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Effect of Bran Sources and Bran Particle Sizes on Quality Attributes of Cholesterol-Free, Low-Salt Muffins

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EFFECT OF BRAN SOURCES AND BRAN PARTICLE SIZES ON QUALITY ATTRIBUTES OF CHOLESTEROL-FREE, LOW-SALT MUFFINS

By

Sandy Wu Daubenmire

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ABSTRACT

EFFECT OF BRAN SOURCES AND BRAN PARTICLE SIZES ON QUALITY ATTRIBUTES OF CHOLESTEROL-FREE, LOW-SALT MUFFINS

By

Sandy Wu Daubenmire

Three cereal brans (oat, rice, and wheat) and four leguminous brans (black-eye pea, navy, pinto, and soy bean) were selected for incorporation into a cholesterol-free, low-salt muffin system. Each bran was ground to two particle sizes: fine (<150 microns) and coarse (425-850 microns). Brans were substituted for 65% of whole wheat flour and water in each muffin formula was adjusted to meet requirements of each bran.

Objective measurements indicated that batter specific gravity and moisture, volume, symmetry, color, tenderness, and compressibility of muffins were significantly changed by bran type. Reducing particle size produced more viscous batter, less moist and higher muffin compressibility.

Hydration capacity and ultrastructure of each bran showed that all coarse bran particles possessed the matrix structure. Reduction of particle size of brans distorted the matrix to

single plant cells with exception of oat and rice brans.

Chemical analyses indicated that muffins prepared with leguminous brans offer higher potential total and insoluble dietary fiber than did muffins with cereal brans. The morphology of microstructure facilitated interpretation of results.

To Joseph, Paul, Margaret Daubenmire,
and Mr. & Mrs. Long P. Wu

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INTRODUCTION

In the newest issue of Recommended Dietary Allowances (RDA), it states that dietary fiber is the subject of considerable recent interest and extensive reviews. Because they are hygroscopic, dietary fibers soften the stool and, hence, promote normal elimination. Fiber-rich diets may also increase satiety (Leeds 1990). Some fiber components, including oat bran and pectin, also lower plasma cholesterol levels, either by binding bile acids or by other mechanisms (RDA 1989). Medical and clinical nutrition studies have shown that dietary fibers can significantly affect carbohydrate and lipid metabolism (Leeds 1985, Wahlqvist 1987, O'Dea et al 1989). For instance, cereal-based dietary fiber (oat, rice, wheat bran) has been promoted for its prophylactic value in laxation, bile acid adsorption and cholesterol inhibition (Spiller and Amen 1978, Miettinen 1987, Weber and Chandhary 1987). The measurement of intakes of dietary fiber at the population level varies among nations (Bright-See and McKeown-Eyssen 1984, Bingham 1987, Ohi et al 1983, Van Staveren et al 1982). In the United States, mean fiber intake is estimated to be approximately 12 g/day (Lanza et al 1987). Health

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authorities suggest Americans should increase their consumption of fruits, vegetables, legumes, and whole-grain cereals.

Meanwhile, the ingredient-supplier, the pharmaceutical industry, and food processing industries are responding to the increased desires of today's consumers for products that can be used to foster their health, vitality, and well-being. Dietary fiber supplements have been very useful as pharmacological tools (Frankenfield and Beyer 1989) because they could be added to a defined diet without changing palatability or texture (Leeds 1990). Nevertheless, the incorporation of dietary fiber into a variety of food products is a better example of such a response (Apling et al 1978, Vetter 1984, Leveille 1985, Story et al 1985, Hurt and Crocco 1986, Toma and Curtis 1989). Studies (Brockmole and Zabik 1976, Mongeau and Brassard 1982, Sosulski and Cadden 1982, Polizzoto et al 1983, Cadden et al 1983, Cadden 1986, Haseborg and Himmelstein 1988, Heaton et al 1988, Kahlon et al 1989) have showed that merely adding fiber or adding brans without altering of the particle size of bran to a food system neither guarantees that the food will possess desirable physiological effectiveness, nor result in palatable products. Food technologists (Pomeranz 1977, Pomeranz et al 1977, Shafer and Zabik 1978, Jeltema and Zabik 1979, Vratanina and Zabik 1978,1980, Collins and Post 1981, DeFouw et al 1982 a,b, Polizzoto et al 1983, Johnson et al 1985, Krishnan et al 1987,

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Chen et al 1988 a,b, Sosulski and Wu 1988, Gould et al 1989, Jasberg et al 1989) have investigated and proven that baked products are acceptable carriers of various fibers by the substitution of fiber components for some of the flour in food systems, such as cakes, cookies, muffins and breakfast cereals.

Consumption of legume-based dietary fiber (black-eye peas, navy, pinto, and soy bean brans) (*Phaseolus vulgaris*) has not been widely accepted (Anonymous 1979, 1987). Resistance to use of legume fiber may be related to: color problems, flavor foreign to bakery foods, relatively short shelf life of the fiber material (Dubois 1978), and limited knowledge on the effect of physical, chemical and physiological properties of leguminous dietary fiber.

Particle size of bran can also affect its water-binding characteristics and the physical properties of cereal and legume brans (Mongeau and Brassard 1982, Hughes and Swanson 1989). Cadden (1987) reported that reducing the particle size of AACC wheat bran decreased water holding capacity (WHC). The differences in WHC which occur within and between fiber sources reflect the absence and presence of matrix structure in the bran cell wall which affects the water imbibing properties of the fiber as well as the ability of the fiber to entrap water. Through the alteration of the physical structure of the fiber, as was the case in wheat bran, the spaces for free water in the fiber matrix are no longer av

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available. In Cadden's study (1987), grinding not only reduced particle diameter, also collapsed the fiber matrix of wheat bran.

In this study, seven fiber sources (three cereal brans - oat, rice, and wheat and four legume brans - black-eye pea, navy, pinto, and soy bean) which had been ground to two particle sizes (U.S. 20-40 mesh and smaller than U.S. 100 mesh) were incorporated into cholesterol-free, low-salt muffins. The control muffin contained both all-purpose and whole wheat (WW) flour (50:50). Brans were substituted for 65% of WW flour. The purpose of this study is to determine the effects of fiber sources and bran particle sizes on physical attributes of muffin quality and to observe the microstructure of brans in three phases. A secondary objective is to discover the potential of leguminous brans for incorporation into refined food systems which will contribute to Northern Regional Research Project 120 Objectives for 1989-1993. This muffin study is also a cooperative effort with Kansas State University. KSU researchers have generated the basic formula and have conducted sensory evaluation using trained taste panel on specific products which Michigan State University personnel considered had the highest quality and therefore the greatest potential for the acceptance by consumers.

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REVIEW OF LITERATURE

Dietary fiber has been recognized as indigestible complex carbohydrates (polysaccharides) in plant cell walls (cellulose, hemicellulose, and pectin) and a variety of gums, mucilages, and algal polysaccharides. There is also a noncarbohydrate component of dietary fiber in plant walls, called lignin which is non-digestible in the mammalian small intestine (RDA 1989).

Chemical Constituents of Total Dietary Fiber

Most fiber is located in the plant cell walls. It can be divided into two major portions. One is water soluble fiber (SDF), another is water insoluble fiber (IDF).

Soluble Dietary Fiber (SDF)

SDF are composed of hemicellulose, pectic substances, gums, and mucilages, modified polysaccharides, and other substances which as they occur naturally in foods are water soluble. Hemicellulose and pectic substances associate with cellulose forming an intricate mixture which is heterogeneous with various degrees of hydrogen bonding and covalent bonding, resulting in the difficulties which researchers have experienced while trying to isolate and analyze the components wi

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without causing modifications during extraction.

Hemicellulose It is the major part of SDF, functioning as the cementing material which holds cells together. Chemically, it is defined as polymers that contain a substantial amount of pentoses, glucuronic acids, and some deoxy sugars. It includes xylans, mannans, and xyloglucans. It is insoluble in water at neutral pH, but soluble in aqueous alkali (Schneeman 1986, 1989).

Studies (Hoseney and Faubion 1981, Hoseney 1984a) indicate that hemicelluloses have their greatest effect in baked products in which they improve the water binding of the flour in which they naturally occur as well as of cereal brans. In bread dough, flour with a significant hemicellulose content has improved mixing quality and reduced mixing energy requirement. These flour hemicelluloses aid in incorporation of protein, and improve loaf volume. Hemicellulose is a good source of dietary fiber; however, the specific nutritional and physiological effects on intestinal motility, stool weigh, stool transit time, and on bile acid and steroid metabolism have not been fully elucidated. Hemicelluloses may have beneficial effects in this regard by facilitating the elimination of bile acids and lowering the level of cholesterol in the blood (Leeds 1990). There are indications that dietary fiber, including hemicelluloses, lessens risk of cardiovascular diseases and colonic disorders, especially colonic cancer. Also, O'Dea et al (1989) reported that diabetic patients on high-fiber diets experience reduced insulin requirements.

Pectic substances These substances comprise the second major portion of SDF. They are found together as part of the cell walls and the middle lamellae of plant cells. Pectic substances include the galacturonans, arabinans, and galactans. The basic structure of pectins is a linear chain of D-galacturonic acid units. The important properties of pectic substances are the degree of esterification, of polymerization and of methylation of the carboxyl groups on the galacturonic acids which affect the formation of water-insoluble protopectins, water-soluble pectinic acids, and colloidal pectins which have the ability to produce strong gels. Most of the textural changes during the maturation and ripening of plants are, however, due to changes in pectic substances (Schneeman 1987).

Besides hemicelluloses and pectic substances, beta-glucans has been classified in the term "noncellulosic polysaccharides" (NCP). Beta-glucans are glucose polymers which contain both beta 1-3 links and beta 1-4 links. Depending upon source, the molecules may be less linear than cellulose and more soluble in water (Schneeman 1987). Oats and barley are cereals rich in beta-glucans.

Gums The third major subdivision of SDF, gums, are considered to be hydrophilic, edible polymeric substances, water-soluble polysaccharide in nature, that can be dissolved or

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or dispersed in water to impart a viscous and/or gelling effect (Olson et al 1987). Anderson and Andon (1988) reported that the use and the characteristics of gums in food products are for preventing syneresis, for emulsification, for thickening, for water binding, for inhibition of staling, for stabilizing foams, and for inhibiting crystallization.

Gums used in the food systems can be natural, modified or synthetic. One way of obtaining gums from their natural source - the neutral sugars, uronic acid and other acid groups, is to precipitate them from an aqueous extract by adding alcohol. Since this is a common step in the analysis of soluble dietary fiber, the gums would be expected to be a part of the SDF separated from food in that manner (Olson et al 1987).

Insoluble Dietary Fiber (IDF)

Cellulose Cellulose is a linear polymer of glucose with beta,1-4 glucose links, and is the main structural component of plant cell walls. It is considered relatively resistant to hydrolysis. The characteristic of cellulose is that it has very strong affinity for water (Schneeman 1986, 1987, 1989).

Lignin Lignin is a highly complex, three-dimensional, nonpolysaccharide polymer which contains phenylpropane units. Lignin are considered very inert, insoluble and resistant to human digestion (Schneeman 1987, 1989).

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Characteristics of Fiber Sources

There are a number of "high-fiber" ingredients available to food industries for use in formulating new fiber-enriched foods or to increase the fiber content of existing formulated foods, such as corn bran (Burge and Duensing 1989), oats bran, rice bran (Normand et al 1987); nevertheless, these are cereal-based brans. Leguminous brans (Cadden et al 1983, Sosulski and Wu 1988, Laszlo 1988), sugar beet fiber (Christensen 1989), fruits fiber (Andres 1981, Chen et al 1988 a,b) and other sources (Chan 1988) have been proposed in various research products and ingredient development in order to provide a meaningful fiber component and incorporate successfully into foods systems (Hurt and Crocco 1986).

Cereal Fiber Sources

Whole-grain flours These include whole-wheat flour, rye flour, brown rice flour, etc. Normally, dietary fiber content of wheat flours range from 2.3 to 12.1%, compared to 0.3% and 3.45% respectively in white flour in which all or part of the bran has been removed (Nyman et al 1984). Determination of total dietary fiber of rice contains 0.3% to 2.2% and rye bread is about 6.5% by the enzymatic-gravimetric method (Prosky et al 1985).

Wheat bran Wheat bran consists of outer pericarp (beeswing bran), inner pericarp, seed coat and aleurone layer which is considered part of the bran. Botanically, it is the outer layers of wheat kernel. During milling process including break rolls operation, middlings purifier, and reduction rolls operation, bran is separated form wheat endosperm. AACC certified wheat bran was processed through an enzyme deactivation steamer with a residence time of about 30 seconds, existing at 213-215°F (100.5-101.5°C) and 16.6% moisture, and into an insulated screw conveyer which held hot bran for about 1.5 minutes. The bran was dried to about 9% moisture, sacked in "scotchguard" three-layer paper, one-layer polyethylene bags and is stored at 0°F (Anon 1984). The color of dietary fiber varies according wheat cultivars which are red and white, hard, soft and durum wheat. For example, bran from white wheat has a milder flavor and lighter color than the bran from red wheat (Vetter 1984). AACC specification data shows that TDF of wheat bran is 38% (Anon 1984). Sosulski and Wu (1988) indicated that wheat bran contained 13.1% of cellulose with 34.3% hemicellulose which is twice the 15% hemicellulose of wild oat bran. Schwarz et al (1988) found that lignin and cutin occurred at higher levels in the inner pericarp and seed coat, but the seed coat contained an elevated level of uronic acids.

<u>Rice bran</u> The source of rice bran comes from the outer brown layer, including rice germ, which has been removed during the milling of brown rice. Immediately, this milling by-product is put into a dry heat extrusion cooker, to deactivate the lipase enzyme and stabilize the rice bran

(Randall et al 1985).

Rice bran is rather a new source of dietary fiber, which is nutritious, has a light, slightly sweet taste, is a good source of protein and iron, and is low in calories and sodium (Babcock 1987). Rice bran products are hypoallergenic, easily digestible, gluten-free and have very good foamability and foam stability. Products prepared using rice bran has been reported to be superior to those of wheat bran (James and Sloan 1984). The foaming capacity and stability play an important role in producing high quality baked products. Nevertheless, the properties of rice bran can be affected by rice variety, growing, storage conditions, milling method, and stabilization methods which may be dry heat, parboiling, and steam injected extrusion at various temperatures and pressure (Carroll 1990).

Rice bran contain 25-40% TDF which is approximately twice the 15-18% fiber content of oat bran. The TDF of rice bran consists mainly of insoluble fiber with only 2.0-2.5% being soluble.

Oat bran As mentioned above, the total dietary fiber of oat bran is less than that of some other commercial dietary fiber sources, but the ratio of soluble dietary fiber to insoluble dietary fiber is higher than in many of the other fiber sources which are being used as food ingredient, ie, wheat bran, rice bran, and barley bran (Seibert 1987). Oat bran consists of 7.2% soluble fiber and is considered a good source of soluble fiber. Beta-D-glucan is the major component of the soluble fiber of oat bran. These glucans are soluble in water and dilute alkali (Webster 1986). These solubility characteristics have been linked to the beneficial physiological effects seen when patients with diabetes ingest oat bran (Toma and Curtis 1986). The beta-D-glucans of oat bran are also hypercholesterolemia (Schneeman 1986, 1989).

Oat bran has been used as an ingredient in both hot and cold cereals. Oat bran has also found commercial success as an ingredient in ready-to-eat cereals (Toma and Curtis 1989).

Leguminous Fiber Sources

Black-eye pea bran Black-eye pea bran is obtained from mechanical decortication, wetting and drying. Black-eye peas (*Vigna unguiculata L.*) are major dietary protein source in East and West Africa and are consumed in the form of steamed or fried foods. Very little study has been reported on black-eye pea bran; however, a few studies have used decorted cowpeas (*Vigna unguiculata,* cv. California blackeye) (Sefa-Dedeh and Stanley 1979, Hung et al 1990).

Navy bean bran and Pinto bean bran Navy bean and pinto bean are of *Phaseolus vulgaris L.* which has minimal differences in gross composition. Deshpande et al (1982) investigated the composition of navy bean bran which is 9.1% of dry weight of navy bean. The content of pinto bean bran is 8.2% of dry weight of pinto bean. They determined that the carbohydrates accounts for up to 76.2% and 71.1% of whole bean flour from pinto seed, and navy bean, respectively. Aquilera et al (1982) produced navy hull flour with dietary fiber contents ranging from 31.2 to 50.2%. Jeltema et al (1983) analyzed the components of dietary fiber in flour from navy bean hulls: water soluble pentose 1.13%, pectin 8.96%, water insoluble hemicellulose 18.0%, cellulose 5.81% and lignin 1.03%. Sefa-Dedeh and Stanley (1979) reported that pinto beans had the longest length (12.35 mm), followed by black-eye pea (10.10 mm), navy bean (8.70 mm), and soy bean (7.55 mm). However, the order of the thickness (um) of seed coat are soybean (93.75), pinto bean (45.75), navy bean (38.75), and black-eye pea (21.5). They also reported that the thinness of seed coat of black-eye peas resulted in the highest rate of water absorption as well as soy beans also showed a relatively high rate of water absorption.

Soy bean bran Soy bean (*Glycine max*) seed coat makes up about 8% of the seed weight and serves as a protective coating for the seed during storage and commercial handling (Wolf and Baker 1981). In commercial product, soy bean cotyledon is distinctly different from soy bean hulls which contains a high level of cellulosic residues (39.4%). Soy bean cotyledon fiber is comprised of cell wall material of soybean cotyledons derived from processing dehulled and defatted soybean flakes. It consists largely of non-cellulosic polysaccharides (77.6%) which are a neutral arabinogalactan and pectin-related acidic polysaccharides (Lo

1989). Above all, cotyledon fiber contains more galactose, arabinose, and uronic acid, and less xylose and mannose than soy hull fiber. Johnson and co-workers (1985) have reported that soy hulls can be an iron source for bread formulation. Soy bean bran can significantly increase daily fecal weight and moisture in humans. It affects directly on the gastrointestinal tract by acting as a regulation agent in nutrient absorption and bowel function. It has also been shown that soy bean bran reduces elevated plasma cholesterol level in animal feeding studies and human clinical trials, this effect may be an indirect effect on blood lipids and glucose metabolism (Lo 1989).

Based upon the major physical properties of dietary fiber - particle size, density, hydration capacity and ion exchange capabilities, soy bran has greater water absorption and hydration capacity than fiber from cereal sources. Therefore, soy bran can assist in stabilizing the fluid system and reduce or prevent syneresis in water-gel products (Lo 1989). Food technologists (Johnson et al 1985, Lo 1989) recommended that soy bean bran, especially from cotyledon, is an excellent ingredient to incorporate into bread system, cakes, muffins and puffed and flaked ready-to-eat cereals to increase fiber content without affecting the texture of the finished product quality because of its bland taste, light color and fine structure.

Characterization and Functionality of Ingredients Used in Baked Products

Flour

On a moisture-free basis, wheat flour contains approximately 80% starch, 14% protein, 4-5% lipid, and 2% pentosans (Chung 1986). Starch is a mixture of a-D-glucose polysaccharides appearing as birefringent granules in plant cells which are insoluble in water at room temperature. In muffin system which utilizes flour of lower protein content, batter is mixed under conditions which suppress optimum gluten development. Therefore, gluten is considered to be a modifier of starch-hydration properties rather than a prime factor in the mechanisms of muffin production. The starch and its property of gelatinization at elevated temperatures which plays the major role in production of the finished product (Vratanina and Zabik 1978). Flour functionality in the muffin system will be summarized further when the development of crumb and crust structure is reviewed.

Egg

Traditional muffin formulation contain whole egg which contains about 74% moisture, 13% protein, and 11% lipids which allow the egg to have a multiplicity of functions in quickbreads. Egg encompasses the role of moisturer, structure builder, and tenderizer. Primarily, albumen proteins in fresh egg white contribute to structure formation as they are aggregated by heat during the baking process. Lipoprotein,

lecithin in the yolk plays an important function for the surface-active properties. Eggs enhance the flavor and color as well as contribute significantly to the nutritional profile of the baked product.

However, egg substitutes are another form of egg products being used in muffin baking. These are cholesterol free, low calorie, liquid, ready-to-use products with approximately 10% protein and 5.5% fat. The ingredients of egg substitute vary according to the manufacture but are typically egg whites, nonfat milk, soybean and/or corn oil, calcium caseinate, salt, lecithin, aluminum sulfate, mono- and diglycerides, as well as artificial flavors and color (beta-carotene).

