Quality of Breads from Hard Red Winter Wheat and Hard White Winter Wheat

by

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(Under the Direction of Robert L. Shewfelt)

ABSTRACT

Bread is a staple in many countries. Knowledge of consumer preference of breads would help in making available products that have been tailored to consumer's specifications. Sensory preference of refined breads by consumers has been a barrier for the whole-wheat bread consumption, in spite of the several health benefits that have been associated with whole-grain products. This study aims at encouraging consumers to include more whole-grains in their diet with minimum compromise in flavor. Whole-wheat breads and refined breads were made using Hard Red Winter (HRW) wheat and Hard White Winter (HWW) wheat. Bread quality was evaluated by consumer testing and instrumental analysis. Mathematical model was used to predict acceptability as a function of sensory descriptors. Instrumental analysis of physical quality characteristics showed a significant difference between the four bread types with regard to color and texture. Higher preference of whole-wheat breads made using white wheat than refined breads from traditional red wheat suggests that consumers can have the combined advantage of nutrition from whole-wheat and minimum compromise in flavor.

INDEX WORDS: Consumer Acceptability, Whole-wheat Breads, Refined Breads, Hard Red Winter Wheat, Hard White Winter Wheat.

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DEDICATION

To my family and friends, whom I love very much.

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INTRODUCTION AND LITERATURE REVIEW:

Bread is a staple in several parts of the globe and also one of the oldest prepared foods. Among all cereals and cereal foods, bread provides best for our nutritional needs (Pomeranz and Shellenberger, 1971). In 53% of the countries bread provides more than half the caloric intake and it is a rich source of carbohydrates, fiber, protein and vitamins (Pomeranz and Shellenberger, 1971).

A BRIEF HISTORY OF BREAD:

It is not known when or where bread originated. However, the known history of bread is longer than the history of any other food. Many ancient civilizations, Egyptians, Babylonians, Hebrews, Ancient Greece, all mastered the art of bread-making several centuries ago (Pomeranz and Shellenberger, 1971) . Excavations in Babylon shows that breads were consumed in 4000 B.C (Pomeranz and Shellenberger, 1971, Wahren. M., (no date)). Breads and grains played a major role in Egyptian life style. It contributed significantly to the country's economy and prosperity.

The bread culture in Egypt was due to the several developments that took place during the Neolithic era (young Stone Age). These breads were flat breads (fairly palatable). At the end of this era, fermentation was discovered accidentally and this discovery took place almost at the same time in several places. Fermentation led to the development of leavened breads that had a better, lighter and improved flavor as a result of baking (Pomeranz and Shellenberger, 1971).

The technique of bread-making migrated to the Mediterranean world (Greece) during the 8th century B.C. The Greeks employed two types of fermentation. They used a process called "spontaneous fermentation" where bakers relied on air-borne microorganisms to leaven the dough. They also used to make breads with grape juice as ferment, and these breads were flat breads (Pomeranz and Shellenberger, 1971).

Rye (Secale cereale) replaced wheat *(Triticum aestivum)* during the Bronze Age. White breads were a rare commodity and were mainly served to the upper classes (Pomeranz and Shellenberger, 1971). Breads made in monasteries were the best and several different varieties of breads were made here; e.g. unleavened, spelt bread, bread baked in ashes, regular leavened bread, bread rolls, etc (Wahren. M., (no date)). In the middle Ages, Northern Europe baked bread twice in a year. Winter-bread was made in autumn, with grain ground on a water mill. The summer-bread was made in spring.

The latter part of 19th century saw a major change in bread culture (Pomeranz and Shellenberger, 1971). With the increasing size of cities, commercial bakeries came into existence. Viennese engineer Mautner, developed a method for bakery-yeast production, which became a huge success. Bakers depended on spontaneous fermentation for many years. Until Leeuwenhoek demonstrated the presence of yeast cells using microscopy, the basic principle of fermentation remained a mystery (Pomeranz and Shellenberger, 1971). Knowledge about aeration and stimulation of enzyme systems in yeasts during the end of the 19th century, helped increase yeast growth on a large scale industrial basis (Pomeranz and Shellenberger, 1971).

In the early 20th century, sugar beet molasses replaced grain extracts as a substrate for yeast. The latest development in bread production is the continuous process, and this was developed primarily in USA. This process is much more efficient and time-saving than batch process (Pomeranz and Shellenberger, 1971). Both batch and continuous processes involve several basic stages of operation. Flour (protein source), salt, Baker's yeast are the basic ingredients and optional ingredients like sugar, shortening, gluten, etc are also usually added (Pomeranz and Shellenberger, 1971). The ingredients are mixed together with water to make the dough and the dough is shaped into loaves to bake the bread. Hence, since time immemorial, cereals and cereal products have been a major source of nutrition for humans and are continuing to do so until today. The bread making process has undergone dramatic development over the ages, from traditional, home baking to commercial industrial production on a large scale basis. Several varieties of breads are available in the market today, allowing consumers to choose according to their preferences (flavor, nutrition, etc.).

BREAD TYPES:

This study deals with two types of breads that are commonly consumed in America; namely, whole-wheat breads and white or enriched breads. Whole-wheat breads are a good source of dietary fiber and are made from whole-wheat flour. When the wheat grain is milled into flour, it contains the entire wheat grain including the bran (coarse outer layer containing tannins, high fiber content), germ (inner layer) and endosperm (starchy middle layer) (Liu 2003). The FDA (Food and Drug Administration) specifies a criterion of at least 51% whole-grain content by weight for a food product to be considered whole grain (Cleveland e*t al.*, 2000, Food and Drug Administration, July 1999).

White or refined breads are generally preferred over whole-wheat breads due to their more appealing flavor and appearance (Bakke and Vickers 2007). During the flour milling process, the bran layer and a part of the endosperm of the wheat grain are stripped off and the flour consists mainly of the starchy germ layer (Liu, 2002). These breads are lower in dietary fiber than whole-wheat breads and are higher in sugar and carbohydrates. They appear white due to bleaching of the flour during the milling process and also because the tannins present in the bran which are responsible for reddish color of whole-wheat breads have been removed (Pomeranz and Shellenberger, 1971).

WHEAT:

Flour is the basic and most important ingredient of bread, without which bread cannot be made. Breads can be made with flours from various cereal sources, but the most widely accepted and commonly consumed bread (white and whole-wheat pan breads) in the West is that which is made from wheat (Pomeranz and Shellenberger, 1971).

Wheat is one of the most important crops grown widely around the world. Its growth is most favorable in the temperate zones. It has always been a major source of carbohydrates, and proteins. This combination is a unique property of wheat that gives it its bread-making qualities (Belderok. *et al.*, 2000).

Anatomy: The wheat kernel is a one-seeded fruit, and has a fruit coat that is attached to the seed, which is called as caryopsis (Pomeranz and Shellenberger, 1971). The kernel comprises of 3 distinct parts, namely, the germ (innermost) layer, mealy endosperm (middle) layer and the outermost layer called bran. In general, 2-3% of the grain is the germ layer, 13-17% is the bran and 80-85% is the starchy inner endosperm (Belderok. *et al.*, 2000). The endosperm mainly is made up of carbohydrates (82%) which contains mainly starch, proteins (13%) and about 1.5% fats (Belderok *et al.*, 2000). Flour for white bread is milled mainly from the endosperm (Fance 1960). The outer layer of the endosperm is called the *aleurone layer* and it has a different structure than the inner endosperm. It is a single layer of cubic shaped cells.

The *aleurone layer* is known to be rich in proteins and enzymes and they contain a substantial amount of the total dietary fiber in the grain (Shewry and Jones 2005). The bran or outer covering is usually removed during milling and it consists of fused pericarp (surrounding the endosperm), the seed coat and the aleurone layer (Belderok 2000).

Genetics: Wheat belongs to the genus *Triticum*. The present-day bread wheat is a hexaploid wheat species called *Triticum aestivum* and they are a result of evolution (crossing and selection) from the original wild type cultivar which was a diploid species (Belderok 2000). *Triticum aestivum* is known to be the most suitable species for bread-making. The hexaploid wheat species has 42 (6 x 7) chromosomes. The genome of *T. monococcum*, a diploid (2 x 7 = 14 chromosomes) ancestor of modern-day wheat is called the A-genome. This wheat consists of two sets of 7 chromosomes. It has been suggested that these 14 chromosomes might have crossed with some unknown diploid wild grass to yield a tetraploid species (28 chromosomes) (Belderok 2000). The genome of the wild parent is the B-genome. The tetraploid genome is called the AB-genome and the plants are genetically described as AABB. *T. aestivum* is said to be a result of a cross between the 28 chromosomes of the tetraploid species and the 14 chromosomes of a weed *Aegilops squarrosa* (also known as *Triticum tauschii*) that grows on the borders of wheat fields. The chromosome of the weed is called D-genome and hence, the genome of *T. aestivum* is called the ABD-genome and the plants of this species are genetically characterized as AABBDD (Nelson. *et al.*, October 1995, Belderok, 2000).

DIPLOID SPECIES (2 x 7 = 14 chromosomes) *T.monococcum* X DIPLOID SPECIES (2 x 7 = 14 chromosomes) unknown wild grass

INFERTILE HYBRID (14 chromosomes)

FERTILE TETRAPLOID (28 chromosomes) X *Aegilops squarrosa*

INFERTILE HYBRID

FERTILE HEXAPLOID

(42 chromosomes)

Triticum aestivum

Fig 1.1: Probable evolutionary path of hexaploid bread wheat- (Belderok, 2000).

