



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 $\approx$ 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.

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**A thesis submitted in partial fulfillment
of the requirements for the degree**

of

Doctor of Philosophy

in

Crop and Soil Science

**MONTANA STATE UNIVERSITY
Bozeman, Montana**

November 1994

D378
D2285

APPROVAL

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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 ≈ 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; Aspinall 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→3, 1→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; Aman 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 horizontal 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 pearlins 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, pearlins 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 pearlins. Hofman (1975) reported that barley pearlins produced a more favorable protein composition than their corresponding parent barley varieties. The pearlins 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→3), (1→4)- β -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→4 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 $\rightarrow$ 4) polymers, consisting of β -D-cellobiosyl residues separated by (1 $\rightarrow$ 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 -----
	Lignin	Cellulose	Cellulose	Insoluble Fiber
		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 ₂ SO 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

hypcholesterolemic 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 (Sinnott 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 D₂ 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 D₃ 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,

regulate cholesterol synthesis in tissues other than the liver. HDL particles are bound to most of the plasma cholesterol obtained from various tissues including the liver (Murray et al., 1988).

High serum LDL and VLDL have been associated with an increased risk in the development of coronary heart disease while high serum HDL have been reported to decrease the risk of coronary heart disease (Albrink et al., 1961; Gofman et al., 1966; Carlson and Bottiger, 1972; Gordon et al., 1977; Castelli et al., 1977; Kannel et al., 1979; Lipid Research Clinics Program, 1984). Plasma lipoproteins can be modified by a change in dietary regimen. Cholesterol content and the ratio of polyunsaturated fats to saturated fats of diets were found to be important in determining LDL and HDL levels in humans (Schonfeld et al., 1982). This is supported by earlier work by Lewis et al. (1981), who also found that diets high in fiber had an additive effect to other cholesterol-lowering diets such as a modified fat diet. Stasse-Wolthuis et al. (1980) also demonstrated that diets high in fiber and(or) pectin had a cholesterol-lowering effect.

Summary

Heart disease and its complications are major problems in industrialized countries. Soluble dietary fiber can be an effective avenue towards partial alleviation of this problem. Barley contains significant amounts of dietary fiber, particularly the soluble form. In the past, air classification and milling of cereal

grains, particularly wheat, have been utilized to concentrate nutrients such as protein, starch and energy (fat). It is plausible that these same techniques can be modified to concentrate other nutrients from barley grain, such as soluble dietary fiber for use as dietary adjuncts for incorporation into traditional or new food products.

CHAPTER 3

EFFECT OF PIN MILLING AND AIR CLASSIFICATION ON PHYSICAL AND CHEMICAL PROPERTIES OF WAXY HULL-LESS BARLEY

Introduction

Air classification affords a process by which specially designed flours can be produced from wheat and other cereal grains for a vast array of food uses. Preliminary work in our laboratory has shown that fractions rich in dietary fiber can be produced from whole ground barley (McGuire and Danielson, 1991). Such a product should have appeal and potential as a human food source when incorporated into traditional or new foods.

Although all fiber fractions have some function in the mammalian system (physiological, nutritional, etc.), the soluble or extractable fiber fraction has attracted considerable attention in the commercial cereal industry as well as the scientific community. In part this is due to the ability of soluble fiber to modify cholesterol metabolism as ascribed to oats (Fisher and Griminger, 1967; Chen et al., 1981; Shinnick et al., 1990) and barley (Newman et al., 1989a, 1989b; McIntosh and Oakenful, 1990; McIntosh et al., 1991). β -glucan, a major component of soluble fiber in barley comprises a large portion of the aleurone and endosperm cell walls.

To date very little information exists concerning air classification of barley in respect to dietary fiber content. Thus the objective of this experiment was to determine whether flour fractions rich in fiber and β -glucans could be obtained from waxy hull-less barley by pin milling and air classification.

Materials and Methods

Barley Cultivar and Air Classifier Set-up

Waxy hull-less barley (AZ 76-19-7WX), developed by the USDA at the University of Arizona, Tucson (R.T. Ramage, personal communication) was hammer milled (Jacobson Pulverator No. 66b, Jacobson Machine Works, Minneapolis, MN) through a 2.38 mm screen, pin milled (Alpine Kolloplex Laboratory Pin Mill model 1607, Alpine American Corporation, Natick, MA) and air classified (Alpine-Augsburg Mikroplex Air Classifier type 132 MP, Alpine American Corporation, Natick, MA) into 36 fractions. Pin mill and air classifier steps are presented in Table 2. The pin mill rpm and degree of opening used for each of the 18 air classification steps are indicated.

Physical and Chemical Analyses

Parent stock and samples of each fraction were analyzed for nitrogen, diethyl ether extractable fat (ether extract) and ash (AOAC, 1988), total, soluble and insoluble dietary fiber (TDF, SDF and IDF, respectively, Lee and Hicks, 1990),

Table 2. Rotor speed, cut point, and quantity recovered from air classifier¹.

PASS NUMBER	PIN MILL ROTOR SPEED RPM	CUT POINT	QUANTITY RECOVERED			
			COARSE FRACTIONS		FINE FRACTIONS	
			Kg	%	Kg	%
1	9000	14°	59.83	90.97	2.04	3.10
2	9000	14°	53.62	81.53	1.91	2.90
3	9000	27°	48.90	74.35	2.72	4.14
4		27°	46.58	70.82	1.91	2.90
5	12000	15°	43.27	65.79	1.59	2.42
6		25°	41.87	63.66	0.95	1.44
7		35°	39.60	60.21	2.27	3.45
8	14000	15°	35.06	53.31	1.54	2.34
9		25°	32.21	48.97	1.45	2.20
10		35°	28.58	43.45	2.99	4.55
11	14000	15°	26.35	40.06	0.73	1.11
12		25°	24.68	37.52	0.91	1.38
13		35°	22.54	34.27	1.59	2.42
14		35°	21.41	32.55	0.73	1.11
15	18000	15°	19.90	30.26	0.95	1.44
16		25°	17.42	26.49	1.13	1.72
17		35°	16.01	24.34	1.13	1.72
18		35°	12.02	18.28	2.54	3.86

¹ Hammer Mill recovery from 68 Kg = 65.77 Kg using 2.38 mm screen.

β -glucan (McCleary and Glennie-Holmes, 1985), neutral extract viscosity (neutral viscosity, Rotter et al., 1989), acid extract viscosity (acid viscosity, Greenberg and Whitmore, 1974) and starch (Åman and Hesselman, 1984). Extracts of the fractions used for acid and neutral extract viscosity measurements were prepared with 3 g of autoclaved (1 h at 121 °C and 15 lbs pressure) barley flour mixed with 75 ml of distilled deionized water or pH 1.5 HCL/KCL acid buffer. Samples for neutral and acid extract viscosity were extracted for 2 and 1 h respectively, centrifuged at 10,000 x g for 30 min and viscosity measured immediately at 30 °C using a Haake falling ball viscometer (Model B, Haake Instruments, Inc., Saddle Brook, NJ). Starch analysis procedures were slightly modified from that of Åman and Hesselman (1984) in that the initial incubation period was 1 h instead of 30 min and samples were centrifuged for 10 instead of 5 min after the second incubation period.

For particle size determinations of the fine air classified fractions a flour sample was added to 200 ml of xylene which dispersed and carried the sample. Optimal sample size was determined with a sample loading curve (Dv plot). Particle size of the fine fractions was determined with a particle size analyzer (Microtrac model 7991-01 Particle Size Analyzer, Microtrac Division, Leeds and Northrup, Largo, FL) and that of the coarse fractions was determined with test sieves (Ro-tap Testing Sieve Shaker, W.S. Tyler Co., Cleveland OH).

Statistical Analyses

PROC CORR was used to determine Pearson's correlation coefficients and probability values among all response criteria measured (SAS, 1988).

Results and Discussion

Mean particle size of the fine flour fractions ranged from 5.98 to 11.80 μ . Approximately 90% or more of particles in each of the fine fractions were smaller than 19 μ . The greatest percentage of coarse fractions 1-3 was distributed on the 40 sieve, fractions 4-5 on the 100 sieve, fractions 6-11 and 16 on the 80 sieve and fractions 12-15 and 17-18 on the 100 sieve.

Percentage TDF in whole barley flour and the fine and coarse fractions are presented in Figure 2. The TDF of whole barley flour was 13.81 % with a consistent increase exhibited in the coarse fractions from fraction 1 (18.57 %) to fraction 18 (38.71 %). The percentage TDF in the fine fractions dropped initially compared to that in the whole barley flour but tended to rise but with intermittent random drops thereafter. The greatest TDF in the fine fractions was in fraction 16 (12.43 %) and the lowest value occurred in fraction 2 (5.03 %). Percentage insoluble dietary fiber of whole barley flour was 8.85 % with the same concentration patterns exhibited in both the coarse and fine fractions as with percentage TDF, with coarse fraction 18 the greatest at 17.55 % (Figure 2). As with TDF, the IDF in the fine fraction dropped initially and tended to rise with intermittent random drops. The fine fraction 2 contained the least amount of IDF (3.62 %).

Percentages of SDF and β -glucan (Figure 3) exhibited the same concentration patterns in the fractions as percentage TDF and IDF, with the whole barley flour containing 4.94 and 9.99 % IDF and β -glucan, respectively. The coarse fraction 18

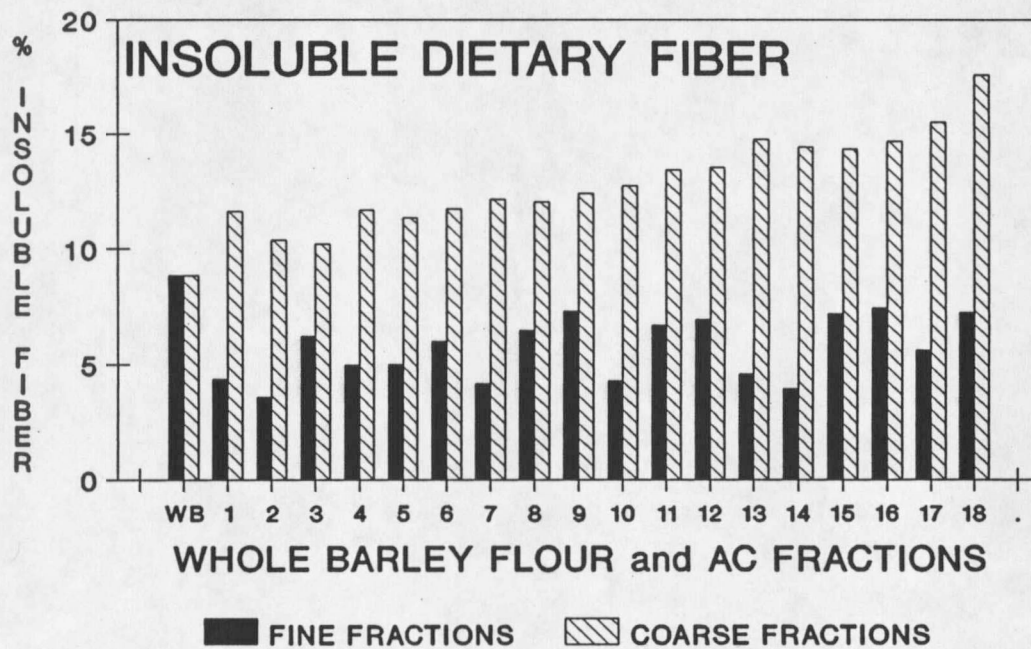
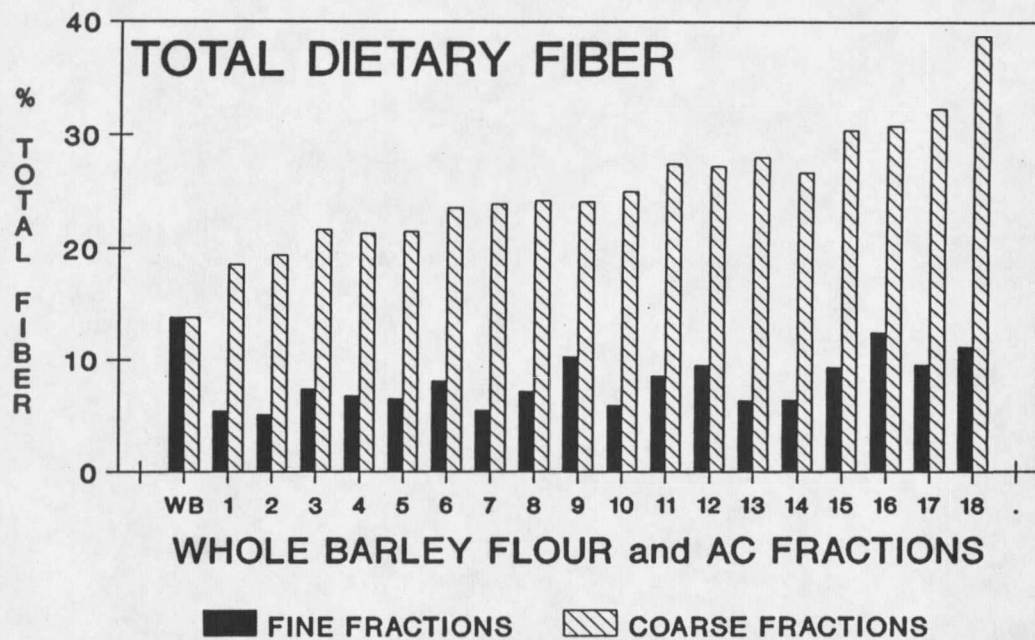


Figure 2. Total and insoluble dietary fiber content of whole barley (WB) flour and air classified (AC) flour fractions.