Honey

Honey is viscous syrup manufactured by bees, *Apis melifera*. Its composition consists of approximately 17% water, 38% fructose, 31% glucose, 7.2% maltose, and 1.5% sucrose. Honey is a natural ingredient with rich content of minerals. The pH range for honey is from 3.4 to 6.1. The viscosity of honey decreases rapidly as the temperature rises. The moisture content also can vary with a 1% increase in moisture adding equivalent to about 3.5°C temperature increase in its effect on viscosity (Anon 1988). It also has Newtonian properties, and thermal conductivity which increases with temperature and total solids. Higher water content of honey tends to be lower its specific gravity. The colors of honey form a continuous range from water white to dark amber. Honey appears lighter in color after granulation. The color of fresh honey is related to its mineral content and is characteristic of its floral source. Color is the main characteristic in caramelization during baking. Other functions are classified as humectancy, sweetener, viscosity, flavor and crystallization. When honey is used as part of a sweetener, moisture retention is enhanced further because of the hygroscopicity of fructose, delaying staling, increasing shelf life and improving the texture of the baked foods (Voll 1974).

Liquid Oil or Shortening

Lipid coats the protein and starch particles, disrupting the continuity of the gluten and starch structure, as "slip phase"; thereby tenderizing the quickbread. In batter, the oil is distributed as globules through the aqueous phase, to emulsify the large amounts of liquids contributing to crumb moisture, and to the softness of the chemically leavened product. Painter's study (1981) showed the emulsified plastic fat used conventionally for layer cake entraps air cells during batter mixing and leads to the development of a fine regular grain, tender texture, and large volume.

Canola oil is a low erucic acid rapeseed oil which has a high content of oleic acid (55-65%) and linolenic acid (9-15%) (Daun 1984). It is an excellent salad and cooking oil, but has the limitation of the crystal instability in bakery goods

(Vaisey-Genser and Ylimaki 1989). In hydrogenated canola oil, there is a phase transition from beta prime to the coarser beta form during storage which has been related to the uniformity in chain length of its triglycerides.

Vaisey-Genser et al (1987) showed that the functionality of canola oil in layer cakes can be improved by adjusting levels of water and using an emulsifier system which contains mono- and diglycerides, polysorbate 60, and sodium stearoyl-2-lactylate. For cakes containing either 52.5 or 31.5% canola oil, yield acceptable cakes could be obtained by using 8% or more of the emulsifier system in combination with 137% or more water, based on flour weight.

Brans

Brans act as a hydrophilic constituent which tends to hold water tenaciously resulting in less water being absorbed by the starch (Vratanina and Zabik 1978). Pentosans and gums of bran can slow the rate of CO_2 diffusion which increases gas retention in baked products (Hoseney 1984b). As the level of bran substitution increases, there is a dilution of the total amount of starch, as well as a dilution of the gluten-forming proteins in the muffin system which produces more tender muffins.

The levels of bran substitution in baked products or breakfast cereals can be classified into three types (Vetter 1984):

1). Low enrichment - The flour is a blend of whole wheat and white flour in the ratio of 50:50, providing about 2-3 g of dietary fiber per serving.

2). Moderate enrichment - It is substituting a nominal level 15%-40%) of bran ingredient to a multigrain or whole wheat flour, providing about 4-6 g of dietary fiber per serving.

3). High enrichment - It is replacing a fairly high level of brans (40%-60%) in the formula, providing about 7-9 g of fiber per serving.

At the present time, powdered cellulose, a FDA approved purified substance derived from cotton or wood pulp, and its derivative microcrystalline cellulose (MCC) are the acceptable ingredients incorporated into cakes and biscuits (Brys and Zabik 1976, Zabik et al 1977, Gorczyca and Zabik 1979, Chen et al 1988b, Fondroy et al 1989, Jasberg et al 1989).

Nonfat Dry Milk (NFDM)

Pearce et al (1984) studied thermal properties and structural characteristics of model cake batters containing nonfat dry milk. The results indicated that the effect of NFDM might alter the water-binding properties of the cake batter system, resulting in less water available for evaporative loss and starch granule swelling. Batters with NFDM absorbed more water earlier during baking than baking batters without NFDM. The results also showed that enthalpies and endotherm onset temperatures for batter model systems were higher with NFDM than in those without NFDM. With the presence of NFDM in batters, the mechanisms of water absorption properties of caseins and the hydrophilic properties of the carbohydrate lactose might also affect the elevation of the starch transformation temperature requirements. They found that the addition of NFDM to the batters did not significantly alter the amount of air incorporation in the batter system as measured by specific gravity, but the evenness of crust color and crumb structure development was affected by the incorporation of NFDM. Crust color appeared darker while cross sections of cakes containing NFDM exhibited more large and nonuniform air cells than did control cakes without NFDM. SEM micrographs of cake crumb showed that the distribution of lipid-containing matrix material was altered by NFDM incorporation in batters. In the formulation which contained 30 g NFDM (20% flour basis), the lipid-containing matrix dispersed in small and medium-sized droplets which was the attribution of the emulsification properties of milk proteins.

Chemical Leavening Agents

The principle leavening mechanism in muffin batter has been shown to occur in three stages. Initially, the mechanical mixing of the dry and the liquid ingredients produces small air bubbles which are finely dispersed during mixing and are retained in the batter (LaBaw 1982). This aeration is followed quickly by the partial formation of gaseous carbon dioxide from the reaction of the leavening acid

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with sodium bicarbonate in water. This action aids in producing the correct batter viscosity. Then, during the bench time, referring to any additional reactions which occur between mixing and baking (Reiman 1983), the leavening rate is being controlled so that the sufficient quantities of acid remain to react with the bicarbonate during baking. Finally, the remaining leavening acid reacts with the bicarbonate to maintain the structure of the muffin up until set of other ingredients during baking in the oven. Carbon dioxide must be released at just the right time during batter preparation and during subsequent baking in order to obtain the desired end-product quality. In this study, baking powder is the combination of sodium bicarbonate, sodium aluminum sulfate (SAS), a slow-acting acid leavener, and monocalcium phosphate, a fast-acting acid leavener. A double-acting system, involving that fast-acting acid leavener reacts immediately with part of the bicarbonate, release ca. 50% of carbon dioxide during mixing and holding period to increase the density and viscosity of the muffin batter, allowing production to control cup fill for weight and batter height. SAS does not release carbon dioxide at the mixing and holding time, but releases 100% carbon dioxide in the reaction of the remained bicarbonate in order to further expand the muffin volume and to hold it up until the muffin has set completely during the baking cycle.

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Water

Water is the solvent for sucrose, baking powder and salt. It is the dispersion medium (continuous phase) of egg, nonfat dry milk, flour and protein. It contributes to the suspension of starch. Chen et al (1984) found that rice bran and wheat bran have higher water binding capacity than oat bran. The study of Vratanina and Zabik (1978) indicated that water levels have to be increased with each increase of bran substituted for flour in the formulation in order to achieve optimum dough handling. However, Polizzoto et al (1983) reported a study in which muffins prepared with 25% (w/w) of the flour substituted with cellulose, corn bran, oat hulls, rice bran, soy bran, wheat bran were evaluated. With the same amount of liquid in the formulation, the results showed that oat hulls and alpha-cellulose had the lowest moisture content and the worst mouthfeel. Additional water should be measured to avoid dry and tough bran muffins.

Development of Batter Structure and Crumb and Crust Structure in Baked Products

Muffin system is a type of quick bread. The texture of the finished product is between cake system and bread-dough system. It neither undergoes the fermentation of carbohydrates to release carbon dioxide by yeast nor attains the gluten formation from glutenin and gliadin which is typical of pan bread. In the muffin transformation process, the wet, viscous, inedible, flavorless batter can turn into golden-br

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golden-brown, aromatic, soft internal texture, with good crumb resilience within the period of fifteen to twenty minutes in the oven. Those quality attributes of muffin are affected by temperature, time, water activity, and formulation which influence the major reactions of leavening, gelatinization, Maillard reaction and retrogradation in bakery products.

Mechanism of Leavening and Gas Retention

As mentioned above, double-acting baking powder releases partial carbon dioxide after mixing and benching time. In this stage, batter is aerated with air bubbles which produces a lighter and more porous form which is responsible for good volume, uniform cell structure, bright crumb color, soft texture, enhanced palatability. Carbon dioxide is fairly soluble in water, thus some of the carbon dioxide combines with water to form carbonic acid, which is a weak, unstable and only slightly ionized acid. Together, with carbon dioxide released by the slow-acting leavener, the dissolved gas vaporizes and becomes available for leavening when the batter is heated in the oven during baking.

Various studies (Hoseney 1984a,b, Pomeranz 1977, Pomeranz et al 1984) have pointed out that carbon dioxide produced by yeast fermentation which dissolved in the aqueous phase of the dough must diffuse to an existing gas cell and enter the cell to make the dough rise. In the past, researchers regarded wheat gluten to be the only substance that causes bread dough to retain gas, but now they suggest that the gums such as locus

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locust bean, xanthan, or pentosans can contribute to the doughs ability to retain gas since these gums are also able to slow down carbon dioxide diffusion rate, and retain the gas in the cell.

Gelatinization

Gelatinization is the collapse (disruption) of molecular order within the starch granule along with concomitant and irreversible changes in properties such as granular swelling, crystallite melting, loss of birefringence, viscosity development, and starch solubilization (Atwell et al 1988). During baking, the starch granules which contain two carbohydrate polymers-amylose (linear or coiling shape) and amylopectin (branch or bushy shape), begin to swell at about 40°C (104°F) and at 50-65°C, respectively (Lineback and Wongsrikasem 1980).

During baking starch molecules vibrate more vigorously, breaking intermolecular bonds and allowing their hydrogen bonding sites to engage more water. The starch granules avidly absorb the free water and protein-held water of the batter. This penetration of water, and the increases separation of more and longer segments of starch chains, increases randomness in the general structure and decreases the number and size of crystalline regions. Continued heating to approximately 60-70°C (140-158°F) reaches the birefringence end point temperature (BEPT) range of gelatinization of wheat starch. Granular structure undergoes deformation into the semi-rigid, self-supporting structure of bread and a proport

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proportion of the granules remains intact because of the limited supply of water (Hoseney 1986). Zobel et al (1988) used x-ray diffraction to investigate the "melting" to starch gelatinization. This occurred over a range of temperature. After melting, the reflections disappear and a broad halo appears, indicating a change from a crystalline to an amorphous (molten) state. Melting temperatures increased as starch moisture content decreased.

Hoseney et al (1983) stated that when starch is heated in water, it changes from a water-insoluble material to a partially soluble and very hydrophilic substance. As a result, a thick paste is produced in which almost all the water has entered the granules. This causes them to swell and push tightly against each other in a honeycomblike manner. In food systems, the starch acts as a temperature-triggered water sink.

Kulp and Lorenz (1981) stated that flours with relatively high levels of starch damage exhibit an increased water absorbing capacity. The damaged starch is, however, readily attacked by amylase prior to gelatinization and liberates its absorbed water. This free water then becomes available for more extensive starch swelling and gelatinization during baking.

Marston and Wannan (1976) stated that the water content of bread dough is normally 40% of its total weight, with 10 to 12% of water evaporating from the dough surface during baking

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and cooling. The results revealed that most of the water losses from the portion within less than 10 mm of the surface, and that little migration occurs from the inner material. Evaporation of water regulates the dough temperature so that, under normal baking conditions, no part of the dough mass reaches a temperature significantly above the boiling point of water until its water content is so low that evaporation is restricted and the balance between heat absorption and evaporation loss is altered. Beyond this stage, formation of "crust" commences, with increasingly important effects on the external color, the flavor and the final structure of product. Hoseney et al (1983) suggested that the amylose fraction of starch is responsible for setting the crumb structure of bread.

Browning Reaction

It is a nonenzymatic browning reactions which proceed at a significant rate above 150°C. It involves the phenomena of caramelization and Maillard reaction which are the principal changes involved in the formation of the flavor and the color of the crust.

During caramelization, thermolysis causes anomeric shifts, ring size alterations, breakage of glycosidic bonds, dehydration with formation of anhydro rings, as in levoglucosan, or introduction of double bonds into sugar rings which produces intermediates to unsaturated rings, such as furans. Conjugated doubled bonds absorb light and produce color. Caramel pigments contain hydroxyl groups of varying acidity, carbonyl, carboxyl, enolic, and phenolic hydroxyl groups. In most baking products, corn syrup is commonly used for making caramel colors and flavors. Caramel flavor in the baked bread is derived from maltol, 3-hydroxy-2-methylpyran-4-one, and isomaltol, 3-hydroxy-2-acetylfuran.

Hodge and Osman (1976) summarized the mechanisms of the Maillard reaction mainly with condensation of a nonionized amino group ($-NH_2$) and a reducing sugar -carbonyl group (-CHO) for enolization and dehydration of sugar to 5-hydroxymethyl-2-furaldehyde (HMF), which might react with amines forming brown or black pigments, melanoidins, with high molecular weights. Such pigments are responsible for the color of bakery products. The result from Maillard's studies indicated that the decrease in the extent to which common sugars brown is in the order of D-xylose > L-arabinose > hexoses (D-galactose, D-mannose, D-glucose, and D-fructose) > disaccharides (maltose, lactose) (Fennema 1985).

During Strecker degradation of alpha-amino acids, volatile flavorants, such as aldehydes, pyrazines, pyridines, pyrroles, and sugar fragmentation products are formed which contribute to the distinctive flavors of bakery products. The characteristic aroma of an amine-carbonyl browning reaction changes with temperature. For instance, proline gives a burnt protein aroma at 100°C, but a pleasant bakery aroma at 180°C. Histidine produces no aroma at 100°C, but cornbread-like, buttery ar

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buttery aromas developed at 180°C. Similarly, in Lane and Nurten's (Buckholz 1988) assessment odors reminiscent of bread, crust, biscuit, cakes and toast were produced when glucose was heated with the amino acids arginine, glutamine, histidine, lysine, proline, serine, threonine and tyrosine in a 1:1 ratio at temperature of 100 and 140°C for periods ranging from 0.5 to 4 min.

Heinze (1989) made an investigation between oven baked cakes and microwave baking. The traditionally baked cakes had a desirable crusty surface texture and "browned" flavor. Hot (325-550°F), dry air removes water from the surface of the cake and concentrates the denatured proteins-amino acid-sugar through Maillard reaction and subsequently provides the crisp texture and "brown" flavor and color of the crust. But in microwave baking, the cake is cooked throughout the entire product, and moisture is driven from the center of the cake to the surface. The surface does not brown because the air around the cake is not heated, and subsequently becomes saturated with moisture. Increased water concentration led to a decreased rate of browning. Nevertheless, flavors are easier to develop for microwave cakes because of the lower processing time and temperature.

White and Parke (1989) agreed that lower pasting temperature save energy and spare heat-sensitive ingredients such as flavors from thermal degradation. The addition of fructose into products can increase gel strength which allows either i

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Retrogradation

Starch retrogradation has been recognized as the event which occurs when starch molecules begin to reassociate in an ordered structure. In its initial phases, two or more molecules may form a simple juncture point which then may develop into more extensively ordered regions. Ultimately, under favorable conditions, a crystalline order appears and precipitation from "solution" occurs (Atwell et al 1988).

Zeleznak and Hoseney (1986) visualized the crumb firming phenomenon that companies the staling process as being mainly the result of retrogradation. They proposed that during the partial gelatinization of the starch granules that takes place as bread bakes, a portion of the linear amylose fraction dissolves and diffuses out of the granules and becomes concentrated in the interstitial aqueous medium. When the bread cools, the hydrogen-bonding tendency of the amylose fraction leads to the formation of an elastic, relatively firm gel in which are imbedded the swollen starch granules. Their dilated state, which imparts softness and resilience to the starch granules and, hence, to the entire crumb, eventually undergoes a degree of retrogradation, involving the branch chains. This brings about a rigidification and firming of the granule structure with a concomitant hardening or firming of the crumb structure.

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According to Kim and D'Appolonia (1977), staling basically involves crystallization-like changes of the starch in the crumb, regardless of the flour protein content. Nevertheless, water-soluble pentosans may slow the rate of retrogradation by affecting the amylopectin fraction of starch, and water-insoluble pentosans affects both amylose and amylopectin. The pentosans retard retrogradation by reducing the amount of starch components available for crystallization. Retrogradation of both amylose and amylopectin characterizes crystallization through the first day of storage; thereafter, amylopectin alone controls retrogradation. Zeleznak and Hoseney (1986) drew some conclusions from their findings that amylopectin will retrograde when it is not in the granular form, and this retrogradation is controlled by the water present during aging. Czuchajowska and Pomeranz (1989) reported that differential scanning calorimetry (DSC) enthalpy cannot be eliminated by wrapping bread or storing crumb under conditions that prevent loss of moisture. Even when there was little reduction in total moisture content and water activity in the center of the crumb still, increases in DSC peaks were substantial.

Krog et al (1989) stated that freshly baked bread contains practically no retrograded amylopectin. During storage, the retrogradation takes place at the highest rate for the first days, and then at a decreasing rate the older the bread.

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The addition of emulsifiers to bread results in changes in the starch components amylose and amylopectin, and the interactions with emulsifiers such as monoglycerides seem to favor interactions with amylose rather than amylopectin. By forming helical complexes with the free, soluble amylose in the dough within the swollen starch granules, increasing the natural content of the amylose-lipid complex, and the monoglyceride will prevent their migration from the granules and, as a consequence, no external gel structure is formed.

Hemicelluloses probably have their greatest effect on baked goods where they improve the water binding of flour. In bread dough, they improve mixing quality, reduce mixing energy, aid in incorporation of protein, and improve loaf volume. Observation showed that plant hemicellulose greatly retards staling of bread as compared with bread containing no hemicellulose (Fennema 1985).

Fructose is an excellent humectant to with the ability to bind moisture to minimize water activity and maximize moisture content to prevent retrogradation (White and Parke 1989).

Characteristics of Fiber in Baked Products

Brockmole and Zabik (1976) studied the incorporation of varying levels and combinations of wheat bran and middlings in white layer cakes. They found that batter viscosity increased with increasing substitution levels, as well as increased tenderness, yellowness and redness, but lightness of the cake crumb decreased. They indicated that wheat bran and/or middling increased water absorption capacity resulting in increasinly viscous cake batter, and evenly distributed gas bubbles.

DeFouw and Zabik (1982a) found that heat treatment of navy bean hulls incorporated into cakes significantly affected physical and sensory characteristics, such as: shrinkage, and color. They also reported that all sugar-snap cookies contained different substitutions of navy bean hulls required significantly less force to shear than did the control without navy bean hulls (DeFouw and Zabik 1982 b). Polizzoto et al (1983) showed that wheat bran and corn bran incorported into muffins resulted in the acceptable characteristics for flavor, mouthful, texture, appearance, aroma, and color based upon sensory evaluation.

Mongeau and Brassard (1982) showed that the bile salt binding and water-holding capacity of wheat fiber are gradually decreased as particle size is reduced. The results also indicated that nutritionally important physicochemical characteristics of wheat fiber are adversely affected as particle size is reduced. Cadden (1986, 1987, 1988) confirmed that water-holding capacity of wheat bran decreased as particle size is reduced. Krishnan et al (1987) reported that there was a decrease in loaf volume of bread with increased oat bran substitution and with reduced oat bran particle size. Farinograph and baking absorption increased with increases in

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oat bran levels in the formula as well as with decreases in particle size of bran. However, smaller oat bran particle sizes increased dietary fiber content as measured by the neutral detergent method.

Sosulski and Wu (1988) indicated that prehydration of the fiber sources enhanced bread water absorption(%) and bread shape, shred, grain and texture on the levels of 5-10 % of bran substitution with either wheat bran, corn bran, field pea hulls or wild oat bran. Johnson et al (1985) found that soy hulls darkened the bread crumb, but there was no significant difference in the loaf reduction on the 5% level of soybean hulls replacement in bread. However, a significant reduction in loaf volume from the control bread when soy bean hulls were added at levels of 7.5% and 10%. Lai et al (1989) proposed that wheat bran binds a relatively large amount of water, which caused gluten hydration and development at an inappropriate absorption level that results in a reduction in loaf volume.

Fondroy et al (1989) studied that oat bran treated with alkaline hydrogen peroxide (called fluffy cellulose) in order to remove lignin and enhance the interaction of cellulosic fiber in cakes. They found that each increasing increment of fluffy cellulose resulted in a volume index reduction in cakes with increase yellowness of the cake crumb.

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Scanning Electron Microscopy (SEM) of Bakery Products

SEM has become a valuable tool to food researchers to observe the morphological structure of the foods in relation to the functionality of the ingredients which can be a great assistance in product development. The applicability of SEM to product development can be observed toward the texture of flour-based products and leguminous products.

Varriano-Marston (1977) made a comparison of dough preparation procedures in the aspects of fixation, dehydration, and frozen or not frozen. Evan et al (1977) studied the ultrastructure of bread dough which was fixed in buffered glutaraldehyde followed by alcohol dehydration and critical point drying. They found that the gluten sheet ruptured at the starch protein interfaces. They thought that might have been a fixation induced artifact. Pomeranz et al (1977) studied that substitution of various fibers in breadmaking revealed a wide variation in gas cell size and shape and in number and size of holes. Pena et al (1982) observed triticale grain and shrivelled grains in relation to the ratio of starchy endosperm to aleurone. Hoseney et al (1983) studied that functionality of starch in baked foods in terms of water absorption and temperature changes. Again, Pomeranz et al (1984) studied wheat, wheat-rye, and rye dough and bread by SEM. They discovered that the rye meal bread crust is coarse and affected by the presence of particles rich in aleurone-pericarp which also weakened the protein-gum matrix.

