THE NUTRITIONAL SIGNIFICANCE
OF DIETARY FIBER

MAY 1977

Prepared for

BUREAU OF FOODS
FOOD AND DRUG ADMINISTRATION
DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
WASHINGTON, D. C. 20204

under

Contract Number FDA 223-75-2090

LIFE SCIENCES RESEARCH OFFICE
FEDERATION OF AMERICAN SOCIETIES
FOR EXPERIMENTAL BIOLOGY
9650 Rockville Pike
Bethesda, Maryland 20014
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by

K. K. Kimura, Ph.D., M.D.

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FOREWORD

The Life Sciences Research Office (LSRO), Federation of American Societies for Experimental Biology (FASEB) provides scientific assessments of topics in the biomedical sciences. Reports are based upon comprehensive literature reviews and the scientific opinions of knowledgeable investigators engaged in work in specific areas of biology and medicine.

This technical report was prepared for the Bureau of Foods, Food and Drug Administration (FDA), in accordance with the provisions of Contract No. 223-75-2090.

The LSRO acknowledges the contributions of the investigators and consultants who have assisted with this study. The report reflects the opinions expressed by participants in an ad hoc study group that met at Beaumont House, FASEB on July 20, 1976, and by other consultants; a judicious attempt has been made to incorporate the different viewpoints and opinions.

The report has been reviewed by these consultants; however, the listing of their names in Section VIII does not imply that they endorse the conclusions of the study. The author accepts responsibility for the contents of the report.

The report was reviewed and approved by the LSRO Advisory Committee consisting of representatives of each constituent society of FASEB under authority delegated by the Executive Committee of the Federation Board. Upon completion of these review procedures the report was approved and transmitted to FDA by the Executive Director, FASEB.

While this is a report of the Federation of American Societies for Experimental Biology, it does not necessarily reflect the opinions of the individual members of its constituent societies.

C. Jelleff Carr, Ph.D.
Director
Life Sciences Research Office
SUMMARY

Epidemiologic observations have suggested that inadequate quantities of fiber in the modern Western diet may have adverse health effects. Investigators have implicated lack of dietary fiber with various diseases and disorders prevalent in the United States and Europe.

Considering the chemical complexity and variability of the plant substances that constitute dietary fiber, identification of the precise components of ingested material requires acceptable analytic methods if an understanding of the nutritional significance of dietary fiber is to be achieved. Recent advances in extraction and analysis techniques suggest that an acceptable, relatively uniform product can be prepared for comparative studies of dietary fiber. In addition, the improved methods will allow more accurate estimates of the amount and composition of fiber in foods.

Although considerable research has been done on the effects of dietary fiber, a significant portion has been with preparations of wheat bran. This type of dietary fiber has been shown to reduce gastrointestinal transit time, to modify the fecal composition, to increase stool weight, and to reduce colonic intraluminal pressure. This report concludes that while these effects are reasonably well documented, the underlying physiological mechanisms are not fully elucidated and require further study.

Several studies have suggested that dietary fiber may influence adversely the absorption of certain essential minerals such as calcium, copper, magnesium, phosphorus, and zinc. The effects appear to be related to chelation of mineral ions by components of the dietary fiber; however, the quantitative aspects of these effects are related to the quantity and the type of ingested fiber. Thus, these effects do not appear significant in the average diet in the United States.

This report concludes that increased dietary fiber has positive therapeutic value in diverticular disease, atonic constipation, and certain hemorrhoidal conditions. Increased dietary fiber provides bulk, gentle laxation, and ease of elimination. The relation of dietary fiber in susceptibility to, prevention of, or therapy of other diseases and disorders remains to be established.

Based upon the scientific evidence available, there is little justification for significantly increasing the fiber content of the American diet, except in individual cases where medical considerations indicate additional dietary fiber may be beneficial.
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I. INTRODUCTION

A. BACKGROUND

The Bureau of Foods, Food and Drug Administration has a continuing interest in the nutritional quality of the diet. The agency is responsible for evaluating and monitoring the safety of foods, establishing regulations, and providing nutrition information to consumers. In addition, the Bureau of Foods encourages a balanced regulatory climate for the development of foods for special dietary use and for protection from nutrition fraud and misleading labeling.