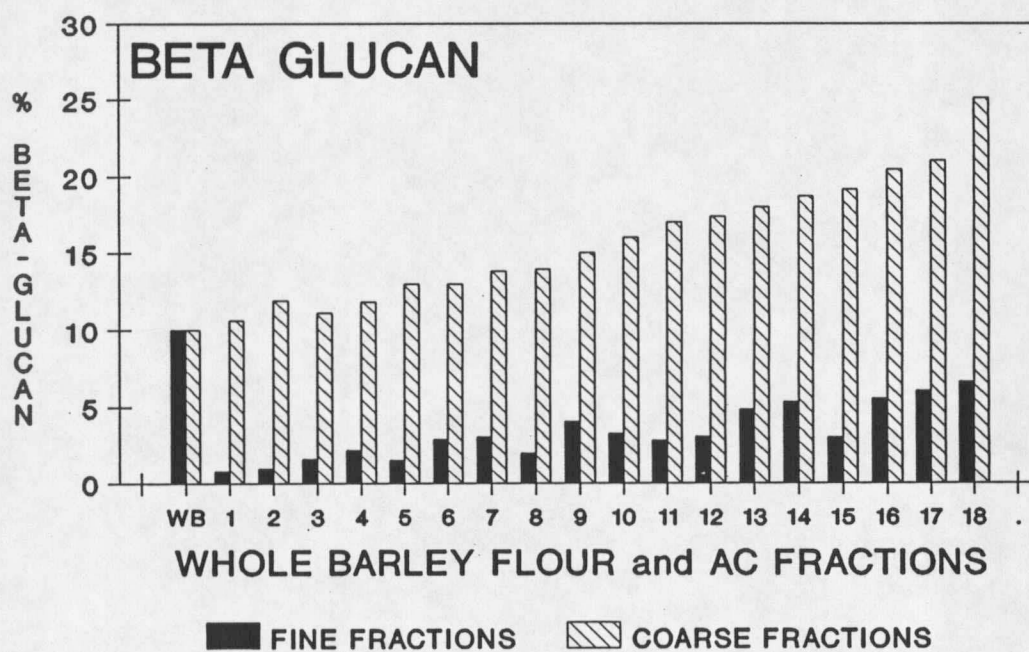
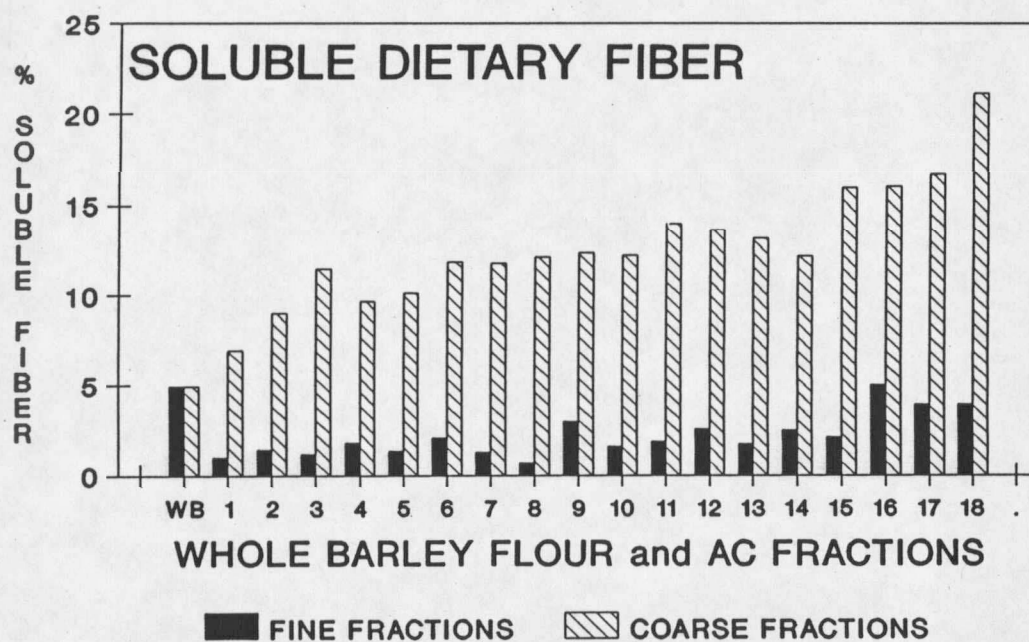


Figure 3. Soluble dietary fiber and β -glucan content of whole barley (WB) flour and air classified (AC) flour fractions.

contained 21.15 % SDF and 25.11 % β -glucan. The greatest percentage SDF in the fine fractions was in fraction 16 (5.00 %) with the lowest occurring in fraction 8 (0.69 %). Fine fraction 1 contained the least amount of β -glucan (0.81 %).

Acid and neutral viscosities (Figure 4) of the whole barley flour were 6.13 cP and 5.48 cP, respectively. Acid viscosity and neutral viscosity of the fine flour fractions were very similar with all fractions having lower cP values than that of the whole barley flour. Coarse fraction 18 was greatest for both acid viscosity (36.03 cP) and neutral viscosity (45.65 cP). Acid viscosity and neutral viscosity were lower than the parent barley flour for coarse fractions 1-8 but then increased rapidly in fractions 9-18.

The whole barley flour contained 54.28 and 1.88 % starch and nitrogen, respectively (Figure 5) and in contrast to fiber components, these components were higher in the fine fractions when compared to the coarse fractions. Percentage of starch and nitrogen decreased rather considerably with each air classification step in the coarse fractions. The starch content of the fine fractions tended to rise, but with considerable variation. The nitrogen content increased in the initial fine fractions compared to the whole barley flour and then tended to decrease with some variability with increasing air classification steps.

Ash and ether extract (Figure 6) percentage increased in both the initial coarse and fine fractions compared to whole barley flour. As with starch and nitrogen the percentage ash in the coarse fractions decreased with increasing air classification steps. Ether extract and ash percentage varied considerably in the fine fractions and

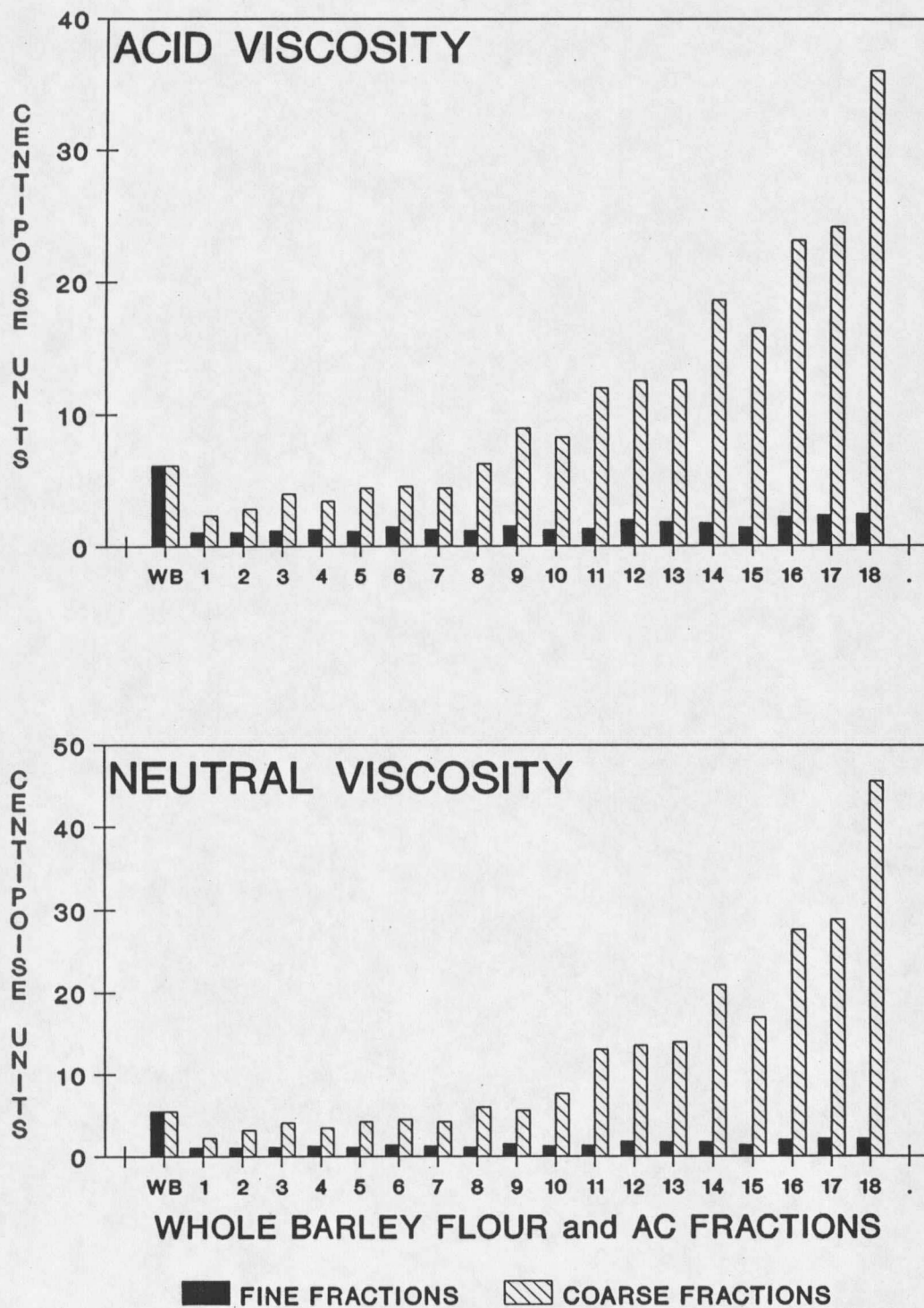


Figure 4. Acid and neutral viscosity of whole barley (WB) flour and air classified (AC) flour fractions.

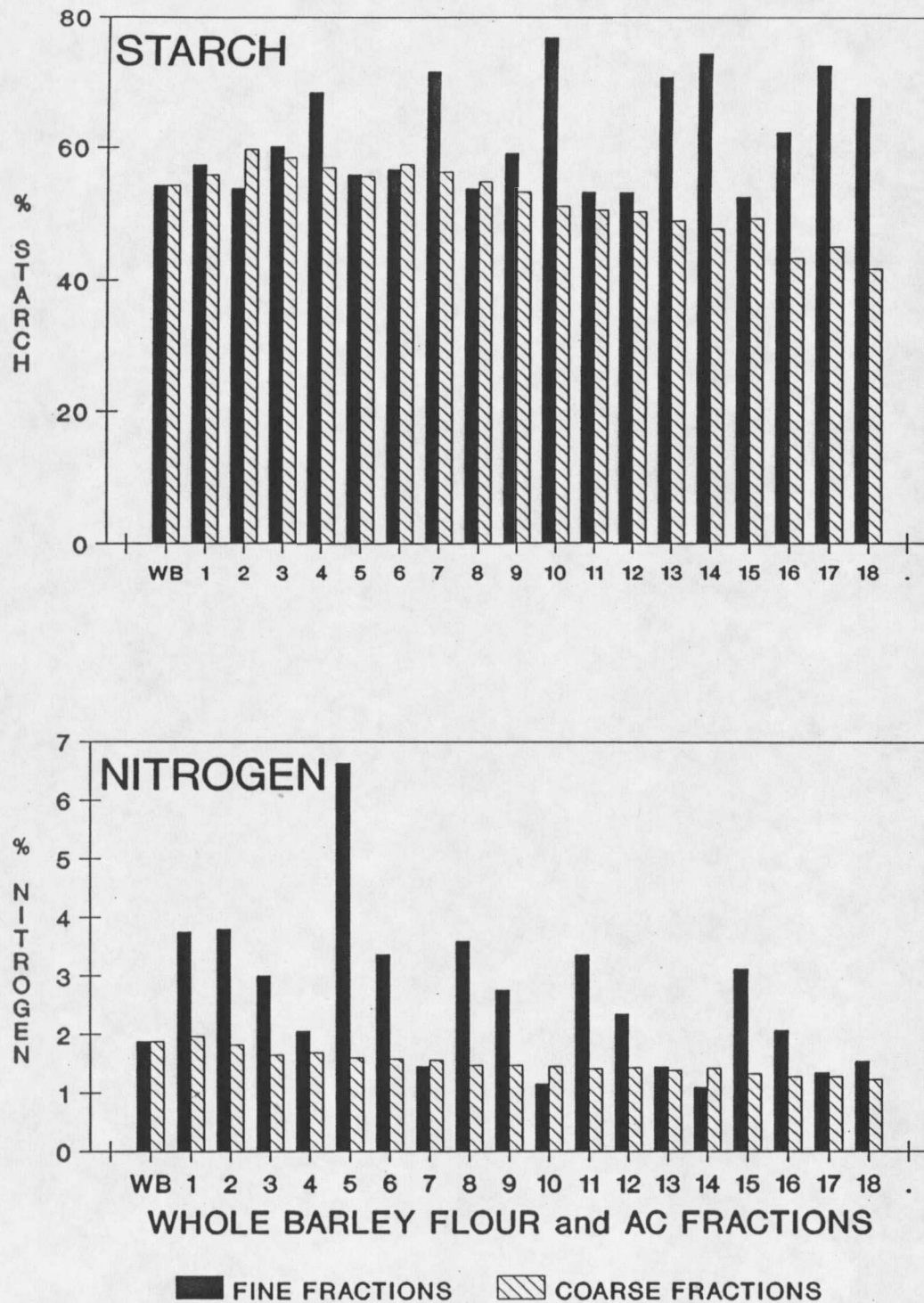


Figure 5. Starch and nitrogen content of whole barley (WB) flour and air classified (AC) flour fractions.