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Microstructure of legumes were studied by Sefa-Dedeh and Stanley (1979). They investigated the locations and structures of various beans, in terms, the rate of water absorption and cooking. They found that soy bean had the thickest seed coat (93.8 um) compared to black-eye peas (21.5 um) and pinto bean (45.8 um) at similar seed dimensions on height and width. Wolf and Baker (1980) further studied the use of SEM to determine the structure of soybeans and soybean protein products. Recently, there were more microstructure of beans revealed in the literature (Hughes and Swanson 1989, Spaeth et al 1989, Hung et al 1990) in terms of the effects of heating, drying and processing treatments.

Chabot (1979) and Chabot et al (1979) studied various preparations of food samples for SEM, and concluded that aqueous fixatives alter the structure of most low-moisture foods. He stated that air drying should be applied to dry samples, such as grains, flours, starch granules of which dry is the natural state. Lee and Rha (1979) observed that freeze drying produces ice crystal damage. Chabot (1979) proposed that the best treatment is no treatment. Varriano-Marston et al (1985) stated that complete destruction of starch granule integrity was affected by slow freezing and fast drying procedures. They recommended that fast freezing rates and controlled sublimation of ice are necessary for maximum structural preservation. Solvent dehydration methods produce a film on gelatinized starch granule surfaces which appeared smooth, non-porous. Solvent dehydration induces agglomeration and compaction of fine fibrous network of starch exudate.

Sargent (1988) completed a detailed review and study on the application of cold stage scanning electron microscopy to food research. He concluded that most foods contain water which in the vacuum of an electron microscopy would rapidly evaporate at ambient temperature. In addition, constituent fats might melt under the electron beam. Cryopreservation and examination at low temperature avoids these problems. Particularly, the structure of emulsified or foamed products can be revealed by freeze-fracture techniques with little artifacts. He concluded that traditional approaches to the hydrated samples had included freeze-drying or critical point-drying of samples before inserting them into the SEM. Those methods were not only time-consuming, but also induced artifacts. Up to 40% shrinkage was common during freeze-drying and gross distortion. However, cryostage might avoid the problems of above methods. This technique involves freezing the specimen and examining it in the SEM at a temperature (usually around -180°C) at which neither is water lost by sublimation nor fats melted by the energy of the electron beam. Meanwhile, commercially available equipment provides means for rapid specimen cooling and transfer to the SEM in a way which avoids frost contamination.

Langton and Hermansson (1989) discovered that the amylose

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network was sensitive to freezing, and freeze artifacts were often observed after cryosectioning of gels. The structure often fractured at the interface between the amylose and the amylopectin- rich regions, ie. wheat starch heated to 120°C, then observed by the low temperature technique. SEM micrograph revealed that the smooth flaky structure of the amylopectin-rich outer layer and small aggregates of released amylose formed.

Swanson et al (1985) compared the structure differences between uncooked and cooked common bean flours. They observed that large (10-30 *u*m) spherical starch granules and smaller (1-5 *u*m) protein bodies were present, but in the cooked flour, starch granules had been gelatinized and protein bodies denatured leaving primarily amorphous material that was irregular in size and shape.

Furthermore, Hughes and Swanson (1989) studied soluble and insoluble dietary fiber in cooked and uncooked common bean (*Phaseolus vulgaris*) seeds. They found that the common bean soluble dietary fiber consisted of thin, irregularly shaped sheets and long, thin rods (2-4 *u*m), from which many of the rods exhibited pods or bulges at one end. In contrast, insoluble dietary fiber fractions consisted primarily of cell wall remnants, with partially digested fragments of the seed coat, with the long cylindrical cells of the seed coat palisade cell layer. They proposed that long, thin fibers which were approximately 10-15 *u*m wide and coarse in appearance could be remnants of the nutrient transporting phloem. They also pointed out the differences between their observation and those reported by Cadden (1987) probably resulted from different preparation procedures and should not be interpreted as significant structural differences. Especially, the soluble dietary fiber is solubilized in water and will result in the structural artifacts due to the extensive dehydration procedures.

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EXPERIMENTAL PROCEDURE

This research was initiated to determine whether the bran sources or the particle size of each bran source would affect the physical quality characteristic of muffins. Additional research was carried out by researchers in the Department of Foods and Nutrition at Kansas State University using many of the same fiber sources and the same particle size for these fiber source. These companion studies concentrated on sensory evaluation of muffins using the same formula as used in the current research as well as a formula optimized with commercial food ingredients.

Fiber Sources and Preparation

The seven different dietary fiber sources used in this study included oat bran purchased from ConAgra, Inc., rice bran donated by Riviana Foods, Inc., certified soft white wheat bran obtained from American Association of Cereal Chemists (AACC), black-eye peas bran, navy bean bran, pinto bean bran, and soy bean bran donated by Quicy Soybean Co.. With the exception of soy bean bran, all legume-based bran sources were processed at Michigan State University fruit and vegetable pilot plant.

Preparation of black-eye pea, navy bean and pinto bean bran

Whole leguminous beans were dried in Hotpoint Automatic convection oven at 150°F for 24-48 hours to inactivate the antinutritional factors, and until the seed coats could be separated from cotyledons easily, afterwhich they were cooled at room temperature. Beans were cracked by a Fitz Mill Model D comminuting machine (W.J. Fitzpatrick Co., Chicago) with a screen size 3.6 cm in diameter. Bean seed coats were decorticated from the cotyledon fragments by either air aspiration (Aguilera et al 1982) or floating off the seed coats with water. Seed coat removal was a time-consuming, labor-intensive process. Then, the desired seed coats were rinsed and dried, using an Etco forced-convection oven, model 186A at 150°F for 24 hours.

Reduction of bran particle size

Particle size of cereal-based brans were reduced by a tandem Quadrumat Jr. II. (Brabender Instruments Inc., S. Hackensack, NJ). Legume-based brans were grounded through Kitchen Aid Mixer (Model 5-C) grinder attachment with the exception of soy bean bran. Commercial product of soy bean bran came in the form of a puffed ball, and was light weight, snow white, and porous. Thus, the soy bean bran was easily reduced in the particle size by the pressure of the hands.

Desired particle size of bran was obtained by placing a 500 g sample of the ground hulls into Sifters Shop # 125 (Great Western Mfg. Co., Leavenworth, KY). The order of the screens corresponded to mesh sizes of U.S. standard sieves in the cabinet was from the large opening sieve to the small opening sieve as follows: 15 mesh, 20 mesh, 21.67 mesh, 40 mesh, 61.67 mesh, 78.33 mesh, 100 mesh, and pan. The nested sieves were locked in the cabinet and shaken for 5 minutes mechanically. Rubber balls (ca. 1 cm in diameter) were placed on the each level of the sieves to force the bran particle size through the screens and to prevent the blinding and clogging the sifter. The material retained on U.S. standard sieves 21.67, and 40 were collected for the sample of coarse grind which was the size between 425 microns and 850 microns. The finely ground hulls were gathered from the sifter pan and had a particle size which was less than 150 microns. Between each sifting of new sample, an air hose, vacuum cleaner and damped cloth were used to clean the sifter in order to eliminate the contamination of fiber sources. In addition, the alternations of sifting of light and dark color of brans were executed to increase the ease of visual inspection of foreign bran particle to avoid contamination of samples. All individual runs of large particle size fiber from one type of fiber source were combined and sifted together for 10 minutes in Sifters to insure uniform particle distribution. Small particle size fibers from one source were similarly treated after which each particle size of each fiber source was sealed, individually, in labeled polyethylene, and stored at 21°C until used.

Muffin Preparation

Ingredient Procurement

Common lots of all purpose flour, all wheat flour, baking powder, canola oil, non-fat dry milk solids, cinnamon, clove, vanilla extract were obtained from Michigan State University Food Stores. Common lot of Scrambler egg substitute was obtained from a local food retailer. Busy Bee Honey was purchased from Barkman Honey Co., Inc.

Muffin Formulation

Based upon honey wheat muffin formulations provided by researchers in the Food and Nutrition Department of Kansas State University (Appendix 1) for modification with varied fiber sources, this researcher developed the present cholesterol-free, low-salt formulation (Table 1), which Scramblers (Worthington Foods, Inc.) were used to substitute fresh eggs, and no additional salt was included, besides the sodium formulated in Scrambler. With 65% bran substitution for whole wheat flour, each bran muffin (50 gm) was estimated to provide at least 1.5 gm Total Dietary Fiber.

Hydration Capacity of Brans

Each fiber source was tested according to AACC 56-20 (AACC 1983). Duplicates two gram samples of each particle size and each fiber source were tested to determine the water hydration capacity (WHC). Based upon WHC, the researcher generated a simple equation and classified all the

Table 1. Formulation of Cholesterol-Free Low-Salt Honey Bran Muffins

Additional Ingredients	Amount	
	Control (g)	65% Bran (%)
Dry Ingredients:		
Gold Medal all purpose flour	100.0	100.0
Gold Medal whole wheat flour	100.0	35.0
Various brans		65.0
Carnation Non-fat Dry Milk (NFDM)	20.0	20.0
Clabber Girl Double Acting Baking Powder	12.0	12.0
McCormick Cinnamon	2.0	2.0
McCormick Clove	0.2	0.2
Wet Ingredients:		
Scramblers' Egg Substitute	108.0	108.0
Busy Bee Honey	80.0	80.0
Puritan Vegetable Oil	40.0	40.0
McCormick Vanilla	4.0	4.0
Distilled Water	147.0	variable[1]

[1] Table 2 gives specific water levels used for each particle size of each bran source.

experimental units into seven groups. The equation was used as: Y=147+65(X-2), Y signified the adjusted amount of water for each bran, X represented the level of hydration capacity for individual bran. One hundred and forty-seven was the basic requirement of water for control muffin, 65 as the percent for bran substitution, 2 was the hydration capacity of the mixture of white flour and wheat flour (50:50)(Table 2). For instance, oat fine bran and wheat fine bran were at the level of 2.2, soy fine bran and wheat coarse bran were chosen to be in one group at the level of 2.8, black-eye pea fine bran, oat coarse bran and soy coarse bran were grouped together at the level of 3.0, black-eye pea coarse bran and navy fine bran and pinto fine bran were at the level of 3.2, and navy coarse bran and pinto coarse bran in the same category at the level of 3.4. Rice fine bran and coarse bran stood alone at the level of 2.6 and 2.4, respectively. This equation was also verified by trials of preliminary test. The purpose of the determination of water hydration capacity was to adjust the water used in the basic muffin formula to compensate for the increased water holding capacity of the fiber sources which were to be substituted for 65% of the whole wheat flour as shown in Table 2 to reflect the additional water requirements of brans which was one of the physical properties of dietary fiber (Rasper 1979).

Experimental Design of Muffin Preparation

A factorial completely randomized block design was applied to eliminate the differences among blocks from experimental error (Petersen 1985). In this design, the treatments consisted of combinations of two factors- sources and sizes. The factor of sources had seven levels (seven types of brans) and the factor of size had two levels (coarse and fine). The control and various fourteen bran treatments were grouped as one block, then randomized the baking order of the treatments within each block. Four replications (blocks) were prepared to be evaluated by the objective measurements. Seven or eight kinds of bran muffins were prepared on one baking day.

Muffin Mix Preparation

Prior to preparation of the muffins, a common mix was prepared containing all dry ingredients except brans. The preweighed ingredients were mixed in Kitchen Aid Mixer, model 5-A, at low speed, 1 minute each for three times, to insure homogeneous distribution. Then, the weight of dry ingredients for one muffin preparation was packed into polyethylene bags, and held at 21°C until used.

Each individual bran was presoaked in a weighing boat with two thirds amount of distilled water usage for 15 minutes prior to the incorporation of bran. The remaining wet ingredients were premixed at low speed for 1 and 1/2 minute with a wire whip, afterwhich the presoaked bran was added to

Table 2. Water Hydration Capacity (WHC) of Various Brans and Additional Volume of Water Required in Muffin Preparation

Bran Types	Particle Sizes	WHC (g/g)	Water (g)
Control[1]		2.08	147
Oat	fine[2]	2.18	160
	coarse[3]	2.87	212
Rice	fine	2.70	186
	coarse	2.59	173
Wheat	fine	2.30	160
	coarse	4.39	199
Black-eye pea	fine	4.20	212
	coarse	6.10	225
Navy bean	fine	4.80	225
	coarse	5.47	238
Pinto bean	fine	4.80	225
	coarse	5.67	238
Soy bean	fine	4.25	199
	coarse	4.90	212

[1] 50:50 of white flour and whole wheat flour
[2] < U.S. mesh 100 (less than 150 microns)
[3] between U.S. mesh 20-40 (between 425 and 850 microns)

egg-honey-oil mixture, and mixed at low speed for 1 and 1/2 min more. A dough hook was used to combine dry ingredients into wet ingredients to avoid gluten development in the batter at low speed. Twelve to fourteen seconds were required to moisten flour.

Baking Procedures

Baking was done immediately following the weighing of six 50 grams of batter into muffin-tin cups lightly pregreased by a commercial pan spray, then baked in a National Reel Type Test Baking Oven for 17 minutes. An oven temperature of 375°F (190.6°C) was maintained by a Partlow Indication Controller, model MF-2-665K1P220. After removal from the oven, the muffins were allowed to cool 5 minutes in the tin. All six muffins were removed from the tin and weighed together, then cooled an additional 25 minutes on racks before other evaluations. Humidity and temperature on each day of baking were recorded by a Weathermeasure Meterorograph, model M701-E in the range of $15\pm5\%$ humidity level, and 21.5 ± 0.5°C.

Quality Evaluation

Physical Measurements

Viscosity, specific gravity of the muffin batter were determined on the same day of preparation. Also, the small portion of batter was kept inside a clear sample bottle stored at 0°C for the evaluation of water activity (Aw) and scanning electron microscopy (SEM).

After the baking loss determination was made on the six muffins of each bake, two muffins were weighed to the nearest 0.01 g for the use in the tenderness determinations. One was cut in the center to measure volume and symmetry, using a modified template designed by the researcher. Then, the samples were wrapped individually in all purpose plastic film to prevent dehydration. The bran muffins selected for color analyses and chemical analyses were frozen at 18°F. Baking loss, tenderness, compressibility, volume by rapeseed displacement and by template and symmetry were determined the same day of preparation.

Batter viscosity. Batter viscosity was determined by a Brookfield Synchro-Lectric Viscometer, model RVF-100, using a no. 6 spindle rotating at 10 rpm. The reading was taking after the dial had made one complete revolution and the reading was then multiplied by conversion factor (1M) to express viscosity in centipoise (cps).

Specific gravity Specific gravity was tested according to AACC method 72-10. Specific gravity was calculated from the ratio of bran muffin batter volume to an equal volume of water at the same temperature.

$$\text{Specific gravity} = \frac{\text{wt. of bran muffin batter}}{\text{wt. of water of an equal volume of batter}}$$

Care was taken to eliminate all air pockets when filling the container with batter.

Water activity After equilibration to room temperature, batter and baked muffin water activities were performed by Thermocouple Psychrometer Sample Changer, model SC-10A, connected with the Decagon NT-3 Nanovoltmeter for reading. The thermocouple Psychrometer determined relative humidity by measuring wet-bulb depression. It was calibrated by 0.5M KCl saturated salt solution at 20°C. The collected readings on temperature and microvolts were transferred into DOS computer program to compute water activity.

Baking loss Baking loss was calculated by the differences between total wt. of six cups of muffin-batter and total wt. of six baked-muffins.

$$\text{Baking loss} = \frac{\text{difference between weight of batter and muffin}}{\text{total wt. of muffin-batter}} \times 100\%$$

Tenderness and compressibility Tenderness was measured with an Allo-Kramer shear press, model T-2100-C equipped with a TR-5 Texturerecorder. Muffin samples were weighed to the nearest 0.01 and placed in the model CS-1 standard shear-compression cell. Tenderness were determined in duplicate and the average value reported for each replication of each variable. The average weight of muffin was 44 gm. Transducer used had a maximum force capacity of 3000 pounds, and the range was at 1/10X. The tenderness value was expressed as pounds force per gram according to the equation,

$$\text{Tenderness} = \frac{\text{Reading x Range x Transducer}}{\text{Sample wt. x 100}}$$

Compressibility was determined using the same instrument, equipped with model TC-1 compression test set. The range was set at 1/30X except the control muffins for which it was at 1/10X.

$$\text{Compressibility} = \frac{\text{Reading x Range x Transducer}}{100}$$

<u>Volume by rapeseed displacement</u> National loaf volumeter was filled with rapeseed to measure the volume of the muffins. The determination of the volume (cc) was calculating the difference between rapeseed volume of chamber with and without muffin.

<u>Volume index and symmetry index by template</u> AACC method 10-91 (AACC 1983) was used to determine volume, and symmetry. The muffins were cut in half horizontally, then laid over a modified template chart to obtain the volume index and symmetry. Afterward, muffins were labeled and wrapped by plastic film, stored in polyethylene bag at -18°C for the use of color determination.

<u>Color</u> The Hunter Color Difference Meter, model D25 optical head, was used for color determination of lightness, redness and yellowness. The instrument was standardized against a white tile (L=91.0, aL=-1.0, bL=0.9), then against a yellow tile (L=78.7, aL=-2.4, bL=23.0) for all the bran muffins. The muffins which had been frozen after the

readings of volume index and symmetry were thawed to room temperature before color was determined. Muffin interior color was determined for each type of muffins. Three readings of each measurement were made by turning the angel of 60 degree and the average was recorded as muffin crumb color.

Moisture Muffin moisture was determined using the AACC procedure 44-40 (AACC 1983). Approximately 2 g samples, weighed into previously dried moisture dishes to the nearest .0001 g. The uncovered samples were dried under a partial vacuum (ca 28 mm Hg) at 92-94°C for twelve hours in a Hotpack vacuum oven, model 633 (Hotpack Corp., Philadelphia, PA). Samples were reweighed after cooling to room temperature in a desiccator. Percentage moisture was calculated according to the formula:

$$\% \text{ Moisture} = \frac{\text{loss of moisture (g)}}{\text{wet wt. of sample (g)}} \times 100$$

Duplicate measures were made on each bake and the average was recorded as percentage moisture. Moisture determinations on the baked muffin involved grinding the muffin left from the compressibility trials to produce homogenous crumb before weighing each sample.

Chemical Measurements

Fiber analyses Fiber analysis was carried out by Kansas State University Chemical Analysis Laboratory for the Department of Food and Nutrition at Kansas State University. Prosky method (1984, 1985, and 1988) which was used to determine soluble, insoluble and total dietary fibers which are reported on a dried weight basis. Determination of soluble, insoluble dietary fiber equation is according to the calculation reviewed by Prosky et al (1988). Total dietary fiber was obtained from summation. Each value is the average of duplicate determinations.

Statistical Testing

The results derived from experiments on the effects of bran sources and particle sizes on the physical properties were analyzed for variance using the MSTAT (1985) program version 5.0. Fisher's Protected Least Significant Difference (FPLSD) (Fisher 1966) test was used to judge the significant difference between any pair of means.

Morphology of Microstructure of Muffin Samples by SEM

The effects of various brans incorporated into muffin batter system were studied. The primary objective of this phase of research was to examine if structural differences could be discerned among muffin batter prepared with the various sources of fiber at the two particle sizes. A secondary objective was to determine any changes of microstructure among the control muffin batter containing only whole wheat flour and the batters in which various sources of fiber at two particle sizes had been substituted at the 65% level for whole wheat flour. The same research was done for the baked muffins.

Specimen Preparation

Control flour and various types and sizes of brans Control flour, three cereals and four legumes were examined. All material were dried at 65°C for one hour in a air drying oven. A thin layer of the specimen was sprinkled onto aluminum stubs, and sputtered coating with gold for four minutes. The coated samples were stored in a desiccator and viewed in an JEOL JSM-35CF SEM at an accelerating voltage of 15 kv and a working distance of 39 mm.

Muffin batter All muffin-batters were kept in the sample jar, stored at 0°C in refrigerator. There were no prefixation or dehydration for specimen preparation. The EMscope SP-2000 Sputter-Cryo system in conjunction with a JEOL JSM-35C SEM was used for this work. A drop of the fresh sample was mounted on the copper stub. The mounted specimen was plunged into subcooled nitrogen in the freezing chamber of the apparatus and cooled to the temperature of the cryogen (ca. -196°C). Then, the sample was transferred, under vacuum, to the electron microscope which had been equipped with a cold stage. The specimen was etched to remove water film which would have obscured surface detail. This was done by heating the sample to -65°C and holding it at that temperature for five to ten minutes based upon the water content of the samples, then cooled further to -90°C. After etching, the sample was moved, under vacuum, to the work chamber. The work chamber contained a copper cold stage cooled to less than -160°C by liquid nitrogen. Here the sample was carefully fractured prior to sputter coating for four minutes. The specimen was then reinserted on the cold stage of the microscope for observation of the frozen hydrated specimen. The microscope stage temperature was maintained at an approximately -150°C by cooling with a dewer of liquid nitrogen. Microscope settings for the cryo stage work using a 15 kV beam.