It is interesting to note that the desirable milling and baking properties of wheat is a unique feature found only in the hexaploid species of the wheat plant and it is absent in the diploid and tetraploid species. The only set of chromosome that is unique in the hexaploid plants is the D-genome that is derived from the *Aegilops squarrosa*. Hence, this third genomic component is said to contribute to the desirable traits in bread making quality of wheat (Belderok, 2000).

Grain Hardness: Wheat grain hardness is an important parameter that is considered while determining milling and baking properties (Belderok, 2000, Shewry and Jones, 2005, Pomeranz and Williams, 1990) of wheat. Two distinct categories of wheat varieties are based on grain hardness; namely, "hard" grains and "soft" grains. The kernels of hard grains generally have a dark, shiny, vitreous appearance, whereas, soft grain kernels have a more opaque and floury look (Fance, 1960). During the milling process, starch damage is higher in hard wheat and this damage is favorable as it contributes to the soft texture and mouth-feel of the crumb of breads. Hard grains are more suited for yeast-leavened bread-making due to their tolerance to fermentation (Pomeranz and Shellenberger, 1971, Belderok, 2000). Starch damage is also known to retard staling of bread (Belderok, 2000). Soft wheat on the other hand, does not undergo extensive starch damage and this property makes it suitable for making products like cakes, biscuits, wafers, etc. Hard wheat grains have higher protein content than soft wheat grains and hard kernels have more resistance to grinding than soft kernels (Belderok, 2000). Hard-kernels forms tenacious, elastic gluten, with good gas-retaining properties and this is attributed to the high protein content (Pomeranz and Shellenberger, 1971). Soft-grains on the other hand have low-elasticity gluten and poor gas-retaining properties. A single gene or more than one gene is attributed to the inheritance of grain hardness (Belderok, 2000). The American bakery and quality practices recommend use of high-protein flours for bread-making process and this property is found more in hard-wheat than soft-wheat (Pomeranz and Shellenberger, 1971).

Wheat grain-proteins and starches: The wheat grain mainly consists of gluten proteins and wheat starch (Belderok, 2000). The proteins can be classified broadly as gluten proteins and non-gluten proteins (Pomeranz and Shellenberger, 1971). The gluten proteins contribute to the dough-formation. The albumins and globulins are low-molecular weight proteins and most of them are physiologically active proteins (enzymes) (Belderok, 2000). These proteins are found in seed-coat, aleurone layer and germ. They contribute to about 25% of the grain proteins. The remaining 75% of proteins are storage proteins, that is, Gliadins and glutenins which are located mainly in the starchy endosperm (Belderok, 2000) and are also called storage proteins. These proteins are said to be technologically active, as they contribute to dough formation and gas-retention, but they do not have any enzyme activity.

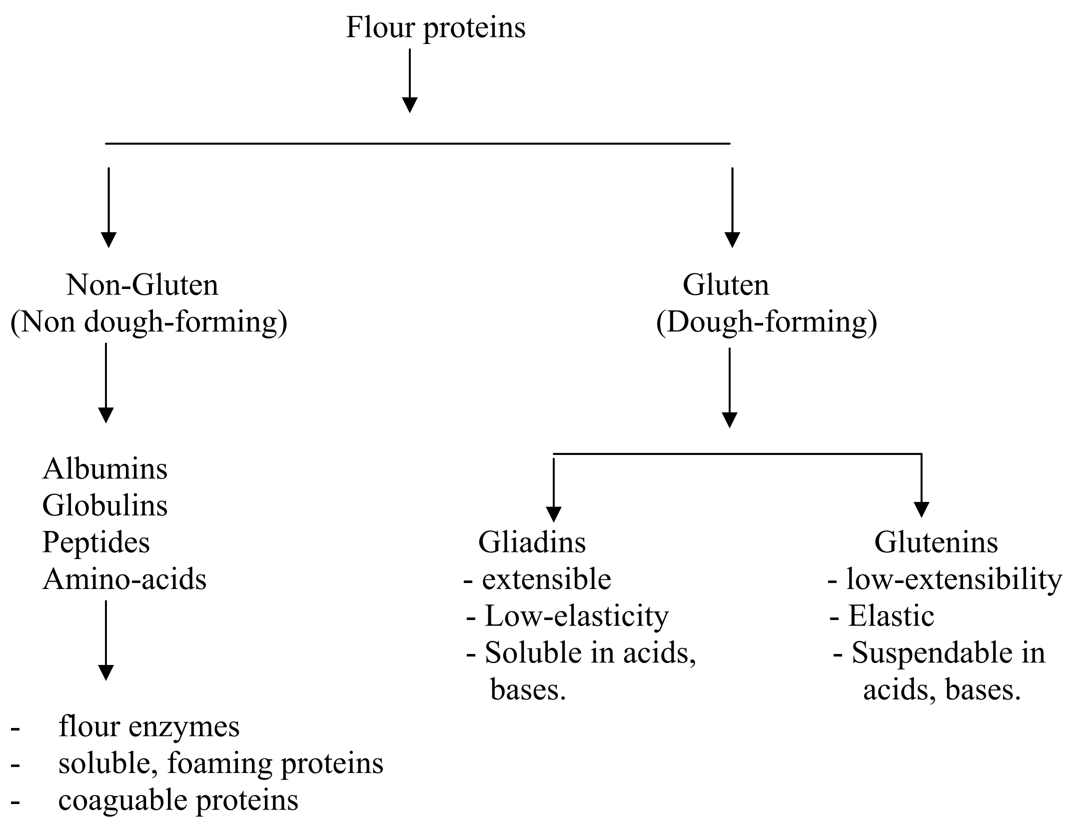

Fig 1.2: Proteins in wheat (adapted from (Pomeranz and Shellenberger, 1971, Holme, 1966).

Wheat starch contributes to about 75% of the grain. It is found in the seeds, mainly in the endosperm in the form of granules. There are two types of starch in wheat grains. One is a large, lenticular type (about 25-40 μm) and the other type is small and spherical (about 10-15 μm). Chemically, two types of starch are identified in wheat grains: amylose (predominantly linear) and amylopectin (highly branched) (Belderok, 2000). During the milling process, part of the starch is mechanically crushed and that starch is called damaged starch. Damaged starch absorbs water and swells when viewed under a microscope and also they do not show double fraction in polarized light as they have lost their crystalline structure (Belderok, 2000). Damaged starch contributes favorably to bread-making quality of wheat as it has two vital properties: it absorbs water faster and in higher amounts than undamaged starch and also it is easily digestible by enzymes to yield breakdown products like maltose and dextrins (Belderok, 2000). Hard-kernels tend to sustain more starch damage than soft-wheat kernels. According to the Approved Methods of the American Association of Cereal Chemists, AACC, St Paul, Minnesota (1990), the optimal starch damage for bread-making is 7% and should not exceed 9%. Excessive starch damage can cause the dough and bread to become sticky and difficult to slice (Belderok, 2000).

Starch-degrading enzymes present in the grains help breakdown large starch molecules and hence reduce the viscosity of a starch suspension. The two main enzymes found in wheat grains are α-amylase and β-amylase (Belderok, 2000). α-amylase breaks glucosidic bonds on a more random basis, while β-amylase cleaves starch at the ends of the polymer. These enzymes together, convert about 85% of starch to sugar. Enzymes have a more rapid degradation action on damaged starch than native starch (Belderok, 2000). Bread made from sprouted wheat is considered to be of inferior quality and this is due to high α-amylase activity. Pre-harvest sprouting generally occurs in rainy conditions and it is not a desirable trait for wheat quality (Belderok, 2000, Bassoi. *et al.*, abr. 2006). Breads baked with sprouted wheat will have a smaller volume and compact interior (Groos. *et al.*, 2002, Mansour, 1993). Therefore, varieties with high sprout resistance must be chosen for bread-making. A good indicator of degree of sprouting is to test for α-amylase activity in the grains and flour (Hagberg-Perten test) (Groos. *et al.*, 2002, Belderok, 2000).