The Life Sciences Research Office (LSRO) was requested by FDA to review recent developments with respect to the growing interest in increasing the amount of fiber-containing foods in the American diet. The need for this study stems from reports of several European investigators recommending an increased amount of "dietary fiber" for the prevention of a wide variety of disease states. Preliminary LSRO examination of the literature revealed a lack of objective, controlled studies to support the proposed nutritional and prophylactic advantages of such a regimen. Therefore, a thorough review of the basis for and validity of these proposals was desirable.

B. SCOPE

This report, based on information obtained from the review of scientific literature on the nature of fiber in the diet of man, emphasizes the need for standard reference fiber preparations for use in laboratory experimental studies and in clinical trials with diets designed to evaluate the physiological properties of dietary fiber. In addition, an examination has been made of the reports on animal studies using high fiber diets to determine the nutritional adequacy, possible dietary hazards, and their relation to clinical investigations of the effects of high-fiber diets.

Included in the report are the opinions of a group of experts (See Section VIII, p 55) convened at Beaumont House, FASEB, on July 20, 1976 to explore the significance of current and proposed studies in this field and to develop suggestions for future research. In addition, a comprehensive search was conducted through the National Library of Medicine MEDLINE
and TOXLINE services for literature dealing with high-fiber diets, the physiological, biochemical, and clinical parameters of such diets and current proposals for including more fiber in diets.

Pertinent factors that have been identified during investigation of this subject over the past year are presented, and the need for further research and priorities for future studies that should provide data for better understanding of the role of food fiber in health and disease are discussed.
II. DEFINITION OF DIETARY FIBER

A. GENERAL DISCUSSION

Dietary fiber is not a single substance or uniform chemical entity. There is no single definition of "dietary fiber" acceptable to all investigators. Some consider it to be that portion of plant material which, ingested as food, is not hydrolyzed by human gastrointestinal enzymes (Cummings, 1976; Southgate, 1976b; Trowell, 1972a, 1974; Trowell et al., 1976). However, it may be partially digested by the microflora of the colon and the digestive product absorbed and utilized. Some experts include in dietary fiber cellulose, hemicellulose, lignin, pectic substances, gums, mucilages, as well as waxes, cutin, and indigestible protein, minerals, and other substances bound in the plant cell wall (Southgate, 1976b, Trowell et al., 1976).

Other knowledgeable scientists classify only the polysaccharides and lignin as dietary fiber and consider the related components to be substances associated with fiber as constituents of the plant cell wall (Cummings, 1976; Spiller et al., 1976). Cellulose, hemicelluloses, and pectin are structural polysaccharides of plant cell walls and, together with lignin, account for a major portion of the cell walls of most land plants. Plant gums and mucilages are not cell wall components but are polysaccharides related in chemical structure and properties to cell wall constituents and are not hydrolyzed by human gastrointestinal enzymes. In contrast to cellulose, hemicelluloses, pectin, and lignin which remain in relatively intact form in the cell walls in many foods, gums and mucilages also enter the diet as ingredients of processed foods where they are added as emulsifiers, viscosity agents, and stabilizers.

In addition, certain chemically modified polysaccharides of plant origin, such as methylcellulose, are similar to native plant polysaccharides, are resistant to digestion, and are frequently included in the broad context of dietary fiber (Southgate, 1976b).

The methodology for separating the components has played an important part in the development of a definition for dietary fiber. For example, crude fiber determinations have been used to estimate the quality of feedstuff of plant origin on the basis that fiber constitutes the least digestible fraction. Unfortunately, crude fiber determinations have
yielded data that are now known to be inaccurate because much of the hemicelluloses, pectic substances, and lignin is erroneously accounted for as available carbohydrates.

Dietary fiber is a term of relatively recent origin. However, the concept of fiber as the portion of plant tissues resistant to digestion is not new. The term crude fiber was coined many years ago originally to refer to this fraction of forages and other animal feeds. It is defined as the residue of plant material left after sequential extraction with organic solvents, dilute acid, and dilute alkali according to a prescribed procedure (Horwitz, 1975). The residue consists of cellulose, hemicelluloses, and lignin; however, none of these components is separated quantitatively. The conventional crude fiber analytical method recovers less than 20 percent of hemicelluloses, 50 to 90 percent of cellulose and 10 to 50 percent of lignin, the yield depending on the particular plant material (Van Soest and McQueen, 1973). Crude fiber analyses have been widely applied, not only to animal feeds but also to human foods, and most tables of food composition list crude fiber rather than dietary fiber content (Watt and Merrill, 1963). Until such time as dietary fiber analytical data are available, foods must be compared on the basis of available data which are essentially crude fiber values. It is essential that the inadequacies of these data as well as information on the cell wall components that are and are not included be presented if meaningful comparisons are to be made.