Baked muffin The specimen of baked muffin were obtained after the determination of moisture content. A small portion, less than $5mm^2$, of the dried sample was mounted on the cryostage copper stub. This specimen was then directly inserted into work chamber, under vacuum, cooled two-three minutes prior to sputter coating for four minutes. The sample was then transferred to the cold stage of the microscope for examination of the frozen specimen. All samples were observed with JEOL JSM-35C SEM at a 15 kV, and a working distance of 15 mm.

RESULTS AND DISCUSSION

To evaluate the feasibility of producing acceptable high fiber baked products, three cereal brans and four legume brans were selected for incorporation into a cholesterol-free, low-salt muffin. These fiber sources were: oat, rice and wheat bran as well as black-eye pea bran and navy, pinto and soy bean bran. Each of the fiber sources were ground to two particle sizes: coarse which had particle size between 425 and 850 microns (between US 20-40 mesh screens) and fine which had particle size of less than 150 microns (pass through US 100 mesh screen). Physical, chemical characteristics and the ultrastructure of the fiber, muffin batters and muffins are reported.

Characteristics of Bran Sources

Hydration Capacity

Among all the brans in this study, the fine particle size had a lower water hydration capacity than the coarse particle size (Figure 1) with the exception of rice bran. Leguminous brans apparently absorbed more water than cereal brans. Among four leguminous brans, coarse black-eye pea bran had the highest hydration capacity, followed by the coarse

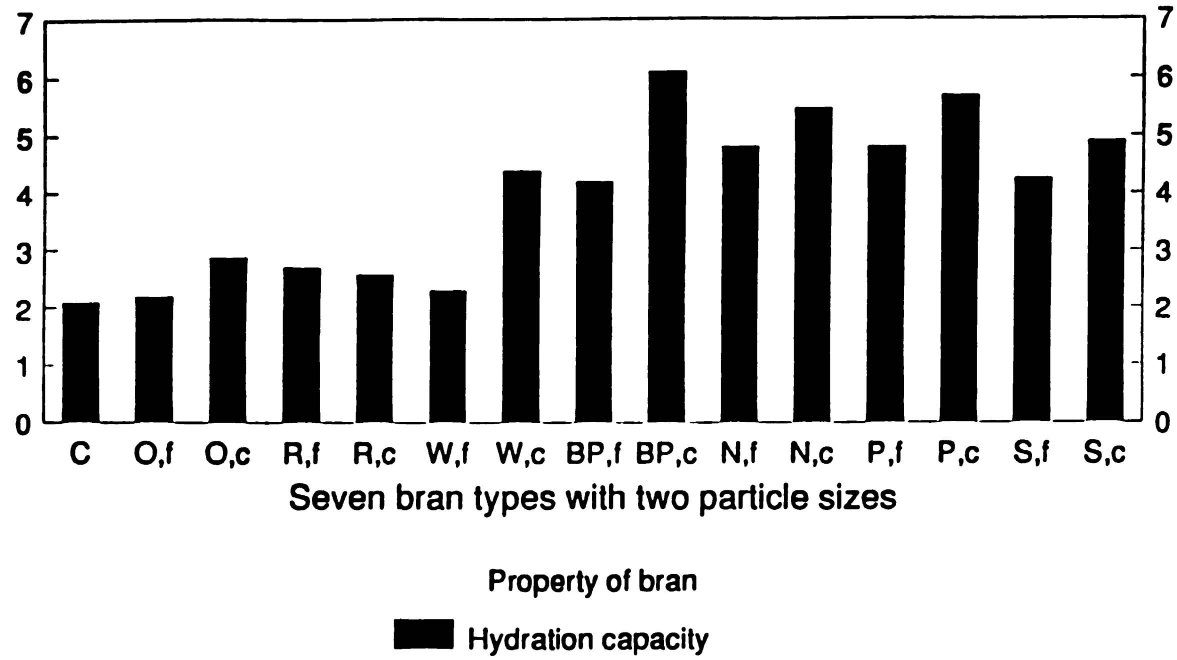

Figure 1. Comparison of water hydration capacity among coarse particle size and fine particle size of seven bran types (C=control flour, O,f=oat,fine, O,c=oat,coarse, R,f=rice,fine, R,c=rice,coarse, W,f=wheat,fine, W,c=wheat,coarse, BP,f=black-eye pea,fine, BP,c=black-eye pea,coarse, N,f=navy,fine, N,c=navy,coarse, P,f=pinto,fine, P,c=pinto,coarse, S,f=soy,fine, S,c=soy,coarse).

pinto bean bran, navy bean bran. Rice bran had the least difference of water hydration capacity (WHC) between fine and coarse particle sizes. Wheat bran had the greatest difference of water hydration capacity between fine and coarse particle sizes. Fine wheat bran has low value on hydration capacity, due, in part, to the collapse of its fiber matrix (Cadden 1987).

All differences in WHC which occur within and among fiber sources are related to the ability of the fiber source to entrap water (Cadden 1987). In this study, fine oat bran had a similar water hydration capacity to that of coarse oat bran. Reducing particle size resulted in a decreasing hydration capacity of oat bran which was the opposite result from that of Cadden's study. This discrepancy might be due to the differences between the procedures used to measure the water hydration capacity of the brans or that the method of processing resulted in a loss of indigestible *B*-glucan that is found in the cell walls of the outer endosperm (Sosulski and Wu 1988). Fine rice bran particles held more water than coarse rice bran in this study.

Ultrastructure

Based upon observation of SEM micrographs of various bran sources, the coarse brans all appeared as sponge-like fragments with a matrix structure (Figures 2-9). The samples selected by the researcher and appearing here have been chosen because they are considered to be representative of each individual grouping of pictures as seen under low and high magnification. All coarse bran particles were photographed at the low magnification between 48 and 600 (Figures 2-9), and all the fine particle size ultrastructure were photographed at the magnification of 1200 (Figures 10-17). However, soy bean bran had more wrinkled, synthetic fibrous surface which might relate to chemical distortion or heat treatment by the commercial processing (Figure 9 and 17). Hydration capacity of brans seemly was related to their ultrastructure.

The components of oat and rice brans for both coarse and fine micrographs (Figures 3,4,11,12, respectively) tended to agglomerate together into a cluster which made detection of individual plant cells difficult. The structure of oat and rice fine brans was not affected by the reduction of particle size, (comparison between Figure 3 and Figure 11, between Figure 4 and Figure 12, respectively), but the structure of particle size which resulted from diminishing of its fiber matrix structure into single plant cell (Figure 5 versus 13, 6 versus 14, 7 versus 15, 8 versus 16, 9 versus 17). The tendency of the oat and rice brans to agglomerate may account for little structural differences in the micrographs of the fine and coarse particles.

Cadden (1987) stated that grinding reduced not only particle diameter, but also the availability of the spaces for the rest of brans were affected visually by reducing the

Figure 2. SEM micrograph of the control flour composed of all purpose flour and whole wheat flour (50:50)(S=starch granules, P=protein, Bar=10 *um*).
Figure 3. SEM micrograph of coarse oat bran (Bar=100 um).
Figure 4. SEM micrograph of coarse rice bran (Bar=100 *um*).
Figure 5. SEM micrograph of coarse wheat bran (Bar=100 *um*).

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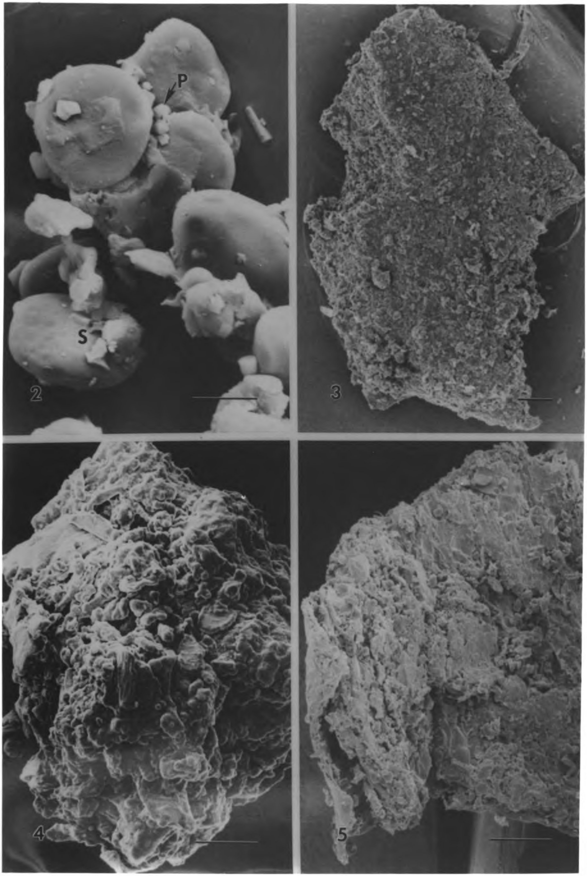

Figure 6. SEM micrograph of coarse black-eye pea bran (Bar=25 um).
Figure 7. SEM micrograph of coarse navy bean bran (Bar=100 um).
Figure 8. SEM micrograph of coarse pinto bean bran (Bar=10 um).
Figure 9. SEM micrograph of coarse soy bean bran (Bar=10 um).

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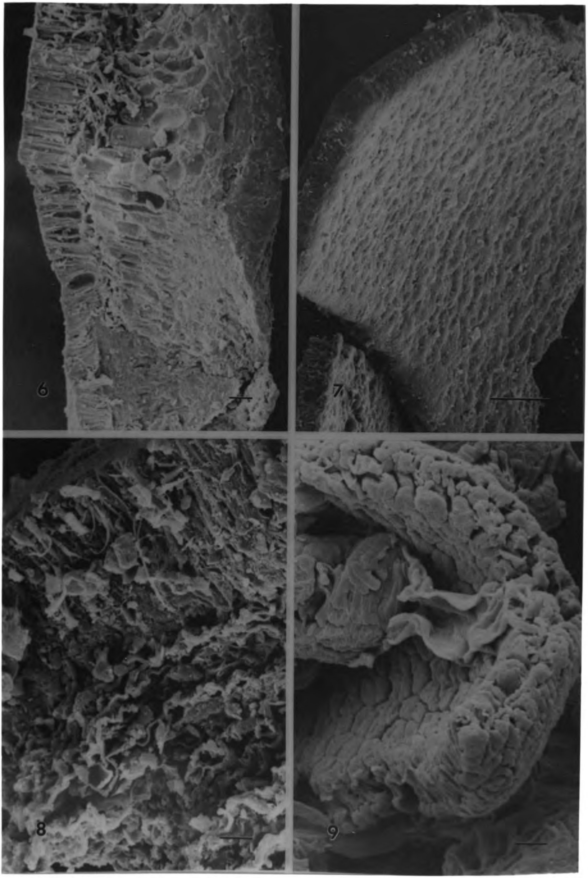
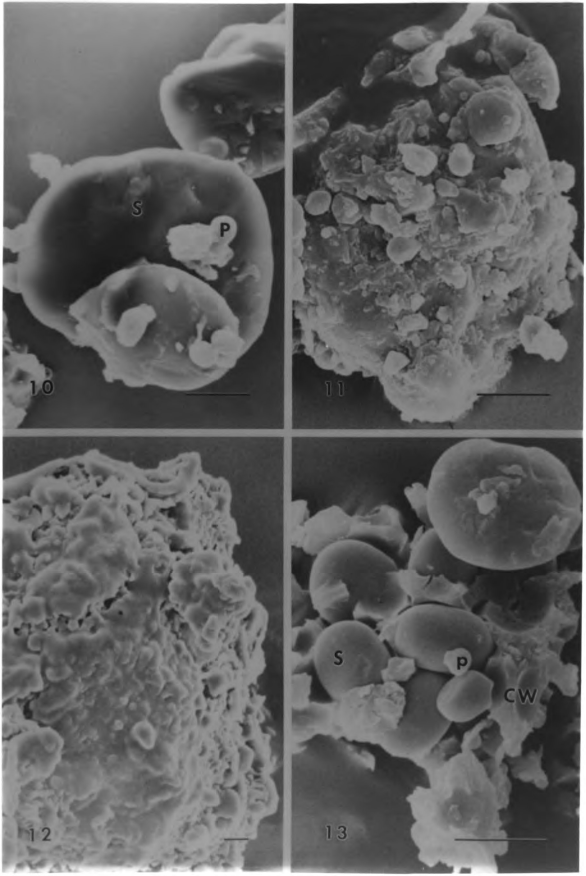


Figure 10. SEM micrograph of the control flour which composed of all purpose flour and whole wheat flour(50:50) (Bar=10 um, S=starch granules, P=protein body).
Figure 11. SEM micrograph of fine oat bran (Bar=10 um).
Figure 12. SEM micrograph of fine rice bran (Baar=10 um).
Figure 13. SEM micrograph of fine wheat bran (S=starch, P=protein, CW=cell wall, Bar=10 um).



10
S
P
11
12
13
S
p
CW

Figure 14. SEM micrograph of fine black-eye pea bran (Bar=10 um).
Figure 15. SEM micrograph of fine navy bean bran (Bar=10 um).
Figure 16. SEM micrograph of fine pinto bean bran (Bar=5 um).
Figure 17. SEM micrograph of fine soy bean bran (Bar=1 um).

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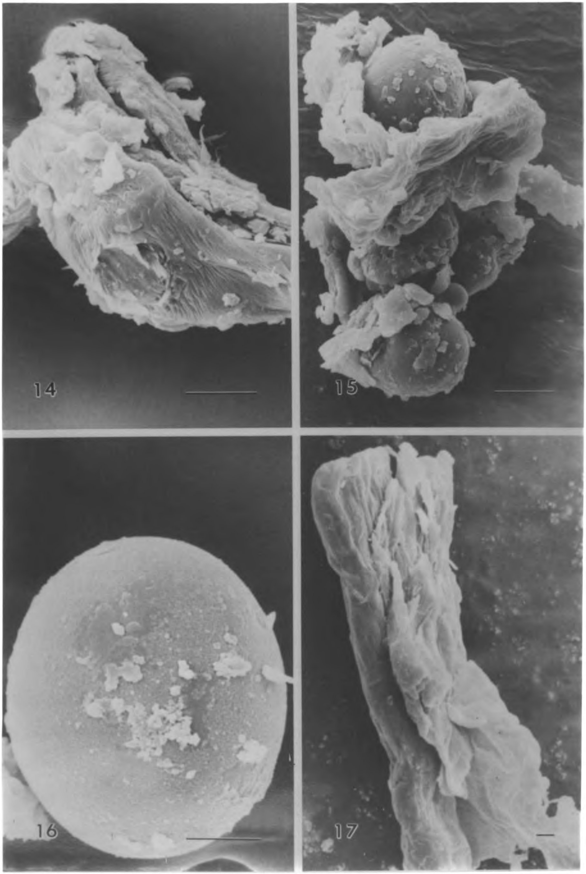


free water in the fiber matrix in the case of wheat bran, but not in oat or rice bran. Processing of oat bran and rice bran differed from the processing of leguminous brans. To process the oat and rice brans, the oat grouts and rice kernels were first steam-treated and kiln-dried to inactive the lipase enzymes present in the bran layers. Layers of the plant cell wall of commercial oat and rice bran were found to have collapsed making identification of component structure impossible. Grinding the oat bran and rice bran particles reduced the mean particle diameter but had no further effect on disrupting physical structure (Figure 3 versus 11, and Figure 4 versus 12). This lack of identifiable plant walls was also confirmed in Cadden's (1987) study on oat groats.

Sources of Variance in Physical Evaluation of Muffin Batters and Muffins

Analysis of variance of physical evaluation test data revealed that the independent variable treatments - bran source were the major source of significant variation in this project. These analyses of variance are included in the Appendices (2-6). More than one-half of the characteristics evaluated by physical measurement means showed significant differences as a result of the type of bran used in the muffin variables. The other independent variable - particle size showed significant variation for only one batter characteristic and two muffin characteristics. Significant interactions between bran sources and bran particle sizes were established for muffin color and selected physical characteristics.

Effect of Particle Size on Muffin Batter and Muffin Characteristics

Viscosity which was tested by Brookfield Viscometer, compressibility which was determined by Allo-Kramer texture press, and moisture content showed significant differences at the 5% level (Table 3) due to bran particle size. Incorporation of fine particle brans in place of 65% of the whole wheat flour in the muffin formulation resulted in higher batter viscosity while substitution of coarse bran reduced the muffin batter viscosity. Brockmole and Zabik (1976) reported that the additions of bran and middlings increase the viscosity in cake batter which may relate to the increased water absorption capacity of the fiber constituents. Jeltema and Zabik (1979) showed that when 30% of the flour in a white layer cake was substituted with either corn bran, soy bran, or oats bran using a particle size similar to that of the flour, the viscosity of the resulting cake batter was increased. They also reported that cakes made with a smaller particle size fiber source (297 *u*) had the greatest increase in viscosity in cake batter. DeFouw et al (1982a) indicated that the addition of 15% of unroasted navy bean hulls in spice-flavored layer cakes also resulted in a thicker batter.

Table 3. Effect of Bran Particle Size on Physical Characteristics of Muffins

	Batter	Baked Muffins	
Muffin Types	Viscosity (cps)	Compressibility (lb)	Moisture (%)
Control	41.7	114.7	35.75
Fine size of brans[1] (<150 microns)	48.0	87.7	39.29
Coarse size of brans[2] (between 425-850 microns)	36.2	78.8	40.48
LSD (P=0.05)	10.27	6.59	0.90

[1] Each mean is the average of values from fifty-two bran muffins incorporated with fine bran particle size.
[2] Each mean is the average of values from fifty-two bran muffins incorporated with coarse bran particle size.

Substitution of bran reduced the force required to compress the muffins (Table 3). Use of coarse brans, reduced the force required to compress the muffin significantly more ($p<0.01$) than the use of fine particle size brans (< 150 *u*). DeFouw et al (1982b) reported that 10-30% substitution of navy bean hulls in sugar-snap cookies decreased shear compression (lb/g).

Use of fine and coarse particle brans produced muffins with a greater percentage of moisture; however, muffins which contained the coarse bran had significantly higher ($p<0.01$) moisture than muffins prepared with fine brans. Sosulski and Wu (1988) found that bread substituted with wheat bran, corn bran, field pea hulls, or wild oat bran all increased water absorption (%). With the exception of wild oat bran, the substitution of wheat bran, corn bran, or pea hulls increased water absorption in proportion to the increment of fiber replacement of wheat flour. Chen et al (1988a) reported that the incorporation of 4, 8, and 12% either apple fiber, wheat bran, or oats bran into muffin batter, increased the density (g/cm^3) of resulting muffins.

Physical Measurement of Muffin Batter

Specific Gravity

Analysis of variance (ANOVA) showed that the type of bran significantly ($p<0.05$) affected the specific gravity of muffin batter. The average specific gravity of each muffin batter from all types of bran used at two particle sizes is shown in Table 4. Table 5 gives the average specific gravity for the batter for each type of bran as well as the control muffin batter. All brans lowered batter specific gravity. Brans were presoaked in the water before being incorporated into other ingredients which resulted in a lighter, more porous batter. This was particularly evident for the following muffin batters: black-eye peas, coarse; navy bean, coarse; and pinto bean, coarse (Table 4). It was assumed that the additional water requirements diluted the density of the total ingredients. Control batter had the least amount of water usage with the highest value for specific gravity as compared with pinto coarse bran muffin batter which had the greatest additional requirement of water and had the lowest value for specific gravity (Figure 18).

This reduction in specific gravity was also confirmed by Sosulski and Wu (1988) who reported that substitution of 20% of wheat bran, corn bran, field pea hulls, or wild oat bran into bread lowered specific volume (cm^3). Chen et al (1984) found that specific volume (cc/g) can be used as an index of capillary structural differences, higher values being

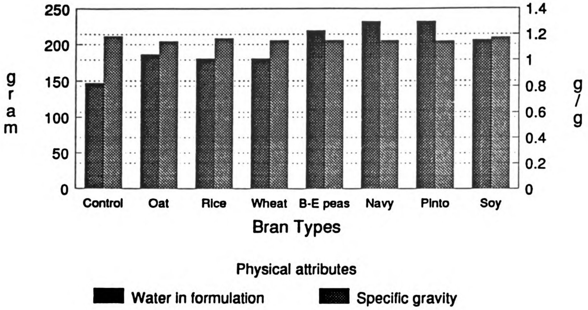


Figure 18. Relation between specific gravity of the muffin batter and water requirement of the brans

associated with greater fiber porosity and the ability to imbibe, but not necessarily retain more water. However, the measurement and method of specific volume (cm^3/g) in the study of Sosulski and Wu (1988) was different from the study of Chen et al (1984).

Viscosity

As previously discussed, muffins prepared with the fine particle size of bran were significantly ($p<0.01$) more viscous than the muffins prepared with the coarse particle size of bran. But, there was no significant difference between the control and the muffins containing any type of bran on the effect of bran sources (Table 4 and 5).

