Chemical composition, physical properties and physiological responses of whole barley and barley fractions
by Alan Douglas Danielson

A thesis submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy in Crop and Soil Science
Montana State University
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Abstract:
Waxy hull-less barley was used to determine if fiber rich flour fractions could be obtained by air classification. Barley air classified into 18 fine and 18 coarse fractions. Percent total (TDF), soluble (SDF) and insoluble dietary fiber (IDF) and β-glucan, starch, nitrogen, ash and ether extract (EE) were determined. Viscosity was quantified under both acid and neutral conditions. Results indicated that air classification can separate fractions that are high in TDF, SDF, IDF, β-glucan, acid viscosity, neutral viscosity, starch, ash and EE. Whole barley, pearled barley and barley pearlings fractions of four hull-less barley genotypes were analyzed for TDF, IDF and SDF, β-glucans, acid viscosity, EE, ash and protein. Scout, Tapper, SB86106 and SR86132 were the barley genotypes studied. Pearlings were collected consecutively from 0-10, 11-20, 21-30, 31-40 and 41-50 seconds, respectively. TDF, IDF, ether extract, ash and protein were increased by ≈ 200 to 350 % in 10 second pearlings compared to whole barley. Four barley genotypes, Arizona Hull-less, Arizona Hull-less sister-line, Waxbar and Shonkin were milled through an 8-roller dry mill. Fractions obtained were analyzed for protein, EE, ash, starch, β-glucans, neutral and acid detergent fiber, acid viscosity, calcium, phosphorus and amino acids. Results indicated that certain components can be concentrated in select milling fractions. Forty adult rats were used in an experiment to evaluate the effect of feeding a high viscosity barley milling fraction on plasma and liver lipids and intestinal viscosity. Rats were allotted to one of the following diets, controls with or without dietary cholesterol, 30 % break shorts, 60 % break shorts or 90 % break shorts with dietary cholesterol. Response criteria measured were plasma lipids and glucose, liver lipids, wet digesta weight and intestinal viscosity. Plasma lipids and glucose were not different for rats fed any of the treatments. Liver cholesterol and triacylglycerol were affected by dietary treatments. Rats fed the two control diets had the lowest wet digesta weight, while rats fed the 90 % break shorts diet had the heaviest wet digesta weight. Intestinal viscosity of the rats increased when fed increasing levels of break shorts. Results indicated that feeding high viscosity barley milling fractions have a beneficial effect on lipid status of adult rats.

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A thesis submitted in partial fulfillment
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of

Doctor of Philosophy

in

Crop and Soil Science

MONTANA STATE UNIVERSITY
Bozeman, Montana

November 1994

APPROVAL

of a thesis submitted by

Alan Douglas Danielson

This thesis has been read by each member of the graduate committee and has been found to be satisfactory regarding content, English usage, format, citations, bibliographic style, and consistency, and is ready for submission to the College of Graduate Studies.

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ACKNOWLEDGEMENTS

I am greatly indebted to Drs. Rosemary K. and C. Walt Newman for serving as my major professors and providing guidance, encouragement, patience and support throughout my graduate program. Just as important to me is the friendship and philosophy they have provided. I will truly miss the excursions to Pony Creek Ridge.

Appreciation is extended to Drs. Charles McGuire, Thomas Ramage and John Paterson for their support, advice and friendship, as well as the time and interest they have shown by serving as members of my graduate advisory committee and reviewing my thesis.

Thanks is extended to Ms. Petrea Hofer for friendship, support, collaboration and laboratory assistance.

My fellow graduate students, Qi Xue, Linji Wang, Ted Mori and Xian Han are acknowledged for their help, support and friendship as well as Dr. Adam Fengler.

I am also greatly indebted to my family, Dad, Mom, Grandma, Aunt Mabel, brothers Kent and Gene, his wife Leslie and children Brian, Caryn and Stephen for all of the love and support they have provided.