Wheat Classes: Classification and sorting of wheat based on kernel color is an important as the color plays a role in milling, baking and taste properties (Pasikatan and Dowell., 2003). Wheat grains can either have a dark, red-brown appearance (red-seeded wheat) or a light, yellowish color (white-seeded wheat) (Belderok, 2000). In this study, breads made from two types of wheat: Hard Red Winter (HRW) wheat and Hard White Winter (HWW) wheat will be compared. HRW is the major wheat type grown in U.S.A. HWW is more susceptible to pre-harvest sprouting than HRW, which lowers the quality of wheat (Belderok, 2000, Bassoi. *et al.*, abr. 2006) and hence is not widely cultivated in America. Flour from the HRW variety is the primary ingredient in most commercial breads (Chang. *et al.*, 1995). HWW is a relatively new classification in United States and is still in the developmental stages by many Agricultural Experiment Stations (AES) and has not yet been widely used in the commercial aspect (Chang. *et al.*, 1995). Bran color is an important discriminator between red and white wheat (Wu. *et al.*, 1999). The plants of HRW and HWW are similar in most aspects but differ mainly in the color of the bran (seed coat) (Paulsen., March 1998). The kernel color is a trait that can be genetically inherited (Wu. *et al.*, 1999, Cooper and Sorrells., 1984). The gene expression however, is not independent of environmental factors (Wu. *et al.*, 1999). The original red wheat had three major genes for the red color, but the modern varieties have one or two genes only (Paulsen., March 1998). The red color of bran is controlled by three loci with partial dominance (Wu. *et al.*, 1999). This was first postulated by Nelsson-Ehle in 1909 in his classical work on genetics of kernel color (Wu. *et al.*, 1999, Bassoi. *et al.*, abr. 2006). Red alleles (R) of a dominant gene are responsible for red testa pigmentation of the bran (Bassoi. *et al.*, abr. 2006, Flintham, 2000). These genes reside on homologous loci on chromosome 3A, 3B and 3D of the hexaploid wheat (Bassoi. *et al.*, abr. 2006, Gale *et al.*, 1995, Flintham *et al.*, 1999, Flintham *et al.*, 1996, Groos. *et al.*, 2002). The red color is expressed as a result of pleiotropic effect of the genes and the color is visible via the seed coat (bran). The gene expression for red color is more complex due to the presence of additional minor genes. As many as six genes may influence kernel color (Wu. *et al.*, 1999, Bassoi. *et al.*, abr. 2006, Freed *et al.*, 1976). Phenolic compounds like proanthocyanidins (PA') and tannins present in the wheat grain have been associated with contribution to seed coat color (Miyamoto and Everson, 1958, Mccallum and Walker., 1990). PA's are colorless oligomers and are converted to colored anthocyanidins by strong acids (Mccallum and Walker, 1990). It has been suggested that PA's in bran of winter wheat may also serve as protective agents against microbial degradation apart from contributing to bran color (Mccallum. and Walker., 1990, Harborne, 1985). Presence of high levels of phenolic acids in bran could possibly contribute to the bitter taste characteristics to whole-wheat breads as phenolic compounds have been associated with bitter tastes in other foods (Bakke. and Vickers., 2007, Mondy and Gosselin, 1988, Robichaud and Noble, 1990, Busch *et al.*, 2006).

White wheat has no major genes for bran color. It is determined by the presence of three recessive genes and when all three genes are present, the grain appears mostly white (Paulsen., March 1998). During the milling process, white kernel color has a higher efficiency of extraction than red kernel color, since a higher flour extraction can be done without sacrificing too much of the color (Wu. *et al.*, 1999). White-wheat does not contain the chemical pigments (phenolic components) that contribute to the red color in red wheat and this might contribute to a milder flavor of white wheat (Paulsen., March 1998).

BREAD MAKING:

The process of bread-making can be broadly classified into two categories and each process is equally important to form an acceptable end-product (Pomeranz and Shellenberger, 1971): a) dough making (mixing, forming and leavening) and b) dough baking. The entire process can be depicted as follows:

Essential ingredients:
Flour, water, salt, yeast

+ → Dough mixing → Fermentation

Optional ingredients:
Sugar, shortening, malt, milk

Fermentation ↓ shaping ↓ Proofing ↓ Baking

Slicing ← Cooling ← Baking

Fig 1.3: Bread making process. adapted from (Pomeranz and Shellenberger, 1971).

Wheat grains are processed (milling) into a more suitable form for bread making; flour. Flour, is the basic ingredient in dough and bread formulations (Cauvain., January 2003). When water is added to the flour, water-insoluble gluten proteins are formed during mixing which form a complex network. In this network, starch, yeast and other dough components get embedded. Water absorption has an effect on the texture of the dough and is critical in providing rheological properties to the dough that makes it suitable for further processing (Lallemand Baking Update., 1997.). The yeast added to the mixture is responsible for the fermentation process and generates carbon-dioxide as an end-product which is required for expansion of the dough mass (aeration). Gluten forms a skeleton of wheat dough, and this traps gas (CO_2) produced during fermentation which has an effect on crumb texture (Lallemand Baking Update., 1997., Pomeranz and Shellenberger, 1971). The dough is then allowed to expand and the process is termed as “proofing”. The continued development of gluten structure helps improve the dough’s rheological properties and its ability to expand when fermentation increases gas pressure (Cauvain., January 2003). The dough is then kneaded down and shaped into loaves and again proofed. During this period, further fermentation and expansion of dough structures occur. They are then placed in ovens and baked at appropriate temperatures and time depending on the bread type. The breads are then removed from the oven, cooled and then sliced and packed for consumption (Cauvain., January 2003).

BREAD FLAVOR

Bread flavor plays a key role in influencing consumer perception of bread quality. The quality of bread is normally defined on the basis of its volume, color, texture and flavor (Quilez. *et al.*, 2006). Flavor is said to be one of the most appreciated sensory characteristic in bread (Caul, 1972, Martinez-Anaya, 1996). The term flavor comprises of the total sensation experienced by the consumer: aroma, taste perceptions and tactile sensations (masticability) in the mouth (Martinez-Anaya, 1996, Caul, 1972, El-Dash, 1967). Bread flavor is very appealing to consumers (Martinez-Anaya, 1996, Coffman, 1965) and has been qualitatively described as being discrete and subtle (Martinez-Anaya., 1996, Drapron and Molard , 1979). Bread flavor remains a challenge due to its very complex flavor profile (Martinez-Anaya, 1996, Katina. *et al.*, 2006). The flavor of bread is composed of a large number of components with very distinctive olfactory characteristics (Drapron and Molard, 1979, Martinez-Anaya, 1996, Quilez. *et al.*, 2006). Bread flavor cannot be attributed to the presence of any one single compound (Coffman, 1965, Drapron and Molard, 1979, Martinez-Anaya, 1996). The flavor components in bread arise from interaction of many factors: ingredients, fermentation, degradation and thermal reactions (Martinez-Anaya, 1996, Quilez. *et al.*, 2006, Chang. *et al.*, 1995, Jackel, 1969). Ingredients in the breadmaking process undergo several changes in order to produce the final full flavor. Studies have shown that fermentation plays a vital role in enhancing flavor of bread (Jackel, 1969, Martinez-Anaya, 1996). Baker and Coffman have said that two processes in breadmaking are essential for the flavor formation in bread: *Fermentation and baking* (Martinez-Anaya, 1996, Coffman, 1965, Baker *et al.*, 1953). Distinctive volatile components that contribute to bread flavor originate as a result of fermentation of sugars by yeast (Martinez-Anaya, 1996, Robinson *et al.*, 1958, Calvel, 1981). Degradation reactions (mechanical and enzymic) help eliminate the starchy residual taste of wheat flour (Martinez-Anaya, 1996, Jackel, 1969). Crust flavor and color are a result of thermal reactions like caramelization and non-enzymatic browning that occurs during the baking process (Jackel, 1969, Drapron and Molard, 1979, Martinez-Anaya., 1996). Volatile compounds are produced from precursors that were already present in the ingredients or are formed as a result of enzymatic and mechanical degradations (Drapron and Molard, 1979, El-Dash, 1967).

Yeasts added during the breadmaking process plays a key role in fermentation process. Sugar added to the flour and those that are formed from the amylolytic degradation of starch are substrates for yeast fermentation (Martinez-Anaya, 1996, Pomeranz and Finney, 1975). Bread yeasts (*Saccharomyces cerevisiae*) generally have saturated kinetics for hexoses and maltose and all specimens possess α–glucosidase and β–fructosidase (invertase) (Martinez-Anaya, 1996, Antuna and Martinez-Anaya, 1993). Bread fermentation occurs under anaerobic conditions (limited oxygen) during which carbon dioxide and ethanol molecules (95% of alcoholic fermentation by-product) are produced as end products (Martinez-Anaya, 1996, Pomper, 1969), which subsequently contribute to flavor development apart from aiding in leavening of bread. Lactic acid bacteria used in the breadmaking process are responsible for lactic fermentation. The main end-product of lactic fermentation (85% in homofermentative species) is lactic acid which helps lower the pH during fermentation (Martinez-Anaya, 1996, Spicher *et al.*, 1987).

Enzymes present in the ingredients (flour and those produced as a result of yeast metabolic activity) and those that are intentionally added in the formulation are very important in development of flavor in the bread. Enzyme activity is usually initiated during the hydration of flour in the mixing stage of breadmaking process and proceeds steadily until high temperatures during baking degrade protein structure. Three distinct enzymic systems are related to enhancement of bread flavor: amylases (α and β), proteases and lipoxygenases. The enzymes generally contribute to flavor development by producing precursors (flavor- producing peptides) either directly or indirectly (Martinez-Anaya, 1996). Amylases hydrolyze α-1,4-glycosidic bonds of starch, amylose and amylopectin. α –amylase is a dextrinizing enzyme that acts on gelatinized starch (random action), while β-amylase has a saccharifying action on damaged or gelatinized starch (acts at non-reducing ends of chains of β-maltose). Lipoxygenase activity is low in wheat flour and is located in the germ and bran. This enzyme oxidizes unsaturated fatty acids like linoleic, linolenic acids that have cis,cis-1,4-pentadiene groups in the presence of molecular oxygen. One of the many results of lipoxygenase activity is production of carbonyl compounds that have an on bread flavor (Martinez-Anaya, 1996).

During bread baking, the rate of enzymatic reactions increases in the first few minutes. Two main thermal, non-enzymatic reactions occur during this stage: Maillard browning and caramelization reactions. The decrease in pH during fermentation enhances browning reactions favorably. The distinct contribution of each of the non-enzymatic reaction to crust aroma is unclear but, it has been accepted that these reactions contribute pre-dominantly to crust aroma (Martinez-Anaya, 1996, Drapron and Molard, 1979). Higher temperatures transform sugars and polysaccharide like starch (to a lesser extent) into colored degradation products and volatiles, carbonyls and furfurals. The total amino acids and reducing sugars and the proportions present on dough surface during baking act as limiting factors in crust aroma quality (Martinez-Anaya, 1996).