Water Activity

Water activity showed significant difference attributable to the interaction of bran sources and particle size on muffin batter (Appendix 2). However, there were no significant difference between control muffin and the muffins prepared with various brans or the muffins prepared with fine or coarse particle sizes (Table 4 and 5).

Physical Measurements of Baked Muffins

Baking Loss, Moisture and Water Activity

Statistical analyses of baking loss showed no significant difference due to the effect of bran sources or particle size

Table 4. Specific Gravity, Viscosity and Water Activity[1] of Muffin Batter Prepared with Various Brans with Two Particle Sizes[2]

Bran Types	Specific Gravity Mean[3]	Specific Gravity SE	Viscosity Mean[3]	Viscosity SE	Aw Mean[4]	Aw SE
Control	1.18	0.01	41.70	2.15	0.94	0.02
Oats,fine	1.14	0.02	45.15	8.43	0.94	0.00
Oats,coarse	1.15	0.01	27.28	4.91	0.95	0.00
Rice,fine	1.16	0.01	30.15	6.94	0.96	0.01
Rice,coarse	1.18	0.01	29.40	5.94	0.95	0.00
Wheat,fine	1.15	0.02	43.45	6.94	0.92	0.01
Wheat,coarse	1.15	0.02	37.90	10.05	0.95	0.00
Black-eye pea, fine	1.16	0.00	45.95	5.52	0.94	0.01
Black-eye pea, coarse	1.14	0.01	59.05	17.87	0.95	0.01
Navy,fine	1.16	0.00	65.48	16.96	0.96	0.01
Navy,coarse	1.14	0.00	25.95	6.44	0.93	0.01
Pinto,fine	1.15	0.01	70.76	9.98	0.94	0.01
Pinto,coarse	1.13	0.01	32.80	7.51	0.95	0.01
Soy,fine	1.18	0.01	41.13	8.17	0.93	0.01
Soy,coarse	1.17	0.01	35.50	1.50	0.96	0.00
LSD (P=0.05)	0.03		27.21			

[1] Mean and standard error of the mean based on four replication.
[2] Fine is <150 microns, and coarse is between 425-850 microns.
[3] Each mean is the average of values from four replications, one sample/replication.
[4] Each mean is the average of values from four replications, three samples/replication.

Table 5. Effect[1] of Various Brans on Specific Gravity, Viscosity and Water Activity Measurements of Muffin Batters

Muffin Types	Specific[2] Gravity (g/g)	Viscosity (cps)	Aw
Control muffin[3]	1.184	41.7	0.937
Cereal brans:			
Oats bran	1.145	36.2	0.946
Rice bran	1.165	29.8	0.952
Wheat bran	1.151	40.7	0.934
Leguminous brans:			
Black-eye peas	1.151	52.5	0.943
Navy bean	1.150	45.7	0.944
Pinto bean	1.143	51.8	0.946
Soy bean	1.172	38.3	0.942
LSD (P=0.05)	0.019	-	-

[1] Each mean is the average of values obtained from fine and coarse muffins with four replications.
[2] Significant at the 5% level.
[3] Control muffin is composed of 50:50 of all purpose flour with whole wheat flour.

as shown in ANOVA tables included in the Table 6 and Appendix 7. Moisture content analyses indicated that the muffins containing any type of bran were generally more moist than the control muffin (Table 6). Moreover, the muffins prepared with leguminous brans had higher water content than the muffins prepared with cereal brans (Table 7). ANOVA of water activity showed no significant difference among any of the muffins (Table 7)(Appendix 8). Chen et al (1988a) reported that the baking loss decreased with the addition of either apple fiber, coarse wheat bran or coarse oat bran muffin when the muffins were baked at 196°C (385°F) for 15 minutes.

Table 6. Baking Loss, Moisture and Water Activity[1] of Baked Muffins Prepared with Two Particle Sizes[2]

	Baking Loss(%)		Moisture(%)		Aw	
Bran Types	Mean[3]	SE	Mean[4]	SE	Mean[5]	SE
Control	8.83	0.27	35.75	0.61	0.90	0.01
Oats,fine	9.52	0.20	35.11	0.46	0.91	0.01
Oats,coarse	9.96	0.05	40.16	0.64	0.92	0.01
Rice,fine	11.00	0.69	40.20	1.54	0.91	0.02
Rice,coarse	10.32	0.54	38.30	1.32	0.92	0.01
Wheat,fine	9.55	0.35	36.40	0.41	0.91	0.01
Wheat,coarse	9.57	0.38	39.24	0.27	0.91	0.01
Black-eye pea, fine	9.76	0.26	41.04	0.77	0.92	0.01
Black-eye pea, coarse	9.85	0.43	43.75	0.90	0.93	0.01
Navy,fine	9.41	0.37	41.79	0.44	0.91	0.02
Navy,coarse	9.95	0.12	42.89	1.06	0.91	0.02
Pinto,fine	9.34	0.63	43.12	0.74	0.91	0.03
Pinto,coarse	10.16	0.55	42.07	0.76	0.93	0.01
Soy,fine	10.00	0.21	40.95	0.85	0.92	0.01
Soy.coarse	9.42	0.74	41.69	1.04	0.91	0.02
LSD (P=0.05)			2.16			
LSD (P=0.01)			2.88			

[1] Mean and standard error of the mean based on four replications.

[2] Fine is <150 microns, and coarse is between 425-850 microns.

[3] Each mean is the average of values obtained from four replications, six samples/replication.

[4] Each mean is the average of values obtained from four replications, two samples/replication.

[5] Each mean is the average of values obtained from four replications, three samples/replication.

Table 7. Effect[1] of Various Brans on Baking Loss, Moisture and Water Activity Measurements of Baked Muffins

Muffin Types	Baking Loss(%)	Moisture(%)	Aw
Control muffin[2]	8.83	35.75	0.896
Cereal brans:			
Oats bran	9.74	37.63	0.917
Rice bran	10.66	39.25	0.913
Wheat bran	9.56	37.82	0.934
Leguminous brans:			
Black-eye peas	9.80	42.40	0.943
Navy bean	9.68	42.34	0.944
Pinto bean	9.75	42.59	0.946
Soy bean	9.71	41.32	0.942
LSD (P=0.05)		1.68	
LSD (P=0.01)		2.25	

[1] Each mean is the average of values obtained from fine and coarse muffins with four replications.

[2] Control muffin is composed of 50:50 of all purpose flour with whole wheat flour.

Volume by Rapeseed Displacement, Volume Index, and Symmetry Index

Volume by rapeseed displacement reflects the over all size of the muffins. Volume index by template illustrates the height of the muffins. Symmetry index shows the curvature of the surface of the muffins. Bran sources significantly affected the volume of the muffins (Table 8 and 9). But bran particle size had no significantly effect on the volume of the muffins (Appendix 9).

Muffin formulations containing various cereal brans in place of 65% of whole wheat flour, even with extra water added, generally yielded muffins having the same or better volume indexes as the control (Table 9). Volume of the muffins was not adversely affected by the cereal brans which produced a slightly higher volume index, but the use of oat and rice bran resulted in muffins which were more peaked (Figure 19). In contrast, the incorporation of leguminous brans significantly ($P<0.01$) reduced muffin volume as measured by rapeseed displacement as well as by the volume index. However, the symmetry indices of the muffins which contained leguminous brans were similar to that of the control. These all had less peaked surfaces than the muffins with oat or rice bran (Table 9). Chen et al (1988a) reported that increase the level of apple fiber, wheat bran or oat bran into muffin decreased the loaf volume as measured by rapeseed displacement. Sosulski and Wu (1988) indicated that substituting flour with wheat bran, corn bran, field pea hulls or wild oat bran decrease loaf volume in proportion to the level of addition of bran. Jasberg et al (1989) reported that replacement of more than 20% of the flour with alkaline hydrogen peroxide treated wheat straw caused a reduction in the height of the center peak, resulting in a slightly flatter cake profile. Pomeranz et al (1977) suggested that the decrease in loaf volume in bread containing fiber substituted for flour was due to the dilution of gluten in bread making. This reduction in loaf volume could also result from the interaction between gluten and fiber material (Chen et al 1988b). Among the leguminous bran muffins, the muffin which contained soy bran ground to a fine particle size, ie., less than 150 microns, had higher volume (cc) and higher height and higher peak than the rest of leguminous bran muffins. Jasberg et al (1989) also found that the volume index of chocolate cake was affected by the percent of replacement of fiber as well as by the amount of water used.

Table 8. Volume and Shape Measurements[1] of Baked Muffins Prepared with Various Bran Sources with Two Particle Sizes[2]

	Volume (cc)		Volume Index (mm)		Symmetry Index (mm)	
Bran Types	Mean[3]	SE	Mean[3]	SE	Mean[3]	SE
Control	125.0	2.89	125.8	2.72	7.0	2.88
Oats, fine	125.0	5.40	131.0	0.71	12.0	1.68
Oats, coarse	120.0	4.56	128.3	1.25	11.3	0.75
Rice, fine	125.0	2.89	129.0	2.12	11.8	0.85
Rice, coarse	122.5	2.50	131.3	3.20	11.3	0.48
Wheat, fine	127.5	3.23	129.5	2.96	8.5	0.50
Wheat, coarse	122.5	2.50	123.5	0.96	9.3	1.65
Black-eye peas, fine	112.5	3.23	108.3	2.46	8.8	1.25
Black-eye peas, coarse	111.3	3.75	112.8	1.93	5.8	0.48
Navy, fine	108.8	1.25	118.0	1.08	9.5	0.65
Navy, coarse	116.3	3.15	114.5	0.96	7.0	1.08
Pinto, fine	112.5	3.23	114.3	1.25	8.8	1.60
Pinto, coarse	117.5	1.44	111.3	1.70	7.3	0.95
Soy, fine	117.5	3.23	121.8	0.95	10.3	0.63
Soy, coarse	112.5	2.50	119.0	2.12	10.0	1.58
LSD (P=0.05)	8.2		5.1		3.1	

[1] Mean and standard error of the mean.

[2] Fine is <150 microns, and coarse is between 425-850 microns.

[3] Each mean is the average of values obtained from four replications, one sample/replication.

Table 9. Effect[1] of Bran Sources on Volume and Shape Characteristics of Baked Muffins

Muffin Types	Volume (cc)	Volume Index (mm)	Symmetry Index (mm)
Control[2]	125.0	126.0	7.0
Cereal brans:			
Oats bran	123.0	130.0	12.0
Rice bran	124.0	130.0	12.0
Wheat bran	125.0	127.0	9.0
Leguminous brans:			
Black-eye peas	112.0	111.0	7.0
Navy bean	113.0	116.0	8.0
Pinto bean	115.0	113.0	8.0
Soy bean	115.0	120.0	10.0
LSD (P=0.05)	5.8	3.6	2.2
LSD (P=0.01)	7.7	4.9	3.0

[1] Each mean is the average of values obtained from fine and coarse muffins from four replications.

[2] Control muffin is composed of 50:50 of all purpose flour with whole wheat flour.

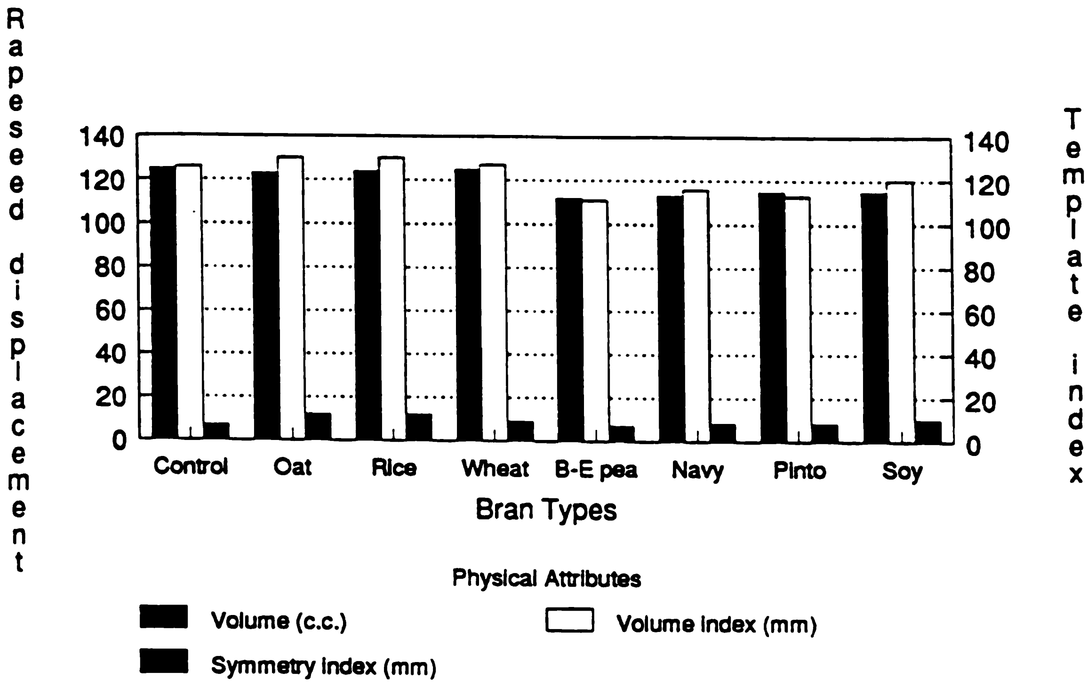


Figure 19. Effect of seven bran sources on volume and shape measurements of the muffins

Hunter Color Measurements

ANOVA established significant difference among the L, aL, and bL color values which reflect the lightness, redness, and yellowness in bran muffins, respectively. The bran sources significantly ($P<0.01$) affected the color of the muffins (Table 10 and 11), but the particle size of the brans used had no effect on the color of the muffins (Appendix 10) except for muffins which contained black-eye peas and pinto bran. Figure 20 represents the effect of bran sources on L, aL, bL color values. Pinto bean and black-eye pea produced the darkest muffins. Oat bran, navy bran and soy bran had very similar lightness, redness and yellowness color values, which could be of commercial importance in the future. It is feasible to replace oat bran with either navy bran or soy bran without a detrimental effect on the color of the resulting bakery products.

The various sources of brans incorporated into muffin affected the L color value of lightness of the muffins significantly. Muffins with fine oat bran, fine soy bean bran, and fine wheat bran had lighter colors than the control muffin (Table 10). Jeltema and Zabik (1979) reported that the substitution of various cereal brans - corn, soy, or oats resulted in a darker cake. Sosulski and Wu (1988) presented results that showed the substitution of 20% wheat bran or oat bran produced a darker colored bread than the control bread.

Table 10. Color Measurements[1] of Baked Muffins Prepared with Various Bran Sources with Two Particle Sizes[2]

	Interior Color					
	L^3		aL^3		bL^3	
Bran Types	Mean[4]	SE	Mean	SE	Mean	SE
Control	43.53	0.74	4.42	0.15	13.83	0.22
Oats,fine	46.21	0.46	3.84	0.06	14.82	0.04
Oats,coarse	44.89	0.67	3.73	0.14	14.51	0.22
Rice,fine	41.58	0.71	4.18	0.07	13.89	0.13
Rice,coarse	43.33	0.47	4.17	0.02	13.65	0.25
Wheat,fine	45.56	0.56	4.08	0.08	14.94	0.38
Wheat,coarse	41.28	1.09	4.90	0.23	14.12	0.08
Black-eye pea, fine	25.38	0.61	2.73	0.13	5.03	0.16
Black-eye pea, coarse	31.66	0.54	2.50	0.12	7.77	0.14
Navy,fine	43.39	0.99	3.18	0.26	13.48	0.22
Navy,coarse	43.41	0.77	3.51	0.09	13.38	0.10
Pinto,fine	31.72	0.64	4.41	0.09	9.17	0.16
Pinto,coarse	31.97	0.66	3.68	0.07	8.54	0.09
Soy,fine	46.20	0.46	3.38	0.04	13.62	0.05
Soy,coarse	45.39	0.56	3.20	0.05	13.20	0.10
LSD (P=0.05)	1.51		0.33		0.43	
LSD (P=0.01)	2.03		0.44		0.58	

[1] Mean and standard error of the mean based on four replications.
[2] Fine is <150 microns, and coarse is between 425-850 microns.
[3] L is lightness, +a is redness, +b is yellowness.
[4] Each mean is the average of values from four replications, one sample/replication, three readings/sample.

Table 11. Effect[1] of Various Brans on Color Measurements[2] of Baked Muffins

Muffin Types	Interior Color L	aL	bL
Control[3]	43.53	4.41	13.83
Cereal brans:			
Oats bran	45.55	3.79	14.66
Rice bran	42.45	4.17	13.77
Wheat bran	43.42	4.49	14.53
Leguminous brans:			
black-eye peas	28.52	2.61	6.40
Navy bean	43.40	3.35	13.43
Pinto bean	31.84	4.05	8.85
Soy bean	45.80	3.29	13.41
LSD (P=0.05)	1.07	0.23	0.31
LSD (P=0.01)	1.43	0.31	0.41

[1] Each mean is the average of values obtained from fine and coarse muffins from four replications, one sample/replication, three readings/sample.

[2] L is lightness, +a is redness, +b is yellowness.

[3] Control muffin is composed of 50:50 of all purpose flour with whole wheat flour.

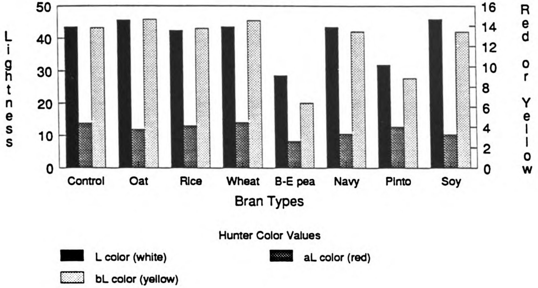


Figure 20 Effect of seven bran sources on L, aL, bL Hunter color values of the muffin

When either fine or coarse black-eye pea or pinto bean bran was incorporated into muffins, the resulting product had a much darker color than control muffin (Table 10). In the process of reducing black-eye pea bran, the section of black eye dots on the seed coat of black-eye peas became a part of the constituents of the fine black-eye pea bran; the rest of seed coat was processed into coarse bran.

Finely ground soft white wheat bran incorporation into the muffins in this study, resulted in muffins with a lighter color than muffins which contained coarse white wheat bran. In contrast, substitution of finely ground rice bran produced slightly darker muffin than did the substitution of coarse rice bran. These type of findings contribute to the significant interactions between bran type and particle size.

Coarse wheat bran incorporated into muffin produced a slightly more red muffin than the control muffin. Muffins which contained fine pinto bran had the same yellowness as the control muffin. The rest of bran muffins were less red, than the control muffin while muffin with black-eye pea bran had the least redness (Table 10 and 11). Jeltema and Zabik (1979) reported that 30% substitution of cereal brans decreased the red color, especially for the cake which contained soy bean. However, Sosulski and Wu (1988) reported that the addition of wheat bran and wild oat bran resulted in more redness than control bread which possessed a slightly negative aL value. Both wheat and oat bran muffins had a negative aL value. Both wheat and oat bran muffins had a significantly (P<0.01) more yellow color than that of the control muffin. In contrast, black-eye pea and pinto bran incorporated into muffins produced a significantly (P<0.01) less yellow value (Table 10 and 11). DeFouw et al (1982b) reported that substitution of either raw navy bean hulls or navy bean hulls which had been subjected to a moderate roasting in sugar-snap cookies resulted in less yellowness than the control cookies. Sosulski and Wu (1988) reported that wheat bran resulted in lower yellowness values in bread.

Tenderness and Compressibility

The particle size did not significantly affect the tenderness values using shear press, but did affect the pounds of force necessary to compress the muffins. ANOVA indicated that they were significant differences for the effect of bran source on muffin tenderness. All of the muffins prepared with various sources brans were more tender than the control muffin. Brans incorporated into muffins reduced the shear value, i.e. lower shear force. Muffins prepared with black-eye peas bran had the lowest shear value (P<0.01) of all the muffins containing any other source of bran (Table 12) but differed from the shear values for muffins containing soy bran only at P<0.05. The control muffin required the highest force per gram to shear and thus were the least tender (P<0.01) (Table 13). Pomeranz et al (1984) reported that brans weakened gluten structure of bread. Weakening of the gluten

Table 12. Tenderness and Compressibility Measurements[1] of Baked Muffins Prepared with Various Brans with Two Particle Sizes[2]

Bran Types	Tenderness (lb/g) Mean[3]	SE	Compressibility (lb) Mean[4]	SE
Control	5.76	0.61	114.75	8.62
Oats,fine	4.08	0.16	103.00	2.38
Oats,coarse	3.73	0.06	71.50	4.77
Rice,fine	3.01	0.38	73.00	7.82
Rice,coarse	3.15	0.36	87.50	3.93
Wheat,fine	3.84	0.22	101.00	7.20
Wheat,coarse	4.35	0.33	85.25	5.33
Black-eye pea, fine	2.41	0.14	73.13	9.00
Black-eye pea, coarse	3.31	0.39	55.00	6.29
Navy,fine	3.21	0.16	65.50	5.91
Navy,coarse	3.41	0.19	60.63	8.07
Pinto,fine	3.32	0.16	90.25	7.25
Pinto,coarse	3.80	0.15	69.50	12.14
Soy,fine	3.39	0.26	80.75	10.02
Soy,coarse	3.12	0.43	86.00	5.96
LSD (P=0.05)	0.67		17.43	
LSD (P=0.01)			23.32	

[1] Mean and standard error of the mean.
[2] Fine is <150 microns, and coarse is between 425-850 microns.
[3] Each mean is the average of values from four replications, two samples/replication.
[4] Each mean is the average of values from four replications, one sample/replication.

structure in muffins probably also occurred, even though the muffin system produces less gluten formation than the bread system. In other words, the incorporation of brans might prevent the firmness of the muffins, due to the fact that bran held water more tightly, thus, the flour protein and starch could not compete for the water which had become bound to the brans through the length of presoaking. So there was less water available for glutenin and gliadin to form gluten which would affect the value of shear force (lb/g). Johnson (1990) reported that storage time (9 hours, 33 hours, and 7 days) had a significant effect on the tenderness characteristic of muffins which contained 5, 15, and 25% replacement levels of waxy rice flour for wheat flour.