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ABSTRACT

Waxy hull-less barley was used to determine if fiber rich flour fractions could be obtained by air classification. Barley air classified into 18 fine and 18 coarse fractions. Percent total (TDF), soluble (SDF) and insoluble dietary fiber (IDF) and β-glucan, starch, nitrogen, ash and ether extract (EE) were determined. Viscosity was quantified under both acid and neutral conditions. Results indicated that air classification can separate fractions that are high in TDF, SDF, IDF, β-glucan, acid viscosity, neutral viscosity, starch, ash and EE. Whole barley, pearled barley and barley pearlings fractions of four hull-less barley genotypes were analyzed for TDF, IDF and SDF, β-glucans, acid viscosity, EE, ash and protein. Scout, Tupper, SB86106 and SR86132 were the barley genotypes studied. Pearlings were collected consecutively from 0-10, 11-20, 21-30, 31-40 and 41-50 seconds, respectively. TDF, IDF, ether extract, ash and protein were increased by $\approx$ 200 to 350 % in 10 second pearlings compared to whole barley. Four barley genotypes, Arizona Hull-less, Arizona Hull-less sister-line, Waxbar and Shonkin were milled through an 8-roller dry mill. Fractions obtained were analyzed for protein, EE, ash, starch, β-glucans, neutral and acid detergent fiber, acid viscosity, calcium, phosphorus and amino acids. Results indicated that certain components can be concentrated in select milling fractions. Forty adult rats were used in an experiment to evaluate the effect of feeding a high viscosity barley milling fraction on plasma and liver lipids and intestinal viscosity. Rats were allotted to one of the following diets, controls with or without dietary cholesterol, 30 % break shorts, 60 % break shorts or 90 % break shorts with dietary cholesterol. Response criteria measured were plasma lipids and glucose, liver lipids, wet digesta weight and intestinal viscosity. Plasma lipids and glucose were not different for rats fed any of the treatments. Liver cholesterol and triacylglycerol were affected by dietary treatments. Rats fed the two control diets had the lowest wet digesta weight, while rats fed the 90 % break shorts diet had the heaviest wet digesta weight. Intestinal viscosity of the rats increased when fed increasing levels of break shorts. Results indicated that feeding high viscosity barley milling fractions have a beneficial effect on lipid status of adult rats.

CHAPTER 1

INTRODUCTION

According to the United States Bureau of the Census (1993) the leading cause of death in the U.S.A. in 1990 was heart disease followed by malignant neoplasms (cancer) and cerebrovascular disease (stroke). It has been reported that inadequate consumption of total dietary fiber along with the consumption of a diet high in saturated fat and cholesterol may contribute to hypercholesterolemia and its relationship to atherosclerosis and colon cancer. Dietary fiber is defined as non-starch polysaccharides (NSP) plus lignin and is found in a variety of foods, principally of plant origin. Research interest on NSP in cereal grains and on their characteristics has been documented in the Journal of the American Chemical Society as early as the nineteenth century (O'Sullivan, 1882). This interest has been strongest in research institutions associated with the brewing and malting industries (Preece and MacKenzie, 1952; Preece and Hobkirk, 1953; Aspinal and Greenwood, 1962; and Aastrup, 1979) since these compounds were found to be responsible for creating high viscosity in the wort which confounds fermentation and filtration processes. Additional interest in barley NSP has been developed in association with feeds for poultry, where barley is used as a main ingredient in their rations. Barley

NSP are the major factors producing poor performance and growth in poultry, especially broilers (Burnett, 1966; Classen et al., 1985; Hesselman and Aman, 1985; Rotter et al. 1989). The response is suspected to be due to the viscosity of the intestinal contents produced by these compounds. Although similar in composition, dietary fiber of different origin has widely different physiological effects. The most recognized difference is solubility. Insoluble dietary fiber, principally cellulose, which is often encrusted with lignin, is generally associated with improving bowel function. Soluble dietary fiber is primarily pectins, pentosans and mixed linked $1 \rightarrow 3$, $1 \rightarrow 4$ β-D-glucans (β-glucans). These compounds are known to influence various phases of lipid metabolism in the gastrointestinal tract, which is often expressed at the cellular level in various organs such as the liver. Cereal grains are excellent sources of dietary fiber, both soluble and insoluble. Wheat and wheat products are primary sources of insoluble fiber, whereas rye, oats and barley contain both soluble and insoluble fiber compounds. Currently oats are the major source of soluble dietary fiber in human foods although barley and barley products are excellent sources of dietary fiber available for inclusion in human diets. However, to date very little barley is consumed due in part to lack of availability at the retail level and consumer knowledge. Consumption of barley as a food in the United States is approximately 450 g per year per capita at the present time, which has not increased since 1970 (United States Bureau of the Census, 1993).