Apart from the above mentioned factors that influence bread flavor formation, mixing operations also have an influence on bread flavor. Excessive mixing can cause an increase in hexanal production, which alters the balance of flavor compounds and can lead to an uncharacteristic flavor of lower consumer acceptance (Martinez-Anaya, 1996, Drapron and Molard D, 1979).

BREAD AND NUTRITION:

Whole wheat breads have a higher nutritional value than refined breads. Dietary guidelines recommend the consumption of whole grains as a preventative measure to reduce risk of some common chronic diseases (Slavin. *et al.*, 1999). Whole-grain foods are a rich source of fiber whereas white breads have low fiber content due to processing of the wheat grain during milling. High-fiber diets have been associated with several possible health benefits like reducing risk of diabetes, coronary heart disease, improved insulin sensitivity, obesity, etc (Merchant. *et al.*, 2006, Liu., 2003, Liu, 2002). Studies have shown that it is possible to achieve a favorable glycemic control by consuming foods with whole-grains, which is not possible with refined grain foods (Liu, 2002). It has also been suggested that consumption of high amounts of refined-carbohydrate foods like white breads can reduce levels of HDL (High Density Lipoprotein) which is a protective lipoprotein for Coronary Heart Diseases (CHD) (Liu, 2002). Refined breads tend to cause a rapid increase in blood glucose levels and insulin than whole-wheat breads.

Whole-wheat breads have high contents of viscous fiber, these foods are digested and absorbed more slowly and hence provide a prolonged feeling of satiety. This increase in satiety has been attributed to the intact grains in the flour, whereas refined wheat breads have processed grains that are stripped off the bran layer. Refining causes an easier and more rapid access of digestive enzymes to the starch in the endosperm which makes the refined products to be more easily digested and absorbed (Liu, 2002, Brand *et al.*, 1985, Heaton *et al.*, 1988, Jenkins *et al.*, 1988). Whole-wheat breads are low in fat and high in protein, vitamins, minerals and dietary fiber (Slavin. *et al.*, 1999). Other beneficial components that have possible health benefits that are present in whole-wheat breads are phenolic compounds like tannins (high concentrations in the bran), lignans, phytoestrogens, tocotrienols, enzyme inhibitors, antioxidants, etc. These compounds are not found in refined breads because the bran layer of the wheat kernel has been removed during processing and what are present in the flour mainly are high levels of starch from the endosperm (Slavin. *et al.*, 1999). Consumption of refined breads has an unfavorable effect on risk of type-2 diabetes (Liu., 2003). American dietary guidelines like USDA and FDA recommend 3 servings (1 ounce equivalent for a 2000 Kcal diet) of whole-grain foods. Studies show that Americans consume only 0.3 servings of whole-grain foods while they consume on an average 2 servings of refined food products (Bakke and Vickers, 2007, USDHHS / USDA, 2005). Hence it is important to increase whole-grain consumption. Whole-wheat breads have a significant nutritional advantage than white breads and it is a recommended diet choice to maintain healthy life-style.

CONSUMER PREFERENCE OF REFINED BREAD:

It has been generally concluded that consumers prefer refined wheat breads over whole-wheat breads (Bakke and Vickers, 2007, Mialon *et al.*, 2002). Consumer preference for refined breads is a commonly cited reason for low-consumption of whole-wheat breads despite recommendation of whole-wheat consumption as a healthier diet choice by the American dietary guidelines (USDHHS /USDA, 2005, Bakke and Vickers, 2007). Sensory preferences (taste and flavor) of refined breads act as a barrier for whole-wheat bread consumption (Bakke and Vickers, 2007). Whole-wheat breads are known to be considerably more bitter than refined wheat breads (Bakke and Vickers, 2007, Chang *et al.*, 1995, Chang and Chamber, 1992). Studies say that the presence of wheat germ could also contribute to bitterness in whole-wheat breads due to enzymatic and non-enzymatic lipid oxidation (Bakke and Vickers, 2007, Lehtinen and Laakso, 2004). The visual appeal of refined wheat breads is also higher than whole-wheat breads. It has been shown that consumers rank flavor as the most important factor for choosing and purchasing food product (Kihlberg *et al.*, 2005, Torjusen *et al.*, 2001, Magnusson *et al.*, 2001). Lower sensory appeal of whole-wheat breads (appearance and flavor) acts a limiting factor for consumers to choose the healthier whole-wheat breads and it has been suggested that modifying ingredients or processing methods could improve the liking of whole-wheat breads to levels of refined wheat breads (Bakke and Vickers, 2007).

The main objective of this study is to determine whether whole-wheat breads made from white wheat (which has a similar appearance as refined wheat breads) are more acceptable to consumers in terms of flavor and quality than refined breads made from typical red wheat. If so, these breads will have the combined advantages of both nutrition and flavor. This combination will encourage consumers to make healthier choices and include more whole-grains in their diet along with minimum compromise on flavor. This study will aid in making available, whole-wheat breads with more acceptable flavor than the characteristic whole-wheat breads and higher nutrition than the typical refined wheat breads.

BREAD TEXTURE:

Texture of bread is an important physical quality characteristic that contributes to consumer acceptability (Pomeranz and Shellenberger, 1971, Gambaro. *et al.*, 2002). It contributes to about 20% to the judgment of bread quality (Scanlon and Zghal, 2001, Pyler, 1988). Bourne et al (1982) explains bread texture as the crumb uniformity and distribution of the cell sizes(Scanlon. and Zghal., 2001). The overall texture is a result of the three-dimensional structure formed from its individual components (Crowley. *et al.*, 2002). Texture is sensed by feeling of touch (tactile) and is related to the deformation of the food under force and can be measured as a function of force, time and distance (Crowley *et al.*, 2002, Bourne, 1982). Traditionally bread crumb texture was scored based on human vision. However, this method of scoring is not reliable, is known to be inconsistent and is liable to vary over a period of time even if evaluated by the same expert (Scanlon and Zghal, 2001, Wang and Coles, 1994). Due to these limitations that could lead to inconsistent results, modern day bread making has shifted to Digital Image Analysis (DIA) for evaluation of bread crumb texture. This technique is more sophisticated, quick, reliable and consistent unlike the traditional method (Scanlon and Zghal, 2001; Chan and Batchelor, 1993). Image texture analysis gives a measure of characteristics such as coarseness, smoothness, etc which can be used for scoring purposes (Scanlon and Zghal, 2001, Gonzalez and Wintz, 1983). The first application of video image analysis of white bread texture was done in 1992 (Scanlon and Zghal, 2001, Bertrand *et al.*, 1992). Flavor is influenced by bread texture (Pomeranz and Shellenberger, 1971). A dense and compact crumb would have a stronger taste sensation than a crumb that has a fine, silky crumb. Differences in bread texture over time are attributed to the changes that occur in the starch, protein, lipids and water (Gambaro. *et al.*, 2002, Brady and Mayer, 1985, D'Appolonia and Morad, 1981). In this study a texture analyzer (TA.XT2i) was used to compare the texture of the four bread types as a measure of firmness.

WATER ACTIVITY (A_W):

Water activity (a_w) is a term used to describe the amount of available water for physical, chemical or microbial activity in the food. Water activity helps determine shelf life of a food (Fellows, 2000). Pure water has a water activity a_w value of unity, whereas absence of any available water is indicated by zero. Bread has a water activity of about 0.96 and it indicates that bread is a perishable food, has higher quantities of available water and the packaging must be designed so as to prevent loss of moisture. In general, at a higher a_w the mobility of reactants is more and complex chemical changes like browning reaches a maximum (Fellows, 2000). Water activity also has an influence on textural changes such as crunchiness and crispiness. A change in water activity (a_w) in bread occurs with time and this change is an important quality parameter in determining the shelf life of the bread. Water activity decreases with crumb ageing (Chinachoti and Vodovotz, 2000).

MOISTURE CONTENT:

Water content of a food is a very important parameter that helps control the foods stability and rate of deterioration. It is also one of the determining factors for shelf-life of the bread. Moisture content of foods has been defined on a wet-weight basis as: m = (mass of water / mass of sample) * 100 (Fellows, 2000). The percentage of moisture in bread is usually about 40% (Fellows, 2000, Crowley *et al.*, 2002). There are certain sites in the food matrix where a portion of the total water in the food gets strongly bound e.g. hydroxyl groups of polysaccharides, carbonyl and amino groups of protein, etc. The moisture content value at that point when all sites are bound by adsorbed water is called the Brunauer-Emmett-Teller (BET) monolayer value (Fellows, 2000, Fennema, 1996). It is at this value of moisture at which the food product is the most stable. The water content of the bread becomes lower at the surface during the baking process and increases at the center of the loaf. The moisture moves away from the surface due to evaporation at high temperature and condensation occurs near the center of the loaf where temperature is lower. Water content plays a role in crust formation and aroma of the bread as it has an effect on reactions like Maillard browning (Thorvaldsson and Skjoldebrand, 1998, Skjolderbrand, 1986). Moisture content also has an influence on starch gelatinization which affects final quality of the bread (Thorvaldsson and Skjoldebrand, 1998, Kokini *et al.*, 1992).