All bran sources reduced the compression value of the muffins in which they were in corporated (Table 12 and 13). The muffins containing fine brans had lower value of compressibility than the muffins containing coarse brans. ANOVA which are included in the Appendix 6 showed that there were significant differences due to the effect of bran source on muffin compressibility, too. Navy bean bran or black-eye pea bran incorporated into muffin had significantly lower values (P<0.01) than the compressibility of the other muffins containing bran (Table 12). Figure 21 shows that the correlation between compressibility and tenderness of the muffins. The reduction of compressibility value might relate to the sponge-liked structure of coarse brans which provide

Table 13. Effect[1] of Various Brans on Tenderness and Compressibility of Baked Muffins

Muffin Types	Tenderness (lb/g)	Compressibility (lb)
Control muffin[2]	5.76	114.75
Cereal brans:		
Oats bran	3.90	87.25
Rice bran	3.08	80.25
Wheat bran	4.10	93.13
Leguminous brans:		
Black-eye peas	2.86	64.07
Navy bean	3.31	63.07
Pinto bean	3.56	79.88
Soy bean	3.26	83.38
LSD (P=0.05)	0.34	12.33
LSD (P=0.01)	0.45	16.49

[1] Each mean is the average of values obtained from fine and coarse muffins with four replications.
[2] Control muffin is composed of 50:50 of all purpose flour with whole wheat flour.

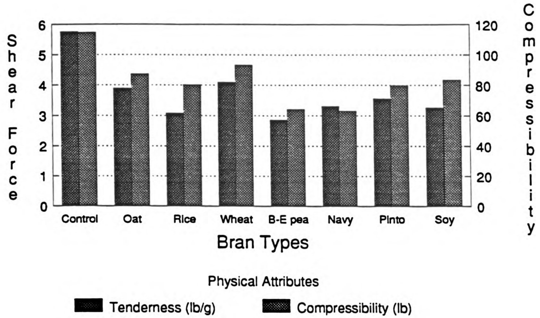


Figure 21. Relation between tenderness and compressibility of the muffins

more spaces for liquid and gas remaining in fiber matrix.

Chemical Analyses of Dietary Fiber

The Prosky method was used to determine total dietary fiber (TDF), soluble dietary fiber (SDF), and insoluble dietary fiber (IDF) by Kansas State University Analytical Laboratory as part of the interstate cooperative efforts of the North Central Regional research project. Table 14 and Table 15 illustrate result of these dietary fiber analyses on a dry weight basis, for the control muffin and muffins with seven types bran ground to two particle sizes.

Muffins prepared with fine navy bean bran substituted for 65% of the whole wheat flour contained the highest TDF value among all of the muffins prepared with any types of bran (Table 14). Muffin prepared with fine oat bran had the lowest TDF value (Table 14). Muffins prepared with all leguminous brans had much higher concentrations of TDF and IDF than TDF and IDF found in the control muffin prepared with all purpose flour and whole wheat flour in a 50:50 ration. The components of insoluble dietary fiber are composed primarily of cellulose and hemicellulose which cause the increase of fecal weight (Schneeman 1986, Ranhotra et al 1988). Sosulski and Wu (1988) reported that field pea hulls and corn bran have exceedingly high content of TDF. TDF content of fine or coarse wheat bran contained lower TDF values than reported the other studies had been reported (Prosky et al 1985, Li and Andrews 1988, Mongeau and Brassard 1990). Low TDF values can be the result of filtration problems (Prosky et al 1988). Muffins prepared with oat bran had the lowest amount of TDF, but the proportion of SDF to TDF was the highest (29.10%). In contrast the proportion of SDF to TDF of control muffin was 21.40%, and the proportion of SDF to TDF of the muffin prepared with coarse soy bran was the lowest (6.30%).

Table 15 reveals that composition of TDF, SDF, and IDF in a 100 gm baked muffin. This allows for comparison of the dietary fiber contribute of each muffin variable. The result showed that muffins prepared with fine navy bean bran provided the highest IDF and TDF, while muffins prepared with fine oat bran had the lowest contribution IDF and TDF to a persons diet. Over all, muffins prepared with leguminous brans offer much higher potential intake TDF and IDF than did muffins prepared with cereal brans. The higher amount of SDF in the control muffin could be the starch which was not fully digested by enzymes used in the Prosky method or retrogradated starch being counted as a part of soluble dietary fiber.

Table 14. Determination[1] of Dietary Fiber on a Dry Weight Basis for Baked Muffins Substituted with Seven Brans Ground to Two Particle Sizes[2]

Bran Muffin Types	TDF %	SDF %	IDF %	Contribution to TDF: SDF %	Contribution to TDF: IDF %
Control	13.27	2.84	10.43	21.40	78.60
Oats, fine	8.11	2.36	5.75	29.10	70.90
Oat, coarse	12.90	2.26	10.64	17.52	82.48
Rice, fine	15.35	2.97	12.38	19.35	80.65
Rice, coarse	14.62	1.84	12.78	12.59	87.41
Wheat, fine	20.82	1.02	19.80	4.90	95.10
Wheat, coarse	16.62	1.34	15.28	8.06	91.94
Black-eye peas, fine	20.47	1.91	18.57	9.33	90.72
Black-eye peas, coarse	22.28	2.36	19.91	10.59	89.36
Navy bean, fine	32.58	2.50	30.08	7.67	92.33
Navy bean, coarse	21.90	1.22	20.68	5.57	94.43
Pinto bean, fine	21.93	1.40	20.53	6.38	93.62
Pinto bean, coarse	24.56	1.99	22.56	8.10	91.86
Soy bean, fine	25.80	2.05	23.74	7.95	92.02
Soy bean, coarse	27.93	1.76	26.17	6.30	93.70

[1] Results of Prosky (AOAC method), based upon the average of two samples (% dry basis), four replications for each sample.

[2] Fine particle size is <150 microns while coarse ranged from 425 to 850 microns.

Table 15. Composition[1] of Dietary Fiber in the Muffins ("as is basis")

Bran Muffin Types	TDF g	SDF g	IDF g
Control	6.88	1.45	5.38
Oats, fine	4.17	1.43	2.94
Oats, coarse	5.90	1.05	4.85
Rice, fine	7.11	1.36	5.77
Rice, coarse	6.79	0.86	5.95
Wheat, fine	10.79	0.56	10.22
Wheat, coarse	8.36	0.68	7.70
Black-eye peas, fine	9.33	0.87	8.46
Black-eye peas, coarse	10.34	1.12	9.22
Navy bean, fine	15.52	1.15	14.39
Navy bean, coarse	9.94	0.56	9.34
Pinto bean, fine	10.12	0.64	9.48
Pinto bean, coarse	11.28	0.94	10.36
Soy bean, fine	11.73	0.92	10.83
Soy bean, coarse	13.39	1.02	12.32

[1] Results of Prosky method (Table 14) converted to "as is" basis for a 100 g baked muffins.

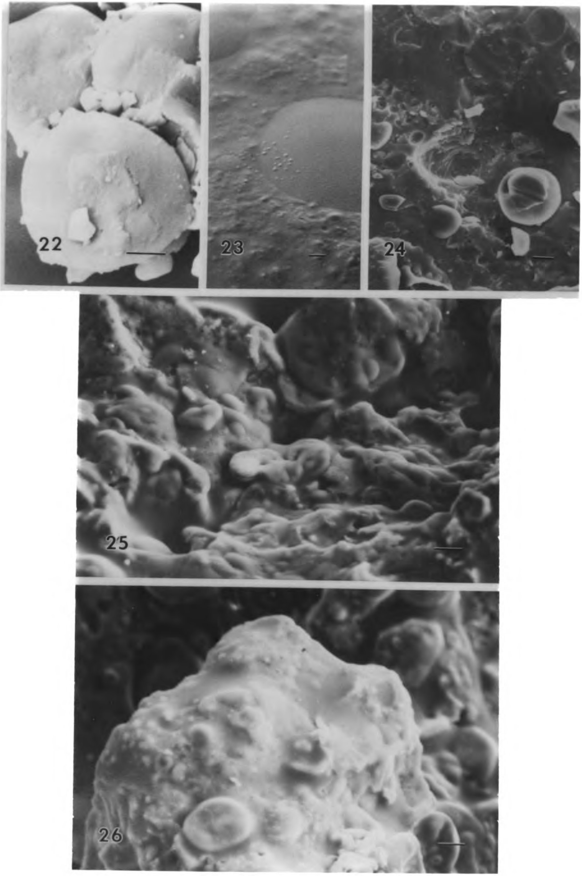
Ultrastructure of Brans, Batters and Muffins

Micrographs of the ultrastructure of brans, brans incorporated into muffin formulation in the stages of batter and baked form are shown in Figures 22-50. The researcher selected to present micrographs using the coarse bran as being the representative of the samples. The ultrastructural study was a series of SEM micrographs from the control muffins, as well as from muffins containing three coarse cereal brans, and four coarse leguminous brans. In addition a series of SEM micrographs from muffin containing one of the cereal brans ground to <150 microns is presented for comparison to those of the muffins containing the cereal bran of the larger particle size (between 425 - 850 microns).

Control Muffin

Scanning electron micrographs of samples from three phases of control muffin production are shown (Figures 22-26). Control flour consisted of all purpose flour and whole wheat flour 50:50 (Figure 22). Starch granules, protein bodies and some remnants of cell walls are intacted together. Control muffin batter was studied at low magnification by cryostage scanning electron microscopy under freeze-unfractured and freeze-fractured condition (Figures 23 and 24, respectively). Freeze-unfractured control batter appeared as an extensive aqueous phase network (Figure 23) which revealed

Figure 22. SEM micrograph of the control flour which composed of all purpose flour and whole wheat flour (50:50) (Bar=5 um).
Figure 23. SEM cryostage micrograph of unfractured muffin batter prepared with the control flour (Bar=7 um).
Figure 24. SEM cryostage micrograph of fractured muffin batter prepared with the control flour (Bar=10 um).
Figure 25. SEM cryostage micrograph of muffin prepared with the control flour (Bar=10 um).
Figure 26. SEM cryostage micrograph of muffin prepared with the control flour (Bar=10 um).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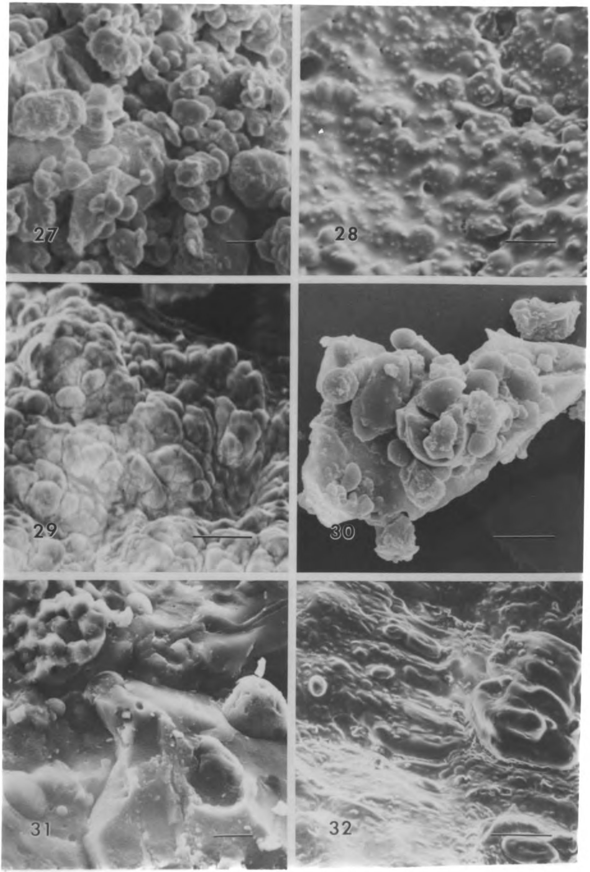
an oil-in-water emulsion. The interior area of this emulsion was also examined (Figure 24). Large bubbles and droplets of oil can be assessed as well as ice crystals identified which have a similarity to the structure of ice cream observed by Sargent (1988). The structure of control baked muffin had a surface which was covered with gelatinized starch granules Figures 25 and 26). The large starch granules expanded and interact with starch-protein matrix and fat droplets in formation of the muffin crumb (Figure 25). At low magnification, the section of the crumb shows a porous system with relatively large gas vacuoles (Figure 26). According to Pomeranz et al (1984) who investigated starch gelatinization in wheat bread, the starch granules inside the vacuoles in areas close to the outside crust are less expanded than those which occur in the interior crumb. They relate this difference to the greater availability of water for starch gelatinization in the interior of the bread than to that in the crust area.

Cereal Bran Muffins

Figures 27-38 reveal the scanning electron micrographs of three phases of bran muffins with 65% substitution of cereal brans for whole wheat flour. Coarse oat bran particle was seen in the form of cluster with the complex carbohydrate components agglomerated together (Figure 27). The cryostage SEM revealed the discontinuity of the aqueous phase with large gas vacuoles and crack (Figure 28). Dented surface may be caused by the incorporation of oat bran. However, in oat bran muffin batter, starch granules remained in their natural level of hydration which also is found in milled wheat endosperm (Sargent 1988). There was considerable interaction between oat bran and other components resulted in the agglomerated matrix (Figure 29). Figures 30-32 are the overview for fine oat bran particles as well as muffin batter and the resulting muffin with fine oat particles. As mentioned previously, the structure of oat bran was not affected by the reduction of particle size. Fine oat bran (Figure 30) remained smaller in diameter than coarse oat bran (Cadden, 1987). Muffin batter which contained fine oat bran appeared denser and harder ice-look at the magnification of 750 (Figure 31) than the coarse oat muffin at the magnification of 430 (compare Figures 28 and 31). Oat bran along with starch-protein matrix, fat droplets, protrusion can be observed in Figure 31. The appearance of the structure may become an estimation of the determination of the parameters like oil droplet size, bubble diameter range and distribution, and ice crystals. The SEM observation of the crumb of fine oat bran muffin consists of large starch granules retained in size and shape and gelatinized starch granules interact with other elements (Figure 32).

Figure 27. SEM micrograph of coarse oat bran (Bar=10 um).
Figure 28. SEM cryostage micrograph of unfractured muffin batter prepared with coarse oat bran (Bar=50 um).
Figure 29. SEM micrograph of muffin prepared with coarse oat bran (Bar=5 um).
Figure 30. SEM micrograph of fine oat bran (Bar=10 um).
Figure 31. SEM cryostage micrograph of unfractured muffin batter prepared with fine oat bran (Bar=10 um).
Figure 32. SEM micrograph of muffin prepared with fine oat bran (Bar=10 um).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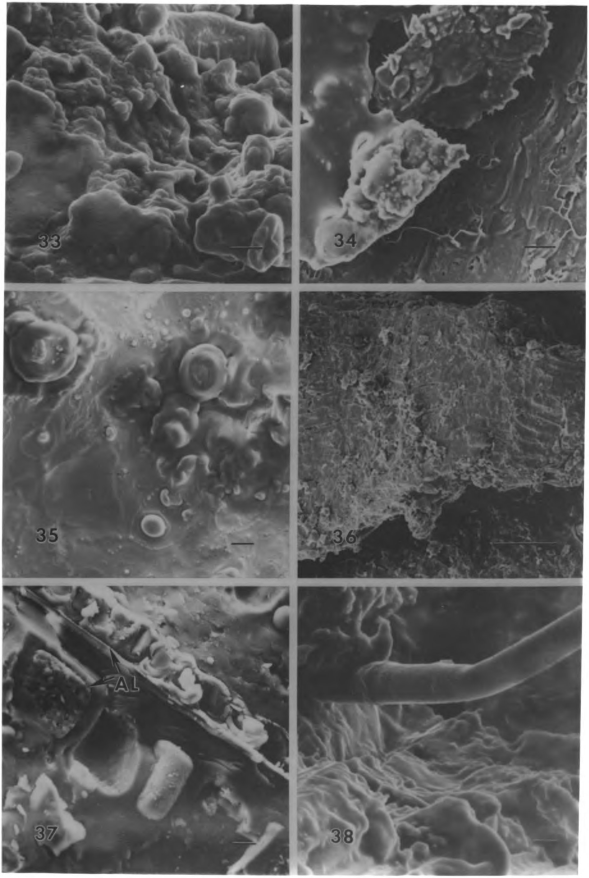
Coarse rice bran is depicted in Figure 33. Freeze-fractured rice bran batter is seen in Figure 34. The structure of batter containing coarse rice bran appears soft and fragile with some development of protein matrix (covering-imbedding-incorporating starch granules) (Pomeranz et al 1984). The cryostage of SEM (Figure 35) in the coarse rice bran muffin revealed the flattened surface covered with modified large starch granules and a mixture of various structures, mainly protein-starch matrix.

Figure 36 is an overview of coarse wheat bran. Figure 37 reveals clearly the aleurone layer particles along with the other components in freeze-fractured batter containing coarse wheat bran. Plague-like bodies occurring at oil/water interface were previously observed (Sargent 1988), and related to high water hydration capacity of the coarse wheat bran. Presoaked bran incorporated into other ingredients forms an oil-in-water emulsion. During the fracture, the fracture plane occurred on the oil side of the interfacial material which caused the droplet to appear smooth and plague-like (Figure 38); otherwise, the water side of the emulsion will be expected to appear rough. A bran particle (Figure 38) forms a foreign body, which may interrupt continuity of the matrix and damage it mechanically. This relates to the disrupted gluten structures (Pomeranz 1984). Hughes and Swanson (1989)

Figure 33. SEM micrograph of coarse rice bran (Bar=10 um).
Figure 34. SEM cryostage micrograph of fractured muffin batter prepared with coarse rice bran (Bar=10 um).
Figure 35.SEM cryostage micrograph of muffin prepared with coarse rice bran (Bar=10 um).
Figure 36. SEM micrograph of coarse wheat bran (Bar=100 um).
Figure 37. SEM cryostage micrograph of fractured muffin batter prepared with coarse wheat bran (AL=aleurone layer, Bar=10 um).
Figure 38. SEM cryostage micrograph of muffin prepared with coarse wheat bran (Bar=10 um).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reported that cooked soluble dietary fiber appears in a rod-like structure which is composed primarily of pectic substances.

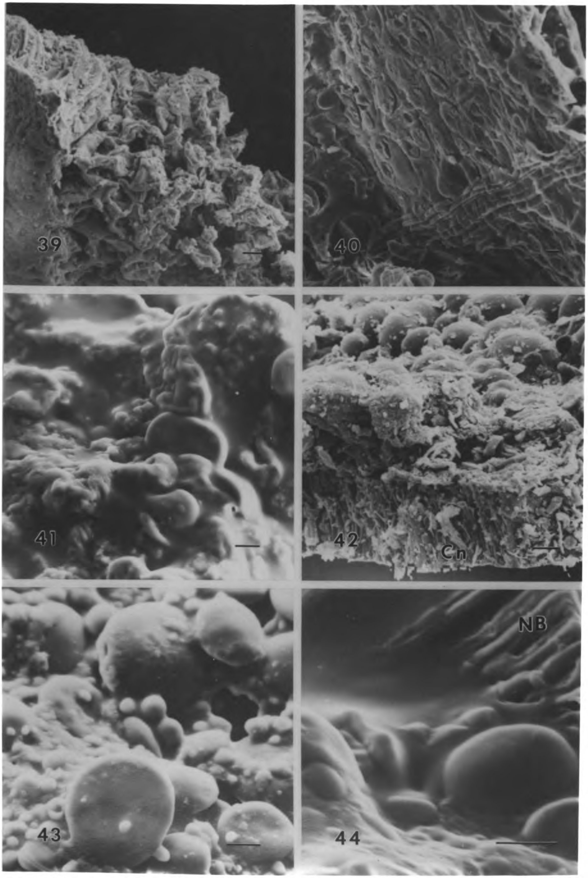
Leguminous Bran Muffins

Microstructures of leguminous brans, bran batters and bran muffins is revealed in Figures 39-50. Figure 39 shows the structure of coarse black-eye peas which look like sponge with numerous compartments which are able to entrap water. Sefa-Dedeh and Stanley (1979) found that black-eye peas had an amorphous seed coat structure and a cotyledon with parenchyma cells containing starch granules and protein bodies. However, all starch and protein bodies have been removed from cell wall remnants (Figure 39). Hughes and Swanson (1989) considered that cotyledon and palisade cell layers are mainly the insoluble dietary fiber fraction. Coarse black eye pea bran can be clearly seen in the batter, with dispersed droplets of emulsion located in the honeycomb structure (Figure 40). The crumb of the muffin which contains coarse black eye pea includes some gelatinized starch covered with the mixture of structures of starch-protein and starch-lipid. Very small gas vacuoles can be found in this muffin structure which shows a weak porous system (Figure 41). Lack of gas vacuoles may explain why the coarse black-eye peas muffin has the lowest volume as measure by rapeseed displacement.