The level of β-glucan and soluble fiber in barley may vary considerably, depending upon cultivar, growing conditions and method of determination

(Anderson et al., 1978; Henry, 1986; Åman and Graham, 1987; Lehtonen and Aikasalo, 1987).

Monogastric animals including rats and humans cannot synthesize β-glucanase in sufficient quantities to completely hydrolyze the β-glucans found in barley grain. Additionally the amount of endogenous β-glucanase found in barley kernels and in the microflora of the gastrointestinal tract is not enough to completely hydrolyze the remaining β-glucans found in barley grain (Champ et al., 1991).

Few chemical or nutritional studies have been reported on barley milling fractions. Objectives of these experiments were to (1) determine if high fiber barley fractions could be obtained by air classifying barley, pearling barley and(or) conventional milling of barley; (2) evaluate intestinal viscosity and liver and plasma lipid responses of adult rats fed varying levels of a high-fiber milling fraction obtained from a waxy hull-less barley (Shonkin).

CHAPTER 2

LITERATURE REVIEW

Historical Perspective of Barley Use and Production

Barley is a field crop found widely scattered over the more temperate parts of the world. It has also been found on the high plateaus in Tibet and Ethiopia, in the Andes mountains of Peru, in the oases in the Sahara desert and north of the arctic circle. Early Egyptians held the belief that barley was the first cereal grain to be utilized by humans for food. The first documented existence of barley is attributed to an Egyptian Neolithic culture dating between 5,000 and 6,000 B.C., found to exist on the shores of a former lake in North Africa. In the course of examining remains of this culture, analyses revealed well preserved grain consisting mainly of barley (Jackson, 1933). Evidence from ancient Egyptian historic records indicates the high reverence in which barley was held. Illustrations of heads of barley grain appear on many Egyptian coins and in written records dated under the fifth (ca. 2440 B.C.), seventh (ca. 1800 B.C.), and seventeenth (ca. 1680 B.C.) dynasties (Derr, 1911). In addition to Egypt, jars containing preserved kernels of barley were discovered south of Baghdad, near ancient Babylon, dating about 3500 B.C. (Hill, 1937).

It has been documented that in 1493 Christopher Columbus brought barley for planting in what is now the United States (Thacher, 1903). Barley was also grown in the U.S. in 1602 in Massachusetts and by colonists in Virginia in 1611 (Harlan et al., 1925). Most early barleys grown in the United States were of the two-rowed variety. It wasn't until settlement of the New World moved west and into Canada that six-rowed varieties became commonplace. Between 1900 and 1940 barley production was centered in the mid-western United States and the northern Great Plains with production being nearly tripled in the latter part of that period to production in the eastern United States prior to 1900. Barley production has since moved further west and north into Canada, into the major producing regions of today. This was due in part to displacement by hybrid corn and soybeans in the midwestern United States, however other factors such as spot blotch, mildew, scald and scab (Weaver, 1950) forced barley production into drier and cooler climates.

Processing

Air Classification

Near the turn of the last century a milling system was adopted to produce wheat flours using roller mills connected to a variety of sieves. More recently, consumer requirements stimulated the development of new techniques and equipment to better separate flour based on its properties. This work contributed to the evolution of the modern day air classification system in which flour can be divided into select particle sizes. Air classification has been used primarily by cereal scientists to

separate high and low protein fractions of wheat flours for specialty baking purposes(Elias and Scott, 1957; Bean et al., 1969a, 1969b).