Most writers agree that the term crude fiber is misleading and has contributed to a great deal of confusion in human dietary discussions. Crude fiber probably should be reserved for use in dealing with forage analyses and forage data. In effect, the term "crude fiber" should be retired from use in human nutrition and not employed in tables listing dietary fiber content of foods for man (Van Soest, 1973). Some writers have suggested clarifying the fiber terminology with such descriptive terms as "purified", "nonpurified", "nonnutritive" fiber (Spiller and Amen, 1976). The degree of "purification" as used by Spiller and Amen (1975) may be misunderstood because the original intent was to differentiate between native fibrous fractions of plant sources such as alfalfa, wheat, fruits and vegetables (nonpurified) and the sum of specified polymeric fibrous components of plant fibers (purified). There will be obvious varying physical properties and hence, degrees of "purity" of hemicelluloses, celluloses, or lignin depending on sources, particle size, degree of milling or grinding, water-holding capacity, and chemical composition. However, the terms "purified" and "nonpurified" lead to misunderstanding and may be misleading if they are transposed into the lay press (Schaller, 1975).
Such a coined word as "plantix" from plant and matrix, proposed by Spiller et al. (1976) is interesting because it underscores the concept that there should be a much better way to describe plant fiber in food. The term plantix refers to the sum of cellulose, hemicelluloses, mucilages, pectins, gums, and lignin by analyses. The term is analagous to "dietary fiber" as used by Trowell (1972c) or "nonpurified plant fiber" (Spiller and Amen, 1975). Plantix is not widely used. Trowell (1977) has stated, "there is little to commend the hybrid neologism plantix to replace other terms for fiber in human foods."

There is growing acceptance by investigators in the field of the term "dietary fiber complex" for the entire group of substances related to ingested fiber. "Dietary fiber" per se is being used to refer to plant cell wall structural materials alone, that is cellulose, hemicellulose, pectic substances, and lignin.

In discussing dietary fiber complex in relation to nutrition research, accurate identification and understanding of the complex nature of dietary fiber must be considered. The following aspects are important considerations:

1. The dietary fiber employed in various studies is not physically and chemically uniform. For example, dietary fiber from wheat bran and from leafy vegetables is not identical (Van Soest, 1976a).

2. It is recognized that ingested fiber does not pass through the gastrointestinal tract passively (Eastwood, 1973). Fiber is not nutritionally inert. In many species, including man, the physiological state of the gastrointestinal tract and the nature of the ration may affect the transit time of foods containing fiber (Mangold, 1934). In a situation where there is an altered physiological state such as diarrhea, there is a greater amount of fluid and gastrointestinal motility. These can change the usual activity of a high-fiber diet in the human gastrointestinal tract.

3. Increased bulk from dietary fiber produces more rapid emptying of and passage through the entire gastrointestinal tract. In addition, bulking effects of dietary fiber (hydrophilic) together with potential ion-binding and bile acid-binding effects can alter the entire physicochemical milieu in the intestines.
4. Bile salts can bind to certain components of fiber and pectic substances and the physical state of the plant cell wall can alter enzymatic activities. Subsequent effects can involve binding of digestive products and hinderance of absorption (Van Soest, 1973).

5. Certain diseases (especially gastrointestinal disorders) and dietary fiber will interact in a number of complex ways, affecting both the dietary fiber in foodstuffs and the manifestation of the disease state.

The chemical complexity and variability of the numerous plant substances that constitute dietary fiber (Table 1) and the complexity of potential interaction of constituents of dietary fiber complex with the gastrointestinal tract and its contents, make it necessary to specify the precise character of the dietary components in terms of some acceptable analytical methods if an understanding of the nutritional significance of dietary fiber is to be achieved (See Section E, p 21).

Table 1. Sources and classification of dietary fiber.