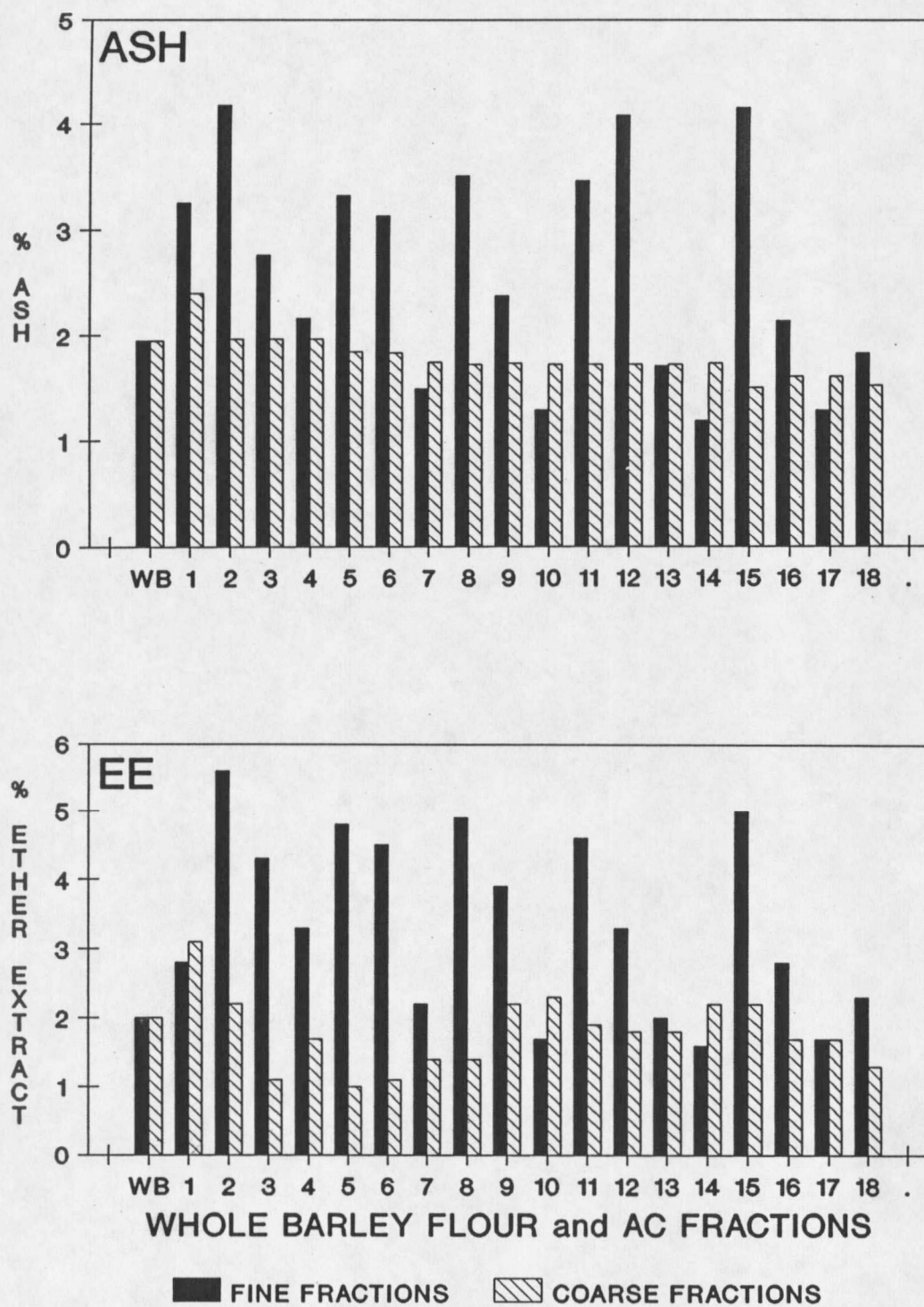


Figure 6. Ash and diethyl ether extractable fat (EE) content of whole barley (WB) flour and air classified (AC) flour fractions.

were not consistent with increasing air classification steps.

Sharp increases in ash, ether extract and nitrogen with decreases in starch in the five fine fractions after air classified steps 4, 7, 10, 14 and 17 are explained by pin-milling of coarse fractions that occurred after these respective steps. Additional pin milling of coarse fractions between air classification steps allows further breakdown of particle size of the fine fractions with a tendency for a concomitant increase in the particle size of the coarse fractions allowing for further segregation of plant components into fine and coarse fractions, respectively.

Correlation coefficients and probability values for components of the fine and coarse fractions are shown in Tables 3 and 4, respectively. Percentage TDF was highly correlated (.627 to .891, $P < .01$) with SDF, IDF and β -glucan. Percentage SDF was positively correlated (.516 to .817, $P < .05$) with IDF and β -glucan and IDF not significantly ($P = .203$) correlated with β -glucan in the fine fractions. All fiber components (TDF, SDF, IDF and β -glucan) were positively correlated (.883 to .984, $P < .01$) with each other in the coarse fractions. Acid viscosity and neutral viscosity were positively correlated (.728 to .925, $P < .01$) with each other and with TDF, SDF and β -glucan but were not correlated with IDF, ash or ether extract in the fine flour fractions. However, β -glucan was negatively correlated (-.657 to -.659, $P < .01$) with ash and ether extract. Acid viscosity, neutral viscosity TDF, SDF, IDF and β -glucan were positively correlated (.883 to .994, $P < .01$) with each other for coarse fractions. Acid viscosity, neutral viscosity, TDF, SDF, IDF and β -glucan were negatively correlated (-.655 to -.857, $P < .01$) with ash but not with ether

Table 3. Correlation coefficients^a and probability values^b of air classified fine fractions¹.

	SDF	IDF	β -GLU	AVIS	NVIS	ASH	EEF	STAR	NITR
TDF	.849 ^a .001 ^b	.891 .001	.627 .005	.743 .004	.728 .004	-.012 NS	-.040 NS	-.142 NS	-.144 NS
SDF		.516 .028	.817 .001	.879 .001	.884 .001	-.345 NS	-.378 NS	.226 NS	-.446 NS
IDF			.315 NS	.450 NS	.421 NS	.276 NS	.259 NS	-.423 NS	.149 NS
β -GLU				.905 .001	.925 .001	-.657 .003	-.659 .003	.573 .013	-.759 .003
AVIS					.996 .001	-.413 NS	-.536 .022	.340 NS	-.597 .009
NVIS						-.443 NS	-.561 .016	.371 NS	-.628 .005
ASH							.869 .001	-.955 .001	.868 .001
EE								-.874 .001	.892 .001
STAR									-.910 .001

¹ TDF=Total dietary fiber; SDF=Soluble dietary fiber; IDF=Insoluble dietary fiber; β -GLU= β -glucan; AVIS=Acid extract viscosity; NVIS=Neutral extract viscosity; EE=Ethyl ether extract; STAR=Starch; NITR=Nitrogen; NS=Non-significant, P > .05.

Table 4. Correlation coefficients^a and probability values^b of air classified coarse fractions¹.

	SDF	IDF	β -GLU	AVIS	NVIS	ASH	EEF	STAR	NITR
TDF	.984 ^a .001 ^b	.952 .001	.976 .001	.954 .001	.940 .001	-.818 .001	-.183 NS	-.927 .001	-.908 .001
SDF		.883 .001	.936 .001	.918 .001	.901 .001	-.857 .001	-.279 NS	-.859 .001	-.913 .001
IDF			.973 .001	.943 .001	.926 .001	-.703 .001	.017 NS	-.976 .001	-.840 .001
β -GLU				.967 .001	.946 .001	-.802 .001	-.052 NS	-.968 .001	-.899 .001
AVIS					.994 .001	-.699 .001	-.077 NS	-.956 .001	-.812 .001
NVIS						-.655 .003	-.111 NS	-.937 .001	-.769 .002
ASH							.366 NS	.666 .003	.937 .001
EE								-.062 NS	.283 NS
STAR									.828 .001

¹ TDF=Total dietary fiber; SDF=Soluble dietary fiber; IDF=Insoluble dietary fiber; β -GLU= β -glucan; AVIS=Acid extract viscosity; NVIS=Neutral extract viscosity; EE=Ethyl ether extract; STAR=Starch; NITR=Nitrogen; NS=Non-significant, P > .05.

extract. Starch % was negatively correlated (-.874 to -.955, $P < .01$) to nitrogen, ash and ether extract and positively correlated (.573, $P < .01$) to β -glucan. Nitrogen was negatively correlated (-.597 to -.910, $P < .01$) to β -glucan, acid viscosity, neutral viscosity and starch and positively correlated (.868 to .892, $P < .01$) to ash and ether extract. This explains in part the drop in both acid and neutral viscosity in the coarse fractions 1-8 (Figure 4). Nitrogen was relatively constant in these fractions and increased dramatically in the early fine fractions whereas fiber components were increasing in all of the coarse fractions. The relationship between fiber and nitrogen components and their effects on extract viscosity are apparently in opposition to one another.

Conclusions

These data demonstrate that pin milling followed by air classification can separate fractions from waxy hull-less barley that are high in TDF, SDF, IDF, β -glucan, acid viscosity, neutral viscosity, ash, ether extract, starch and nitrogen. TDF, SDF, IDF, β -glucan, acid viscosity and neutral viscosity rich fractions can be obtained from coarse air classified waxy barley flour fractions with ash, ether extract, starch and nitrogen rich fractions obtained from fine air classified waxy barley fractions. The viscosity measurements are reflective of the nitrogen components as well as the TDF components.

Potential Applications

Air classification affords a process by which specially designed barley flour fractions can be produced for use in a vast array of products. Flour rich in soluble dietary fiber would be especially desirable for increasing the intake of this component in food. The fraction selected for a specific food application would be determined by the functional characteristics imparted to the food product as well as economics of production. Obviously there must be a compromise between desirable functional characteristics and the number of air classification passes that are economically feasible.

The high fiber air classified waxy barley fractions may be used as food stabilizers and thickening agents as are guar and xanthum gum. High fiber barley flour fractions demonstrate many of the same chemical and physical properties exhibited by commercial food stabilizers now available on the market. Some food products to which waxy barley flour fractions could be added include ice cream, fermented and non-fermented sausages, yogurt, baby foods and sauce mixes. Products requiring high protein of cereal origin could also be developed from the fine barley flour fractions produced by air classification. The potential of utilizing air classified fractions from waxy barley is vast and needs to be further explored.

CHAPTER 4

COMPOSITION OF WHOLE BARLEY, BARLEY PEARLINGS AND PEARL BARLEY FROM CANADIAN NON-WAXY HULL-LESS BARLEY

Introduction

Pearling of barley is an extension of a procedure called blocking which is accomplished using a coarse circular emery stone that is rotated on a horizontal axis and enclosed within a perforated metal container. Initially, the lemma, palea and part of the seed coat of covered barley are removed, and as pearling continues, the rest of the seedcoat, pericarp, aleurone layers and germ are removed (Weaver et al., 1981). The outer portion of the kernel which is removed is generally referred to as pearlins and the remaining portion of the endosperm is termed pearl barley.

Pearling affords a process by which barley can be used as pearl barley in many commercial foods such as soups, salads and vegetable mixtures. In the past, pearlins have generally been relegated to use in animal feeds. However, the pearlins may offer a source of nutrients including dietary fiber for human consumption that has thus far been overlooked. Both pearl barley and barley pearlins are known to contain essential food nutrients, although the exact composition has not been determined. The objective of this experiment was to

compare the chemical and physical composition of non-waxy hull-less barley pearlings and pearl barley to the corresponding whole barley parent genotype.

Materials and Methods

Non-waxy hull-less barley genotypes (Scout, Tupper, SB86106, SR86132) developed in the barley breeding program at the Crop Development Centre at the University of Saskatchewan, Saskatoon, Sask. S7N0W0 Canada were used in this experiment. Prior to pearling, all foreign material was removed from the barleys. Equal quantities (800 g) of each barley isotype were pearled utilizing a laboratory scale pearler (Strong Scott Pearler, Model 109B, Seedburo Equipment Company, Chicago, Illinois 60607 USA). Pearlings were collected consecutively from 0-10 sec., 11-20 sec., 21-30 sec., 31-40 sec. and 41-50 sec., respectively.

Physical and Chemical Analyses

Whole barley, pearled barley and barley pearling fractions of the four barleys from two crop years were analyzed independently for total, insoluble and soluble dietary fiber (TDF, IDF and SDF, respectively, Lee and Hicks, 1990), β -glucans (McCleary and Glennie-Holmes, 1985), acid extract viscosity (acid viscosity, Greenberg and Whitmore, 1974), diethyl ether extractable fat (ether extract), ash, and Kjeldahl protein (protein, AOAC, 1988). Extracts of the fractions used for

viscosity measurements were prepared with 3 g of autoclaved (1 h, 121 °C, 15 lbs pressure) barley flour mixed with 75 ml of pH 1.5 HCL/KCL acid buffer. Extraction duration was 1 h, then samples were centrifuged at 10,000 x g for 30 min. and viscosity measured immediately at 30 °C using a Haake falling ball viscometer (Model B, Haake Instruments, Incorporated, Saddle Brook, New Jersey, USA).

Statistical Analyses

Data were analyzed by PROC GLM and PROC CORR were used to determine analysis of variance, Pearson correlation coefficients and probability values among all response criteria measured (SAS, 1988).

Results and Discussion

Barley pearlings and pearl barley yields are shown in Table 5. The pearling yield was the greatest for the 0-10 second pearling period with a decrease in yield through the 41-50 second period for SB86102 and SR86132. Tupper and Scout exhibited the highest pearling yield at the 41-50 second period.

Total and insoluble dietary fiber levels are shown in Figure 7. TDF concentration was the lowest ($P < .05$) for all barley genotypes in the pearl barley, 41-50 sec pearlings and 31-40 sec pearlings with the greatest TDF ($P < .05$) exhibited in the 0-10 sec pearlings. Whole barley had TDF values equal ($P > .05$)

Table 5. Barley pearlings and pearl barley yields (%) combined for 1988 and 1989 crop years¹.

	<u>Scout</u>	<u>Tupper</u>	<u>SB86106</u>	<u>SR86132</u>	<u>Average</u>
0-10 sec pearling	15.50	16.00	17.00	15.50	16.00
11-20 sec pearling	11.00	11.00	11.50	11.00	11.13
21-30 sec pearling	10.50	10.00	9.50	9.50	9.88
31-40 sec pearling	9.00	9.50	9.50	9.50	9.38
41-50 sec pearling	12.00	10.50	8.50	9.50	10.13
Pearl barley	42.00	43.00	44.00	45.00	43.50

¹ Initial starting amount of each whole barley was 800 g.

to that of 21-30 and 31-40 sec pearlings. The TDF values were not significantly different ($P > .05$) for the whole and pearl barley between barley genotypes. However, TDF contents of Tupper and SR86132 were significantly ($P < .05$) greater than TDF content in SB86106 in the 0-10 sec pearling samples and SB86106 was significantly greater ($P > .05$) than TDF in Scout in the 41-50 sec pearlings. The IDF levels exhibited the same pattern as TDF for all barley genotypes. The IDF values were not significantly different ($P > .05$) for the whole and pearl barley between barley genotype. The IDF content of SB86106 was lower ($P < .05$) than the other three barleys for the 0-10 sec fraction and greater ($P < .05$) than Scout for 21-30 sec pearling fraction.

No difference ($P > .05$) existed in SDF (figure 8) level in whole barley, barley pearlings and pearl barley within any of the barley genotypes or between barley genotypes.