Elias and Scott (1957) used grinding and air classification to produce two flour fractions, fine and coarse, from two English soft and hard wheat samples. The fine fraction had a crude protein content of 20 % and particle size from 1-15 μ while the coarse fraction had a crude protein content of 7.5 % and with particle size ranging from 15-100 μ. It was also demonstrated that the fine fractions were rich in protein and made superior bread compared to the coarse fractions or the parent stock. Wichser (1958) used four commercially produced air classified flour fractions to demonstrate some practical applications of air classification. Fractions containing more starch granules and less protein were specifically useful for pastries while a high protein fraction improved bread baking quality over the parent stock. Bean et al. (1969a, 1969b) studied baking characteristics of both low and high protein fractions of five cultivars of Kansas hard red winter wheat (Bison, Comanche, Pawnee, Triumph and Wichita). A high protein fine fraction was separated into seven additional fractions each of which was added to a base mix to produce bread dough containing 12 % crude protein. Fractions from the five different cultivars were compared to determine bread baking properties. A low protein coarse fraction was ground and reclassified into seven different fractions and used to test for cultivar differences in quality of cookies and layer cakes.

MacArthur and D'Appolonia (1976, 1977) studied carbohydrate rich fractions obtained by air classification of wheat. Ten cultivars of hard red spring wheat were

milled and ten different streams of each cultivar were air classified into three different fractions. The content of sugar, starch and pentosans present was determined in these fractions. Unexpectedly, the high protein fraction of all the flour streams contained the highest yield of total sugars, reducing and non-reducing sugars, lipids, small granules and water soluble pentosans.

Dick et al. (1977) analyzed two hard red spring wheats to determine rheological properties of three air classified fractions (containing either low, medium, and high protein). The high protein fraction exhibited the greatest improvement in bread quality over their respective straight-grade flour blends from both cultivars.

Stringfellow et al. (1976) studied the effect of air classification on protein and amino acid content of air classified fractions obtained from triticale grain. Unlike wheat flour, the medium size fractions instead of fine fractions exhibited the greatest content of crude protein with a concomitant increase in the relative amount of lysine.

Pomeranz et al. (1971) milled five cultivars of barley (Primus, Larker, Paragon, Betzes, and Atlas) by conventional roller milling and then air classified the fractions. A shift in protein, ash and ether extract was evident for selected flour stream composites during air classification. These authors postulated that barley utilization might be expanded by using high protein fractions in preparing foods low in carbohydrates, lipids and minerals while a low protein fraction rich in carbohydrates could be useful as a substrate for the brewing industry.

Pomeranz et al. (1976) used sieving and air classification to separate barley malt

flour into fractions of various compositions and enzyme activities. Fractions containing either high or low levels of protein and α-amylase were successfully obtained.

Vose and Youngs (1978) air classified barley and malted barley into starch flour and protein flour. Starch flour and protein flour yields were 66 and 14 % for barley and 65 and 12 % for malted barley, respectively. Scanning electron microscopy revealed that malt starch granules were damaged by milling.

Leslie et al. (1973) air classified three rapeseed cultivars(low, medium and high glucosinolate levels) and chemically and biologically evaluated the different fractions. Results indicated that growth inhibitors, such as glucosinolates, were removed in the air classification procedure. These authors stated that it may be economically feasible to use this process to produce edible products from rapeseed.

More recently, Cloutt et al. (1986), air classified three legume species (cowpea, faba bean, and pigeonpea). Flours of the different legume species differed considerably in starch granule size and distribution. The fractions collected ranged in particle size from 6-25 μ and as the classifier speed was decreased, the cut point size increased along with an increase in the percentage of starch.

Air classification affords a process by which tailor-made flours can be produced for a vast array of uses. One such product is an air classified fraction from whole ground barley that is rich in dietary fiber components. Fiber-rich fractions have high potential as a human food source either when incorporated into traditional foods or for development of new food products.

Pearl Barley and Pearlings

Pearling of barley is an extension of a procedure called blocking which removes the lemma and palea and part of the seed coat of covered barley. As the procedure continues, the seedcoat, pericarp, and aleurone layers are removed (Weaver et al., 1981). This is generally accomplished using a coarse circular emery stone which is rotated on a horizonal axis and enclosed within a perforated metal container. Basically, pearling is the removal of the hull and other outer tissues (testa, pericarp, aleurone and germ) of the barley kernel. This is often termed decortication. The pearlings consist of the fraction removed from the endosperm in the pearling process. The remaining endosperm is termed pearl barley. Due to the difference in composition of the barley kernel, the two fractions, pearlings and pearl barley, differ considerably in chemical composition. As the percentage of decortication continues, pearled barley contains less insoluble dietary fiber and more soluble dietary fiber and β-glucan. Conversely the reverse is true in the pearlings. Hofman (1975) reported that barley pearlings produced a more favorable protein composition than their corresponding parent barley varieties. The pearlings were as high in lysine and higher in arginine as found in high-lysine barley cultivars. Fedorchenko and Sosedove (1974) reported that the protein complex of pearl barley can be influenced by different hydrothermal treatment methods and thus rendering it less soluble. When steam pressure was increased, pearl barley proteins were more resistant to proteolytic enzymes *in vitro*.

