63.1	8.9	2376	570	4.0	1.44	52.1	7.3	22.6
	7	68.75	23.75	7.5	37.8	78.2	8.8	2415	602	4.0	1.43	56.3	6.4	22.3
	8	23.75	68.75	7.5	36.9	84.1	8.4	2688	709	5.0	1.34	57.7	6.6	21.8
	9	45	45	10	38.7	79.7	8.1	2605	724	5.0	1.33	56.5	6.8	21.5
	10	73.75	23.75	2.5	37.4	65.9	9.1	2576	602	4.0	1.36	55.6	6.7	23.0
	11	0	100	0	38.6	91.8	8.7	1923	548	5.0	1.27	58.5	6.9	22.9
	12	100	0	0	37.2	63.1	9.3	2482	588	4.0	1.46	54.6	6.6	22.7
	13	0	90	10	38.3	69.8	7.3	2655	697	4.0	1.33	58.6	6.8	22.7
	14	90	0	10	37.8	67.3	9.3	2333	539	4.0	1.44	54.6	6.9	22.5

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Genotype	Design point	SGF g	DFFS g	DFFB g	Moisture %	Gradient g/s	Distance traveled mm	Area under peak g mm	Peak Force g	Roll-ability	Thick-ness mm	Color L	Color a	Color b
CDC Fibar S00	1	90	0	10	35.3	112.4	8.1	3286	954	4.0	1.38	60.3	6.3	22.1
	2	0	90	10	37.8	127.8	8.8	3358	952	5.0	1.30	58.6	6.8	22.6
	3	50	50	0	37.0	98.2	8.3	2894	814	5.0	1.36	55.8	7.1	23.0
	4	0	95	5	42.5	84.3	8.3	2549	687	5.0	1.27	59.6	6.5	22.1
	5	0	100	0	37.2	87.9	8.5	3480	935	5.0	1.36	60.1	6.8	22.6
	6	100	0	0	35.9	101.4	8.6	3396	945	4.5	1.39	58.8	6.3	21.8
	7	68.75	23.75	7.5	34.1	125.5	8.5	3815	1073	5.0	1.36	59.8	6.4	22.3
	8	23.75	68.75	7.5	35.9	105.7	8.1	3062	861	5.0	1.34	61.7	6.5	21.9
	9	45	45	10	33.7	102.1	8.3	3024	847	5.0	1.37	58.8	7.2	22.3
	10	73.75	23.75	2.5	36.5	99.2	8.4	3263	901	5.0	1.36	56.3	7.9	23.3
	11	0	100	0	35.4	111.0	8.7	3618	974	5.0	1.32	58.5	6.9	22.9
	12	100	0	0	38.1	96.8	9.1	3510	885	5.0	1.38	59.7	6.3	22.1
	13	0	90	10	39.1	113.7	8.4	3799	1050	5.0	1.28	58.7	6.8	23.0
	14	90	0	10	35.5	131.0	8.9	4213	1161	5.0	1.43	54.6	6.9	22.5
CDC Freedom B00	1	90	0	10	34.13	102.7	9.6	1886	570	2.5	1.58	68.1	4.1	21.7
	2	0	90	10	40.23			3600	905	3.0	1.57	60.9	6.1	22.9
	3	50	50	0	40.29	74.2	9.8	1791	517	3.5	1.59	62.2	6.3	23.8
	4	0	95	5	35.51	73.1	9.8	3144	834	4.5	1.47	63.3	5.8	22.6
	5	0	100	0	38.04	71.3	8.7	2395	618	3.5	1.45	61.5	6.2	23.0
	6	100	0	0	35.83	94.4	10.4	1851	550	3.0	1.65	70.7	3.4	20.0
	7	68.75	23.75	7.5	32.68	89.8	8.9	2573	714	3.0	1.46	68.8	4.2	21.9
	8	23.75	68.75	7.5		74.7	8.6	2992	797	3.0	1.38	64.1	6.0	23.6
	9	45	45	10	34.97	102.8	10.1	2481	656	3.0	1.43	65.3	5.0	12.2
	10	73.75	23.75	2.5		92.5	10.6	3966	959		1.36	67.8	4.4	21.5
	11	0	100	0	41.37	72.0	8.7	3118	800	3.0	1.53	61.2	6.2	22.7
	12	100	0	0	32.62	95.5	10.5	2321	651	3.0	1.62	69.0	3.9	21.4
	13	0	90	10	39.00	73.0	8.8	4665	1110	4.0	1.42	64.4	5.0	21.9
	14	90	0	10	37.21	110.3	11.1	1609	507	2.5	1.72	68.0	3.9	20.7

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Genotype	Design point	SGF	DFFS	DFFB	Moisture	Gradient	Distance traveled	Area under peak	Peak Force	Roll-ability	Thick-ness	Color		
		g	g	g	%	g/s	mm	g mm	g		mm	L	a	b
Condor B00	1	90	0	10	37.48	53.7	8.7			3.0	1.45	65.10	3.90	21.10
	2	0	90	10	42.09	64.2	8.9	2518	683	4.5	1.41	60.20	5.00	21.30
	3	50	50	0	39.27	60.1	8.3	1478	436	4.5	1.41	65.00	4.30	21.10
	4	0	95	5	41.48	87.5	10.0	3234	809	4.0	1.38	59.80	5.00	21.20
	5	0	100	0	43.22	84.2	10.4	2847	731	4.0	1.38	61.40	4.80	21.10
	6	100	0	0	37.27	55.1	8.6	1230	367	2.0	1.46	65.50	3.70	20.50
	7	68.75	23.75	7.5	40.82	62.7	8.2	1496	453	2.5	1.46	62.00	4.70	21.80
	8	23.75	68.75	7.5	41.27	67.4	8.7	1891	538	4.5	1.45	60.80	5.00	21.50
	9	45	45	10	39.89	62.5	8.9	1581	457	3.0	1.40	61.60	4.60	21.50
	10	73.75	23.75	2.5	38.59	68.4	9.1	1611	453	2.5	1.45	63.40	4.30	20.60
	11	0	100	0	29.26	91.2	11.0	2609	710	4.5	1.38	60.60	4.70	20.10
	12	100	0	0	37.76	42.0	8.8	1150	328	2.5	1.49	65.80	3.70	20.70
	13	0	90	10	41.70	88.9	9.8	2633	723	5.0	1.37	60.70	5.40	22.20
	14	90	0	10	37.48	57.6	8.6	1710	550	2.5	1.45	63.80	4.00	21.10
Millhouse B00	1	90	0	10	35.88	50.0	7.4	2523	696	3.0	1.59	64.2	4.8	22.6
	2	0	90	10	37.51	77.4	8.9	1890	565	3.5	1.43	63.4	4.5	21.3
	3	50	50	0	40.79	47.0	7.4	1048	318	3.0	1.46	63.9	4.6	20.4
	4	0	95	5	37.71	75.3	9.5	2496	694	3.5	1.48	60.3	5.3	21.7
	5	0	100	0	39.19	69.6	9.9	2348	615	4.3	1.47	61.9	5.3	22.2
	6	100	0	0	37.81	46.9	7.8	1084	319	2.5	1.76	69.7	3.2	20.9
	7	68.75	23.75	7.5	38.24	46.0	7.9	1075	317	2.5	1.68	65.4	4.0	20.2
	8	23.75	68.75	7.5	38.72	59.9	8.5	1665	453	3.5	1.56	62.6	4.9	21.9
	9	45	45	10	38.93	50.8	8.7	1436	391	2.5	1.57	62.1	5.1	22.4
	10	73.75	23.75	2.5	38.90	51.4	7.7	1153	345	3.0	1.60	68.0	3.8	20.9
	11	0	100	0	40.21	69.8	9.6	2276	600	4.5	1.49	62.4	5.1	22.0
	12	100	0	0	37.30	41.1	7.8	1428	378	2.0	1.71	67.8	3.8	20.7
	13	0	90	10	37.99	76.6	8.9	2163	571	4.0	1.50	63.5	4.7	21.7
	14	90	0	10	36.38	49.8	7.4	1063	346	2.5	1.62	67.8	3.7	20.3