COLOR:

The visual appeal of bread is an important attribute that has been known to drive consumer acceptability (Scanlon and Zghal, 2001, Seneca, 1956). Color contributes to this property of bread. Characteristic golden brown color of bread results from complex reactions like Maillard reactions and other non-enzymatic browning reactions (caramelization reactions) (Fellows, 2000). Conversion of sugars and dextrins (from starch) to furfural and hydroxymethyl furfural, carbonization of sugars, fats and proteins also contribute to color formation. The above mentioned reactions occur during the baking process. Other factors like the type of wheat used to make the bread also has an effect on bread color. The pigments in the wheat, amount of bran present in the flour have an effect on bread color. Xanthophylls, flavones and carotenes are wheat flour pigments that contribute to crumb color (Al-Hooti *et al.*, 2000, Lepage and Sims, 1968, Kulp *et al.*, 1980, Anderson and Perkin, 1931). In general, majority of consumers prefer white crumb color in bread.

The main objective of the second part of this study was to measure and compare the different physical quality characteristics of breads made from Hard Red Winter (HRW) wheat and Hard White Winter (HWW) wheat. Whole-wheat breads and refined breads made from the two wheat types were compared by instrumental analysis for four physical quality characteristics: texture, water activity (a_w), color and moisture content.

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CHAPTER 2

CONSUMER-BASED EVALUATION OF BREADS MADE FROM HARD RED AND HARD WHITE WINTER WHEAT

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ABSTRACT:

Whole-wheat breads are considered a healthy option to include whole-grains in diet and to increase fiber intake, but sensory preferences of refined breads are a barrier for consumption of whole-wheat breads. Whole-wheat breads and white breads were made from two wheat types, namely, Hard Red Winter (HRW) wheat and Hard White Winter (HWW) wheat. The results from descriptive analysis and consumer tests showed that breads made from white wheat had a higher rate of acceptability than those made from red wheat. Acceptability was predicted as a function of three sensory descriptors: color, grain aroma and beany flavor.

INTRODUCTION:

The USDA dietary guidelines recommend including whole grain products in the diet to maintain good health and nutrition (Cleveland, 2000, USDHHS / USDA, 2005). Consumption of whole grains has been associated with a number of health benefits, mainly attributed to the high fiber content of such foods (Slavin, 2003). High fiber diets have been associated with reduced risk of chronic diseases like obesity, coronary heart diseases, type 2 diabetes, etc (Cleveland, 2000, Shewry and Jones, 2005). USDA and FDA recommend 3 servings (1 ounce equivalent for a 2000 Kcal diet) of whole-grain foods daily. Studies have shown that Americans consume only 0.3 servings of whole-grain foods while they consume on an average 2 servings of refined food products (Bakke and Vickers, 2007, USDHHS /USDA, 2005). Consumption whole-wheat breads are a healthy way to include whole-grains in the diet and increase fiber intake. However, consumers generally choose white breads (low in fiber and high in sugar content) over whole-wheat breads due to its more appealing appearance and flavor (Bakke and Vickers, 2007), thereby compromising nutritive value. Consumer acceptability is the ultimate determinant of a product's success in the market and lack of appeal to consumers may result in the product not being consumed. Hence it is important to take into consideration, the consumer's preference and specifications while designing a food product. In the present study whole-wheat breads and refined breads were made using two wheat classes namely; Hard Red Winter (HRW) wheat and Hard White Winter (HWW). The flour from red wheat is the primary ingredient in majority of the commercial breads in America (Chang. *et al.*, 1995). White wheat is not so widely used and is a relatively new classification of wheat in the United States. It is still in the developmental stages in many Agricultural Experiment Stations (AES) and is yet to be used in a commercial scale (Chang. *et al.*, 1995).

The major discriminator between the white and red wheat is their bran (seed coat) color (Wu. *et al.*, 1999). The bran color is mainly a genetically inherited characteristic (Wu. *et al.*, 1999, Cooper and Sorrells, 1984). The original red wheat had three major genes for red color, but the modern varieties have one or two genes only (Paulsen, 1998). Red alleles R of a dominant gene are attributed to the red testa pigmentation of the bran (Bassoi. *et al.*, 2006, Flintham, 2000). The red color is expressed as a pleiotropic effect of the genes and is visible via the bran. White wheat on the other hand has no dominant gene for seed coat color. It has three recessive genes, which when present make the wheat grain appear almost white (Paulsen, 1998). Furthermore, presence of phenolic compounds like proanthocyanidins has also been shown to contribute to color of the bran in red wheat (Mccallum and Walker, 1990, Harborne, 1985). The phenolic compounds are present in high levels in the seed coat and could possibly contribute to bitter taste and astringency in whole-wheat breads made using this wheat type (Bakke and Vickers, 2007). White wheat does not contain phenolic compounds that contribute to red color in red wheat and this might contribute to milder flavor and appearance of whole-wheat breads made using this wheat class (Paulsen,1998). Bread flavor has a major influence on consumer perception of bread quality (Quilez *et al.*, 2006). In general, flavor preference of refined breads is a barrier to the consumption of whole-wheat breads which though healthier, lacks in sensory appeal to the consumers (Bakke and Vickers, 2007).

In an attempt to combine the advantages of both flavor and nutrition, the objective of this study is to determine if whole-wheat breads made from white wheat are more acceptable to consumers than breads made using the traditional red wheat. Whole-wheat breads made using white wheat has an appearance similar to that of refined breads made with red wheat that consumers prefer, with the nutritional advantages of whole-wheat.

MATERIALS AND METHODS:

Four types of breads were used in this study. Whole-wheat breads and white or refined breads were made from both Hard Red Winter (HRW) wheat and Hard White Winter (HWW) wheat. The bread samples were then evaluated by an experienced sensory panel for select sensory descriptors. Consumer evaluation was also done for the bread samples as a measure of willingness to purchase, followed by a survey questionnaire.

Breadmaking process*:*

The breads used for this study were baked in a conventional oven in the laboratory kitchen in University of Georgia at Athens (UGA). The HRW flour (King Arthur's) for whole-wheat bread and white bread was purchased at the local Kroger store. The HWW flour for whole-wheat bread and white bread was provided by ConAgra. The breads were baked in the UGA oven for four out of the six sensory tests. The breads for the first two sensory tests were commercially available breads purchased at the local Kroger.

Whole-wheat bread:

The formulation and preparation method for whole-wheat bread was adapted from the "preparedpantry" website (Http://Www.Preparedpantry.Com/Whole-Wheatbreadrecipe.Htm.) with slight modifications to the original formulation. The following proportions of ingredients were used to prepare two loaves of bread: 6 cups whole wheat flour, 2 tablespoon wheat gluten, a sachet of active dry yeast, 2.5 cups of water, 1.5 tablespoon salt, 1/3 cup brown sugar for red wheat and 1/3 cup refined sugar for white wheat and 4 tablespoons of melted and slightly cooled butter.

Dough preparation: The yeast contents were emptied into the mixer and ¼ cup warm water (about 32 ^{o}C) was added and allowed to stand for 5 min for the yeast to be activated. The flour, salt, sugar and water were then added to the mixer and were mixed with the dough hook for two minutes. Then the wheat gluten and butter were added and mixed for about 4 minutes (this allows the gluten to form). Once the dough was formed, it was placed in a large greased bowl and covered with a plastic wrap and was placed in refrigeration temperature (4 ^{o}C) overnight. On the day of baking, the dough was removed to room temperature (3-4 hours). At this time, the dough rose to nearly twice its size. The dough was then kneaded (by hand) for about a minute and then shaped into two loaves and placed in greased bread pans and covered with a plastic wrap and was left at warm temperature (about 34-36 ^{o}C) for an hour and a half or until it doubled in size

Baking: The oven was pre-heated to about 176^{o}C. The loaves were placed in the oven and baked for 35-40 min. The pans were then removed from the oven and allowed to cool completely to room temperature before slicing.

White bread:

The formulation and preparation method for white bread was adapted from the southern food-U.S. cuisine" website (Http://Wwsouthernfood.About.Com/Od/Yeastbreads/R/Blbb205.Htm)for basic white bread with slight modifications to the original formulation. The following proportions of ingredients were used to prepare two loaves of bread: 6 cups refined flour, a sachet active dry yeast, 2.5 cups warm water (32 ^{o}C), 1 tablespoon salt, 2.5 tablespoon sugar and 1.5 cup melted butter.

Dough preparation: The yeast contents were emptied into a mixer and mixed with ¼ cup of warm water (32 ^{o} C) and allowed to stand for 5 minutes to activate the yeast (appearance of gas bubbles confirms that the yeast is active). The flour, salt, sugar, butter and water were then added and mixed with the dough hook until a soft, elastic dough was formed (about 4 minutes). The dough was then placed in a large greased bowl and allowed to rise for two hours (or until the dough rises to twice its size) in a warm place (34-36 ^{o}C). The dough was then kneaded by hand for about 1 minute and cut into two and shaped into loaves. The loaves were then placed in greased bread pans and covered with a plastic wrap. The loaves were then allowed to rise to about twice its size (about an hour and a half).

Baking: The oven was pre-heated to about 204^{o}C. The loaves were placed in the oven and baked for 30 minutes. The pans were then removed from the oven and allowed to cool completely to room temperature before slicing.