Roller-milling

Traditionally, whole barley is not roller-milled as with wheat and oats. Milled barley flour, as opposed to whole barley flour (meal) is generally produced from pearl or pot barley (Bhatty, 1993b). Covered and hull-less barleys have been milled, either dry or tempered, with wheat milling equipment in numerous experiments as cited by Bhatty (1993b). Three fractions are generally produced in roller milling, namely flour, shorts and bran. The flour is principally endosperm tissue; the shorts contain cell wall tissue and some inner cell tissue from the aleurone and endosperm; the bran (excluding the hull in covered barley) consists of testa, pericarp, germ and portions of the aleurone layers (Bhatty, 1993b). Danish researchers have developed a disc mill for dry milling of barley (Munck et al., 1988).

Flour yields have been reported to vary from 51 to 74 % depending upon the barley cultivar, the type of roller mill and procedures used in the roller-milling (Pomeranz et al., 1971; Cheigh et al., 1975; McGuire, 1979; Bhatty, 1986, 1987, 1992, 1993a). The average flour yield from roller-milling barley is generally in the range of 65 to 68 % with an increase of about 10 % with hull-less cultivars. Barley flour is rich in starch, contains about 15 % protein and is somewhat higher in ash than wheat flour (1.1 verses 0.6 %) (Bhatty, 1987). Although the flour is principally derived from the endosperm, the removal of the cell-wall material reduces the percentages of both soluble and insoluble dietary fiber. Roller-milling concentrates these components in the shorts and bran fractions. The bran contains a greater percentage of insoluble fiber compared to that in the shorts (R.K. Newman, personal

communication).

Dietary Fiber

The current interest in dietary fiber in terms of research and clinical application is largely attributable to the original observations and hypothesis evolved by Trowell and Burkitt (1975). They observed the differences in the pattern and nature of diseases affecting the affluent western population as opposed to more primitive populations in Africa. They attributed differences in diet, particularly the quantity of non-absorbable plant material, as related to digestive disorders as well as incidence of chronic diseases. Although Trowell and Burkitt (1975) originated these concepts, research interest on "fiber" in cereal grains was documented in the Journal of the American Chemical Society as early as the nineteenth century (O'Sullivan, 1882). Current research has related fiber intake to the prevention of hypercholesterolemia, diverticulosis, constipation, hypertension, and gallstones as well as to the control of diabetes and to some extent obesity (Southgate, 1986). The earliest term related to fiber in food was crude fiber. This is an elementary definition as it is a measure of only a small fraction of what is truly food fiber. However, published food and feed composition tables listed only crude fiber for many years, and it is only within the last three to five years that analyzed values of the total fiber and components have been available.

Definition

Dietary fiber was first defined by Trowell et al. (1976) as "plant material that is unavailable for decomposition by mammalian digestive enzymes". Theander et al. (1989) proposed a more specific definition based on chemical structure. These authors' definition of dietary fiber as "non-starch polysaccharides plus lignin" is more encompassing of the various chemical components of food fiber.

Classification and Composition

Total dietary fiber can be classified by histological examination as 1) structural polysaccharides, 2) structural nonpolysaccharides and 3) nonstructural polysaccharides (Ink and Hurt, 1987). Structural polysaccharides are associated with the cellwall forming a supportive skeleton and include hemicelluloses and cellulose (Albersheim, 1977). Cellulose, hemicellulose, lignins and phenolic compounds are usually classified as insoluble dietary fiber. Nonstructural polysaccharides are a class of dietary fiber which includes mucilages, gums, pectin and mixed-linked $(1\rightarrow3),(1\rightarrow4)$-$\beta$-D-glucans. These gel-forming polysaccharides form the ground substance or matrix for the cell skeleton (Southgate, 1986).