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Genotype	Design point	SGF g	DFFS g	DFFB g	Moisture %	Gradient g/s	Distance traveled mm	Area under peak g mm	Peak Force g	Roll-ability	Thick-ness mm	Color L	Color a	Color b
Millhouse S00	1	90	0	10	37.7	66.3	9.2	1527	466	2.0	1.51	71.7	3.2	18.4
	2	0	90	10	40.0	74.8	10.8	1788	511	3.5	1.47	60.9	5.6	20.4
	3	50	50	0	40.7	69.0	10.7	1882	537	3.0	1.55	67.0	4.0	19.1
	4	0	95	5	42.1	73.1	11.1	2154	547	4.0	1.38	63.9	4.7	20.4
	5	0	100	0	39.2	87.4	10.9	2042	537	4.0	1.40	61.8	5.2	21.3
	6	100	0	0	37.0	64.0	9.2	1363	431	3.5	1.58	72.2	3.2	18.5
	7	68.75	23.75	7.5	38.4	64.4	9.5	1425	453	3.0	1.48	69.5	3.9	20.7
	8	23.75	68.75	7.5	41.0	67.3	10.8	1970	554	5.0	1.50	62.5	5.3	21.2
	9	45	45	10	40.4	62.4	10.0	1466	431	3.5	1.47	68.1	3.8	19.1
	10	73.75	23.75	2.5	37.7	65.5	10.1	1839	531	3.0	1.56	70.4	3.4	18.3
	11	0	100	0	40.6	83.2	10.8	2520	668	4.5	1.39	61.2	5.7	21.5
	12	100	0	0	37.6	65.2	9.4	1120	339	2.5	1.60	71.8	3.3	18.6
	13	0	90	10	42.2	70.5	10.3	2204	581	4.0	1.37	63.7	4.8	21.1
	14	90	0	10	38.3	60.0	9.7	1361	433	2.0	1.55	72.7	2.8	17.8
Millhouse S01	1	90	0	10	38.3	67.2	8.7	2176	652	2.5	1.66	75.7	2.5	20.1
	2	0	90	10	40.1	76.3	9.3	3003	746	3.0	1.58	67.5	3.0	20.2
	3	50	50	0	37.8	71.7	8.4	2075	590	3.5	1.55	70.2	3.2	21.0
	4	0	95	5	40.5	77.5	9.8	2034	531	3.0	1.51	68.2	2.9	21.2
	5	0	100	0	39.6	79.0	9.9	2470	666	4.0	1.46	67.3	3.4	22.1
	6	100	0	0	36.5	78.6	7.8	1947	610	3.0	1.55	78.1	1.8	18.3
	7	68.75	23.75	7.5	38.0	67.2	8.1	1843	533	3.0	1.60	75.5	2.0	19.5
	8	23.75	68.75	7.5	38.6	73.2	8.7	1929	509	3.0	1.38	68.8	3.4	21.9
	9	45	45	10	38.2	70.9	8.4	2119	589	3.0	1.56	71.0	2.9	21.2
	10	73.75	23.75	2.5	37.6	68.4	8.2	1918	550	3.0	1.50	74.1	2.8	21.8
	11	0	100	0	38.8	78.6	9.7	2407	591	3.0	1.45	66.9	3.6	21.4
	12	100	0	0	35.1	78.1	8.3	2122	649	3.0	1.59	76.7	2.2	20.0
	13	0	90	10	40.4	78.7	9.6	2786	686	3.0	1.58	66.5	3.4	21.1
	14	90	0	10	38.5	69.8	8.4	2307	671	3.0	1.70	76.1	2.2	18.1

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Genotype	Design point	SGF g	DFFS g	DFFB g	Moisture %	Gradient g/s	Distance traveled mm	Area under peak g mm	Peak Force g	Roll-ability	Thick-ness mm	Color L	Color a	Color b
HB 805 B00	1	90	0	10	37.5	86.0	8.6	1942	597	4	1.38	63.1	5.9	21.6
	2	0	90	10	41.6	50.9	9.4	1558	405	4	1.31	61.2	7.3	23.7
	3	50	50	0	40.7	82.1	9.7	1904	544	3	1.53	68.1	4.6	21.2
	4	0	95	5	40.2	50.1	10.2	2325	583	4	1.39	59.7	7.2	22.8
	5	0	100	0	40.4	58.6	10.1	2305	641	4.5	1.29	62.7	6.7	23.0
	6	100	0	0	37.5	89.6	7.9	1319	451	4.5	1.36	61.9	7.0	23.6
	7	68.75	23.75	7.5	36.2	58.9	8.9	2463	724	4	1.50	66.2	5.0	21.7
	8	23.75	68.75	7.5	39.3	80.6	9.8	2635	706	4	1.49	65.2	5.0	21.1
	9	45	45	10	37.5	86.0	9.1	2183	611	3.5	1.52	65.1	5.0	20.3
	10	73.75	23.75	2.5	36.0	74.2	8.5	1836	554	3	1.48	67.3	4.6	19.9
	11	0	100	0	39.9	56.0	10.3	2248	518	3.5	1.54	59.9	5.7	21.5
	12	100	0	0	37.7	90.2	8.9	1890	564	4	1.35	62.9	6.3	23.1
	13	0	90	10	41.6	47.5	10.1	1670	389	4	1.36	65.0	5.5	22.1
	14	90	0	10	36.9	89.8	8.2	1614	514	4	1.46	61.0	6.6	22.7
HB 805 S00	1	90	0	10	36.3	104.3	7.2	2661	897	3.5	1.48	68.0	3.6	18.5
	2	0	90	10	39.4	73.3	8.5	2424	652	4.5	1.39	60.0	5.8	21.8
	3	50	50	0	37.6	81.0	8.2	2528	736	4.3	1.37	61.1	4.9	19.4
	4	0	95	5	39.1	77.3	9.4	3119	793	5.0	1.29	59.1	5.5	20.9
	5	0	100	0	37.4	87.4	8.3	3280	957	3.5	1.33	60.1	5.5	21.3
	6	100	0	0	36.0	106.4	7.5	2939	950	3.0	1.45	66.4	3.7	19.0
	7	68.75	23.75	7.5	36.3	85.3	8.2	3123	991	5.0	1.37	66.7	3.7	18.2
	8	23.75	68.75	7.5	38.7	70.6	9.3	2989	781	5.0	1.33	61.0	5.4	21.4
	9	45	45	10	38.3	70.7	7.4	2383	683	4.5	1.36			
	10	73.75	23.75	2.5	36.2	87.1	7.4	2692	866	4.0	1.45	64.3	4.4	19.1
	11	0	100	0	37.6	88.7	9.0	3660	981	4.8	1.33	59.0	5.7	21.0
	12	100	0	0	36.2	105.6	7.5	2861	945	3.5	1.44	68.1	3.3	18.0
	13	0	90	10	37.6	69.6	8.2	2538	689	5.0	1.36	60.1	5.1	20.2
	14	90	0	10	36.6	99.1	8.2	3261	983	4.0	1.42	62.3	4.6	19.9