β -glucan concentration (Figure 8) was the lowest ($P < .05$) in the 0-10 sec pearlings and the greatest ($P < .05$) in the 41-50 sec pearlings and pearl barley for

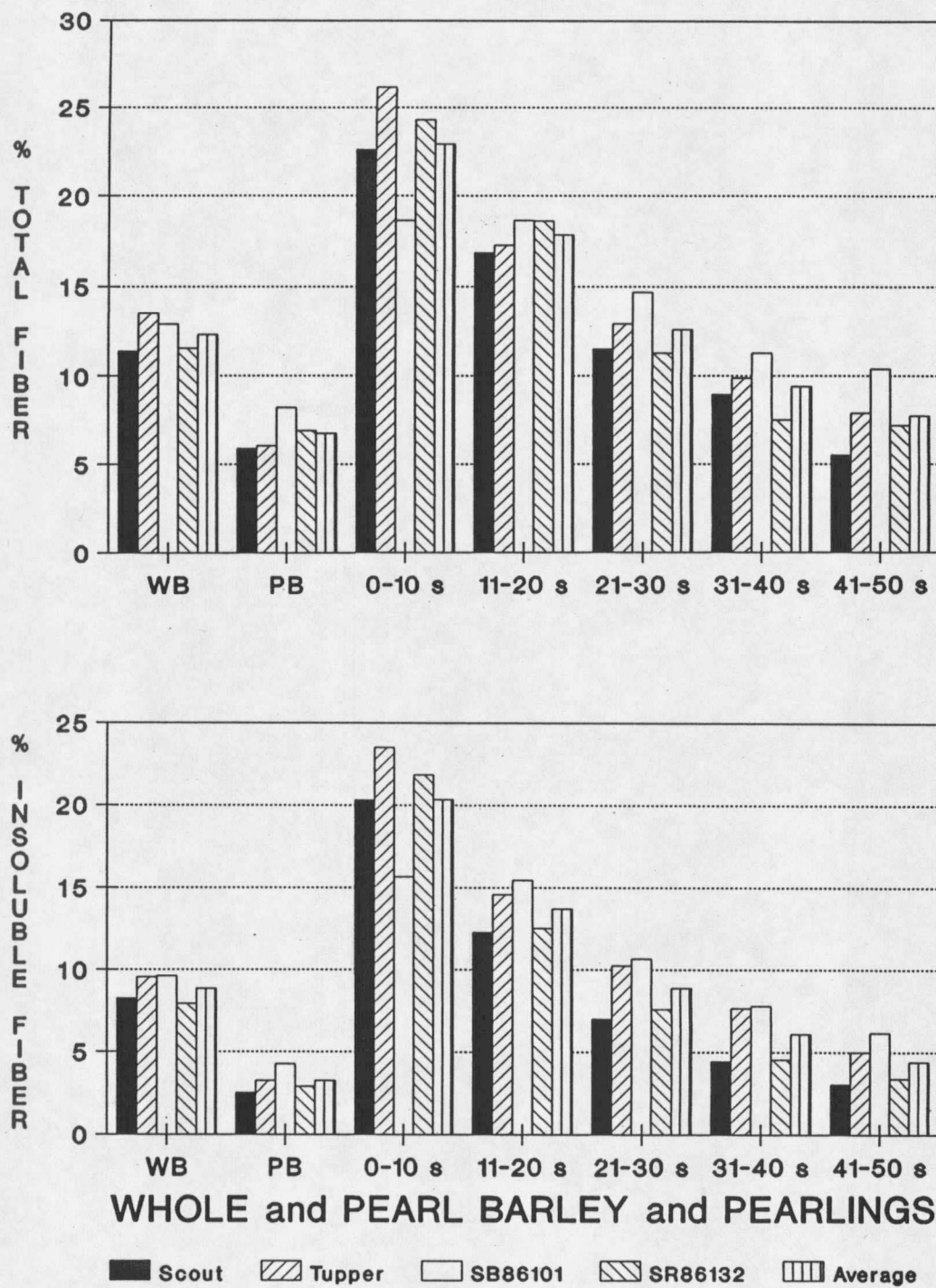


Figure 7. Total and insoluble dietary fiber content of whole barley (WB), pearled barley (PB) and barley pearlings at five consecutive 10 second (s) intervals.

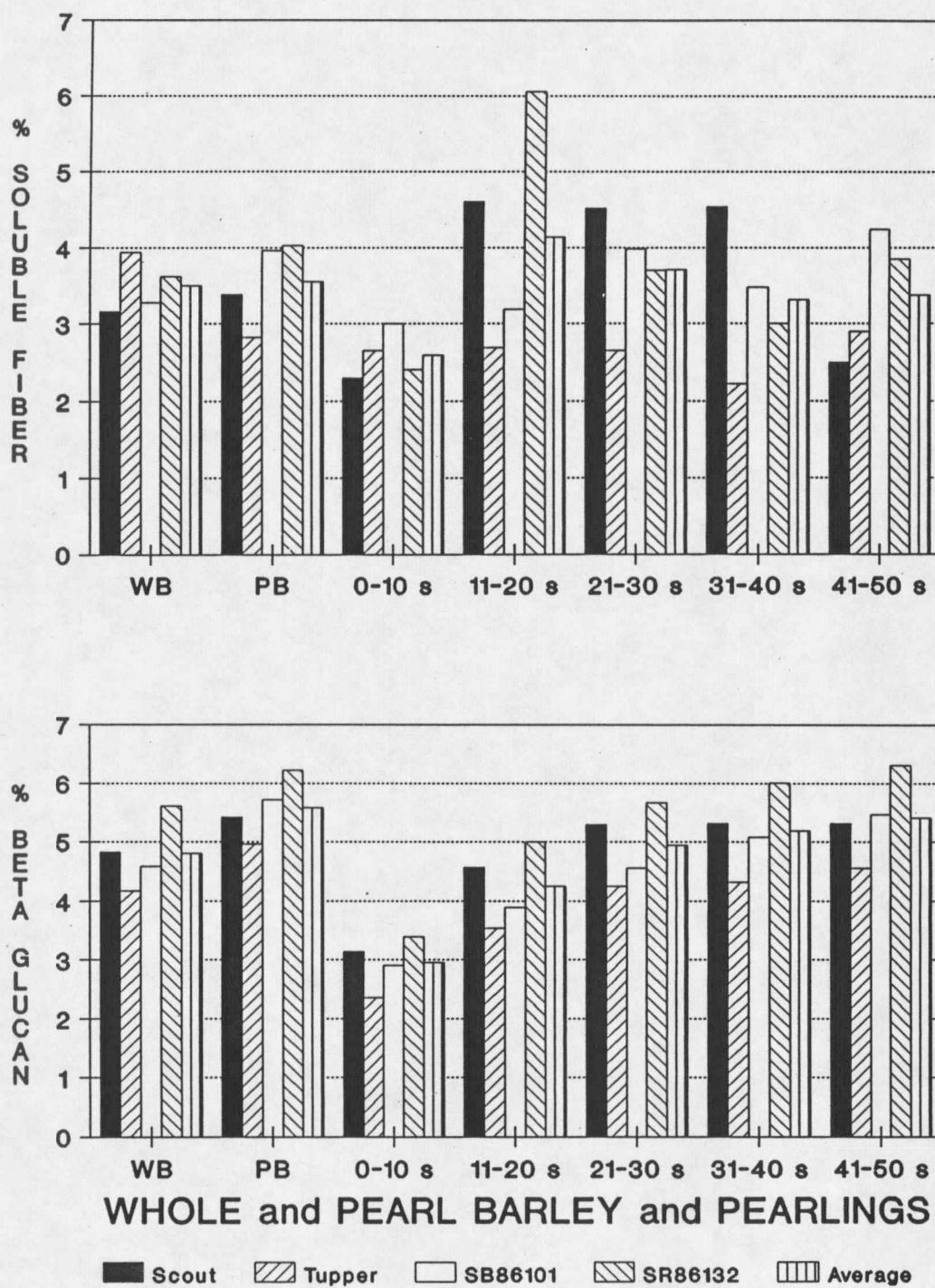


Figure 8. Soluble dietary fiber and β -glucan content of whole barley (WB), pearled barley (PB) and barley pearlings, at five consecutive 10 second (s) intervals.

all genotypes. Whole barley β -glucan levels were similar ($P > .05$) to intermediate barley pearlings for all genotypes. β -glucan content of the whole barley was lower ($P < .05$) in Tupper than in SR86132 and Scout but not different ($P > .05$) than SB86106 while β -glucan in Tupper was lower ($P < .05$) in pearl barley when compared to SB86106 and SR86132. SR86132 had a significantly ($P < .05$) greater amount of β -glucan than Tupper and SB86106 in the 0-10 sec pearling sample. SR86132 and Scout had greater ($P < .05$) content of β -glucan than did Tupper and SB86106 in the 11-20 sec and 21-30 sec pearling fractions. In the 31-40 sec and 41-50 sec pearling samples Tupper had the lowest ($P < .05$) β -glucan content with Scout and SB86106 having intermediate levels ($P < .05$) and SR86132 the highest ($P < .05$) amount.

Comparisons of acid viscosity and protein levels are shown in Figure 9. Acid viscosity concentration was the lowest ($P < .05$) in the whole barley, 0-10 sec and 11-20 sec pearlings with greatest ($P < .05$) concentration found within 21-30 sec, 31-40 sec and 41-50 sec pearlings and pearl barley. Acid viscosity of 0-10 sec and 11-20 sec pearlings were not different ($P > .05$) for all four barleys. Tupper was lower ($P < .05$) in acid viscosity than SB86106 and SR86132 with Scout intermediate and not significantly ($P > .05$) different than the other three barleys for the whole barley samples. However, SR86132 had a greater ($P < .05$) acid viscosity than Scout and Tupper in the 21-30 sec, 31-40 sec and 41-50 sec pearling samples. SB86106 also had greater ($P < .05$) acid viscosity in the 31-40 sec and 41-50 sec pearlings when compared to Scout and Tupper. Acid viscosity from pearl barley of

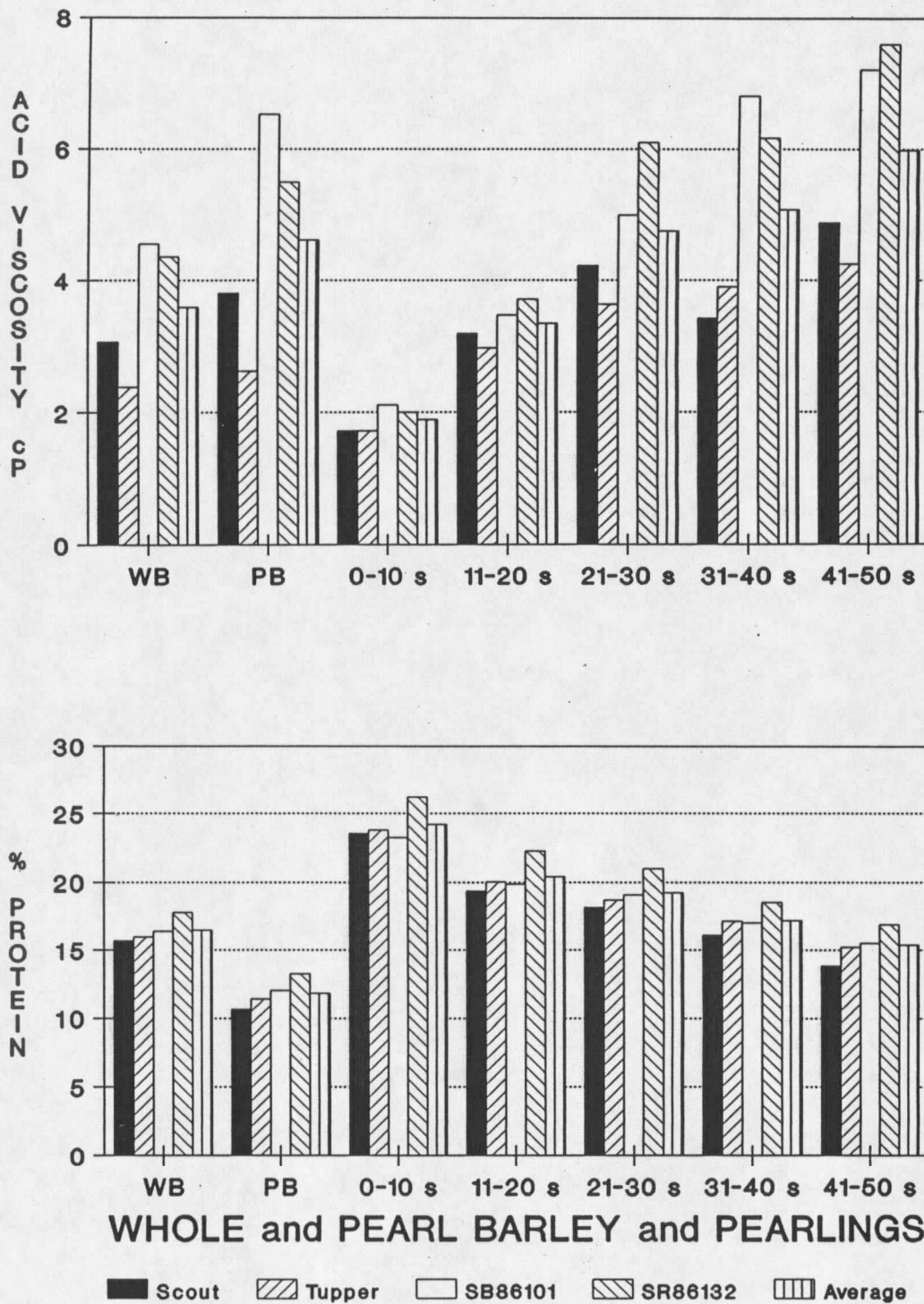


Figure 9. Acid viscosity and protein content of whole barley (WB), pearled barley (PB) and barley pearlins, at five consecutive 10 second (s) intervals.

Tupper was not different ($P > .05$) than acid viscosity of Scout but was lower ($P < .05$) than acid viscosity of SB86106 and SR86132 while Scout was not different ($P > .05$) than SR86132 but was lower ($P < .05$) than SB86106.

Protein (Figure 9) was not different ($P > .05$) for whole barley and 31-40 sec pearlins. Protein was significantly ($P < .05$) lower for Scout when compared to SR86132 for 0-10 sec, 11-20 sec, 21-30 sec and 41-50 sec pearlins and pearl barley with Tupper and SB86106 being intermediate and not significantly ($P > .05$) different than Scout and SR86132.

Ash (Figure 10) exhibited the same pattern as protein within barley genotypes. Ash decreased linearly following each additional pearling period. Ash content of the pearl barley and 41-50 sec pearlins was the lowest ($P < .05$) with the 0-10 sec pearlins containing the greatest ($P < .05$) amount. Ash was not significantly ($P > .05$) different between the four barley genotypes for any of the samples measured.