Another type of classification refers to insoluble and soluble dietary fiber, and is popular today because it relates to differences in physiological function of the two forms. The chief components of dietary fiber are cellulose, lignins and the non-cellulosic polysaccharides. Cellulose is a linear α-linked $1\rightarrow4$ glucose polymer, resistant to digestive amylases, but capable of degradation by cellulases produced by intestinal microflora (Selvendran, 1984). Lignin is a cross-linked polymer of

oxygenated phenylpropane units. It is very resistant to degradation and is almost completely excreted in the feces (Hartley and Jones, 1977). The non-cellulosic polysaccharides are a highly diverse group and include pectic substances, gums, mucilages and algal compounds. β-glucan, found largely in barley and oats, is a major component of soluble fiber in barley, which comprises a large portion of the aleurone and endosperm cell walls (Henry, 1987). β-glucans are linear (1→4) polymers, consisting of β-D-cellotetrasyl residues separated by (1→3) linkages arranged in an independent or random manner (Basic and Stone, 1981). The structure and configuration of β-glucan reduces inter-molecular associations making it partially water soluble (Åman and Graham, 1986). The high molecular weight as well as the irregular conformation of β-glucan contributes to high solution viscosity (Bengtsson et al., 1990). Figure 1 is a schematic representation of the various fiber components with indication of solubility classification.

Analytical Methods

One of the major sources of confusion about nutritional significance of fiber in the diet has been the problem associated with its analysis. Table 1 is a summary of analytical methods for fiber and dietary fiber.

The earliest measurement of fiber was crude fiber, which was the material (largely cellulose and lignin) remaining after extraction with dilute acid and alkali (Williams and Olmsted, 1935). This method provides a gross underestimation of the fiber content of food and a corresponding overestimate of the available

Total Dietary Fiber	Nonstarch Polysaccharide	Noncellulosic Polysaccharide	Other Polysaccharide	Soluble Fiber
				---------
			Pectin	Some Soluble
			Hemicellulose	Some Insoluble

		Cellulose	Cellulose	Insoluble Fiber
	Lignin	Lignin	Lignin	

Figure 1. Fiber components and solubilities of total dietary fiber (Asp and Johansson, 1984).

carbohydrates, which is often calculated as the difference by weight from the total of the sum of fat, protein, fiber, ash and moisture. The crude fiber analytical value for barley may be as low as 10 to 20 % of the total dietary fiber content (Newman and McGuire, 1985).

To overcome these problems, Van Soest (1963a, 1963b) developed two gravimetric techniques, the acid and neutral detergent fiber methods. The acid detergent method solubilizes all constituents except cellulose and lignin, roughly comparable to the crude fiber method. The neutral detergent fiber method consists of an extraction which leaves hemicellulosic materials. This technique estimates dietary fiber better than the crude fiber method but still may underestimate the more soluble substances.

Enzyme techniques provide a more comprehensive method of fiber analyses. An

Table 1. Summary of analytical methods used to determine dietary fiber and fiber (Jenkins, 1988).

Analytical Measurement	Outline of Method and Fraction Actually Measured	Nature of Fraction Measured
Dietary Fiber		
Total (McCance et al., 1936)	Preparation of residue insoluble in alcohol. Measurement of starch and protein and deduction of these from the residue.	All components of dietary fiber in one fraction.
Components (Southgate, 1969)	Sequential extraction and hydrolysis of residue insoluble in alcohol.	Noncellulosic polysaccharides as component hexoses, pentoses and uronic acids; cellulose as glucose; lignin as the residue insoluble in 72 % (W/W) H_2SO_4.
Total (Prosky et al., 1984)	Enzymatic digestion of defatted residue to remove protein and starch.	All components of dietary fiber in one fraction minus some soluble fiber.
Fiber		
Acid Detergent(ADF, Van Soest, 1963a)	Extraction of food with boiling acid detergent solution. Measurement of organic matter in residue.	Cellulose plus lignin.
Neutral Detergent (NDF, Van Soest 1963b).	Extraction of food with boiling neutral detergent solution and weighing residue.	Cell wall materials less water-soluble components.
Crude (AOAC, 1988)	Extraction of food with boiling acid and alkali. Measurement of organic matter in residue.	Cellulose plus lignin (incomplete in many foods).