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Genotype	Design point	SGF g	DFFS g	DFFB g	Moisture %	Gradient g/s	Distance traveled mm	Area under peak g mm	Peak Force g	Roll-ability	Thick-ness mm	Color L	Color a	Color b
SB 94893	1	90	0	10										
B00	2	0	90	10	40.8	117.4	9.5	4301	775	3.5	1.44	60.0	6.0	23.9
	3	50	50	0	35.9	63.4	8.1	1722	513	3.5	1.29	59.3	5.9	24.0
	4	0	95	5	35.3	130.9	9.2	4102	1198	3.5	1.30	60.9	5.3	22.7
	5	0	100	0	39.4	119.5	8.5	3488	1011	3.5	1.38	60.5	6.2	23.9
	6	100	0	0	35.0	71.9	8.8	2296	637	3.0	1.31	58.9	4.9	22.8
	7	68.75	23.75	7.5	36.8	65.2	7.6	1642	493	2.5	1.46	58.0	5.7	23.2
	8	23.75	68.75	7.5	39.1	81.3	7.3	1945	596	3.0	1.37	61.3	5.7	23.6
	9	45	45	10										
	10	73.75	23.75	2.5										
	11	0	100	0	39.4	133.6	10.0	5315	1330	3.0	1.40	60.0	6.1	23.6
	12	100	0	0	34.7	72.3	8.8	2331	671	3.0	1.35	61.4	4.7	22.6
	13	0	90	10	39.6	115.3	8.8	3753	751	3.5	1.40	60.4	6.2	24.5
	14	90	0	10	34.3	88.2	7.0	1863	620	3.0	1.57	57.1	5.7	23.6
SB 94893	1	90	0	10	31.8	126.4	7.0	2422	885	3.5	1.31	62.5	3.8	21.0
S00	2	0	90	10	41.9	103.4	8.4	2978	871	3.0	1.40	62.7	4.8	22.0
	3	50	50	0	36.9	121.0	7.5	2797	912	3.0	1.32	62.9	4.1	21.7
	4	0	95	5	40.5	95.8	8.7	3053	844	4.0	1.44	61.0	4.7	19.8
	5	0	100	0	43.0	93.8	8.5	2948	802	4.0	1.38	63.1	4.5	21.4
	6	100	0	0	34.4	125.9	6.1	1988	772	2.0	1.36	65.5	3.3	21.0
	7	68.75	23.75	7.5	34.8	113.5	7.7	2593	867	3.0	1.35	62.7	3.9	20.9
	8	23.75	68.75	7.5	41.6	113.1	7.6	2734	862	4.5	1.37	64.9	3.8	21.2
	9	45	45	10	39.5	124.0	7.4	2792	921	4.5	1.39	62.5	4.3	21.9
	10	73.75	23.75	2.5	36.9	113.1	7.0	2353	794	2.5	1.35	62.1	4.0	21.1
	11	0	100	0	41.1	88.0	8.9	2751	782	4.0	1.30	63.2	4.3	20.9
	12	100	0	0	34.2	125.3	7.4	2716	925	2.0	1.33	63.3	3.7	20.7
	13	0	90	10	40.4	105.5	8.8	3302	937	3.5	1.37	62.3	4.6	21.4
	14	90	0	10	32.4	141.5	6.7	2614	950	2.0	1.30	60.7	4.1	21.1

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Genotype	Design point	SGF	DFFS	DFFB	Moisture	Gradient	Distance traveled	Area under peak	Peak Force	Roll-ability	Thick-ness	Color		
		g	g	g	%	g/s	mm	g mm	g		mm	L	a	b
SB 94893	1	90	0	10	31.9	116.5	7.5	2562	871	3.5	1.56	69.4	3.1	21.7
S01	2	0	90	10	39.8	86.8	8.3	2526	723	3.0	1.42	64.7	4.4	23.2
	3	50	50	0	37.8	85.0	7.5	2010	637	3.5	1.45	66.6	3.9	23.2
	4	0	95	5	39.7	82.3	8.1	2287	667	4.0	1.42	63.0	4.9	23.3
	5	0	100	0	40.8	91.0	9.1	3063	824	2.5	1.38	62.5	5.0	24.0
	6	100	0	0	34.4	110.8	6.9	2159	776	2.5	1.51	69.4	3.1	21.4
	7	68.75	23.75	7.5	35.8	90.2	8.2	2205	702	4.0	1.59	68.4	3.4	21.8
	8	23.75	68.75	7.5	36.4	105.2	8.8	3055	890	4.0	1.46	65.2	4.3	22.5
	9	45	45	10	37.1	95.1	7.7	2386	737	4.0	1.50	66.0	4.0	22.8
	10	73.75	23.75	2.5	35.1	110.8	7.7	2652	847	3.5	1.50	66.7	3.8	22.9
	11	0	100	0	39.3	81.2	9.4	2629	759	2.5	1.41	64.1	4.3	22.4
	12	100	0	0	32.1	115.1	7.8	2630	863	2.5	1.51	69.0	3.1	21.7
	13	0	90	10	39.7	99.8	8.3	2868	831	3.0	1.41	65.2	4.4	23.8
	14	90	0	10	34.1	116.9	7.7	2767	898	4.0	1.52	69.7	3.0	21.2

Appendix V Chemical Composition of the Tortilla Formulations

Table V.a) Chemical Composition of The Blends for Waxy Cultivars

Genotype	Design point	Moisture	SGF	DFFS	DFFB	Amylose	Protein	β-glucan	Total starch	TDF
		%	g	g	g	g/100g	g/100g	g/100g	g/100g	g/100g
CDC Candle B00	6	31.2	100	0	0	3.3	16.1	3.9	66.3	13.0
	12	35.1	100	0	0	3.3	16.1	3.9	66.3	13.0
	1	34.6	90	0	10	3.3	16.0	4.4	65.9	13.9
	14	29.3	90	0	10	3.3	16.0	4.4	65.9	13.9
	10	37.1	73.75	23.75	2.5	3.2	16.4	4.9	64.3	14.7
	7	37.8	68.75	23.75	7.5	3.2	16.4	5.2	64.1	15.2
	3	35.1	50	50	0	3.1	16.8	5.8	62.3	16.1
	9	36.8	45	45	10	3.1	16.7	6.2	62.3	16.7
	8	36.7	23.75	68.75	7.5	3.0	17.0	7.0	60.5	18.0
	5	37.0	0	100	0	2.9	17.6	7.8	58.3	19.2
	11	36.9	0	100	0	2.9	17.6	7.8	58.3	19.2
	4	39.8	0	95	5	2.9	17.5	7.9	58.5	19.4
	2	38.6	0	90	10	2.9	17.3	8.0	58.7	19.5
	13	37.4	0	90	10	2.9	17.3	8.0	58.7	19.5
CDC Fibar B00	6	35.9	100	0	0	0.0	17.9	6.9	58.7	18.2
	12	37.2	100	0	0	0.0	17.9	6.9	58.7	18.2
	1	37.7	90	0	10	0.0	17.7	7.7	58.5	19.0
	14	37.8	90	0	10	0.0	17.7	7.7	58.5	19.0
	10	37.4	73.75	23.75	2.5	0.0	17.8	8.1	56.9	19.7
	7	37.8	68.75	23.75	7.5	0.0	17.7	8.5	56.7	20.1
	3	40.7	50	50	0	0.0	17.7	9.1	55.0	21.0
	9	38.7	45	45	10	0.0	17.6	9.6	55.1	21.5
	8	36.9	23.75	68.75	7.5	0.0	17.5	10.5	53.4	22.6
	5	40.6	0	100	0	0.0	17.5	11.3	51.2	23.7
	11	38.6	0	100	0	0.0	17.5	11.3	51.2	23.7
	4	37.0	0	95	5	0.0	17.4	11.4	51.5	23.8
	2	36.0	0	90	10	0.0	17.4	11.6	51.7	23.9
	13	38.3	0	90	10	0.0	17.4	11.6	51.7	23.9

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TableV.b) Chemical Composition of The Blends for Low-Amylose Cultivars.