Ether extract concentration was the lowest ($P < .05$) in the pearl barley and the greatest ($P < .05$) concentration in the 0-10 sec pearling fraction (Figure 10). Ether extract decreased linearly following each additional pearling period. Ether extract was not significantly ($P > .05$) different between the four barleys for whole barley, pearl barley and 11-20 sec and 41-50 sec pearling samples. However, 0-10 sec pearlins had a greater ($P < .05$) ether extract in the SR86132 barley followed by Scout which was greater ($P < .05$) than Tupper and SB86106 which were not different ($P > .05$) from one another. Ether extract of the 21-30 sec pearlins was lowest ($P < .05$) for Scout and greatest ($P < .05$) for SB86106 with Tupper and

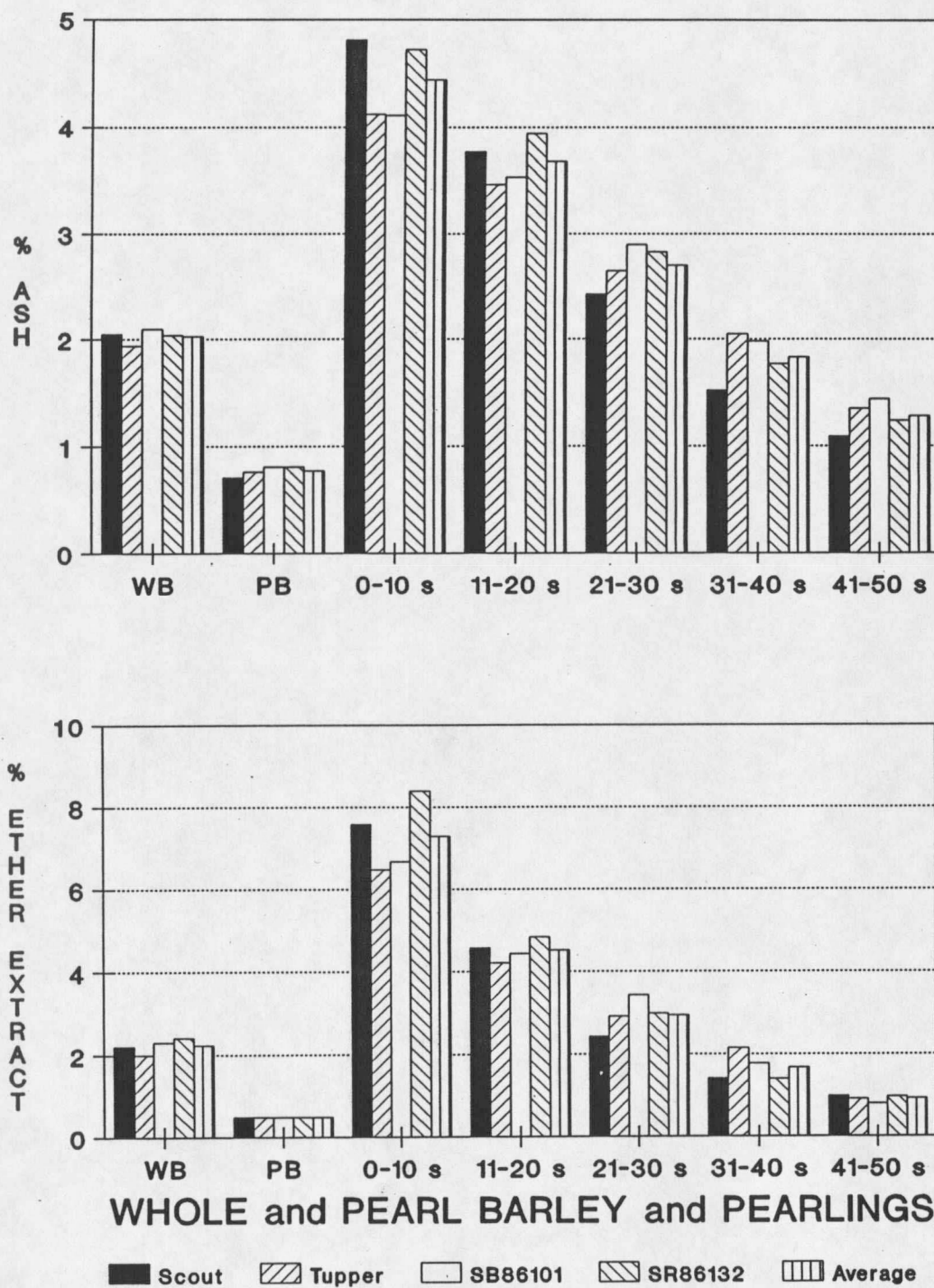


Figure 10. Ash and diethyl ether extractable fat (ether extract) content of whole barley (WB), pearled barley (PB) and barley pearlings, at five consecutive 10 second (s) intervals.

SR86132 being intermediate and not different ($P > .05$) from either of the other two barleys. Ether extract of the 31-40 sec pearlins was the lowest ($P < .05$) for Scout and SR86132 and highest ($P < .05$) for Tupper with SB86106 being intermediate and not different ($P > .05$) from the other three barleys.

Pearson's correlation coefficients and probability values are shown in Table 6. The TDF, was positively correlated ($P < .001$) with IDF, ether extract, ash and protein. This indicates that TDF, IDF, ether extract, ash and protein are located in greater concentrations in the outer layers of the kernels of non-waxy hull-less barley. β -glucan and acid viscosity were positively correlated ($P < .001$) with one another but negatively correlated ($P < .001$) with IDF, ether extract, ash and protein indicating that these components are located in deeper layers within kernels of non-waxy hull-less barley. The SDF was not correlated ($P > .05$) with TDF, IDF, acid viscosity, ether extract, ash and protein. However, SDF was positively correlated ($P < .004$) with β -glucan but not as highly correlated as the other components were to one another. This could be explained in part by the fact that not all β -glucan is soluble and could be expressed as part of the IDF. Protein, ether extract and ash were negatively correlated with β -glucan ($P < .001$) and acid viscosity ($P < .017$). Overall, pearling of non-waxy hull-less barley creates a relationship in which TDF, IDF, ether extract, ash and protein components and their effects are apparently in opposition to β -glucan and acid viscosity component effects.

Chemical and physical characteristics of pearl barley and pearlins in

Table 6. Pearson's correlation coefficients^a and probability values^b of whole barley, barley pearlings and pearl barley¹.

	IDF	SDF	β -GLU	AVIS	EEF	ASH	PROTEIN
TDF	.977 ^a .001 ^b	.043 NS	-.773 .001	-.526 .001	.923 .001	.917 .001	.845 .001
IDF		-.169 NS	-.842 .001	-.574 .001	.942 .001	.900 .001	.840 .001
SDF			.376 .004	.258 NS	-.146 NS	.020 NS	-.029 NS
β -GLU				.753 .001	-.788 .001	-.706 .001	-.608 .001
AVIS					-.588 .001	-.466 .001	-.317 .017
EEF						.946 .001	.901 .001
ASH							.938 .001

¹ TDF=Total dietary fiber; IDF=Insoluble dietary fiber; SDF=Soluble dietary fiber; β -GLU= β -glucan; AVIS=Acid viscosity; EE=ethyl ether extractable fat; PROTEIN=Kjeldahl protein (nitrogen multiplied by 6.25); NS=Non-significant, $P > .05$.

relationship to the respective parent barleys have not been thoroughly examined.

Larsen and Oldfield (1961) reported the chemical composition of whole barley, pearl barley and barley hulls but failed to mention the composition of the pearlings. Additionally, analytical procedures used to measure fiber in earlier studies were very crude compared to today's methods of analyses.

Data presented in this study indicate that barley pearlings are a good source of high TDF and IDF (Figure 7). This type of fiber has been determined to be desirable for proper bowel function and may help in preventing or inhibiting some

types of colon and other cancers (Jenkins et al., 1979). Increases in fecal bulking allows human anaerobic bacteria to degrade structural polysaccharides to yield short chain volatile fatty acids, acetic, propionic and butyric (VFA) in the lower gastrointestinal tract (Salysers et al., 1977a, 1977b). It has been hypothesized that absorption of VFAs in the colon for entry into portal circulation might be one of the active paradigms in preventing gastrointestinal cancers (Cummings, 1981). In addition, propionate has been reported to inhibit 3-hydroxy-3-methylglutaryl CoA reductase, the rate limiting enzyme in hepatic cholesterol synthesis and has been shown to reduce serum cholesterol in laboratory rats (Ide et al., 1978; Chen et al., 1984). β -glucan, another component believed to have health benefits in human lipid metabolism, can be obtained in pearl barley and in greater concentrations in barley pearlins. A concomitant decrease in ether extract in pearl barley as shown in this data, is desirable for low-fat diets while barley pearlins, high in ether extract, ash and protein, may have use in food preparation requiring energy from fat along with increased mineral and protein density.

Conclusions

When considering the best source for TDF or other components in any of the fractions from the four barleys studied, differences that occurred between non-waxy hull-less barley genotypes must be considered. Different barleys and different environmental growing conditions will alter the yield of pearlins and pearl barley

as well as exact levels of nutrients in these fractions. However, these data demonstrate that tailor-made barley food products, such as ones containing high oil, high protein or high fiber, may be developed to meet special needs for the cereal industry by utilizing pearlings and(or) pearl barley. In the development of specific food sources utilizing pearl barley and barley pearlins, food scientists need to consider that TDF, IDF, ether extract, ash and protein are found in the greatest concentration in the same fraction, while β -glucan and acid viscosity are found in greatest concentration elsewhere. Different trends in composition of pearl barley and pearlins are illustrated in this data.

CHAPTER 5

PROXIMATE ANALYSES, VISCOSITY AND AMINO ACID CONTENT OF SELECT BARLEY MILLING FRACTIONS

Introduction

Barley has not traditionally been roller-milled on a large commercial scale to obtain flour and bran as have other grains such as wheat and oats. Barley flour was darker than wheat flour but comparable in other respects. Barley bran was comparable to oat bran in chemical composition and was lighter in color. Several scientists have milled barley under a variety of tempering conditions utilizing different types of laboratory scale mills. Cheigh et al. (1975) tempered barley to 14 and 15 % moisture prior to milling in a Buhler mill and obtained flour yields between 60 and 75 %. Bhatti (1986, 1987) reported an average 72 % flour yield utilizing an Allis-Chalmers experimental mill to roller-mill barley. The objective of this experiment was to determine the chemical and physical nature of select milling fractions obtained from waxy and non-waxy hull-less barleys processed through a laboratory scale wheat roller-mill.

Materials and Methods

Barleys, milling set up, and chemical and physical analyses

Four barley genotypes, Arizona Hull-less (waxy), Arizona Hull-less sister-line (non-waxy), Waxbar (waxy) and Shonkin (waxy) were used in this experiment. Prior to milling, all barleys were tempered to 10 % moisture for 12 h. The barleys were milled through a 8-roller dry mill at the USDA Western Wheat Quality Laboratory (Washington State University, Pullman WA 99164 USA). Figure 11 illustrates the setup and flow-chart of the mill. The rollers were adjusted and set for milling hard red wheat. Second break flour through fourth middlings were combined and deemed flour. Each milling fraction was analyzed for Kjeldahl protein (protein), diethyl ether extractable fat (ether extract)(AOAC,1988), starch (Åman and Hesselman, 1984), β -glucans (McCleary and Glennie-Holmes, 1985), neutral detergent fiber (NDF), acid detergent fiber (ADF)(Van Soest, 1963a, 1963b), acid extract viscosity (acid viscosity)(Greenberg and Whitmore, 1974), ash and calcium (AOAC, 1988), phosphorus (Fiske and Subbarow, 1925) and amino acids (except for tryptophan) (AAA Laboratory, 6206 89th Avenue SE, Mercer Island, WA 98040 USA). Amino acids were determined only on the milling fractions with the greatest yield (flour, shorts, red dog and bran) and fifth middlings, due to sample availability. Extracts of the fractions used for viscosity measurements were prepared with three g of barley flour mixed with 75 ml of pH 1.5 HCL/KCL acid buffer. Samples were extracted for 1 h, followed by centrifugation at 10,000 x g for

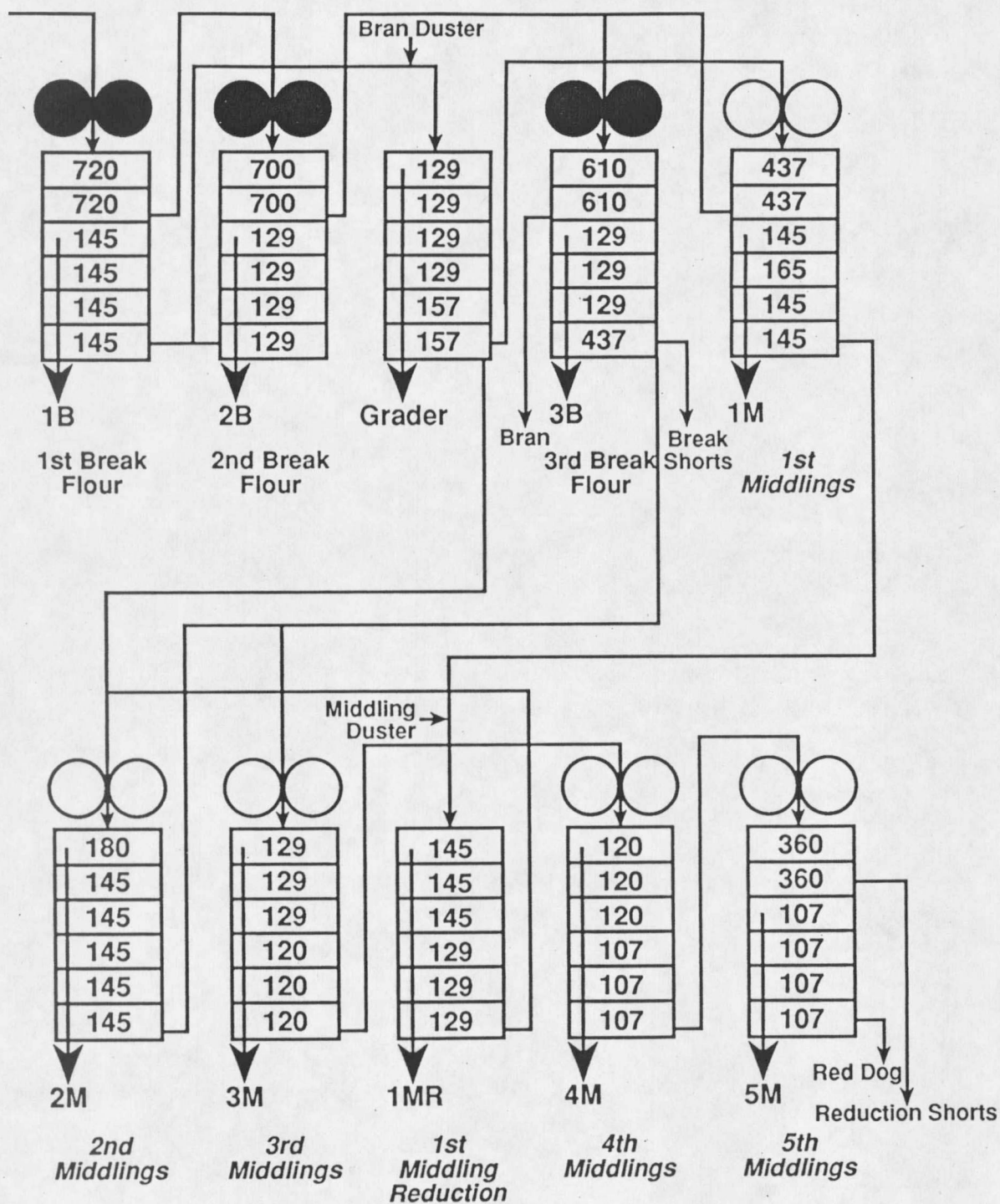


Figure 11. Milling flow chart for MIAG MULTOMAT 8-roller dry mill used to obtain barley milling fractions (sieve cloth openings in microns).