<table>
<thead>
<tr>
<th>Sources</th>
<th>Chemical description</th>
<th>Classical nomenclature</th>
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<tbody>
<tr>
<td>Plant cell wall structural materials</td>
<td>Polysaccharides</td>
<td>Cellulose</td>
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<td>Hemicellulose</td>
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<td>Pectic substances</td>
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<td></td>
<td>Noncarbohydrates</td>
<td>Lignin</td>
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<td></td>
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<td>Cutin, suberin and other waxes</td>
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<td>Cell wall minerals</td>
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<td>(e.g., silicates)</td>
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<td></td>
<td>Cell wall proteins</td>
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<tr>
<td>Nonstructural materials</td>
<td>Polysaccharides Natural</td>
<td>Cellulose (intra-cellular)</td>
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<td>Pectic substances</td>
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<td></td>
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<td>Mucllages</td>
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<td>Algal polysaccharides</td>
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<td>Chemically altered polysaccharides</td>
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Modified from Southgate (1978b)
B. CHEMICAL ASPECTS

In green plants, the fibrous material includes hemicelluloses (primarily pentosans and hexosans), cellulose, and lignin, along with waxes, cutin, pectic substances, mucilages, and gums. As previously noted, this complex mixture is usually reported as crude fiber, but in fact this latter term includes only that portion of the food or forage resisting hydrolysis by boiling first with sulfuric acid and subsequently with sodium hydroxide. Crude fiber contains only portions of the lignin, cellulosic substances, and hemicelluloses after acid hydrolysis. Most Western diets contain twice as much of the hemicelluloses by weight as crude fiber (cellulose and lignin) (Southgate and Durnin, 1970).

In addition to these differences between fibrous materials in situ and dietary fiber complex, fibers from different plant sources are not the same. The proportions and even the biochemical properties of dietary fiber complex constituents vary from species to species and within members of a species. Van Soest and McQueen (1973) concluded that unless statements about the action of fiber in human nutrition are qualified by detailed description of the fiber origin and composition, they are not particularly meaningful. For example, in most whole cereal grains there is two to three times the quantity of hemicellulose as there is cellulose and lignin; however, this difference is less for fleshy fruits and vegetables (Southgate, 1969).

Plant cell walls are primarily cellulose fibrils embedded in a continuous phase of lignin, pectin, and hemicelluloses, of which the latter predominate. Pectin is localized largely in the primary wall of the middle lamella in 1 to 4 percent concentration. Some lignin and a major portion of hemicelluloses are found mixed with cellulose in both the primary and secondary cell wall. The physical properties of the plant cell wall depend largely on interactions between these three main components. Even at a very early stage of cell differentiation, cellulose, hemicelluloses, and pectic substances are found as main components (Southgate, 1976a, 1976b). The major components of dietary fiber complex are as follows:

1. **Cellulose**

Twenty to fifty percent of the dry matter of plants consists of β-1,4-pyranosidic chains of glucose (Spiller and Amen, 1976). Cellulose exists in large amounts in grasses, legumes, and other forage plants. Dietary celluloses, as found in combination with hemicelluloses, lignin, cutin, and silica in the plant wall, are essentially unchanged during food preparation and cooking and may have different properties than isolated industrial celluloscs. Although cellulose from all forage plants is similar in chemical structure, its digestion by the ruminant varies from 0 to 100
percent depending on the source and the maturity of the forage. Nonruminants digest less cellulose than ruminants, but the digestibility of celluloses varies with the plant species and the animal species consuming them as well as with the individual within the species (Hirschberg, 1942).

The physical properties of plant cell walls are influenced by the proportions of cellulose, hemicelluloses and lignin. Lignin has plastic properties and together with cellulose gives wood its rigid character; hemicelluloses with branched polysaccharides are usually associated closely with lignin. The fibrous nature of cellulose results from the side-by-side crystallization of its extended linear chains of α-1, 4-anhydroglucose residues. For example, cotton, in contrast to the stem and leaf structure, is relatively pure cellulose and also has a high degree of crystallinity.

Cellulose of cell walls in immature parenchymatous tissue, characteristic of most vegetable pulp, has little fibrous character and appears as a gel if isolated in a hydrated form. In drying it becomes insoluble and cannot be readily reconstituted to its original state. Comparison of in vitro digestion rates (using rumen inoculum from forage-fed animals) showed greater digestion rates for immature ryegrass and alfalfa when compared to ground Whatman number 41 paper (purified wood cellulose) or surgical cotton (Van Soest, 1973).

2. Hemicelluloses

The term hemicellulose is a common name for a complex series of heteroglycans based on three types of homopolymeric backbone chain (xylans, mannans, and galactans) and one type of mixed-polymeric chain, glucomannans. Principally pentosans and often called noncellulosic polysaccharides, hemicelluloses are the least understood substances of the plant cell wall. The term hemicellulose was first coined by Schulze in 1891 when it was believed that the polysaccharide extracted from the plant cell wall with dilute alkali was a precursor of cellulose (Aspinall, 1959).