Genotype	Design point	Moisture %	SGF g	DFFS g	DFFB g	Amylose g/100g	Protein g/100g	β-glucan g/100g	Total starch g/100g	TDF g/100g
HB 805 B00	6	37.5	100	0	0	11.43	13.81	3.82	71.42	10.50
	12	37.7	100	0	0	11.43	13.81	3.82	71.42	10.50
	1	37.5	90	0	10	11.15	14.00	4.61	69.70	11.90
	14	36.9	90	0	10	11.15	14.00	4.61	69.70	11.90
	10	36.0	73.8	23.75	2.5	10.77	14.61	4.77	67.31	12.95
	7	36.2	68.8	23.75	7.5	10.63	14.70	5.16	66.45	13.65
	3	40.7	50	50	0	10.19	15.40	5.40	63.67	14.92
	9	37.5	45	45	10	10.04	15.43	6.03	62.72	15.88
	8	39.3	23.8	68.75	7.5	9.51	16.14	6.58	59.47	17.63
	5	40.4	0	100	0	8.95	16.99	6.97	55.91	19.34
	11	39.9	0	100	0	8.95	16.99	6.97	55.91	19.34
	4	40.2	0	95	5	8.93	16.92	7.21	55.83	19.60
	2	41.6	0	90	10	8.92	16.86	7.44	55.74	19.86
	13	41.6	0	90	10	8.92	16.86	7.44	55.74	19.86
HB 805 S00	6	36.0	100	0	0	10.80	13.81	3.82	67.48	10.50
	12	36.2	100	0	0	10.80	13.81	3.82	67.48	10.50
	1	36.3	90	0	10	10.59	13.96	4.61	66.18	11.90
	14	36.6	90	0	10	10.59	13.96	4.61	66.18	11.90
	10	36.2	73.8	23.75	2.5	10.43	14.60	4.77	65.18	12.95
	7	32.3	68.8	23.75	7.5	10.33	14.68	5.16	64.53	13.65
	3	37.6	50	50	0	10.13	15.40	5.40	63.33	14.92
	9	38.3	45	45	10	9.99	15.39	6.03	62.44	15.88
	8	38.7	23.8	68.75	7.5	9.73	16.11	6.58	60.79	17.63
	5	37.4	0	100	0	9.47	16.99	6.97	59.18	19.34
	11	37.6	0	100	0	9.47	16.99	6.97	59.18	19.34
	4	39.1	0	95	5	9.43	16.91	7.21	58.94	19.60
	2	39.4	0	90	10	9.39	16.82	7.44	58.70	19.86
	13	40.6	0	90	10	9.39	16.82	7.44	58.70	19.86

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Table V.c) Chemical Composition of the Blends for Non-Waxy Cultivars.

Genotype	Design point	Moisture %	SGF g	DFFS g	DFFB g	Amylose g/100g	Protein g/100g	β-glucan g/100g	Total starch g/100g	TDF g/100g
AC Hawkeye B00	6	37.8	100	0	0	19.1	12.3	3.2	74.2	9.4
	12	36.9	100	0	0	15.8	12.3	3.2	74.2	9.4
	1	33.2	90	0	10	17.9	12.7	3.4	72.0	10.9
	14	36.7	90	0	10	15.9	12.7	3.4	72.0	10.9
	10	37.4	73.8	23.75	2.5	16.0	13.3	3.8	70.3	12.2
	7	24.2	68.8	23.75	7.5	19.7	13.5	4.0	69.2	13.0
	3	37.2	50	50	0	18.4	14.1	4.5	67.2	14.6
	9	48.2	45	45	10	16.7	14.3	4.6	65.6	15.6
	8	33.7	23.8	68.75	7.5	17.5	15.0	5.2	62.9	17.6
	5	37.7	0	100	0	18.7	15.8	5.8	60.2	19.7
	11	36.2	0	100	0	16.0	15.8	5.8	60.2	19.7
	4	40.8	0	95	5	19.7	15.8	5.8	59.8	20.0
	2	34.0	0	90	10	15.8	15.9	5.8	59.3	20.2
	13	35.4	0	90	10	19.1	15.9	5.8	59.3	20.2
CDC Dawn B00	6	36.50	100	0	0	18.2	14.2	3.3	70.4	10.2
	12	37.41	100	0	0	18.2	14.2	3.3	70.4	10.2
	1	35.49	90	0	10	17.6	14.5	3.5	67.9	11.9
	14	34.30	90	0	10	17.6	14.5	3.5	67.9	11.9
	10	34.88	73.8	23.75	2.5	16.8	15.3	4.1	65.0	13.7
	7	32.42	68.8	23.75	7.5	16.5	15.5	4.2	63.7	14.5
	3	35.71	50	50	0	15.6	16.3	4.9	60.3	16.5
	9	36.53	45	45	10	15.2	16.5	5.0	58.7	17.6
	8	35.19	23.8	68.75	7.5	14.1	17.4	5.7	54.5	20.2
	5	37.12	0	100	0	13.0	18.5	6.5	50.1	22.9
	11	35.87	0	100	0	13.0	18.5	6.5	50.1	22.9
	4	36.79	0	95	5	12.9	18.4	6.5	49.8	23.1
	2	35.46	0	90	10	12.8	18.4	6.5	49.6	23.3
	13		0	90	10	12.8	18.4	6.5	49.6	23.3

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CDC Freedom B00	6	35.83	100	0	0	19.9	12.0	3.4	72.1	9.6
	12	32.62	100	0	0	19.9	12.0	3.4	72.1	9.6
	1	34.13	90	0	10	19.5	12.5	3.8	70.5	11.0
	14	37.21	90	0	10	19.5	12.5	3.8	70.5	11.0
	10		73.8	23.75	2.5	18.8	12.6	4.3	68.0	12.4
	7	32.68	68.8	23.75	7.5	18.6	12.8	4.5	67.2	13.0
	3	40.29	50	50	0	17.8	12.9	5.1	64.4	14.6
	9	34.97	45	45	10	17.6	13.3	5.4	63.6	15.5
	8		23.8	68.75	7.5	16.7	13.6	6.1	60.3	17.5
	5	38.04	0	100	0	15.7	13.8	6.8	56.7	19.6
	11	41.37	0	100	0	15.7	13.8	6.8	56.7	19.6
	4	35.51	0	95	5	15.6	14.0	6.9	56.7	19.8
	2	40.23	0	90	10	15.6	14.1	6.9	56.7	20.0
	13	39.00	0	90	10	15.6	14.1	6.9	56.7	20.0
Condor B00	6	37.27	100	0	0	18.8	13.9	3.2	71.3	11.9
	12	37.76	100	0	0	18.8	13.9	3.2	71.3	11.9
	1	37.48	90	0	10	18.3	14.4	3.7	69.3	13.1
	14	37.48	90	0	10	18.3	14.4	3.7	69.3	13.1
	10	38.59	73.8	23.75	2.5	17.8	15.0	4.4	67.4	14.2
	7	40.82	68.8	23.75	7.5	17.5	15.2	4.7	66.4	14.8
	3	39.27	50	50	0	16.9	15.9	5.5	64.1	16.2
	9	39.89	45	45	10	16.6	16.2	5.8	62.9	16.9
	8	41.27	23.8	68.75	7.5	15.8	17.1	6.8	60.0	18.6
	5	43.22	0	100	0	15.1	17.9	7.8	57.0	20.4
	11	29.26	0	100	0	15.1	17.9	7.8	57.0	20.4
	4	41.48	0	95	5	15.0	18.0	7.8	56.8	20.6
	2	42.09	0	90	10	14.9	18.0	7.9	56.5	20.7
	13	41.70	0	90	10	14.9	18.0	7.9	56.5	20.7