30 min. Viscosity of the supernatant was measured immediately at 30 °C using the Haake (Model B, Haake Instruments, Inc., Saddle Brook, NJ USA) falling ball viscometer.

Statistical analysis

Combined genotype data were analyzed by the General Linear Models (PROC GLM) procedure to determine analysis of variance values and differences between means generated by the four genotypes were analyzed by the Least-square Means (LSMEANS) test if the F-test was significant at the 0.05 P-level (SAS, 1988).

Results and Discussion

Chemical composition and physical measurements of four whole barley genotypes are shown in Table 7. These data are consistent with that of hull-less barley grown in a semi arid environment, such as western Montana and Arizona, although protein levels are one to four percentage points higher than normally reported for covered barleys grown in these areas (Newman and McGuire, 1985). However, they were relatively consistent among waxy types and lowest in the non waxy cultivar. Starch content was typical of that in hull-less barley (Bhatty, 1993b) and inversely related to protein level.

Although the chemical components were relatively consistent across genotypes,

Table 7. Chemical composition and physical measurements of four whole barley genotypes.

	<u>Arizona Hull-less</u>	<u>Arizona Hull-less Sisterline</u>	<u>Waxbar</u>	<u>Shonkin</u>
<u>Chemical Composition, %</u>				
Protein	15.2	14.1	17.0	17.9
Ether extract	2.9	2.4	2.7	2.6
Starch	57.7	63.8	57.6	56.4
β -Glucan	10.5	6.5	6.6	6.9
NDF	8.2	7.9	7.2	8.9
ADF	2.0	1.9	1.6	1.8
Ash	1.9	2.3	2.1	1.9
Calcium	0.03	0.01	0.01	0.01
Phosphorus	0.32	0.42	0.42	0.40
<u>Physical Measurements</u>				
Test weight, kg/hl	80.5	80.9	79.6	80.2
% Thin	20.1	25.3	30.1	17.9
% Plump	58.7	53.4	29.5	50.2
Kernel weight, mg	32.9	34.7	29.5	40.2
Acid extract viscosity, cP*	4.0	2.4	4.6	4.6

* Centipoise

the following differences are noted. Arizona Hull-less had the greatest amount of ether extract, β -glucan, ADF, calcium and % plump kernels. Arizona Hull-less Sisterline contained the most starch, ash and phosphorus and had the greatest test weight. Waxbar had the most thin kernels, acid extract viscosity and the same content of phosphorus as Arizona Hull-less Sisterline. Shonkin contained the greatest amount of protein and NDF, had heavier kernels and acid extract viscosity was equal to that of Waxbar.

The comparisons of yield, chemical composition and physical measurements as follows are made on the means of the four genotypes. Percent yield of each milling

fraction from each barley and the average of the four genotypes is shown in Table 8. First break flour, fifth middlings, red dog, and reduction shorts were the smallest ($P < .05$) milling fractions recovered. However, red dog was not different ($P > .05$) from break shorts in milling yield. Break shorts and flour exhibited the same ($P > .05$) milling yield percentage. Bran was the largest ($P < .05$) fraction recovered.

Protein, ether extract and starch are also shown in Table 8. First break flour and flour were lower ($P < .05$) in protein content (average of the four barleys) when compared to all other milling fractions which were not different ($P > .05$) from one another. Fifth middlings, red dog and reduction shorts had higher ($P < .05$) levels of ether extract compared to that in first break flour and all other milling fractions were not different ($P > .05$) from these fractions. Red dog, reduction shorts and bran had the lowest ($P < .05$) content of starch with break shorts containing the next lowest ($P < .05$) content. First break flour and flour milling fractions contained the greatest ($P < .05$) amount of starch with fifth middlings containing about 12 % less starch ($P < .05$).

β -glucan, NDF and ADF content and acid viscosity measurements of the milling fractions are shown in Table 9. β -glucan was lowest ($P < .05$) in first break flour and flour followed by fifth middlings, red dog and reduction shorts. Bran and break shorts had the highest ($P < .05$) level of β -glucan but were not greater ($P > .05$) than that of red dog or reduction shorts. First break flour, flour and fifth middlings contained the least ($P < .05$) NDF followed by break shorts and reduction

Table 8. Milling yield, protein, diethyl ether extractable fat (ether extract) and starch content of milling fractions from four barley genotypes.

	Arizona Hull-less	Arizona Hull-less Sisterline	Waxbar	Shonkin	Average	STD Error
<u>Milling yield, %</u>						
First break flour	1.0	4.0	5.5	4.7	3.8 ^a	.98
Flour	14.9	21.5	35.5	20.6	23.1 ^c	4.38
Fifth middlings	0.7	1.3	1.5	1.0	1.1 ^a	.18
Red dog	6.1	7.5	10.6	6.4	7.6 ^{ab}	1.03
Break shorts	10.5	16.0	15.4	16.0	14.5 ^{bc}	1.33
Reduction shorts	1.3	1.5	4.0	2.0	2.3 ^a	.62
Bran	65.5	48.2	27.5	49.3	47.6 ^d	7.79
<u>Protein, %¹</u>						
First break flour	9.1	10.3	11.1	13.6	11.0 ^a	0.94
Flour	10.4	11.1	13.3	14.5	12.3 ^a	0.95
Fifth middlings	13.6	12.6	17.1	19.1	15.6 ^b	1.52
Red dog	13.3	13.1	16.5	17.5	15.1 ^b	1.12
Break shorts	11.9	13.8	16.8	15.9	14.6 ^b	1.09
Reduction shorts	11.7	14.7	16.7	15.2	14.6 ^b	1.06
Bran	13.8	17.2	17.8	16.0	16.2 ^b	0.87
<u>Ether Extract, %¹</u>						
First break flour	1.5	1.4	1.9	1.4	1.5 ^a	0.14
Flour	1.5	1.5	1.4	2.8	1.8 ^{ab}	0.34
Fifth middlings	3.0	1.5	2.1	4.8	2.8 ^b	0.71
Red dog	2.6	1.5	2.6	4.4	2.8 ^b	0.60
Break shorts	2.2	1.9	2.2	2.3	2.1 ^{ab}	0.10
Reduction shorts	2.4	2.6	2.6	3.0	2.7 ^b	0.13
Bran	1.6	2.8	2.9	2.1	2.4 ^{ab}	0.33
<u>Starch, %¹</u>						
First break flour	71.8	79.0	77.6	75.0	75.9 ^d	1.58
Flour	73.5	78.8	77.0	71.8	75.3 ^d	1.60
Fifth middlings	65.5	72.8	60.6	58.5	64.3 ^c	3.17
Red dog	49.8	58.6	45.1	42.1	48.9 ^a	3.59
Break shorts	56.2	64.3	55.2	58.1	58.4 ^b	2.04
Reduction shorts	50.6	52.7	47.8	49.1	50.1 ^a	1.06
Bran	51.7	49.0	51.5	53.4	51.4 ^a	0.91

¹ Dry matter basis.

^{abcde} Means in the average column within single response variable with different superscripts differ at $P < .05$.

Table 9. β -glucan, neutral detergent fiber (NDF), acid detergent fiber (ADF) and acid extract viscosity (acid viscosity) of milling fractions from four barley genotypes.

	Arizona Hull-less	Arizona Hull-less Sisterline	Waxbar	Shonkin	Average	STD Error
<u>β-Glucan, %¹</u>						
First break flour	5.1	2.7	3.0	2.5	3.3 ^a	0.61
Flour	5.4	2.8	3.1	2.1	3.4 ^a	0.72
Fifth middlings	6.7	4.5	5.7	4.0	5.2 ^b	0.60
Red dog	6.5	6.8	5.9	5.5	6.2 ^{bc}	0.30
Break shorts	5.1	8.0	9.1	8.4	7.6 ^c	0.86
Reduction shorts	6.6	7.0	5.7	5.5	6.2 ^{bc}	0.35
Bran	7.4	7.6	7.5	8.8	7.8 ^c	0.33
<u>NDF, %¹</u>						
First break flour	7.4	3.5	11.0	6.2	7.0 ^a	1.55
Flour	5.6	6.4	5.8	6.8	6.1 ^a	0.28
Fifth middlings	9.0	4.5	11.4	7.0	8.0 ^a	1.48
Red dog	15.2	15.8	17.4	19.5	17.0 ^c	0.96
Break shorts	13.6	10.0	16.1	13.7	13.4 ^b	1.25
Reduction shorts	15.2	13.0	18.4	16.7	15.8 ^{bc}	1.15
Bran	15.0	18.0	22.9	12.7	17.1 ^c	2.21
<u>ADF, %¹</u>						
First break flour	2.2	1.2	2.3	1.8	1.9 ^{ab}	0.26
Flour	0.7	1.4	1.5	1.5	1.3 ^a	0.18
Fifth middlings	0.6	4.3	2.1	2.2	2.3 ^{abc}	0.78
Red dog	4.1	3.4	4.6	4.8	4.2 ^{cd}	0.31
Break shorts	4.2	3.7	2.9	3.4	3.6 ^{abc}	0.28
Reduction shorts	4.3	2.9	4.7	4.3	4.1 ^{bc}	0.39
Bran	5.8	11.4	5.3	3.4	6.5 ^d	1.73
<u>Acid Viscosity, cP</u>						
First break flour	1.5	1.4	1.5	1.5	1.5 ^a	0.03
Flour	1.7	1.3	1.9	1.4	1.6 ^a	0.13
Fifth middlings	2.5	1.7	3.7	2.1	2.5 ^{ab}	0.41
Red dog	11.7	8.7	15.4	10.5	11.6 ^c	1.43
Break shorts	4.0	3.1	11.1	4.7	5.7 ^c	1.83
Reduction shorts	6.6	7.4	10.9	10.9	9.0 ^d	1.14
Bran	3.1	3.2	6.5	5.7	4.6 ^{bc}	0.87

¹ Dry matter basis.

^{abcde} Means in the average column within single response variable with different superscripts differ at $P < .05$.

shorts. Red dog and bran contained the greatest ($P < .05$) amount of NDF. However, reduction shorts contained a similar ($P < .05$) level of NDF as break shorts, red dog and bran. First break flour, flour, fifth middlings and break shorts had the lowest ($P < .05$) content of ADF while red dog and bran contained the greatest ($P < .05$) amount of ADF. However, red dog was not different ($P < .05$) from fifth middlings, break shorts and reduction shorts. First break flour, flour and fifth middlings were lowest ($P < .05$) in acid viscosity measurements. However, acid viscosity of fifth middlings was not different ($P > .05$) from that of bran. Bran and break shorts measured the same ($P > .05$) in acid viscosity. Reduction shorts was next in increased acid viscosity, being intermediate and different ($P < .05$) from all other milling fractions. Red dog was the most ($P < .05$) viscous of all of the milling fractions.

Ash, calcium and phosphorus content of the milling fractions are shown in Table 10. First break flour and flour contained less ($P < .05$) ash when compared to all of the other milling fractions. Bran, reduction shorts and red dog had the greatest ($P < .05$) levels of ash. However, reduction shorts were not different ($P > .05$) from break shorts and red dog was not different ($P > .05$) from either break shorts or fifth middlings in ash content. There was no difference ($P < .05$) in calcium content between any of the milling fractions. First break flour, flour and fifth middlings contained the lowest ($P < .05$) amount of phosphorus with fifth middlings containing the same ($P > .05$) amount of phosphorus as that in red dog, break shorts and reduction shorts. Bran contained the greatest ($P < .05$) amount of

Table 10. Ash, calcium and phosphorus content of milling fractions from four barley genotypes.

	Arizona Hull-less	Arizona Hull-less Sisterline	Waxbar	Shonkin	Average	STD Error
<u>Ash, %¹</u>						
First break flour	1.8	1.3	1.1	1.4	1.4 ^a	0.14
Flour	1.5	1.2	1.1	1.5	1.3 ^a	0.08
Fifth middlings	2.0	1.7	1.9	2.2	1.9 ^b	0.11
Red dog	2.1	2.0	2.4	2.8	2.3 ^{bcd}	0.19
Break shorts	2.1	2.0	2.4	2.0	2.1 ^{bc}	0.10
Reduction shorts	2.2	2.6	2.7	2.6	2.5 ^{cd}	0.12
Bran	2.5	3.3	2.7	2.2	2.7 ^d	0.23
<u>Calcium, %¹</u>						
First break flour	.02	.01	.03	.02	.02	0.005
Flour	.01	.02	.01	.03	.02	0.005
Fifth middlings	.04	.01	.01	.02	.02	0.008
Red dog	.05	.01	.01	.01	.02	0.011
Break shorts	.03	.02	.01	.01	.02	0.005
Reduction shorts	.03	.01	.01	.01	.02	0.005
Bran	.04	.04	.02	.02	.03	0.006
<u>Phosphorus, %¹</u>						
First break flour	.34	.31	.54	.33	.38 ^a	0.06
Flour	.31	.43	.25	.38	.34 ^a	0.04
Fifth middlings	.51	.26	.54	.62	.48 ^{ab}	0.08
Red dog	.46	.61	.68	.74	.62 ^{bc}	0.06
Break shorts	.48	.45	.62	.57	.53 ^{bc}	0.04
Reduction shorts	.49	.45	.64	.70	.57 ^{bc}	0.06
Bran	.53	.70	.72	.58	.63 ^c	0.05

¹ Dry matter basis.

^{abcd} Means in the average column within single response variable with different superscripts differ at $P < .05$.

phosphorus but was not different ($P > .05$) than that contained in red dog, break shorts or reduction shorts.