Sensory Descriptive Analysis (SDA):

An experienced panel consisting of ten members evaluated the bread samples for selected sensory descriptors: color, grain aroma, denseness, bitterness, astringency and beany flavor. The descriptors were chosen based on previous studies on bread flavor (R.L. Shogren. *et al.*, 2003). The panel evaluation of breads was done once a week for six weeks. Commercial samples were used in order to calibrate panelists for the chosen sensory attributes. For each test, the bread samples were freshly baked the evening prior to the test. Standards with known intensities for each of the sensory descriptor were provided to familiarize with the descriptors. Bread samples were baked in the UGA Food Science and Technology laboratory kitchen. Whole-wheat breads and white breads made from Hard Red Winter wheat and Hard White Winter wheat served as samples in these tests. The six descriptors the panelists had to evaluate in the breads and the standards used for each descriptor are indicated in the Table 2.1.

Sample serving and coding: The bread crust was removed and one slice of bread was cut into four pieces and placed in zippered bags immediately and sealed. The bags were coded with random three-digit codes and served to the panelists at normal room temperature. The test was conducted in a panel room in the Food Science and Technology department at UGA. Panelists were provided with standards at beginning of each test to refresh their memory of the standard references and their intensities. The intensity of each descriptor as perceived by the panelist was recorded in a ballot in each session. All intensities were evaluated on a standard scale of 15cm (R.L. Shogren. *et al.*, 2003). The panelists cleansed their palates between each sample with water or unsalted crackers. The panelists were given food reward (candy) at the end of each test-session.

Consumer Testing:

Consumer testing of the bread samples was conducted on two separate days, at two different locations within the University of Georgia-Athens campus. For each test, the bread samples were freshly prepared in the UGA laboratory kitchen. The bread crust was removed and each slice was cut into 4 pieces and placed in zippered bags and sealed immediately. The bags were coded with random three-digit codes and served with water to cleanse palate between samples. Consumers were asked to taste the samples and mark their preference based on a 5-point willingness to purchase scale. The consumers also answered a questionnaire that accompanied their survey ballots which helped obtain additional information in the various aspects consumers consider when they purchase breads.

Statistical Analysis:

Correlation testing was conducted by linking attribute scores from the sensory descriptive analysis and consumer acceptability by multivariate correlation analysis. Predictive model was further obtained using multiple regression using the JMP (5.1) from SAS (Statistical Analysis Software) institute.

RESULTS AND DISCUSSION:

Sensory Descriptive Analysis: The results from the SDA (Figure 2.1) show that the major difference between the breads was found in grain aroma and color. Differences between the breads with respect to astringency, bitterness, denseness and beany flavor were also detected. The bread with the maximum intensity of brown color was observed in the whole wheat bread made from HRW wheat followed by the whole wheat bread made from HWW wheat. The refined breads made from HRW and HWW had the least intensity for color and were closer to value for white. A significant difference was detected in intensity of grain flavor between the whole wheat breads and white breads made from both wheat types. However, the intensities of grain flavor were similar for both the whole-wheat breads. A similar response was noted in grain flavor and observed for the two refined breads.

The intensity of beany flavor was similar for all four bread types. The denseness was maximum for the HRW whole wheat bread followed by HWW whole wheat. The denseness was least in the refined breads and there was no significant difference in the denseness of the two refined breads. Whole-wheat breads made from HRW wheat was evaluated to be the most bitter among the four bread types, while the HWW refined breads was the least bitter. Whole-wheat breads made from HWW wheat had an average bitterness of 1.9 while refined breads made from HRW had an average intensity of 1.1. Whole-wheat breads made from HRW wheat had the highest value for astringency, and refined bread made from HWW wheat had the lowest astringency. Whole-wheat bread made from HWW wheat had an average astringency of 2.0 while refined bread made from HRW wheat averaged a 1.3.

From these results, it can be seen that whole-wheat breads made from HRW wheat has the highest intensities for all the sensory descriptors that were evaluated. One of the main objectives of this study was to determine if the whole-wheat breads made from HWW wheat was milder in bitterness, color (visual appearance) and astringency unlike the characteristic whole-wheat breads made from HRW wheat which make them unacceptable. A significant difference between the two whole-wheat breads was found with respect to color. Also, with regard to the other sensory descriptors, the whole-wheat breads made using HWW were lower and milder in intensities than those made using HRW wheat. From the SDA results, it can be seen that of all the four bread types evaluated in this study, the whole-wheat breads had the highest intensities of the sensory descriptors while the refined breads had the lowest. And among the whole-wheat breads which are of main concern in this study, those made from HWW was milder in all the sensory descriptors and this may contribute favorably to acceptability of these bread with regard to flavor.

Consumer Evaluation: Results from the consumer evaluation show that the breads made using Hard White Winter wheat had a higher preference than those made using Hard Red Winter wheat. Refined breads made from HWW wheat had a 64% acceptability rating whereas the whole-wheat breads made from HWW wheat had an acceptability rate of 62%. Whole-wheat breads and refined breads made using HRW wheat had acceptability ratings of 59% and 60% respectively. It is also evident from the tests that consumers preferred whole-wheat breads made using HWW wheat more than refined breads made from HRW wheat. In general refined breads made from red wheat are preferred over whole-wheat breads made from the same due to its more appealing flavor, thereby compromising on nutrition (Bakke and Vickers, 2007). It is unlikely, however, that the preference of whole-wheat breads made from white wheat is large enough to be commercially significant.

Linking Consumer Acceptability and Sensory Descriptors:

The correlation coefficients of the six descriptors with the consumer acceptability are shown in Table 2.2. A multivariate regression equation linking the consumer acceptability of the breads as a function of the sensory descriptive was obtained. The following formula predicts acceptability as a function of three of the six descriptors: color, grain and beany. Acceptability was positively related to grain flavor. Positive correlation favors scoring and drives acceptability. Consumer acceptability had a negative correlation with bread color and beany flavor. Negative correlation does not favor scoring. This suggests that a lighter color and less beany flavor would be more acceptable for the breads and presence of grain flavor would favor acceptability.

$$\boxed{\%\ \textbf{Acceptability} = 40.321 - 1.4004\ \textbf{Color} + 8.19207\ \textbf{Grain} - 5.4604\ \textbf{Beany}}$$

Mathematical models aid in providing some insight as to how the presence or absence of sensory descriptors influence consumer acceptability of the product. However, this prediction formula for acceptability holds good only for the four bread types used in this study is not applicable to products outside this range.

CONCLUSIONS:

Breads made using white wheat had a higher acceptability than those made using the traditional red wheat. Whole-wheat breads made from white wheat had a higher acceptance rate than refined breads made using red wheat. This suggests that consuming whole wheat breads made from white wheat could contribute to the nutritional advantages of whole-wheat without having to compromise on flavor which is the most important attribute that drives consumer acceptability. However, refined breads made using white wheat had the highest rate of preference among all the four bread types, which indicates that consumers still prefer refined products. Mathematical model was used to predict acceptability as a function of three sensory descriptors: color, grain and beany. Grain flavor had a positive correlation with acceptability while color and beany was negatively related to acceptability.

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Table 2.1: Sensory descriptors, their definition and standard references on a scale of 15 cm. (adapted from Shogren *et al.*, 2003, Haglund *et al.*, 1998, Tandon *et al.*, 2003)

Descriptor	Definition	Reference
1) Color	Scale goes from bright light brown, golden brown to white/grayish	0=white, 5=gray, 10=light brown, 15=golden brown
2) Grain (aroma)	A light baked wheat flour aromatic	White bread (Sara Lee)=5 Wheat germ (Kretchners)=7.5
3) Beany flavor (aroma+taste)	A musty starchy flavor associated with cooked beans	Lima beans (canned, Kroger) = 4.5
4) Denseness (texture)	The size and ratio of air cells to solid product that is determined during compression of sample with molars on the first bite.	White bread (Sara Lee)=4 English muffin (Thomas)=6 Bagel (Thomas)=14
5) Bitter (taste)	A fundamental taste factor. E.g. taste of caffeine in water	0.01% caffeine solution=2 0.02% caffeine solution=3.5
6) Astringency (taste)	The puckering sensation perceived on the tongue surface	Grape juice (Welchs) =6.5

Table 2.2: Average intensities with Standard Error for the various sensory descriptors for the different breads.

Sample	Color	Bitterness	Grain	Beany	Astringency	Denseness
HWW Refined Bread	0.91 ± 0.39	0.87 ± 0.22	4.83 ± 0.19	2.48 ± 0.22	1.13 ± 0.31	4.43 ± 0.62
HRW Refined Bread	1.37 ± 0.39	1.15 ± 0.27	4.58 ± 0.07	2.80 ± 0.26	1.31 ± 0.17	4.59 ± 0.16
HWW Whole-wheat	9.53 ± 0.33	1.91 ± 0.23	6.72 ± 0.14	3.45 ± 0.17	2.09 ± 0.26	6.49 ± 0.32
HRW Whole-wheat	12.21 ± 0.58	2.30 ± 0.13	6.60 ± 0.21	3.13 ± 0.19	2.26 ± 0.12	7.12 ± 0.49

Table 2.3: Pearson Correlation Coefficients of Sensory Descriptors with Consumer Acceptability.