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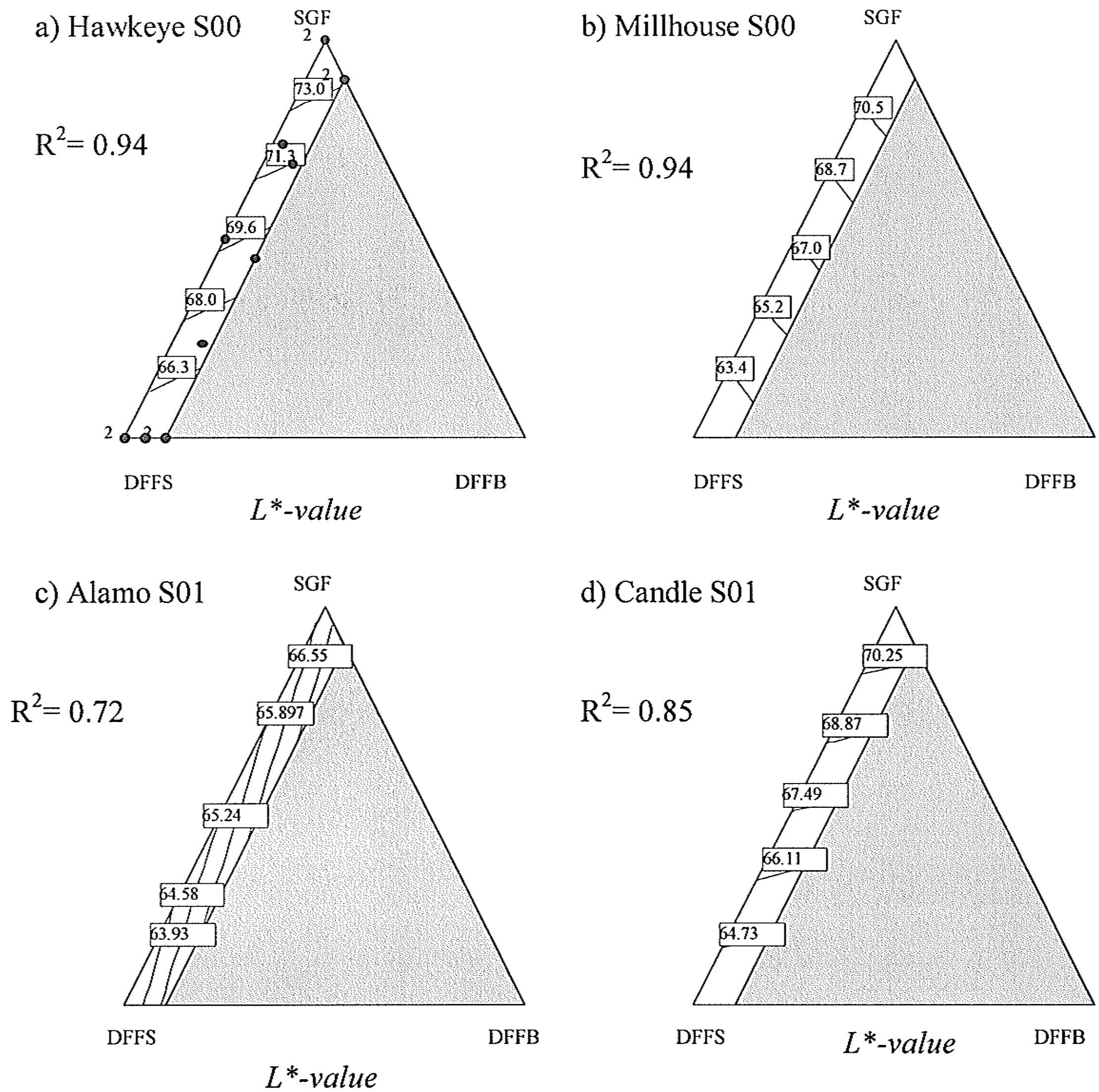
	6	37.81	100	0	0	19.2	13.4	3.0	71.5	9.7
	12	37.30	100	0	0	19.2	13.4	3.0	71.5	9.7
	1	35.88	90	0	10	18.7	13.6	3.5	69.7	11.1
	14	36.38	90	0	10	18.7	13.6	3.5	69.7	11.1
	10	38.90	73.8	23.75	2.5	18.1	14.3	3.9	67.3	12.3
	7	38.24	68.8	23.75	7.5	17.9	14.4	4.1	66.4	13.0
Millhouse	3	40.79	50	50	0	17.1	15.2	4.6	63.7	14.5
B00	9	38.93	45	45	10	16.8	15.3	4.9	62.6	15.4
	8	38.72	23.8	68.75	7.5	16.0	16.0	5.5	59.3	17.3
	5	39.19	0	100	0	15.0	17.0	6.2	55.8	19.3
	11	40.21	0	100	0	15.0	17.0	6.2	55.8	19.3
	4	37.71	0	95	5	15.0	16.9	6.3	55.7	19.5
	2	37.51	0	90	10	14.9	16.9	6.3	55.5	19.7
	13	37.99	0	90	10	14.9	16.9	6.3	55.5	19.7