extracted residue is subjected to a series of enzymatic hydrolyses for specific components. The most widely used is the Prosky et al. (1984) method, whereby starch is gelatinized in fat-extracted material by heating in a boiling water-bath with termamyl (heat stable α-amylase). The substrate is then enzymatically digested with protease and amyloglucosidase to remove protein and starch. Soluble dietary fiber is precipitated with ethanol, then the remaining residue is filtered and washed with ethanol and acetone. After subtraction of the protein and ash values, the difference is calculated as dietary fiber. This is the current method accepted by the Association of Official Analytical Chemists (AOAC, 1988) although there are constant modifications.

The most specific fiber analysis is determination of the component sugars by gas chromatography (Southgate, 1969), with further modifications (Southgate and Englyst, 1985). An alternative method developed in Sweden has also gained considerable acceptance (Theander and Westerlund, 1986).

Physical and Physicochemical Properties

The major attributes of fiber that are of interest today are water-holding capacity, viscosity and cationic exchange. These properties affect physiological effects of fiber consumption as well as behavior of fiber-containing grain products in food preparation (Andon, 1987).

Water-holding capacity is important in reducing colonic transit time and expanding fecal bulk. This property of insoluble dietary fiber, such as cellulose in wheat bran, provides effective prevention of constipation (Cummings et al., 1978).

Water-holding capacity is important to the soluble fibers as well. Hydration of these fiber components forms a gel matrix which can increase intestinal viscosity. Increased intestinal viscosity can decrease gastric emptying rate and interfere with nutrient absorption by reducing diffusion through the unstirred water layer of the small intestine (Schneeman, 1986).

Cationic exchange properties are found in polysaccharides with free carboxyl groups, therefore plant fibers may act as ion-exchange resins. Cation exchange is affected by the number of free carboxyl groups and uronic acid content of the polysaccharides (Kay, 1982). Although the ability of fiber to make minerals unavailable for absorption has been claimed (Kay, 1982), Gordon (1988) reported that the inhibition of mineral availability in mammals is insignificant. Organic molecules, such as bile salts, may be adsorbed to fiber and have additional physiological effects (Story, 1986). Mammalian enzymes are unable to degrade dietary fiber, but microflora in the large intestine are able to degrade polysaccharides to varying degrees depending upon the type of polysaccharide (Cummings and Branch, 1986). Cellulose is only partially degraded, whereas more soluble nonstructural polysaccharides are almost totally digested by microbes. Microbial degradation leads to formation of volatile short-chain fatty acids which are absorbed and utilized (Kay, 1982), but also may influence lipid metabolism (Smith and Bryant, 1979; Cummings, 1981).

Physiological Effects and Health Benefits of Dietary Fiber

Water soluble plant polysaccharides have been documented as effective

hypocholesterolemic agents (Judd and Truswell, 1985). Soluble fiber, particularly barley and oat β-glucan have been shown to lower total serum cholesterol and low density lipoprotein cholesterol (LDL) and to elevate high density lipoprotein cholesterol (HDL) in experimental animals (Fisher and Griminger, 1967; Imaizumi and Sugano, 1986; Fadel et al., 1987; Lund et al., 1989; Shinnick et al., 1990; Newman et al., 1991;) and humans (Newman et al., 1989a; McIntosh et al., 1991; Jenkins et al., 1993). Two current theories attempt to explain the mechanisms of the cholesterol lowering effect. Increased intestinal viscosity can interfere with fat and cholesterol absorption (Wang et al., 1992; Gallaher et al., 1993a, 1993b). Certain soluble fibers also bind to bile acids and steroids causing their excretion and subsequent alterations in cholesterol metabolism (Anderson and Chen, 1986) In addition the rate of absorption of sugars is decreased when fiber is consumed, lowering the blood glucose response (Jenkins et al. 1987; Wood et al., 1990; Xue et al., 1992). This effect is particularly important in delaying or modifying elevated blood sugar in diabetes and is related to the cholesterol effect (Anderson, 1986).

Various estimates of dietary fiber intake in the United States have been published with estimates ranging from 11.1 g to 23.3 g of total dietary fiber daily. Current recommendations are for consumption of 25-30 g daily, of which 25 to 30 % should be soluble and the remaining content insoluble (Pilch, 1987).