Descriptor	**Acceptability**
Color	- 0.4321
Grain	- 0.2179
Beany	- 0.3535
Denseness	- 0.4418
Bitterness	- 0.5588
Astringency	- 0.4756

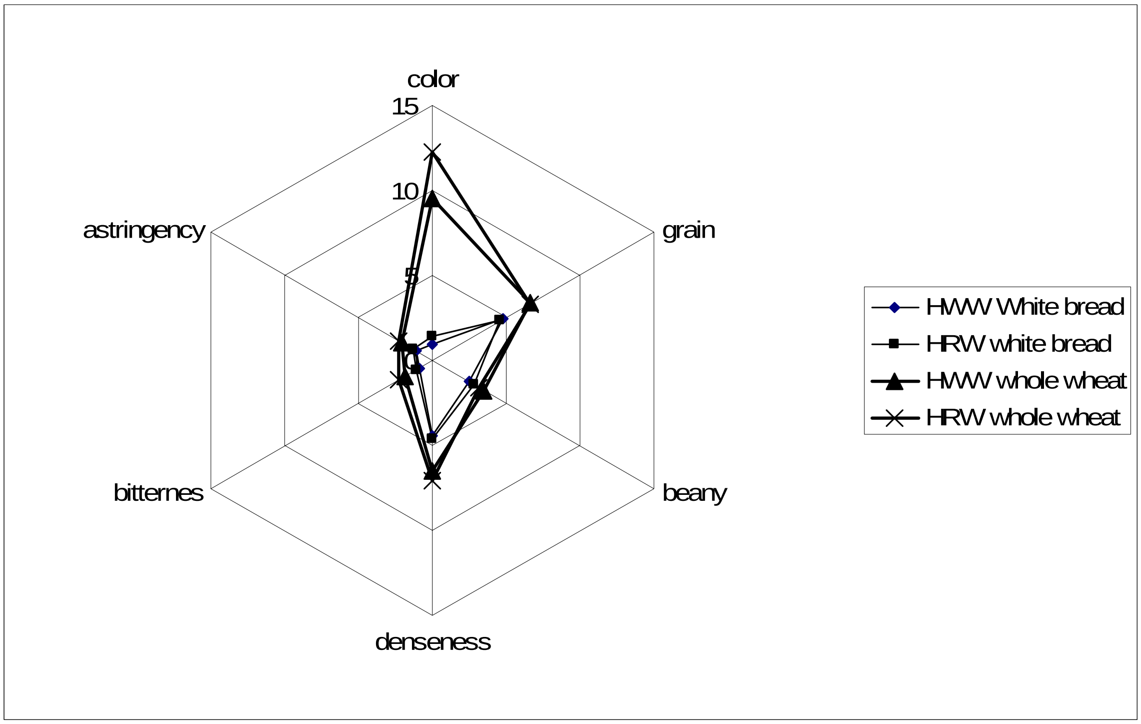

Fig 2.1: Average intensities of the various sensory descriptors perceived by the panel for the four bread types.

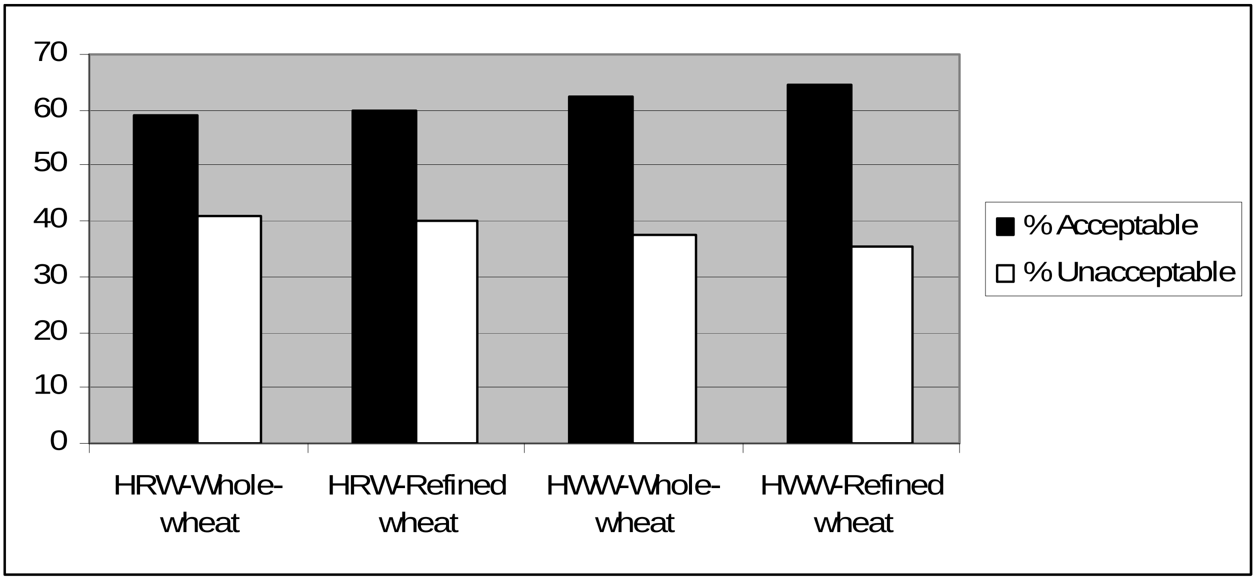

Fig 2.2: % Acceptability and unacceptability of the four bread types. HRW-Hard Red Winter wheat, HWW-Hard White winter wheat.

CHAPTER 3

PHYSICAL PROPERTIES OF BREADS MADE FROM HARD RED AND HARD WHITE WINTER WHEAT.

Balasubramanian, S., Shewfelt R.L. To be submitted to *Journal of Food Quality*.

ABSTRACT:

Visual appearance and texture of bread are quality attributes that have been known to have an influence on consumer acceptability. Moisture content and water activity are hidden quality characteristics that contribute to shelf stability. Textural properties (crumb firmness), moisture (% moisture), water activity and color (L*, C*, H*, a* and b*) were compared for whole-wheat and refined breads made from Hard Red Winter (HRW) wheat and Hard White Winter (HWW) wheat. The results showed that there was a significant difference in Lightness (L*), Chroma (C*), Hue angle (H*) and firmness of the crumb between whole-wheat breads and refined breads. The type of wheat used also has an influence on crumb firmness and color (lightness and hue angle). Whole-wheat breads from white wheat had significantly Higher L* and H* value and lower firmness than whole-wheat breads from red wheat.

KEY WORDS: Whole-wheat breads, refined breads, Texture, Moisture, Color, Water Activity, Hard Red Winter wheat, Hard White Winter wheat.

INTRODUCTION:

In addition to flavor, texture and color are also important factors in influencing consumer perception of bread quality (Chang *et al.*, 1995, Scanlon and Zghal, 2001). Though quality of bread is difficult to define, textural quality and visual appearance are indicators of bread freshness to consumers and help determine acceptability (Gambaro *et al.*, 2002, Scanlon and Zghal, 2001, Seneca, 1956, Snyder, 1930). Macroscopic, microscopic and molecular components of the food form a three-dimensional network which influences the product's textural properties (crumb firmness, crumb chewiness, denseness, crust firmness, etc.) (Crowley *et al.*, 2002). Although texture has been defined as a sensory characteristic, human evaluation of texture is time consuming, expensive and is likely to offer poor reproducibility (Bourne, 1982, Crowley *et al.*, 2002, Szczesniak, 1987). Instrumental analysis of texture is rapid, and the results are more consistent and have a higher precision and reproducibility (Crowley *et al.*, 2002). One of the important texture parameter in bread is firmness, which has been defined as the "amount of force required to bite through the bread sample" (Carson and Sun, 2000). Bread crumb texture has been studied using instruments like the texture analyzer (Carson and Sun, 2000, Bourne, 1998, Szczesniak, 1998). Kokini (1985) states that the "accuracy of an objective method in measuring a quality parameter of a food is determined by its correlation to sensory evaluation of that attribute" (Gambaro *et al.*, 2002, Kokini, 1985). Additional studies have shown that firmness is a textural attribute that has relatively higher correlation between sensory and instrumental analysis (Gambaro *et al.*, 2002, Szczesniak, 1998, Meullenet *et al.*, 1998, Carson and Sun 2000).

Moisture content of bread is critical for determining shelf-life, freshness and staling quality (Xie *et al.*, 2003).Amount of water in the bread has an effect on complex reactions like Maillard browning, crust formation and development of aroma (Thorvaldsson and Skjoldebrand, 1998, Skjolderbrand, 1986). Bread usually has a moisture content of about 40% (Baik and Chinachoti 2000). At high temperatures of baking, water at the surface of the loaf evaporates and moves toward the center where condensation occurs due to lower temperature. This moisture redistribution influences crust formation (Thorvaldsson and Skjoldebrand, 1998). Bread has high water activity: 0.95-0.96 (Fellows, 2000) and hence is categorized as a highly perishable food. Water activity indicates the amount of available water for microbial activity and helps determine shelf-stability of the bread (Fellows, 2000, Fennema, 1996).

Color of bread is the visual quality attribute that has an influence on consumer's perception of freshness and quality (Scanlon and Zghal, 2001). Bread's characteristic color is a result of wheat pigments in the flour, non-enzymatic browning reactions like Maillard browning and caramelization reactions and other changes that occur in the starches (carbonization of sugars), fats and proteins (Al-Hooti *et al.*, 2000, Fellows, 2000) in the bread. Bread crumb fineness influences color based on the reflection of incident light (Al-Hooti *et al.*, 2000, Kruger and Reed, 1988). Pigments like xanthophylls and flavones in the wheat flour have been identified as contributors to bread color (Al-Hooti *et al.*, 2000).