Coarse navy bran is seen in Figure 42. Large starch granules and small protein bodies are located next to cotyledons in coarse navy bran (Figure 42). The muffin batter which contained coarse navy bean bran which showed the presence of wheat starch, navy bean starch, protein bodies, ice crystals, droplets of mixture elements and different sizes of gas vacuoles by freeze-unfractured cryostage SEM. The baked muffin with coarse navy bean bran (Figure 44) demonstrated a similar structure to the muffin which contains coarse black-eye pea bran with the presence of navy bean bran interacting with protein-starch matrix. These muffins also exhibited reduced volumes.

The appearance of coarse pinto bean bran is relatively flat which is the exterior surface of the palisade cell layer in uncooked insoluble dietary fiber (Figure 45) and similar to exterior surfaces previously observed uncooked common bean insoluble dietary fiber (Hughes and Swanson 1989). Batter which contained coarse pinto bean bran showed an uneven surface covered with different size of particles which can be assessed as milk crumb particles which have not been adequately broken up, oil droplets, gas vacuoles and starch-protein matrix (Figure 46). The muffin substituted with 65% of coarse pinto bean bran revealed the interaction of bran particle with the mixture of other elements (Figure 47). There are no visible gas vacuoles or cracks detected. A very fine veil-like of gluing mixture seals over the pinto bean bran which may be a protein-gum matrix as had been described

Figure 39. SEM micrograph of coarse black-eye pea bran (Bar=20 um).
Figure 40. SEM cryostage micrograph of fractured muffin batter prepared with coarse black-eye pea bran (Bar=10 um).
Figure 41. SEM cryostage micrograph of coarse black-eye pea bran (Bar=10 um).
Figure 42. SEM micrograph of coarse navy bean bran (Cn=cotyledon, Bar=10 um).
Figure 43. SEM cryostage micrograph of muffin prepared with coarse navy bean bran (Bar=10 um).
Figure 44. SEM cryostage micrograph of muffin prepared with coarse navy bean bran (NB=navy bean cotyledon, Bar=10 um).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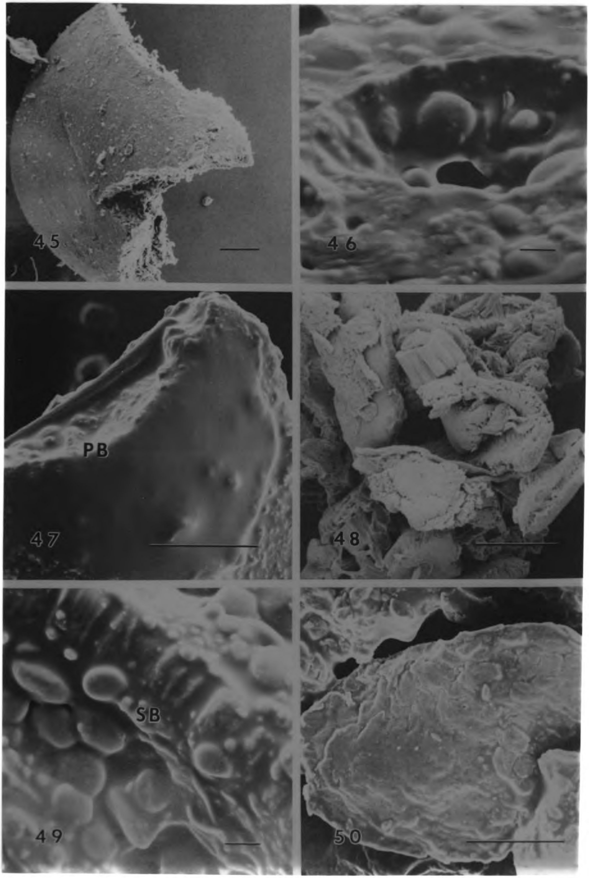
by Pomeranz et al (1984). The cryostage SEM provided useful information on the structural characteristics of insoluble and soluble dietary fiber on pinto bean bran muffin.

Soy bean bran shows a different seed coat and cotyledon structure as compared to the other leguminous brans (Figure 48). The soy bean bran possessed a distinct palisade layer in addition to a subepidermal layer. This subepidermal layer was composed of structures similar to hourglass cells in the hilum region of non-oilseed legume seeds (Sefa-Dedeh and Stanley 1979). After heat treatment, the insoluble dietary fiber appears as a rolling, uneven surface which is caused by differential swelling of the palisade cells during heating. Figure 49 reveals that soy bean bran stands out in the freeze-unfractured muffin batter, covered with the mixture of other elements with some air holes. In the baked muffin containing coarse soy bran (Figure 50), large well-swollen starch granules seem to be absent. However, after heating the surface of the muffin became smooth and various components of the muffins have interacted together. The larger air spaces in this muffin system as compared to the other muffins with leguminous brans may have contributed to the higher volume index of the muffin containing soy bran as compared to those with other leguminous brans.

Figure 45. SEM micrograph of coarse pinto bean bran (Bar=100 um).
Figure 46. SEM cryostage micrograph of unfractured muffin batter prepared with coarse pinto bran (Bar=10 um).
Figure 47. SEM cryostage micrograph of muffin prepared with coarse pinto bran (PB=pinto bean particle, Bar=100 um).
Figure 48. SEM micrograph of coarse soy bean bran (SB=soy bean particle, Bar=100 um).
Figure 49. SEM cryostage micrograph of unfractured muffin batter prepared with coarse soy bean bran (Bar=10 um).
Figure 50. SEM cryostage micrograph of muffin prepared with coarse soy bean bran (Bar=100 um).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SUMMARY AND CONCLUSIONS

The purpose of this study was to evaluate the feasibility of producing acceptable high fiber baked products. Three cereal brans and four leguminous brans were selected for incorporation into a cholesterol-free, low-salt muffin system. Brans were substituted for 65% of whole wheat flour and the level of water in each muffin formula was adjusted to meet the water requirements of each bran; therefore, the water was different from that used in the formula for the control muffin. These bran types were: oat, rice and wheat bran for the cereal types as well as black-eye pea bran and navy, pinto and soy bean bran for the leguminous types of bran. Each of the bran types was ground to two different particle sizes: fine which had particle size of less than 150 microns (pass through US 100 mesh screen) and coarse which had particle size between 425 and 850 microns (between US 20-40 mesh). Physical, chemical characteristics and the ultrastructure of the fiber, muffin batters and muffins were studied.

Physical measurement of the muffin batters examined were specific gravity, viscosity, and water activity. Muffin quality characteristics examined included baking loss, moisture, water activity, volume by rapeseed displacement, volume index, symmetry index, color, tenderness and compressibility. Chemical analyses of the muffin were total dietary fiber, soluble dietary fiber, and insoluble dietary fiber. Ultrastructure of brans, batters and muffins were also observed.

Objective measurements of the quality characteristics of the muffin indicated that viscosity of batter and baking loss, water activity of the muffins were not significantly affected by the bran sources. But specific gravity of batter and moisture content, volume by rapeseed displacement, volume index, symmetry index, lightness, redness, yellowness, tenderness, and compressibility of the muffins were significantly changed by the type of bran incorporated into the formulation. Muffins prepared with cereal brans had higher volume by rapeseed displacement, higher height, were more peaked, more yellow and less moist than muffins prepared with leguminous brans. Leguminous bran muffin batter appeared more viscous than cereal bran muffin which resulted in higher values using the shear press, such as: less tender, greater force required to compress than those muffins containing cereal bran.

In relation to particle sizes, fine particle size of bran incorporated into muffin batter produced more viscous batter than muffin batter which contained coarse brans. Moisture content and compressibility were significantly affected by particle size. Muffins containing fine brans had less water content due to less water required, and higher compressibility than muffins contain coarse brans. The interaction of bran types and particle sizes significantly affected water activity of muffin batter and moisture content, lightness, redness, yellowness, and compressibility of the muffins. Based upon these results, the selection of the bran type and size to incorporate into bakery system requires adjustments of water in order to produce an acceptable product.

The characteristics of bran sources examined were hydration capacity and ultrastructure. Coarse bran particle had much higher capacity to hold and bind water than fine bran particle with the exception of rice and oat brans. Ultrastructure examination using scanning electron microscopy confirmed the structures of rice and oat bran were not distorted by the reduction of the particle size. In contrast, ultrastructure examination of all the rest of bran sources - wheat bran, black-eye pea bran, navy bean bran, pinto bean bran, and soy bean bran confirmed the absence of matrix structure due to the grinding process.

Chemical analyses using Prosky methods indicated that muffins prepared with all leguminous brans had much higher concentrations of total dietary fiber and insoluble dietary fiber than total dietary fiber (TDF) and insoluble dietary fiber (IDF) found in the control muffin prepared with all purpose flour and whole wheat flour in a 50:50 ratio. Also, muffins prepared with leguminous brans offer much higher potential intake TDF and IDF than did muffins prepared with cereal brans. The proportion of soluble dietary (SDF) to TDF from oat bran was the highest (29.1%) compared with the proportion of SDF to TDF of the muffin prepared with soy bran (6.30%).

The observation of microstructure showed coarse bran particle possessed a sponge-like structure in contrast to fine bran particle which, being confined into a single plant cell imbibed less water than coarse bran with matrix structure. The morphology of microstructure facilitated the interpretation of physical and chemical characteristics. With the improvement of scanning electron microscopy (SEM) equipment, cryostage SEM micrographs with freeze-fracture showed that control muffin batter and all cereal bran muffin batters had cement-like interior compacted together, with quite smooth surface. In contrast, all leguminous bran muffin batter had rough surface with the presence of coarse bran particle. The roughness of surface is related to leguminous brans composed of higher insoluble dietary fiber. In contrast, the cereal brans had a higher soluble dietary fiber content which is solubilized in water thus contributing to the smooth appearance of the muffin batters. Muffin batters or baked muffins prepared with fine particle size provide less distinguished information than muffin batters or baked muffins prepared with coarse particle size which had been viewed without difficulty.

Processing coarse particle size into fine particle size demands new technology, equipment, time, and man power. Based upon the study, in order to increase the volume of the products, fine particle size of oat bran, rice bran, wheat bran seems to be more satifactory than coarse particle size of those brans. Leguminous brans may not adversely affect the bakery products requiring a flattened surafce, ie. cookies or bars. In order to produce more tender bakery products, the incorporation of either cereal or leguminous brans of either particle size is appropriate. Also, the incorporation of any type of bran into bakery product reduced the force to compress the product.

The reduction of wheat bran incorporated into muffin produced the product possesses lighter color, and higher volume than the muffin prepared with coarse particle size. Black-eye pea bran and pinto bean bran result in the dark products which may be applied to chocolate type bakery products. In contrast, black-eye pea bran and pinto bean bran will adversely affect the product which has the characteristic of yellowness and lightness. All the brans hold more water in the final product which could enhance shelf life.

Above all, in corporation of oat bran, or rice bran from cereal source and navy bean bran or soy bean bran from legume source using either particle size produced no significant difference in the final products. Thus, these types of bran have the greatest potential for use to increase fiber content in acceptable baked muffins.

PROPOSALS FOR FURTHER RESEARCH

Although the results of this study indicate that incorporation of cereal brans: oat, rice, and wheat, and leguminous brans: black-eye pea, navy bean, pinto bean and soy bean with two particle sizes: fine, being less than 150 microns and coarse being between 450 to 825 microns into muffin system is a feasible method of increasing dietary fiber intake, further investigation is warranted. The following areas are proposed:

1. The effect of bran substitutions in other bakery formulations needs to be studied. Based upon the water hydration capacity, changes in the water level and/or the addition of emulsifiers, needs further investigation.

2. The physiological effect of bran particle size, especially from the leguminous sources needs to be studied.

3. The technology of reduction of particle size needs to be available to the food manufacturers.

4. Fiber substitution in other baked or microwavable products, such as cookies, cakes, biscuits, breads, or extruded breakfast products, or in other food systems, such as gravy, meat sauce, or dairy products needs to be studied. In order to increase the intake of dietary fiber in the diet, a

variety of pre-hydrated fiber needs to be available for consumption.

5. The method of chemical analyses of retrograded starch needs to be reviewed in relation to the particle size of fiber.

6. Studies are needed to determine the effect of fiber incorporation on product stability and shelf life. The microbial growth in bran products needs to be investigated.

7. The effect of enzymatic and/or chemical treatment on bran sources needs to be researched.

LITERATURE CITED

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Aguilera,J.M., Lusao,E.W., Uebersax,M.A., and Zabik,M.E. 1982. Development of food ingredients from navy beans (*Phaseolus vulgaris*) by roasting and air classification. J. Food Sci. 47:1151.

American Association of Cereal Chemists. 1983. Approved Methods of the AACC. 8th Ed. Method 44-40, and 56-20. The Association: St. Paul, MN.

Andres,C. 1981. Natural bulking agents provide fiber and desired texture. Food Processing. May:66.

Anonymous. 1979. Dietary fiber. Food Technol. 33:35.

Anonymous. 1984. AACC Certified Wheat Bran. American Association of Cereal Chemists, St. Paul, MN.

Anonymous. 1987. Dietary fiber comparison chart. Cereal Foods World. 32:556.

Anonymous. 1988. Honey from nature's food industry. National Honey Board, Food Technology Progran. San Francisco, CA.

Apling,E.C., Khan,P., and Ellis,P.R. 1978. Guar/wheat bread for therapeutic use. Cereal Foods World. 23:640.

Atwell,W.A., Hood,L.F., Lineback,D.R., Varriano-Marston,E., and Zobel,H.F. 1988. The terminology and methodology associated with basic starch phenomena. Cereal Food World. 33:306.

Babcock,D. 1987. Rice bran as a source of dietary fiber. Cereal Foods World. 32:538.

Bingham,S. 1987. Definitions and intakes of dietary fiber. Am. J. Clin. Nutr. 45:1226.

Bright-See,E., and McKeown-Eyssen,G.E. 1984. Estimation of per capita crude and dietary fiber supply in 38 countries. Am. J. Clin. Nutr. 39:821.

Brockmole,C.L. and Zabik,M.E. 1976. Wheat bran and middlings in white layer cakes. J. Food Sci. 41:357.

Brys,K.D., and Zabik,M.E. 1976. Microcrystalline cellulose replacements in cakes and biscuits. J. Am. Diet. Assoc. 69:50.

Buckholz,L.L.Jr. 1988. The role of maillard technology in flavoring food products. Cereal Food World. 33:547.

Burge,R.M., and Duensing, W.J. 1989. Processing and dietary fiber ingredient application of corn bran. Cereal Foods World. 34:535.

Cadden,A.M. 1986. Effects of particle size and breadmaking on physiological responses of meal-fed rats to AACC wheat bran. J. Food Sci. 51:188.

Cadden,A.M. 1987. Comparative effects of particle size reduction on physical structure and water binding properties of several plant fibers. J. Food Sci. 52:1595.

Cadden,A.M. 1988. Moisture sorption characteristics of several food fibers. J. Food Sci. 53:1150.

Cadden,A.M., Sosulski,F.W., and Olson,J.P. 1983. Physiological responses of rats to high fiber bread diets containing several sources of hulls or brans. J. Food Sci. 48:1151.

Carroll,L.E. 1990. Functional properties and applications of stabilized rice bran in bakery products. Food Technol. 44:74.

Chabot,J.F. 1979. Preparation of food science samples for SEM. Scanning Electron Microscopy III:9.

Chabot,J.F., Hood,L.F., and Liboff,M. 1979. Effect of scanning electron microscopy preparation methods on the ultra structure of white bread. Cereal Chem. 56:462.

Chan,J.K.C., and Wypyszyk,V. 1988. A forgotten natural dietary fiber: Psyllium Mucilloid. Cereal Foods World. 33:919.

Chen,H., Rubenthaler,G.L., Leung,H.K., and Baranowski,J.D. 1988a. Chemical, physical, and baking properties of apple fiber compared with wheat and oat bran. Cereal chem. 65:244.

Chen,H., Rubenthaler,G.L., and Schanus,S.E. 1988b. Effect of apple fiber and cellulose on the physical properties of wheat flour. J. Food Sci. 53:304.

Chen,J.Y., Piva,M., and Labuza,T.P. 1984. Evaluation of water binding capacity (WBC) of food fiber sources. J. Food Sci. 49:59.

Christensen,E.H. 1989. Characteristics of sugarbeet fiber allow many food uses. Cereal Foods World. 34:541.

Chung,O.K. 1986. Lipid-protein interactions in wheat flour, dough, gluten, and protein fractions. Cereal Foods World. 31:242.

Collins,J.L., and Post,A.R. 1981. Peanut hull flour as a potential source of dietary fiber. J. Food Sci. 46:445.

Czuchajowska,A., and Pomeranz,Y. 1989. Differential scanning calorimetry, water activity, and moisture contents in crumb center and near-crust zones of bread during storage. Cereal Chem. 66:305.

Czuchajowska,A., Pomeranz,Y., and Jeffers,H. 1989. Water activity and moisture content of dough and bread. Cereal Chem. 66:128.

Daun,J.K. 1984. Composition and use of canola seed, oil, and meal. Cereal Foods World. 29:291.

DeFouw,C., Zabik,M.E., Uebersax,M.A., Aguilera,J.M., and Lusas,E. 1982. Note on "Use of unheated and heat-treated navy bean hulls as a source of dietary fiber in spice-flavored layer cakes". Cereal Chem. 59:229.

DeFouw,C., Zabik,M.E., Uebersax,M.A., Aguilera,J.M., and Lusas,E. 1982. Effects of heat treatment and levels of navy bean hulls in sugar-snap cookies. Cereal Chem. 59:245.

Deshpande,S.S., Sathe,S.K., Cornforth,D., and Salunkhe,D.K. 1982. Effects of dehulling on functional properties of dry bean (*Phaseolus vulgaris* L.) flours. Cereal Chem. 59:396.

Dubois,D.K. 1978. The practical application of fiber materials in bread production. Bakers' Digest. 52:30.

Evans,L.G., Volpe,T., and Zabik,M.E. 1977. Ultrastructure of bread dough with yeast single cell protein and /or emulsifier. J. Food Sci. 42:70.

Fennema,O.R. 1985. Ch. 3. Carbohydrates, 2nd Ed. Page 69-137. Marcel Dekker, Inc., NY.

Fisher,R.A. 1966. The Design of Experiments, 8th ed., Ch. 10. Hafner, New York.

Fondroy,E.B., White,P.J., and Prusa,K.J. 1989. Physical and sensory evaluation of lean white cakes containing substituted fluffy cellulose. Cereal Chem. 66:402.

Frankenfield,D.C., and Beyer,P.L. 1989. Soy-polysaccharide fiber: effect on diarrhea in tube-fed, head-injured patients. Am. J. Clin. Nutr. 50:533.

Gorczyca,C.G., and Zabik,M.E. 1979. High fiber sugar-snap cookies containing cellulose and coated cellulose products. Cereal Chem. 56:537.

Gould,J.M., Jasberg,B.K.,Dexter,L., Hsu,J.T., Lewis,S., and Fahey,G.C.,Jr. 1989. High-fiber, noncaloric flour substitute for use in baked foods. Properties of alkaline peroxide-treated lignocellulose. Cereal Chem. 66:201.

Haseborg,E., and Himmelstein,A. 1988. Quality problems with high fiber breads solved by using hemicellulose enzymes. Cereal Foods World. 33:419.

Heaton,K.W., Marcus,S.N., Emmett,P.M., Bolton,C.H. 1988. Particle size of wheat, maize, and oat test meals: effects on plasma glucose ane insulin responses and on the rate of starch digestion in vitro. Am.J.Clin.Nutr. 47:675.

Heinze,R.F. 1989. Developing microwavable flavors for popcorn and cakes. Cereal Foods World. 34:334.

Hodge,J.E. and Osman,E.M. 1976. Ch.3 in Principles of Food Science, Part I, Food Chemistry. Fennema,O., Ed. Marcel Dekker, NY.

Hoseney,R.C. 1984a. Functional properties of pentosan in baked food. Food Technol. 38:114.