Table V d) Chemical Composition of the Blends for High-Amylose Cultivars

Genotype	Design point	Moisture	SGF	DFFS	DFFB	Amylose	Protein	β-glucan	Total starch	TDF
		%	g	g	g	g/100g	g/100g	g/100g	g/100g	g/100g
SB 94893 B00	6	35.0	100	0	0	20.7	20.2	6.6	52.2	19.2
	12	34.7	100	0	0	20.7	20.2	6.6	52.2	19.2
	1		90	0	10	20.7	19.9	7.1	52.2	19.8
	14	34.3	90	0	10	20.7	19.9	7.1	52.2	19.8
	10		73.8	23.75	2.5	20.9	19.7	7.7	52.8	20.3
	7	36.8	68.8	23.75	7.5	20.9	19.6	8.0	52.8	20.6
	3	35.9	50	50	0	21.1	19.3	8.6	53.3	21.3
	9		45	45	10	21.1	19.1	8.9	53.2	21.7
	8	39.1	23.8	68.75	7.5	21.3	18.8	9.7	53.7	22.6
	5	39.4	0	100	0	21.6	18.4	10.6	54.4	23.4
	11	39.4	0	100	0	21.6	18.4	10.6	54.4	23.4
	4	35.3	0	95	5	21.5	18.4	10.7	54.3	23.5
	2	40.8	0	90	10	21.5	18.4	10.7	54.2	23.6
	13	39.6	0	90	10	21.5	18.4	10.7	54.2	23.6
SB 94893 S00	6	34.4	100	0	0	24.5	16.9	6.0	61.5	17.2
	12	34.2	100	0	0	24.5	16.9	6.0	61.5	17.2
	1	31.8	90	0	10	24.3	16.8	6.5	60.9	18.1
	14	32.4	90	0	10	24.3	16.8	6.5	60.9	18.1
	10	36.9	73.8	23.75	2.5	24.0	16.9	7.1	60.0	19.2
	7	34.8	68.8	23.75	7.5	23.8	16.9	7.4	59.7	19.6
	3	36.9	50	50	0	23.4	17.1	8.1	58.7	21.0
	9	39.5	45	45	10	23.3	17.0	8.4	58.4	21.5
	8	41.6	23.8	68.75	7.5	22.9	17.1	9.3	57.3	23.0
	5	43.0	0	100	0	22.3	17.3	10.1	56.0	24.8
	11	41.1	0	100	0	22.3	17.3	10.1	56.0	24.8
	4	40.5	0	95	5	22.3	17.3	10.2	56.0	24.8
	2	41.9	0	90	10	22.3	17.2	10.3	56.0	24.8
	13	40.4	0	90	10	22.3	17.2	10.3	56.0	24.8
SB 94893 S01	6	34.4	100	0	0	23.2	17.4	5.2	58.1	16.4
	12	32.1	100	0	0	23.2	17.4	5.2	58.1	16.4
	1	31.9	90	0	10	23.0	17.5	5.5	57.6	16.7
	14	34.1	90	0	10	23.0	17.5	5.5	57.6	16.7
	10	35.1	73.8	23.75	2.5	22.4	17.1	6.1	56.1	17.5
	7	35.8	68.8	23.75	7.5	22.3	17.1	6.3	55.9	17.6
	3	37.8	50	50	0	21.6	16.8	7.0	54.2	18.5
	9	37.1	45	45	10	21.6	16.9	7.1	54.1	18.6
	8	36.4	23.8	68.75	7.5	20.9	16.6	7.9	52.4	19.5
	5	40.8	0	100	0	20.1	16.1	8.8	50.4	20.7
	11	39.3	0	100	0	20.1	16.1	8.8	50.4	20.7
	4	39.7	0	95	5	20.2	16.2	8.7	50.5	20.6
	2	39.8	0	90	10	20.2	16.3	8.7	50.7	20.5
	13	39.7	0	90	10	20.2	16.3	8.7	50.7	20.5

Appendix VI Effects of Milling Fractions on Color and Texture Parameters



-Fig. I Effect of milling fractions on *L*-value*
-continued-

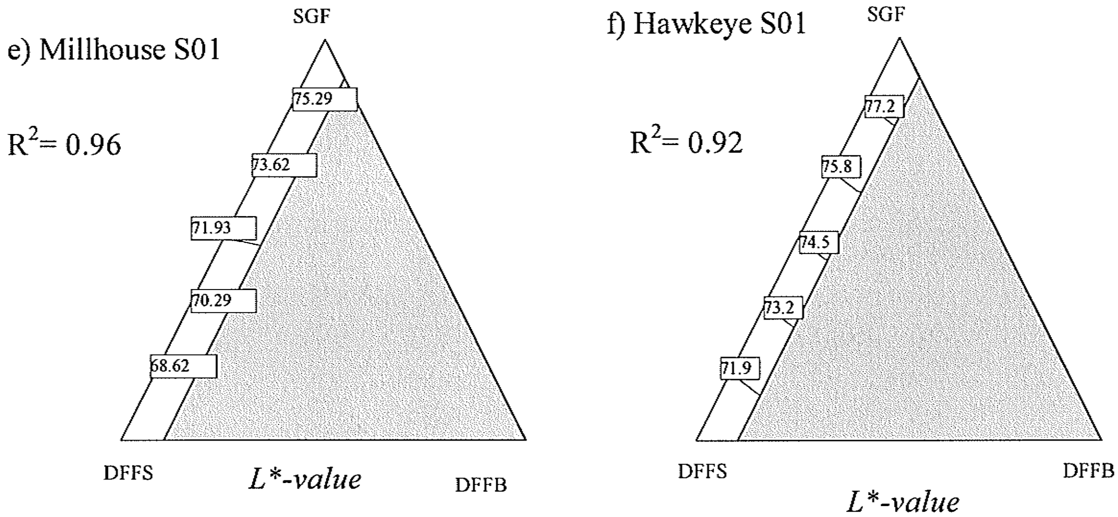
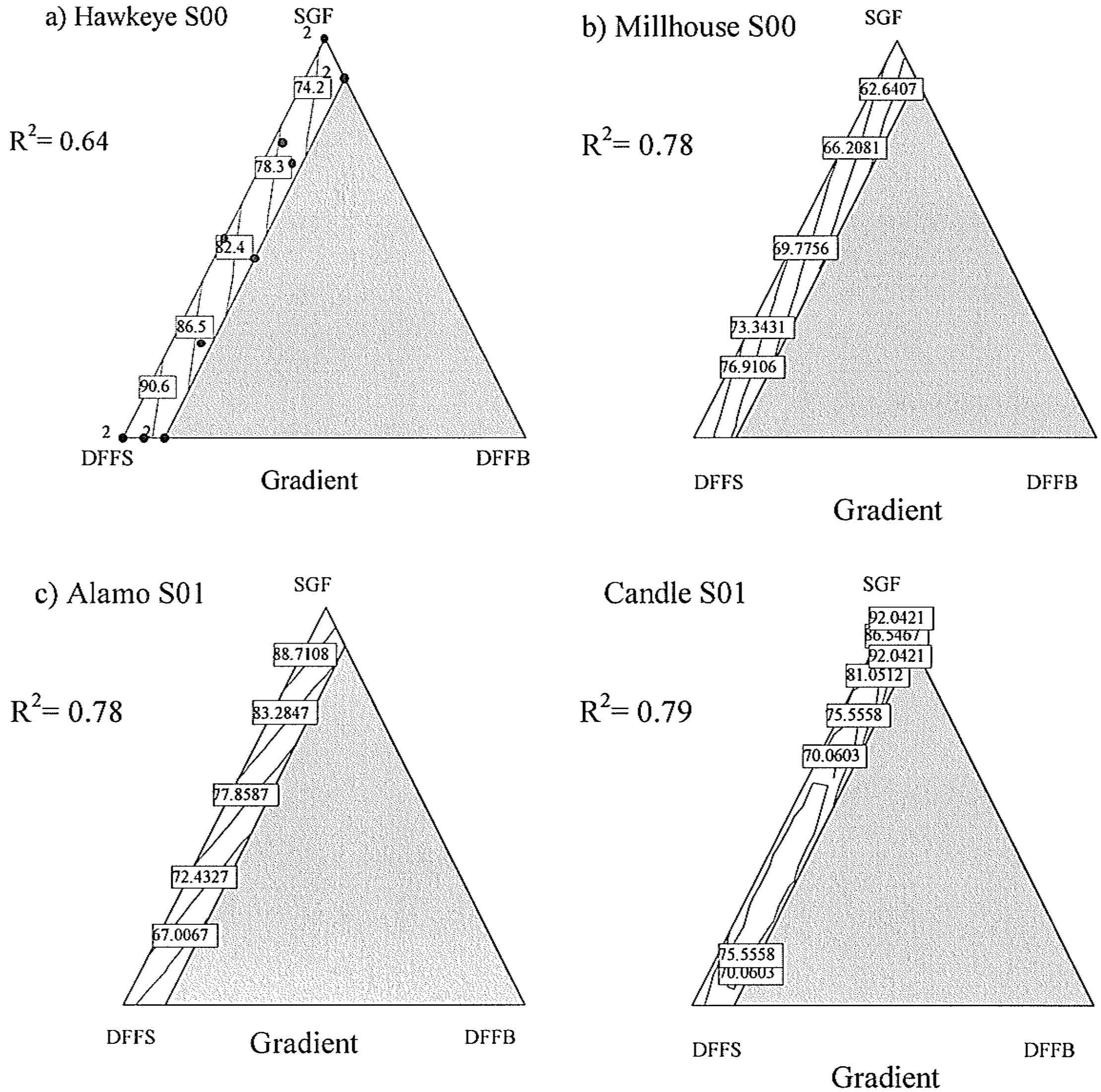