Amino acid contents of the milling fractions are shown in Table 11. Alanine, arginine, glycine and histidine contents were the lowest ($P < .05$) in the flour.

Table 11. Amino acid content (g/16g N) of barley milling fractions from four barley genotypes.

Amino Acid	Milling Fraction					Standard Error
	Flour	5 th Middlings	Shorts	Red Dog	Bran	
Ala ¹	3.95 ^a	4.48 ^b	4.41 ^b	4.59 ^b	4.36 ^{ab}	.07
Arg ¹	4.26 ^a	5.24 ^b	4.83 ^b	5.23 ^b	4.89 ^b	.10
Asp ²	5.73 ^a	6.51 ^b	6.45 ^b	6.75 ^b	6.36 ^b	.12
Glu ¹	29.61 ^b	26.91 ^a	26.98 ^a	26.14 ^a	27.42 ^a	.38
Gly ¹	3.75 ^a	4.32 ^b	4.28 ^b	4.46 ^b	4.21 ^b	.08
His ¹	2.27 ^a	2.44 ^b	2.44 ^b	2.45 ^b	2.39 ^{ab}	.02
Ile	3.80	3.82	3.90	3.87	3.88	.03
Leu	7.23	7.26	7.35	7.34	7.30	.03
Lys ²	3.30 ^a	3.93 ^b	3.74 ^b	3.93 ^b	3.64 ^{ab}	.08
Met	1.34	1.35	1.29	1.30	1.28	.02
Phe	5.79	5.59	5.70	5.52	5.70	.05
Pro	12.35	11.10	11.37	10.94	11.48	.18
Ser	4.55	4.61	4.68	4.72	4.65	.03
Thr	3.69	3.89	3.89	3.97	3.84	.04
Tyr ¹	3.19 ^a	3.14 ^a	3.25 ^{ab}	3.36 ^b	3.22 ^a	.02
Val	5.20	5.41	5.43	5.45	5.37	.05

¹ Means within same row with different superscripts differ, $P < .05$.

² Means within same row with different superscripts differ, $P < .10$.

fractions with fifth middlings, shorts and red dog containing the greatest ($P < .05$) amounts. Bran was intermediate for alanine and histidine, being not different ($P > .05$) from flour, fifth middlings, shorts and red dog. Glutamic acid level was greater ($P < .05$) in flour than that in all other milling fractions. Tyrosine was highest ($P < .05$) in the red dog milling fraction but not different ($P > .05$) from that in the shorts fraction. However, the content of tyrosine in the shorts fraction was also not different ($P > .05$) from that contained in the flour, fifth middlings, and bran milling fractions. Lysine and aspartic acid were also present in lesser ($P < .10$) concentration in barley flour, with lysine content of the shorts being intermediate. The essential amino acids tended to be concentrated in the fifth middlings, shorts and red dog milling fractions and were lowest in the flour. This was especially true with lysine.

Chemical and physical characteristics of barley milling fractions for barley have not been studied as extensively as that in wheat flour, bran and shorts. Results of this study indicate that certain components of barley can be isolated in relatively high concentration in select milling fractions. Starch is concentrated in the flour fractions and β -glucan in the red dog, shorts and bran fractions. The essential amino acids, especially lysine, tend to be concentrated in the high-fiber fractions. However, since milling of barley has not been thoroughly examined many problems still exist in regard to mechanical manipulation of the barley kernel. Flour yield in this experiment was substantially lower when compared to data reported by Cheigh et al. (1975), McGuire (1979), Bhatti (1986, 1987). However, different types of

mills were used in the earlier experiments from that used in this study and the barleys were of different genotypes and were raised under different environmental conditions. Roller settings were also no doubt different in this study which altered flour yield thus influencing the composition of all components. The roller settings in this study were for the "normal" milling of wheat and were not adjusted to obtain maximum flour yields with barley. Changes in roller settings to increase the yield of flour, would have an appreciable effect on the composition of the fractions. If industry is open to using roller-milling to process barley for flour and(or) to concentrate certain components, much research must be conducted for transfer to commercial scale milling. It may be necessary to design a roller-mill specifically to process barley.

CHAPTER 6

EFFECT OF A HIGH VISCOSITY BARLEY MILLING FRACTION ON RAT INTESTINAL VISCOSITY AND LIVER LIPIDS

Introduction

β -glucan is a major component of soluble fiber in barley, which comprises a large portion of the aleurone and endosperm cell walls. The structure and configuration of β -glucan reduces inter-molecular associations making it partially water soluble. A water solution of β -glucans extracted from barley flour is viscous which is ascribed to the molecular weight and concentration of the respective β -glucans (Bengtsson et al., 1990). The high molecular weight and irregular conformation of β -glucan contribute to high solution viscosity *in vitro* and *in vivo* (Wang et al., 1992). A linear decrease has been reported in low density lipoprotein concentration of humans when fed increasing levels of β -glucan (Davidson et al., 1991).

Mammalian enzymes are unable to degrade dietary fiber, but microflora in the large intestine degrade fiber components to varying degrees depending upon the specific compound. Cellulose is only partially degraded, whereas more soluble nonstructural polysaccharides are almost totally digested by microbes. Water-

holding capacity is enhanced by the presence of sugar residues with free polar groups which occur in nonstructural polysaccharides. Hydration of these fibers when they are consumed causes a gel matrix to form which can increase intestinal viscosity. Increased intestinal viscosity can decrease gastric emptying rate and nutrient absorption by reducing diffusion through the unstirred water layer to absorptive surfaces of the small intestine (Schneeman, 1986).

The objective of this experiment was to determine the efficacy of feeding a high fiber milling fraction obtained from waxy hull-less barley (Shonkin) on plasma and liver lipid content, intestinal viscosity, and digesta weight when fed at 30, 60 and 90 % of a diet to adult rats.

Materials and Methods

Shonkin barley was milled utilizing an 8-roller dry mill at the USDA Western Wheat Quality Laboratory (Washington State University, Pullman Washington 99164 USA). Prior to milling the barley was tempered to 10 % moisture for 12 h. The break shorts obtained in the roller-milling procedure contained 8.38 % β -glucan and were selected for this experiment. Forty adult rats were randomly allotted to one of five dietary treatments shown in table 12. Two control diets with (0.5 %) and without added cholesterol were prepared with alphacel (cellulose) as the fiber source. Treatment diets were formulated to contain 30, 60 and 90 % break shorts, respectively, and all contained 0.5 % cholesterol. Cornstarch was added to the

Table 12. Diet Composition of Adult Rat Diets.

	Dietary Treatment				
	Positive Control	Negative Control	30 % Shorts	60 % Shorts	90 % Shorts
Break shorts			30.00	60.00	90.00
Alphacel	4.16	4.16			
Corn starch	70.38	70.38	50.14	25.72	1.04
Corn oil	4.50	5.00	3.85	3.20	2.55
Casein	15.53	15.53	10.49	5.45	.40
Arginine	.04	.04	.05	.05	.06
Methionine	.19	.19	.27	.35	.44
Lysine				.03	.31
Cholesterol	.50		.50	.50	.50
Vitamin-mineral mix	4.70	4.70	4.70	4.70	4.70

control diets as an energy source and was replaced by the barley break shorts in other diets. All diets were formulated to meet or exceed requirements set by The National Research Council (1978) for adult rats.

Rats (Sasco, Inc., P.O. Box 66 DTS, Omaha, Nebraska 68101 USA) were housed in a light (12 h light and 12 h dark) and temperature (22.2 ° C) controlled room and allowed unlimited access to food and water. All animals were housed and used in compliance with the Montana State University policy on animal care and use. Duration of the experiment was 21 days. Rats were sacrificed at the termination of the study without fasting. Plasma, intestinal contents and livers were collected. Plasma samples were analyzed (DT 60 Kodak Blood Analyzer, Eastman Kodak, Rochester, New York USA) for cholesterol, triacylglycerols, high density lipoproteins and glucose. Intestinal contents were weighed and intestinal viscosity determined.

Intestinal contents were diluted with 30 ml of cold HCL-KCL buffer (0.2 mol/L, pH 1.5), vigorously mixed with a vortex blender for 30 seconds and allowed to precipitate for 1 minute. The top 28 ml of solution was then transferred to the UL adaptor of a Brookfield synchro-lectric viscometer (Brookfield Engineering Laboratories, Stoughton, Massachusetts 02072 USA). The viscometer was calibrated with a viscosity standard purchased from the manufacturer at 73.4/sec shear rate and 20 ° C which were the same conditions used for viscosity determination on the diets and intestinal contents. Viscosity of the diets and intestinal contents were determined as described by Greenberg and Whitmore (1974). Livers were blotted dry, weighed and frozen in liquid nitrogen. Liver cholesterol and triacylglycerol levels were determined by methods of Folch et al. (1957) and Bligh and Dyer (1959). Dietary treatments were analyzed for kjeldahl protein (protein), ethyl ether extractable fat (ether extract) and ash (AOAC, 1988), total, soluble and insoluble dietary fiber (Lee and Hicks, 1990) (TDF, SDF and IDF, respectively), β -glucan (McCleary and Glennie-Holmes, 1985), and acid extract viscosity (Greenberg and Whitmore, 1974).

Data were analyzed by the General Linear Models (PROC GLM) procedure to determine analysis of variance values and differences between means were analyzed by the Least-square Means (LSMEANS) test if the F-test was significant at the 0.05 P-level. In addition, orthogonal contrasts were determined on diets containing dietary cholesterol, eliminating negative control (SAS, 1988).

Results

Chemical and physical composition of the diets are shown in Table 13. Each additional level of break shorts added increased ash, TDF, SDF, IDF and β -glucan content and viscosity measurement of respective diets. Average initial weight of the rats was 275.13 ± 3.18 g with average final weight at 298.80 ± 5.22 g. There were no differences ($P > .05$) due to diet in diet consumption or weight gain.

Table 13. Chemical and Physical Composition of Adult Rat Diets.

	Dietary Treatment				
	Positive Control	Negative Control	30 % Shorts	60 % Shorts	90 % Shorts
Protein, %	14.9	14.7	14.7	14.9	15.3
Ether extract, %	5.0	5.1	5.1	5.2	5.4
Ash, %	2.7	2.6	3.1	4.0	4.5
TDF, %	4.6	5.0	4.8	8.9	12.5
SDF, %	.2	.2	2.1	3.8	5.2
IDF, %	4.4	4.8	2.7	5.1	7.3
β -G, %			2.3	4.6	6.9
Viscosity, cP	1.0	1.0	1.7	3.5	7.6

¹ TDF, SDF and IDF=Total, soluble and insoluble dietary fiber, respectively; β -G= β -glucan; Viscosity=acid extract viscosity.

Plasma and liver lipid, plasma glucose, and digesta analyses and liver weight are shown in Table 14. A graphic representation of the significant data is shown in Figure 12. Plasma cholesterol, triacylglycerol, high density lipoproteins and glucose levels were not different ($P > .05$) due to dietary treatment. Liver weights were

Table 14. Plasma and Liver Lipid, Plasma Glucose, Digesta Weight and Viscosity and Liver Weight of Adult Rats Fed a High Viscosity Barley Milling Fraction.

	Dietary Treatment					P-value	Standard Error
	Positive Control ¹	Negative Control ²	30 % Shorts ¹	60 % Shorts ¹	90 % Shorts ¹		
<u>Plasma analyses, mg/dl</u>							
Cholesterol	52.0	37.5	43.0	40.3	46.8	.3811	2.45
Triacylglycerides	73.8	74.0	80.4	80.4	68.3	.2050	2.69
High density lipoproteins	33.5	42.8	39.9	36.2	42.6	.2226	1.53
Glucose	106.9	120.3	123.3	102.8	107.6	.1964	3.28
<u>Liver analyses</u>							
Weight, g	15.60 ^{ab}	16.50 ^b	14.90 ^{ab}	13.90 ^a	13.90 ^a	.0013	.44
Cholesterol, mg/g	12.40 ^c	3.10 ^a	6.30 ^b	5.70 ^{ab}	3.80 ^{ab}	.0001	.66
Triacylglycerol, mg/g	13.20 ^b	5.40 ^a	6.50 ^a	5.80 ^a	3.80 ^a	.0003	.78
<u>Digesta analyses</u>							
Wet digesta weight, g	1.50 ^a	1.73 ^{ab}	2.65 ^{bc}	3.33 ^c	5.23 ^d	.0001	.32
Intestinal viscosity, cP	.18 ^a	.27 ^b	.65 ^{bc}	1.36 ^{cd}	1.94 ^d	.0155	.20

^{abcd} Means in same line with different superscripts differ, $P < .05$.

¹ + 0.5 % cholesterol.

² no added cholesterol.