Hoseney,R.C. 1984b. Gas retention in bread doughs. Cereal Foods Worlds. 29:306.

Hoseney,R.C. 1986. Principles of Cereal Science and Technology. Am. Assoc. of Cereal Chem., St. Paul. MN.

Hoseney,R.C., and Faubion,J.M. 1981. A mechanism for the oxidative gelation of wheat flour water-soluble pentosans. Cereal Chem. 58:421.

Hoseney,R.C., Lineback,D.R., and Seib.P.A. 1983. Role of starch in baked foods. Bakers' Digest. 57:65.

Hughes,J.S. Swanson,B.G. 1989. Soluble and insoluble dietary fiber in cooked common bean (Phaseolus Vulgaris) seeds. Food Microstructure 8:15.

Hung,Y.-C., McWatters,K.H.,Phillips,R.D., and Chinnan,M.S. 1990. Effects of pre-decortication drying treatment on the microstructure of cowpea products. J.Food Sci. 55:774.

Hurt,H.D., and Crocco,S.C. 1986. Dietary fiber: marketing implications. Food Technol. 40:124.

James,C., and Sloan,S. 1984. Note on "Functional properties of edible rice bran in model systems". J. Food Sci. 49:311.

Jasberg,B.K., Gould,J.M., and Warner,K. 1989. High-fiber, noncaloric flour substitute for baked foods. Alkaline peroxide-treated lignocellulose in chocolate cake. Cereal Chem. 66:209.

Jeltema,M.S., and Zabik,M.E. 1979. Fiber components-quantitation and relationship to cake quality. J. Food Sci. 44:1732.

Jeltema,M.A., Zabik,M.E., and Thiel,L.J. 1983. Prediction of cookie quality from dietary fiber components. Cereal Chem. 60:227.

Johnson,C.D., Berry,M.F., and Weaver,C.M. 1985. Soybean hulls as an iron source for bread enrichment. J. Food Sci. 50:1275.

Johnson,F.C.S. 1990. Characteristics of muffins containing various levels of waxy rice flour. Cereal Chem. 67:114.

Kahlon, T.S., Chow,F.I., Hudson,C.A., Lindgren,F.T., and Betschart,A.A. 1989. Influence of wheat bran particle size on vitamin A and E and cholesterol in rats. Cereal Chem. 66:103.

Kim,S.L. and D'Appolonia,B.L. 1977. Bread staling studies. III. Effect of pentosans on dough, bread and staling rates. Cereal Chem. 54:225.

Krishnan,P.G., Chang,K.C. and Brow,G. 1987. Effect of commercial oat bran on the characteristics and composition of bread. Cereal Chem. 64:55.

Krog,N. Oleson.S.K. Toernaes,H., and Joensson,T. 1989. Retrogradation of the starch fraction in wheat bread. Cereal Foods World. 34:281.

Kulp,K., and Lorenz,K. 1981. Starch functionality in white pan breads. Bakers' Digest. 55:24.

LaBaw,G.D. 1982. Chemical leavening agents and their use in bakery products. Bakers' Digest. 56:16.

Lai,C.S., Davis,A.B., and Hoseney,R.C. 1989. Production of whole wheat bread with good loaf volume. Cereal Chem. 66:224.

Langton,M., and Hermansson, A.-M. 1989. Microstructural changes in wheat starch dispersions during heating and cooling. Food Microstructure. 8:29.

Lanza,E., Jones,Y., Block,G., and Kessler,L. 1987. Dietary fiber intake in the U.S. population. Am. J. Clin. Nutr. 46:790.

Laszlo,J.A. 1988. Content and stability of ferrous iron in soybean hulls. Cereal Chem. 65:20.

Lee,C.H., and Rha,C.K. 1979. Application of scanning electron microscopy for the development of materials for food. Scanning Electron Microscopy. III:17.

Leeds,A.R. 1985. Dietary Fibre Perspectives 1 - Reviews and Bibiography. John Libby & Co. Ltd., London, UK.

Leeds,A.R. 1990. Dietary Fibre Perspectives 2 - Reviews and Bibiography. John Libby & Co.Ltd., London, UK.

Leveille,G.A. 1985. The importance of dietary fiber in food. Bakers' Digest. 59:34.

Li,B.W., and Andrews K.W. 1988. Technical communications on "Simplified method for determination of total dieatry fiber in foods." J. Assoc. Off. Anal. Chem. 71:1063.

Lineback,D.R., and Wongsrikasem,E. 1980. Gelatinization of starch in baked products. J.Food Sci. 45:71.

Lo,G.S. 1989. Nutritional and physical properties of dietary fiber from soybeans. Cereal Foods World. 34:530.

Marston,P.E., and Wannan,T.L. 1976. Bread baking: The transformation from dough to bread. Bakers' Digest. 50:24.

Miettinen,T.A. 1987. Dietary fiber and lipids. Am. J. Clin. Nutr. 45:1237.

Mongeau,R. and Brassard,R. 1982. Insoluble dietary fiber from breakfast cereals and brans: Bile salt binding and water-holding capacity in relation to particle size. Cereal Chem. 59:413.

Mongeau,R. and Brassard,R. 1990 Determination of insoluble, soluble, and total dietary fiber: collaborative study of a rapid gravinetric method. Cereal Foods World. 35:319.

MSTAT. 1985. Michigan State University Statistics Package. Version 5.

Normand,F.L., Ory,R.L., and Mod,R.R. 1987. Binding of bile acids and trace mineral by soluble hemicellulose of rice.

Food Technol. 41(2):86.

Nyman,M., Siljstroem,M., Pedersen,B. and Bach Knudsen,K.E., Asp, N.-G., Johansson,C.-G., and Eggum,E.O. 1984. Dietary fiber content and composition in six cereals at different extraction rates. Cereal Chem. 61:14.

O'Dea,K., Traianedes,K., Ireland,P., Niall,M., Sadler,J., Hopper,J., and De Luise,M. 1989. The effects of diet differing in fat, carbohydrate, and fiber on carbohydrate and lipid metabolism in Type II diabetes. J. Am. Diet. Assoc. 89:1076.

Ohi,G., Minowa,K., Oyama,T., Nagahashi,M., Yamazaki,N., Yamamoto,S., Nagasako,K., Hayakawa,K., Kimura,K., and Mori,B. 1983. Changes in dietary fiber intake among Japanese in the 20th century: a relationship to the prevalence of diverticular disease. Am. J. Clin. Nutr. 38:115.

Olson,A., Gray,G.M., and Chiu,M,C. 1987. Chemistry and analysis of soluble dietary fiber. Food Technol. 41:71.

Painter,K.A. 1981. Functions and requirements of fat and emulsifiers in prepared cake mixes. J. Am. Oil Chem. Soc. 58:92.

Pearce,L.E., Davis,E.A., and Gorden,J. 1984. Thermal properties and structural characteristics of model cake batters containing nonfat dry milk. Cereal Chem. 61:549.

Pena,R.J., Nagarajan,P., and Bates,L.S. 1982. Grain shrivelling in secondary hexaploid Triticale. II. Morphology of mature and developing grains related to grain shrivelling. Cereal Chem. 59:459.

Petersen,R.G. 1985. Design and Analysis of Experiments. Ch. 6 and 7. p. 112-165. Marcel Dekker,Inc., New York, NY.

Polizzoto,L,M., Tinsley,A.M., Weber,C.W., and Berry,J.W. 1983. Dietary fibers in muffins. J. Food Sci. 48:111.

Pomeranz,Y. 1977. Fiber in breadmaking: A review of recent studies. Bakers' Digest. 51:94.

Pomeranz,Y., Shogren,M.D, Finney,K.F., and Betchtel,D.B. 1977. Fiber in breadmaking-Effects on functional properties. Cereal Chem. 54:25.

Pomeranz,Y., Meyer,D., and Seibel,W. 1984. Wheat, wheat-rye and rye dough and bread studies by scanning electron microscopy. Cereal Chem. 61:53.

Prosky,L., Asp,N.-G., Furda,I., DeVries,J.W., Schweizer,T.F., and Harland,B.A. 1984. Determination of total dietary fiber in foods, food products, and total diets: Interlaboratory study. J. Assoc. Off. Anal. Chem. 67:1044.

Prosky,L., Asp,N.-G., Furda,I., Devries,J.W., Schweizer,T.F., and Harland,B.A. 1985. Determination of total dietary fiber in foods, food products. J. Assoc. Off. Anal. Chem. 68:677.

Prosky,L., Asp,N.-G., Schweizer,t.F., DeVries,J.W., and Furda,I. 1988. Determination of insoluble, soluble, and total dietary fiber in foods nad food products: Interlaboratory study. J. Assoc. Off. Anal. Chem. 71:1017.

Rajchel,C.L., Zabik,M.E., and Everson,E. 1975. Wheat bran and middlings - a source of dietary fiber in banana, chocolate, nut and spice cakes. Bakers' Digest. 49:27.

Randall,J.M., Sayre,R.N., Schultz,W.G., Fong, R.Y., Mossman,A.P., Tribelhorn,R.E., and Saunders,R.M. 1985. Rice bran stabilization by extrusion cooking for extraction of edible oil. J. Food Sci. 50:361.

Ranhotra,G.S., Gelroth,J.A., and Bright,P. 1988. Effect of the source of fiber in bread on intestinal responsed and nutrient digestibilities. Cereal Chem. 65:9.

Rasper,V.F. 1979. Chemical and physical properties of dietary cereal fiber. Food Technol. 33:40.

Recommended Dietary Allowances. 1989. 10th ed. Published by National Academy Press, Washington,D.C. Page 39-43.

Reiman,H.M. 1983. Chemical leavening systems. Bakers' Digest. 57:37.

Sargent,J.A. 1988. The application of cold stage scanning electron microscopy to food research. Food Microstructure 7:123.

Schneeman,B.O. 1986. Dietary fiber: Physical and chemical properties, methods of analysis, and physiological effects. Food Technol. 40:104.

Schneeman, B.O. 1987. Soluble vs. insoluble fiber-different physiological responses. Food Technol. 41:81

Schneeman,B.O. 1989. Scientific Statud Summary: Dietary Fiber. Published by the Institute of Food Technologists. Food Technol. 43:133.

Schwarz,P.B., Kunerth,W.H., and Young,V.L. 1988. The distribution of lignin and other fiber components within hard red spring wheat bran. Cereal Chem. 65:59.

Sefa-Dedeh,S., and Stanley,D.W. 1979. Textural implications of the microstructure of legumes. Food Technol.33:77.

Seibert, S.E. 1987. Oat bran as a source of soluble dietary fiber. Cereal Foods World. 32:552.

Shafer,M.A.M. and Zabik,M.E. 1978. Dietary fiber sources for baked products: Comparison of wheat brans and other cereal brans in layer cakes. J. Food Sci. 41:357.

Sosulski,F.W., and Cadden,A.M. 1982. Composition and physiological properties of several sources of dietary fiber. J. Food Sci. 47:1472.

Sosulski,F.W., and Wu,K.K. 1988. High-fiber breads containing field pea hulls, wheat, corn, and wild oat bran. Cereal Chem. 65:186.

Spaeth,S.C., Debouck,D.G., Tohme,J., and Beem J. 1989. Microsturcture of *Nunas:* Andean popping beans (*Phaseolus vulgaris L.*) Food Microstructure. 8:263.

Spiller,G.A., and Amen,R.J. 1978. Topics in Dietary Fiber Research. Plenum Press, New York, N.Y.

Story,L., Anderson,W., Chen,W.L., Karounos,D., and Jefferson,B. 1985. Adherence to high-carbohydrate, high-fiber diets: Long-term studies of non-obese diabetic men. J. Am. Diet. Assoc. 85:1105.

Swanson,B.G., Hughes,J.S., and Rasmussen, H.P. 1985. Seed microstructure: Review of water imbibition in legumes. Food Microstruc. 4:115.

Toma,R.B., and Curtis,D.J. 1986. Dietary fiber: its role for diabetics. Food Technol. 40:118.

Toma,R.B., and Curtis,D.J. 1989. Ready-to-eat cereals: role in a balanced diet. Cereal Foods World. 34:387.

Van Staveren,W.A., Hautvast,J., Katan,M., Van Montfort,M.A.J., and Van Oosten-Van Der Goes,H.G.C. 1982. Dietary fiber consumption in an adult Dutch population. J. Am. Diet. Assoc. 80:324.

Vaisey-Genser,M., Ylimaki,G., and Johnston,B. 1987. The selection of levles of canola oil, water, and emulsifier system in cake formulation by response-surface methodology. Cereal Chem. 64:50.

Vaisey-Genser,M., and Ylimaki,G. 1989. Baking with a canola oil products. Cereal Foods World. 34:246.

Varriano-Marston,E. 1977. A comparison of dough preparation procedures for scanning electron microscopy. Food Technol. 31:32.

Varriano-Marston,E., Zeleznak,K., Nowotna,A., and Wilmington,DE. 1985. Structural characteristics of gelatinized starch. Starch/Staerke. 37(10):326.

Vetter,J.L. 1984. Fiber as a food ingredient. Food Technol. 38:64.

Voll,H. 1974. New adaptation of honey to bread baking. Baker's Digest. 48:45.

Vratanina,D.L., and Zabik,M.E. 1978. Dietary fiber sources for baked products: Bran in sugar-snap cookies. J. Food Sci. 43:1590.

Vratanina,D.L. and Zabik,M.E. 1980. Bran as a source of dietary fiber in oatmeal cookies. J. Am. Diet. Assoc. 77:26.

Wahlqvist,M.L. 1987. Dietary fiber and carbohydrate metabolism. Am. J. Clin. Nutr. 45:1232.

Webster,F.H. 1986. Oats: Chemistry and Technology. Am. Assoc. of Cereal Chem., St. Paul. MN.

Weber,F.E., and Chandhary,V.K. 1987. Recovery and nutritional evaluation of dietary fiber ingredients from a barley by-product. Cereal Foods World. 32:548.

White,J.S. and Parke,D.W. 1989. Fructose adds variety to breakfast. Cereal food World. 34:392.

Wolf,W.J., and Baker,F.L. 1980. Scanning electron microscopy of soybeans and soybean protein products. Scanning Electron Microscopy. III:621.

Wolf,W.J., Baker,F.L., and Bernard,R.L. 1981. Soybean seed-coat structural features: pits, deposits and cracks. Scanning Electron Microscopy. III:531.

Yiu,S.H. 1986. Effects of processing and cooking on the structural and microchemical composition of oats. Food Microstructure. 5:219.

Zabik,M.E., Shafer,M.A.M., and Kukorowski,B.W. 1977. Dietary fibre sources for baked products. Comparison of cellulose types and coated-cellulose products in layer cakes. J. Food

Sci. 42:1428.

Zeleznak,K.J., and Hoseney,R.C. 1986. The role of water in the retrogradation of wheat starch gels and bread crumb. Cereal Chem. 63:407.

Zobel,J.F., Young,S.N., and Rocca,L.A. 1988. Starch gelatinization: An x-ray diffraction study. Cereal Chem. 65:443.

APPENDICES

Appendix 1. Honey Wheat Muffin Formulations for Modification with Varied Fiber Sources (from Kansas State University)

Combine liquid ingredients:
23.4 g whole egg
66.8 g water
50.0 g vegetable oil (Puritan)
45.5 g honey (Busy Bee, USDA grade A)

Mix in Kitchen Aid (Model 5-C) mixer for 1 min. at speed 1 using wire whip; scrape mix 1 min. more.

Combine dry ingredients:
48.6 g all -purpose flour
59.2 g whole wheat flour
5.8 g baking powder (Clabber Girl double acting)
2.9 g salt (Carey iodized)

Mix 1 min at speed 1, wire whip; scrape; mix 1 min; scrape; mix 1 more min.

Combine dry ingredients with liquid ingredients-mix by hand until moistened (lumps will be present).
Spray muffin tins lightly with PAM.
Weigh 75 g into each cup.
Bake 375°F for 17 min.

Appendix 2. Analyses of Variance - Two Factors Factorial Design for Objective Measurements of Muffin Batter Containing Seven Fibers of Two Particle Sizes[1]

		Mean Squares		
Source	df	Specific Gravity	Viscosity	Water Activity
Replication	3	33.89***[2]	222.21	0
Bran type	6	8.92**[2]	557.32	0
Bran particle size	1	3.16	2535.33**	0.001
Bran type X Particle size	6	4.33	763.6	0.001***
Residual	39	3.70	361.81	0

[1] Fine is <150 microns, and coarse is between 425-850 microns.
[2] ** significant at the 5% level of probability.
*** significant at the 1% level of probability.

Appendix 3. Analyses of Variance - Two Factors Factorial Design for Baking Loss, Moisture Content and Water Activity of Muffins Containing Seven Fibers of Two Particle Sizes[1]

		Mean Squares		
Source	df	Baking Loss	Moisture Content	Water Activity
Replication	3	34.26***[2]	66.59	72.23***
Bran type	6	1.09	38.64	2.35
Bran particle size	1	0.12	25.68	4.25
Bran type X Particle Size	6	0.64	11.53***	2.52
Residual	39	0.52	2.76	3.58

[1] Fine is <150 microns, and coarse is between 425-850 microns.
[2] *** significant at the 1% level of probability.

Appendix 4. Analyses of Variance - Two Factors Factorial Design for Volume and Symmetry Measures of Muffins Containing Seven Fibers of Two Particle Sizes[1]

		Mean Square		
Source	df	Volume by Rapeseed Displacement	Volume Index	Symmetry Index
Replication	3	162.35***[2]	25.02	5.49
Bran type	6	250.74***	518.75***	24.08***
Bran particle size		111.16	36.16	17.16
Bran type X Particle size	6	52.83	26.54	3.45
Residual	39	32.54	12.90	4.83

[1] Fine is <150 microns, and coarse is between 425-850 microns.
[2] *** significant at the 1% level of probability.

Appendix 5. Analyses of Variance - Two Factors Factorial Design for Color of Muffins Containing Seven Fibers of Two Particle Size[1]

		Mean Square		
Source	df	Lightness (L)	Redness (aL)	Yellowness (bL)
Replication	3	11.40***[2]	0.13	0.51***
Bran type	6	389.23***	3.26***	82.31***
Bran particle size	1	1.03	0.003	0.002
Bran type X Particle size	6	20.92***	0.47***	2.96***
Residual	39	1.12	0.05	0.09

[1] Fine is <150 microns, and coarse is between 425-850 microns.
[2] *** significant at the 1% level of probability.

Appendix 6. Analyses of Variance - Two Factors Factorial Design for Tenderness and Compressibility of Muffins Containing Seven Fibers of Two Particle Sizes[1]

		Mean Squares	
Source	df	Tenderness	Compressibility
Replication	3	1.03***[2]	1031.30***
Bran type	6	1.57***	1020.81***
Bran particle size	1	0.73	1450.45***
Bran type X Particle Size	6	0.39	511.92***
Residual	39	0.22	148.80

[1] Fine is <150 microns, and coarse is between 425-850 microns.
[2] *** significant at the 1% level of probability.

Appendix 7. Means[1] of Bran Particle Sizes[2] on Baking Loss, Tenderness, and Moisture Content Measurements of the Muffins

Muffin Types	Baking Loss	Tenderness	Moisture Content
Control	8.83	5.76	35.75
Fine brans	9.68	3.63	39.29
Coarse brans	9.76	3.83	40.48

[1] Each mean is the average of values from fifty-two bran muffins incorporated with either fine or coarse bran size.
[2] Fine is <150 microns, and coarse is between 425-850 microns.

Appendix 8. Means[1] of Bran Particle Size[2] on Specific Gravity and Water Activity Measurements of Muffin Batter and Water Activity Measurements of Muffins

Muffin Types	Muffin Batter		Baked Muffin
	Specific Gravity	Water Activity	Water Activity
Control	1.184	0.937	0.896
Fine size of brans	1.160	0.940	0.910
Coarse size of brans	1.155	0.946	0.915

[1] Each mean is the average of values from fifty-two bran muffins incorporated with either fine or coarse bran size.
[2] Fine particle size is <150 microns, and coarse particle size is between 425-850 microns.

Appendix 9. Means[1] of Bran Particle Sizes[2] on Volume and Shape Measurements of Baked Muffins

Muffin Types	Volume (cc)	Volume Index (cm)	Symmetry Index (cm)
Control	125.0	126.0	7.0
Fine bran	119.0	122.0	10.0
Coarse bran	118.0	121.0	9.0

[1] Each mean is the average of values from fifty-two bran muffins incorporated with each fine or coarse bran sizes.
[2] Fine is <150 microns, and coarse is between 425-850 microns.

Appendix 10. Means[1] of Bran Particle Sizes[2] on Color Hunter Measurements of the Muffins

Muffin Types	L[3]	aL[3]	bL[3]
Control	43.53	4.41	13.83
Fine bran	40.44	40.68	12.35
Coarse bran	40.68	3.76	12.37

[1] Each mean is the average of values from fifty-two bran muffins incorporated with either fine or coarse bran size.
[2] Fine is <150 microns, and coarse is between 425-850 microns.
[3] L is lightness, +aL is redness, and +bL is yellowness.