Fig. I Effect of milling fractions on *L*-value*



-Fig. II Effect of milling fractions on gradient.
-continued-

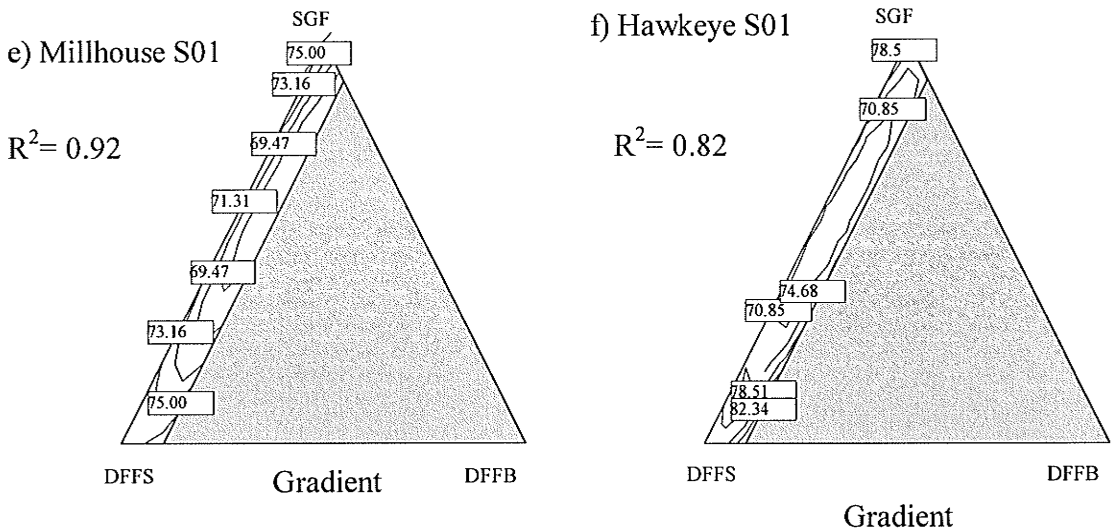
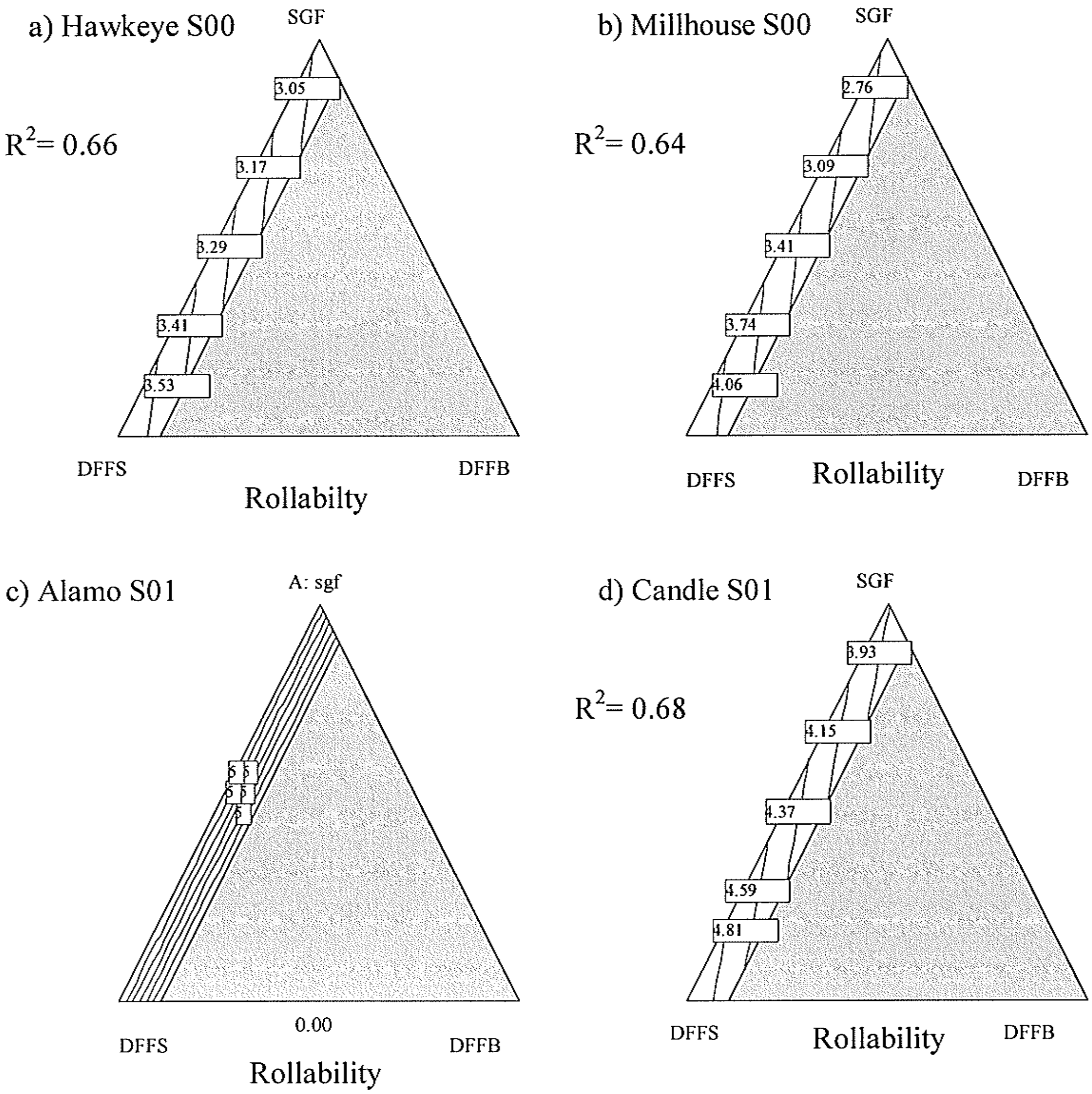