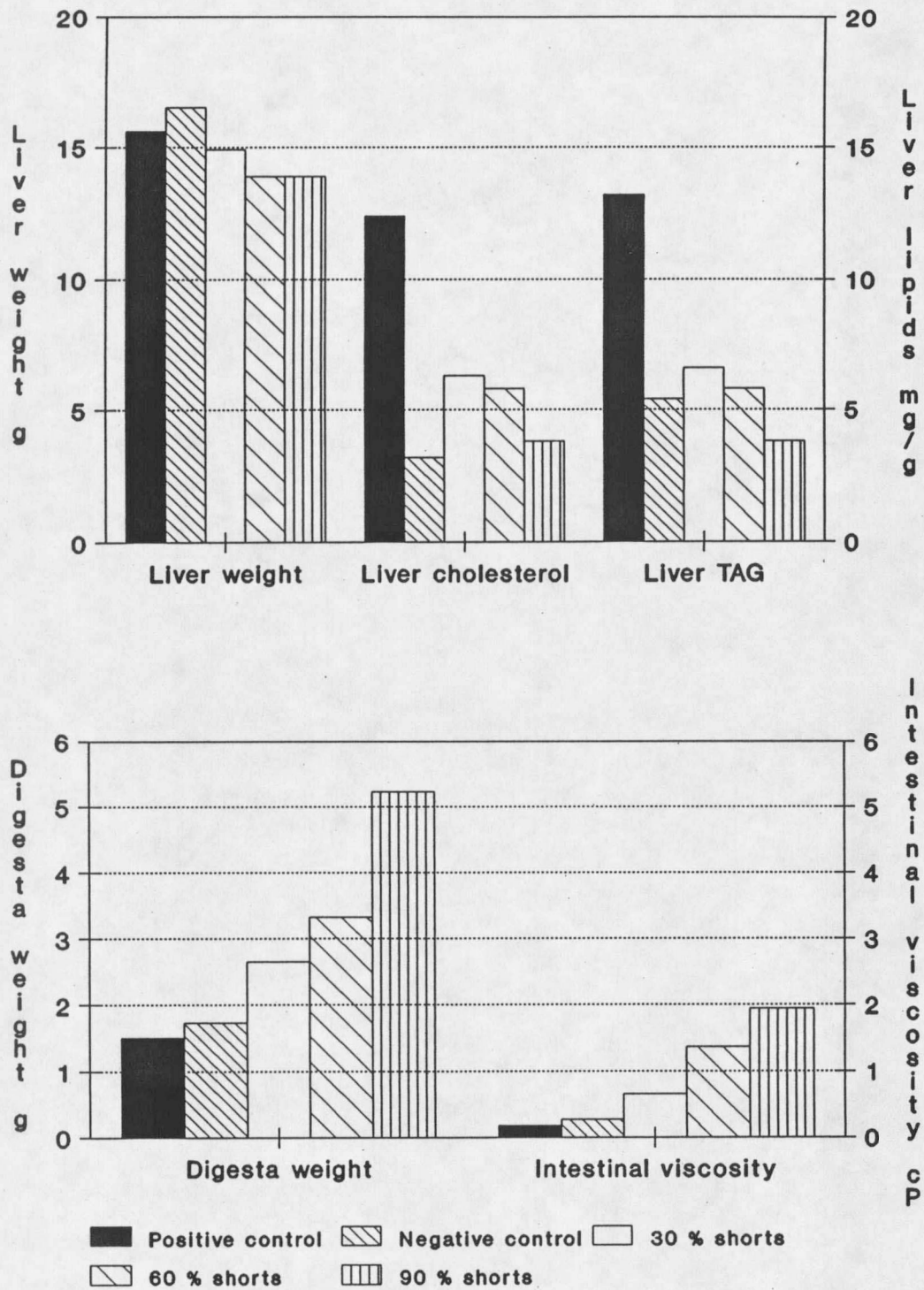


Figure 12. Liver weight, cholesterol and triacylglycerol (TAG) content, digesta weight and intestinal viscosity of adult rats fed a barley milling fraction.

numerically lowest in rats fed diets with added cholesterol compared to the rats fed the negative control diet. However, these differences were significant ($P < .05$) only for those rats fed the 60 % and 90 % break shorts diets. Liver cholesterol was the greatest ($P < .05$) in rats consuming the positive control diet. The rats fed the negative control, 60 % and 90 % break shorts had the lowest ($P < .05$) liver cholesterol levels with rats fed 30 % break shorts being intermediate but not different ($P > .05$) from other break shorts fed rats. Liver triacylglycerol content was the lowest ($P < .05$) for rats consuming the negative control and break shorts diets with rats fed the positive control diet having the greatest ($P < .05$) content of liver triacylglycerol. Rat wet digesta weight was the greatest ($P < .05$) for rats fed the 90 % break shorts diet and lowest ($P < .05$) for rats fed the two control diets. Wet digesta weights in rats consuming the 30 % and 60 % break shorts diets were intermediate.

Orthogonal contrast probability values are shown in Table 15. The rat wet digesta weight increased linearly ($P < .05$) with each additional amount of break shorts included in respective diets. Conversely, rat liver cholesterol and triacylglycerol content decreased linearly ($P < .05$) with each additional amount of break shorts included in respective diets. Rat intestinal viscosity tended ($P = .0770$) to increase with each additional amount of break shorts included in respective diets.

Table 15. Orthogonal Contrast of Response Criteria of Adult Rats Fed a Barley Milling Fraction and Dietary Cholesterol.

	Model P-value	Contrast P-value		
		Linear	Quadratic	Cubic
<u>Plasma</u>				
Cholesterol	.5589	.5013	.2123	.9128
Triacylglycerol	.1454	.7231	.0387	.3266
High density lipoprotein	.3218	.1590	.9865	.2224
Glucose	.1725	.5497	.4007	.0482
<u>Liver</u>				
Weight	.0091	.0756	.6556	.7041
Cholesterol	.0001	.0001	.0563	.1373
Triacylglycerol	.0004	.0001	.1116	.2719
<u>Digesta</u>				
Wet digesta weight	.0003	.0001	.3532	.3613
Intestinal viscosity	.0770	.0077	.9387	.8412

Discussion

In this experiment, adult rats consuming barley break shorts diets had increased digesta weight, intestinal viscosity and decreased liver cholesterol and triacylglycerols supporting the conclusions of Wang et al. (1992). In other reports guar gum has been shown to reduce the absorption of cholesterol and lipids in rats (Gallaher and Schneeman, 1986; Ebihara and Schneeman, 1989; Ikeda et al., 1989). Additionally, high intestinal viscosity content has been reported in rats fed methylcellulose (Topping et al., 1988), xanthum gum and guar gum (Ikegami et al., 1990) and hamsters fed hydroxypropyl methylcellulose (Gallaher et al., 1993a). Researchers

have also reported that materials that increase intestinal viscosity can be effective in lowering plasma cholesterol and that only moderate increases in viscosity are necessary to achieve this effect (Gallaher et al., 1993b). The cholesterol synthesis in rats is similar to that in humans in that the liver is the predominant site of synthesis (Shrago et al., 1971). Small intestinal viscosity created by soluble dietary fiber appears to be involved in the physio-chemical effect resulting in the reduction of liver lipid levels in animals. Viscosity in the small intestinal contents may act as a physical barrier obstructing the action of digestive enzymes with respective substrates or by reducing the absorption of dietary cholesterol through the unstirred water layer. A second mode of action may possibly be the adsorption of dietary cholesterol to dietary fiber components. The implied effects of feeding a high viscosity barley diet are increased intestinal viscosity leading to interference with cholesterol and fat absorption. Barley is a good source of dietary fiber, in particular β -glucans. Milling of barley is an effective procedure that can be used to increase fiber levels in select milling fractions, which can lead to the production of foodstuffs high in dietary fiber.

CHAPTER 7

SUMMARY

Waxy hull-less barley (AZ76-19-7WX) developed in Arizona was used to determine if fiber rich flour fractions could be obtained by pin milling and air classification. Barley was pin milled and air classified into 18 fine fractions and 18 coarse flour fractions. Cut points ranged from 14 to 35 degrees. Pin milling between fraction collections ranged between 9,000 and 18,000 rpm. Percent total dietary fiber (TDF), soluble dietary fiber (SDF), insoluble dietary fiber (IDF) and β -glucan, starch, nitrogen, ash and diethyl ether extractable fat (ether extract) were determined. Viscosity was quantified under both acid (acid viscosity) and neutral (neutral viscosity) conditions. All analyses were determined on the whole grain barley flour and each fraction. Total dietary fiber ranged from 18.57-38.71%, SDF from 6.96-21.15%, IDF from 10.21-17.55%, β -glucan from 10.64-25.11%, AVIS from 2.32-36.03 cP and NVIS from 2.22-45.65 cP, starch from 41.85- 59.61%, nitrogen from 1.23-1.96 %, ash from 1.50-2.40% and ether extract from 1.0-3.1% for the coarse fractions. The fine fraction percent of TDF, SDF, IDF, β -glucan, acid viscosity (cP), neutral viscosity (cP), starch, nitrogen, ash and ether extract ranged from 5.02-12.43, 0.69-5.00, 3.62-7.44, 0.81-6.58, 1.06-2.41, 1.04-2.17, 52.50-76.77,

1.09-6.63, 1.19-4.17 and 1.60-5.60, respectively. These data indicate that pin milling followed by air classification can separate fractions from waxy hull-less barley that are high in TDF, SDF, IDF, β -glucan, acid viscosity, neutral viscosity, starch, ash and ether extract. The TDF, SDF, IDF, β -glucan, acid viscosity and neutral viscosity are concentrated in the coarse flour fractions with the starch, ash and ether extract concentrated in the fine fractions. Overall, the potential of utilizing air classified fractions from waxy barley is vast and needs to be further explored.

Whole barley, pearled barley and barley pearlings fractions of four hull-less barley genotypes grown over two crop years were analyzed independently for TDF, IDF and SDF, β -glucans, acid viscosity, diethyl ether extractable fat (ether extract), ash and Kjeldahl protein (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 from samples produced 1988 and 1989. Treatment differences for TDF, IDF, β -glucan, acid viscosity, ether extract, ash and protein were significant ($P < .0001$). β -glucan and acid viscosity increased ($P < .05$) in the pearlings from 10 to 50 seconds, while TDF, IDF, ether extract, ash, and protein decreased ($P < .05$). TDF, IDF, ether extract, ash and protein were increased by ≈ 200 to 350 % in 10 second pearlings compared to whole barley. Best source for TDF in any of the fractions from the four barleys studied was from the 0-10 second pearlings from Tupper, while 0-10 second pearlings from Scout, Tupper and SR86132 were the best sources of IDF. However, SB86106 and SR86132 were the pearl barleys to choose for the highest level of β -glucan. In developing

foodstuffs with a high viscosity, the choice would be pearl barley obtained from SB86106 or SR86132. If development of energy, mineral and protein dense foodstuffs were desirable, the barley fraction to select would be SR86132 0-10 second pearlings. TDF, IDF, ether extract, ash and protein were positively correlated ($P < .001$) with one another and negatively correlated ($P < .001$) with β -glucan and acid viscosity. In the development of specific food sources utilizing pearl barley and barley pearlings, food scientists need to consider that TDF, IDF, ether extract, ash and protein are found in the greatest concentration in the same fraction, with β -glucan and acid viscosity found in greatest concentration elsewhere. Different trends in composition of pearl barley and pearlings are illustrated in these data.

Four barley genotypes, Arizona Hull-less (waxy), Arizona Hull-less sister-line (non-waxy), Waxbar (waxy) and Shonkin (waxy) were milled through an 8-roller dry mill following tempering at 10 % moisture for 12 h. Fractions obtained were first break flour, flour, fifth middlings, red dog, break shorts, reduction shorts and bran. The fractions were analyzed for protein, ether extract, ash, starch, β -glucans, neutral and acid detergent fiber (NDF and ADF, respectively), acid viscosity, calcium, phosphorus and amino acids. Protein was higher ($P < .05$) in fifth middlings, red dog, break shorts, reduction shorts and bran when compared to first break flour and flour. First break flour and flour contained the greatest ($P < .05$) concentration of starch and the least ($P < .05$) fiber while β -glucan and fiber was concentrated ($P < .05$) in red dog, break and reduction shorts and bran. Acid viscosity was the greatest ($P < .05$) in the red dog fraction. The essential amino

acids were more concentrated ($P < .10$) in the high-fiber fractions and lowest ($P < .10$) in the flour fractions. Results of this experiment indicate that certain components of barley can be isolated in relatively high concentration in select milling fractions obtained from a wheat roller-mill. Starch is concentrated in the flour fractions and β -glucan in the red dog, shorts and bran fractions. The essential amino acids, especially lysine, tend to be concentrated in the high-fiber fractions. If industry is open to using roller-milling to process barley for flour and(or) to concentrate certain components, much research must be conducted for transfer to commercial scale milling.

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. Shonkin barley was milled into 14 fractions utilizing an 8-roller dry mill. The fraction selected for this experiment was classified as break shorts. The break shorts contained 8.38 % β -glucan. Rats were randomly allotted to one of the following diets, controls with (0.5 %) or without dietary cholesterol, 30 % break shorts, 60 % break shorts or 90 % break shorts with 0.5 % dietary cholesterol. All treatments were formulated to meet or exceed the National Research Council's requirements for adult rats. Experimental duration was 21 d at which time rats were sacrificed, small intestine contents removed and viscosities determined. Response criteria measured were plasma lipids and glucose, liver lipids, wet digesta weight and intestinal viscosity. Plasma lipids and glucose were not different ($P > .05$) for rats fed any of the treatments. The rats fed the control diets with and

without dietary cholesterol and the 30 % break shorts diet exhibited the heaviest ($P < .05$) liver weights. Liver cholesterol content from rats fed the control diet with cholesterol were the highest ($P < .05$) with rats fed control diet without cholesterol, 60 % break shorts and 90 % break shorts having the least ($P < .05$) amount. The rats fed the control diet with cholesterol also had the greatest ($P < .05$) amount of liver triacylglycerol with rats fed all other diets being lower and not different ($P > .05$) from one another. The rats fed the two control diets had the lowest ($P < .05$) wet digesta weight, while rats fed the 90 % break shorts diet had the heaviest ($P < .05$) wet digesta weight. Intestinal viscosity of the rats increased ($P < .05$) when fed increasing levels of break shorts. These data indicate that consumption by adult rats of a high viscous barley milling fraction contributes to high viscosity in the small intestine which tends to lower plasma cholesterol and effectively lowers liver lipid levels. Barley is a good source of dietary fiber, in particular β -glucans. Milling of barley is an effective procedure that can be used to increase fiber levels in select milling fractions, which can lead to the production of foodstuffs high in dietary fiber.

The relationship between diet and overall general health has become a topic of renewed interest during the past two decades. Along with increased technology and communication systems, the tendency for a sedentary lifestyle has increased, as well as preference for a high fat, high caloric diet. Associated with a change in lifestyle has been an increase in certain chronic diseases such as heart disease and cancer (U.S. Bureau of the Census, 1993), which have forced individuals to look at diet and

health along with exercise as control measures. Over a century ago it was discovered that cholesterol was an important constituent of atherosclerosis plaque, and was present in the blood (Vogel, 1847). Since that time, a huge volume of research has been directed toward obtaining a better understanding of the precise nature of the relationship between atherogenesis and cholesterol.

Americans, however, are among the best fed people in the world in regard to nutrient availability, and are now healthier than at anytime in history while public interest in diet and health is at an all-time high (Bentley, 1986). Americans must continue to decrease their consumption of low-nutrient foods that are high in fat, sugar or alcohol while maintaining a balanced nutrient intake through proper selection of foods. The choice of foods from a variety of commodities, including low-fat meat and milk can still assure a balanced intake of nutrients (Hansen et al., 1986). With heart disease and cancer being the number one and number two causes of death in the U.S., respectively (U.S. Bureau of the Census, 1993), scientists will continue to play an important role in the nutrition of people in the future.

Barley and barley fractions contain prominent amounts of soluble dietary fiber, a component that has been demonstrated to lower plasma and liver lipids. The data presented in this dissertation supports and augments existing information about barley. Additional information is needed to clarify milling techniques in respect to different conditions and cultivars. Transfer of these conclusions to the public sector in addition to the scientific sector follows a logical progression for improved health and utilization of barley and barley products.

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