The objective of this study is to measure and compare the texture, moisture content, water activity and color of whole-wheat breads and refined breads made from two wheat classes: Hard Red Winter (HRW) wheat and Hard White Winter (HWW) wheat.

MATERIALS AND METHODS:

Sample preparation: The four bread samples: whole-wheat breads and refined breads from red and white wheat were prepared as mentioned in Balasubramanian S. and Shewfelt R. (2007).

Texture measurement:

Firmness of the crumb was measured using a Texture Analyzer (TA.XT2i Stable Microsystems) with slight modifications to the Approved Method (AACC) (AACC, 2000). The compression disc used was an aluminum disc with 35-mm flat end (probe P/35). Sample slice of 10 mm thickness was used. The selected settings were pretest, test and post-test speed of 1.0, 1.7 and 10.0 mm/sec respectively and a 60% deformation (6 mm compression into sample). Each sample was measured at three different parts of the crumb for firmness. The maximum peak force [N] was recorded as the firmness value. The values reported for each bread type is an average of the different measurements. The samples were discarded after measurement.

Moisture Analysis:

Crumb moisture was measured using a Moisture Analyzer (Mettler Toledo). 1.5 g of the sample was used for each measurement at 70^{o}C in the rapid-drying mode. Percentage moisture was recorded for the four bread types at the end of the drying cycle. The water activity was determined using an AquaLab Series 3 Water activity meter.

Instrumental Analysis of Color:

The color of each sample was measured using a Minolta CR-300 series Chroma Meter. The data processor model was DP-301. L*a*b* readings were converted to chroma (C*) and hue angle (H*).

Statistical Analysis: An analysis of variance was performed to compare the data obtained for the different breads. Significance was accepted at p= 0.05 level. The means with the standard error for each physical characteristic tested for all the four bread types is reported in Table 3.1.

RESULTS AND DISCUSSION:

From the texture measurements, it was observed that whole-wheat breads were much firmer than refined breads (Table 3.1.). Moisture content was similar for all the bread types with the exception of HRW had significantly lower moisture**.** Water activity (a_w) for all the bread samples was in the range of 0.94-0.96. As expected, refined breads were significantly lighter (L*) than whole-wheat breads. Whole wheat bread from HWW was lighter than from HRW, but no significant difference was noted in lightness of the refined breads. Color differences in whole and refined breads were also observed with chroma (C*) and hue angle (H*).A higher C* corresponds to a more saturated, intense coloration. As H* decreases from 90˚ to 75˚, the color becomes more reddish brown.

Texture and visual appearance are physical quality characteristics perceived by the consumer and have been known to drive acceptability of breads (Scanlon and Zghal, 2001). Increased firmness has been related to staling and contributes unfavorably to consumer acceptability (Bice and Geddes, 1949, Xie *et al.*, 2003). It is known that a white crumb color has a higher preference rate by consumers (Al-Hooti *et al.*, 2000). The lighter crumb color of whole-wheat breads (higher L value) made using white wheat rather than whole-wheat breads from red wheat suggests that these breads may be more acceptable in terms of visual appeal. The results for crumb texture and color are consistent with the sensory results for these four bread types (Balasubramanian and Shewfelt, 2007). Instrumental texture analysis showed that whole-wheat breads made from white wheat were less firm than whole-wheat breads made from red wheat. The bread texture was evaluated as a measure of denseness in the sensory studies which also showed that whole-wheat breads from white wheat have lower denseness compared to its red wheat counterpart (Balasubramanian and Shewfelt, 2007). These textural attributes (lower firmness and denseness) of whole-wheat bread from white wheat contribute favorably to acceptability which is proven in the consumer study. The results for color from instrumental analysis showed that the crumb color is lighter in the whole-wheat breads made with white wheat. This is evident from the higher L* value of these breads and larger hue angle (Table 3.1). This supports the results from the sensory studies which showed that whole-wheat breads from white wheat has a lighter crumb color and has a higher preference than those from red wheat. Moisture content and water activity are hidden quality characteristics that contribute to the freshness of bread and helps in determining the shelf-life of the bread (Baik and Chinachoti, 2000).

SUMMARY AND CONCLUSION:

Instrumental analysis of texture, moisture content, water activity and color was performed and the results were compared for whole-wheat breads and refined breads made using red wheat and white wheat. Moisture and water activity of the whole-wheat breads from white wheat are similar to that of the refined breads. Analysis of texture as a measure of firmness showed that crumb of whole-wheat breads from white wheat are less firm than its counterpart from red wheat. Less firmness of bread crumb has been attributed to enhance acceptability. Higher L* and larger H* show that whole-wheat bread from white wheat have significantly lighter color and less red than those from red wheat thereby enhancing visual appeal. These attributes (texture and color) of whole-wheat breads from white wheat will contribute favorably to its acceptability over the traditional whole-wheat breads. However, the sample size used in this analysis is too small to be commercially significant.

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Table 3.1: Mean and Standard Error values of moisture content, water activity, texture and color for each of the four bread types.

Bread Type	Hard Red Winter Wheat		Hard White Winter Wheat	
	Whole-wheat bread	Refined bread	Whole-wheat bread	Refined bread
Physical attribute				
Moisture (%)	40.6 ± 0.23	41.8 ± 0.17	41.6 ± 0.27	41.8± 0.29
Water Activity	0.969 ± 0.0003	0.961 ± 0.0003	0.959 ± 0.0003	0.943 ± 0.0006
Firmness (N)	8.1 ± 0.15	2.5 ± 0.12	6.4 ± 0.07	2.7 ± 0.10
Color				
L*	57.8 ± 0.42	77.7 ± 0.66	62.6 ± 0.91	78.7 ± 0.49
C*	20.4 ± 0.27	16.2 ± 0.56	20.5 ± 0.33	12.8 ± 0.30
H*	74.2 ± 0.33	95.3 ± 0.60	85.8 ± 0.19	94.8 ± 0.15
a*	5.6 ± 0.14	-1.5 ± 0.14	1.5 ± 0.08	-1.1 ± 0.02
b*	19.6 ± 0.26	16. 2 ± 0.57	20.4 ± 0.32	12.8 ± 0.30

CHAPTER 4

SUMMARY AND CONCLUSION:

Consumers have certain specifications with regard to flavor and quality (that make the product acceptable) and that must be taken into consideration while designing a food product. Qualitative research gives a better understanding of consumer perception of a product (Van Trijp and Schifferstein, 1995). Whole-grain products have been associated with several health benefits like reduced risk of coronary heart disease, obesity, diabetes, etc.(Merchant *et al.*, 2006, Liu, 2003). This has been attributed to the presence of high levels of dietary fiber in such foods. Whole-wheat breads are a good choice in increasing dietary fiber. Flavor preference is the key factor that drives consumer acceptability (Bakke and Vickers, 2007). Sensory preference of refined breads acts as a barrier for whole-wheat bread consumption. In this study, whole-wheat breads and refined breads made from two wheat types were evaluated: Hard Red Winter (HRW) and Hard White Winter (HWW) wheat for quality as perceived by the consumer.

In chapter 2, the four bread types were evaluated by descriptive analysis and consumer studies. Panelists scored the four bread types for six sensory attributes (color, denseness, astringency, bitterness, grain and beany). Consumer studies showed that breads made using white wheat had a higher preference rate than breads made using traditional red wheat. Whole-wheat breads made from white wheat had a higher acceptance rate than refined breads made using red wheat. Acceptability was expressed as a function of sensory descriptors. Prediction model showed that grain flavor had a positive correlation with acceptability while presence of beany flavor and color did not contribute favorably to acceptability. This suggests that consuming whole wheat breads made from white wheat has the nutritional advantages of whole-wheat without having to compromise on flavor which is the most important attribute that drives acceptability. However, higher preference rate of refined breads points out that consumers still prefer refined products. Since the whole wheat made using white wheat is more preferred than refined breads of red wheat, consumers can be encouraged to include more whole-wheat in their diet. It is not clear, however, that these differences will be commercially significant.

The main objective of chapter 3 was to measure and compare four physical quality characteristics: texture, color, moisture content and water activity for the four different bread types by instrumental methods. Consumers in general preferred less firmness (a characteristic of refined breads) in breads. Textural analysis showed that whole-wheat breads made from white wheat were less firm than whole-wheat breads made from red wheat suggesting that they may have a higher acceptability rate. Consumers also preferred a lighter crumb color (Al-Hooti *et al.*, 2000). The color for the whole-wheat breads from white-wheat was lighter than that of red wheat. This may contribute favorably to visual appearance for consumers. Texture and visual appearance is known to drive consumer acceptability of breads. However, moisture content and water activity are hidden quality characteristics that contribute to the freshness of bread and helps in determining the shelf-life of the bread. The results from the instrumental analysis were consistent with the sensory results in terms of color and texture for the four bread types studied. It can hence be concluded that whole-wheat breads made from white wheat would have a better acceptability based on texture and color than those made from the typical red wheat.

This study provides an insight into consumer's perception of quality and preference of different bread types. The results also showed that the type of wheat used has an influence on sensory characteristics and texture of the breads. This information will be useful in tailoring the product right from the wheat breeding stage to the final production of bread as per consumer preferences. However, commercial significance of this study is still unclear and further research is necessary to determine the chemical components in the whole-wheat bread from white wheat that contributes to flavor perception. And also linking consumer acceptability with instrumental analysis will help provide a better understanding of acceptability and consumer perception of quality.

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