Fig. II Effect of milling fractions on gradient



-Fig. III Effect of milling fractions on rollability
-continued-

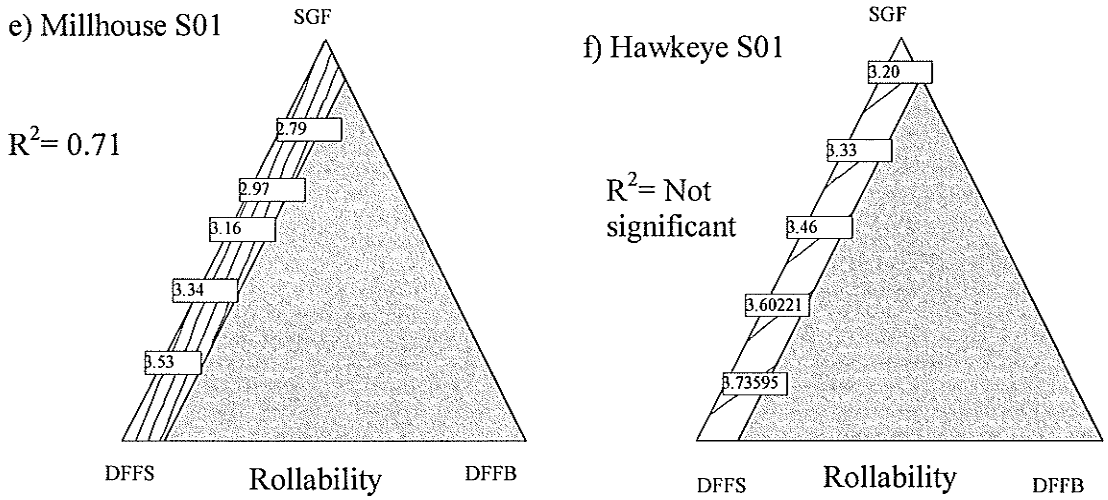


Fig. A3 Effect of milling fractions on rollability

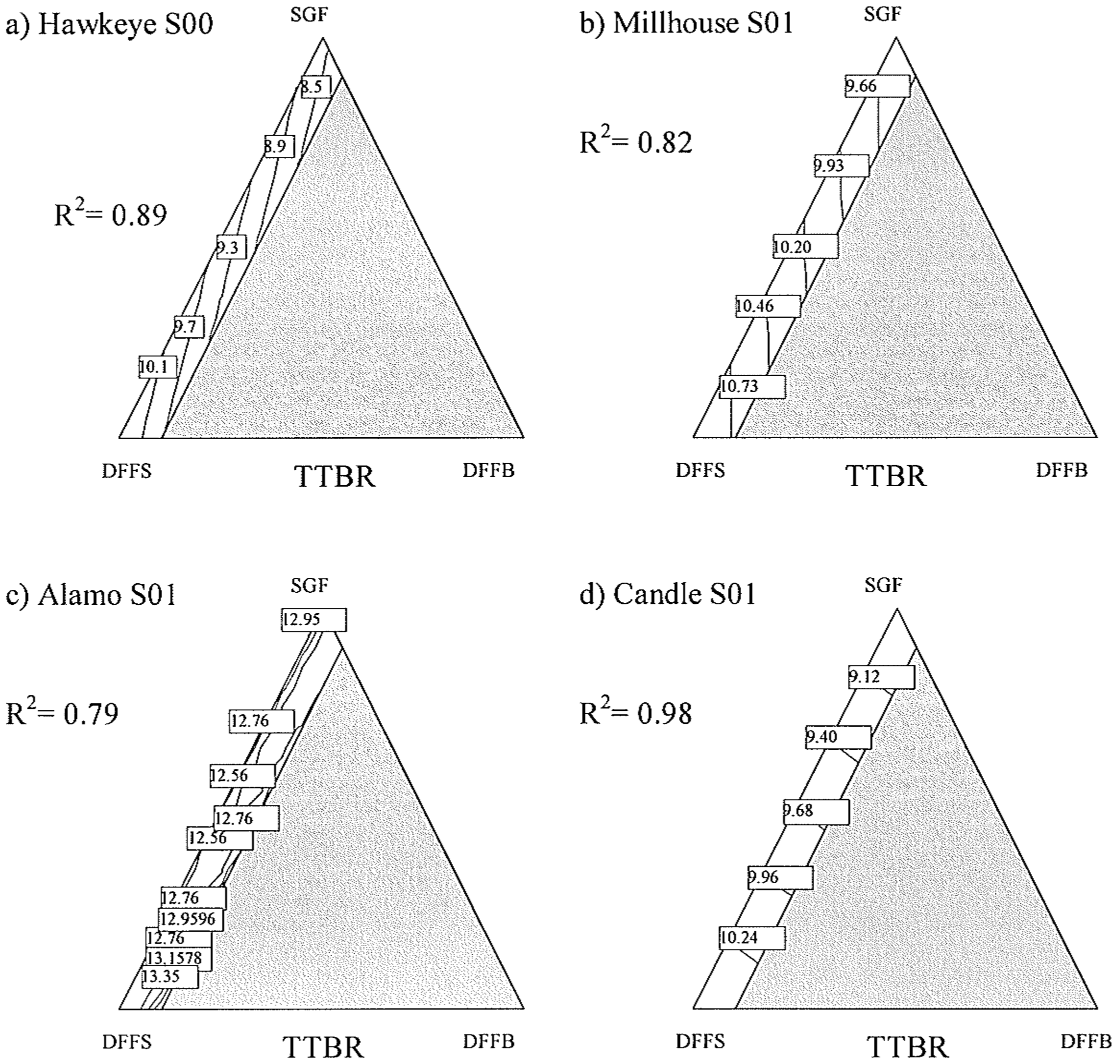


Fig. IV Effect of milling fractions on TTBR
-continued-

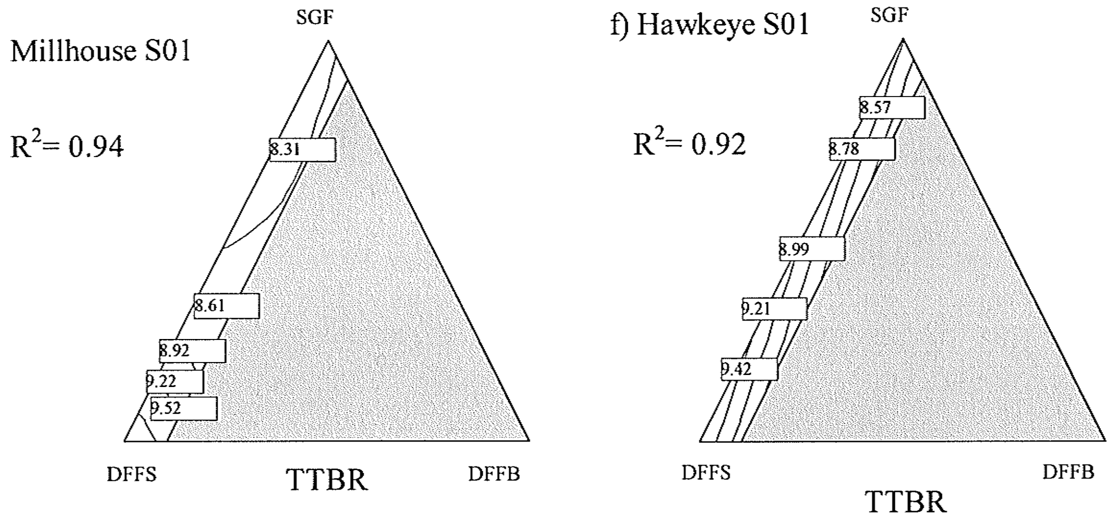


Fig. IV Effect of milling fractions on TTBR