Lipid Definitions, Functions and Metabolism

Cholesterol

The primary functions of cholesterol are as a modulator of the fluidity of eucaryotic membranes and as a precursor of bile acids, fecal sterols, sex hormones and cholecalciferol. The major pathway of degradation of cholesterol in animals and man is the conversion to bile acids (sterols). Cholesterol, coprostanol and cholestanol are the major sterols excreted by mammals in which coprostanol and cholestanol are formed from cholesterol by microorganisms in the intestine (Murray et al., 1988).

Although cholesterol is an essential metabolite in mammals, it can also become a main factor in cardiovascular disease by contributing to the accumulation of fatty materials (plaque) in the arterial walls of medium and large arteries. This condition can lead to myocardial infarcts or strokes (Lipid Research Clinics Program, 1984).

Dietary cholesterol contributes to total body cholesterol but a major portion is synthesized endogenously (Quintao et al., 1971; Mattson et al., 1972). Researchers have established that virtually all organs and tissues are capable of synthesizing cholesterol (Dietschy and Siperstein, 1967). Goodman and Noble (1968) described the turnover of cholesterol in the plasma of man as a two-pool model among various tissues.

Dietary modification can help to control serum cholesterol values (American Heart Association, 1978). Lopez et al. (1966) reported a positive correlation between

serum cholesterol levels and the percent of calories derived from simple sugars, and a very high negative correlation between serum cholesterol levels and percent of calories derived from complex carbohydrates. In documented population studies, using standard methods for diet and coronary heart disease assessment, no population that subsists on a low-fat, low cholesterol diet, or low-saturated fat, low cholesterol diet has an appreciable amount of coronary heart disease (Glueck et al., 1976).

A diet high in saturated fat, cholesterol or a combination of the two is a predisposing factor for a high incidence of coronary heart disease (Sinnett and Whyte, 1973; Sacks et al., 1975; Glueck and Conner, 1978). It is recommended that the average daily intake of cholesterol by adults be less than 300 mg (American Heart Association, 1968; Stamler et al., 1970). According to the U.S. Bureau of the Census (1993) however, the cholesterol available for civilian consumption per capita per day ranged from 510 mg in 1955 to 440 mg in 1988. Balaban and Wright (1987) reported that a decreased consumption of milk, eggs, butter, and animal fats results in lower blood cholesterol levels and that a 5 mg daily decrease in cholesterol in a population results in an estimated 5 % decline in the population's risk of developing coronary heart disease.

Jurgens et al. (1967, 1968) reported that vitamin D_2 depressed blood cholesterol in swine and rats regardless of whether or not dietary cholesterol was provided in the respective diets. Jurgens et al. (1970) also reported that vitamin D_3 reduced blood cholesterol or at least stabilized blood cholesterol in pigs fed a highly saturated

fat diet of coconut oil, while blood cholesterol levels increased when fed in combination with a polyunsaturated fat diet of safflower oil. Cholesterol content of the pork tissue was stable regardless of the diet fed.

Triacylglycerols

The primary function of triacylglycerols is as an energy reserve for which purpose fats are more efficient than are proteins and(or) carbohydrates. Theoretically, stored triacylglycerols can provide the basal energy requirements for over 70 d of fasting in the normal adult and for well over a year in the very obese individual (Cahill, 1970).

Dietary fats and carbohydrates are known to influence plasma triacylglycerol concentrations (Anderson, 1967). The amount of influence is governed by factors such as amount consumed (Lees and Fredrickson, 1965), genetics of the individual (Fredrickson et al., 1967), type of carbohydrate in the diet (Kaufmann et al., 1966) and presence or absence of obesity (Albrink and Meigs, 1964; Grace and Goldrick, 1968).

Blood Lipoproteins

The four major classes of blood lipoproteins are: 1) chylomicrons, 2) very low density lipoproteins (VLDL), 3) low density lipoproteins (LDL), and 4) high density lipoproteins (HDL). Chylomicrons carry triacylglycerols from the intestines to other tissues except kidney tissue. VLDL bind triacylglycerols synthesized in the liver, while LDL, which are produced by the degradation of the lipid portion of VLDL,