These numerous water-insoluble polysaccharide polymers are related neither biosynthetically nor structurally to cellulose (Cummings, 1976). Hemicellulose molecules having 150-200 sugar units per molecule are usually smaller than those of cellulose. Trowell (1973) questioned the nutritional role of hemicelluloses in man and has proposed that the term hemicelluloses should be replaced by the chemical name of the component polysaccharides, e.g., xylans.

Classically, after dilute alkali extraction, the residue can be fractioned into the following:
a. Hemicellulose A fractions are glucuronoxylans which precipitate out with dilute acetic acid treatment.

b. Hemicellulose B fractions are galactans and arabinoxylans which precipitate out with ethanol after removal of hemicellulose A.

c. Hemicellulose C fractions, obtained by extraction with strong alkali under nitrogen, consist of matrix polysaccharides (Southgate, 1976a, 1976b).

According to Cummings (1976), a more useful classification of hemicelluloses in terms of their possible role in human nutrition would be as the acidic and neutral hemicelluloses, depending on the number of uronic acid residues that they contain:

a. Acidic hemicelluloses show more variety than the neutral hemicelluloses and are in general smaller and more highly branched. They contain a higher proportion of uronic acids.

b. Neutral hemicelluloses are typically isolated from cereals. These hemicelluloses have a backbone of 1,4-α-D-xylose units with short side chains of arabinose in furanose form. The ratio of xylose to arabinose varies with the specific genetic strain of the plant. However, digestibility is related to lignification and not to the acidic character of the polysaccharide in lignified tissue (Gaillard, 1962, 1966).

Three properties of hemicelluloses similar to those of gums and believed to be important in human physiology are water-holding capacity, digestibility, and capacity to bind trace mineral ions and bile acids. As they pass through the human gastrointestinal tract, hemicelluloses are digested to a greater extent than cellulose. However, the extent of digestion is variable. Williams and Olmsted (1936a) reported human digestibility of cellulose and hemicellulose to be 38.3 and 56.0 percent respectively, whereas Southgate and Durnin (1970) noted apparent digestibilities of 29.4 and 87.2 percent for these substances. In humans, there is some relationship between age and digestibility since older subjects digest hemicelluloses more completely. Little work has been done on the digestive aspects of hemicellulose from plant tissues that characteristically form part of the human diet. Most of the studies on human digestibility have been on hemicelluloses derived from wood (Timell, 1964, 1965).

3. Lignin

Lignin, or more properly "the lignins," is a group of complex aromatic polymers based on phenylpropane residues formed by the
condensation of phenolic plant alcohols such as coumaryl, coniferyl, and sinapyl alcohols. They generally have low molecular weights between 1000 and 4500 (Cummins, 1976). Knowledge of the structure of lignin has been derived primarily from studies of wood lignin but lignins in vegetable foods are likely very different from those in wood (Sarkanen and Ludwig, 1971). Lignins are highly insoluble and constitute the major part of the extraction residue left after treatment of the plant cell wall with 72 percent sulfuric acid. The lignin fraction is extremely difficult to measure accurately using existing methods and all reported values need to be viewed with some caution. Wood may have up to 50 percent lignin in the cell wall, while wheat straw cell walls contain about 23 percent; cabbage, 6 percent; and apples, 25 percent (Sarkanen and Ludwig, 1971). Most conventional analyses for lignin tend to give high results because of the isolation of nonlignin substances. Insoluble humins may be formed during digestion of carbohydrate and protein constituents with strong acid, and they will be included in the lignin fraction. Also, nonenzymatic browning reactions occur during baking, frying, and other cooking processes and produce indigestible substances that are recovered with lignin. The latter group of substances probably accounts for most of the material reported as lignin in human foods (Van Soest, 1965; Van Soest and Robertson, 1977).

4. Pectic Substances

The pectins and pectic acids are present in plant cell walls and also present in the intercellular layer. Pectin content on a dry basis may be as high as 30 percent in citrus peel and 15 percent in apple pomace. The pectic substances are composed of polymers of 1,4-α-D-galactopyranosyluronidic acid units. Other sugars identified with the polymer molecule are D-galactose, L-arabinose, and L-rhamnose, and occasionally trace amounts of others. Isolated pectic substances are soluble in hot water, although undegraded pectin in the cell wall appears as the calcium salt and is not as soluble (Aspinall, 1970).

By definition, pectic substances include pectic acids, pectinic acids, and pectins. Pectins have a high degree of methylation of the carboxylic acid groups. Pectinic acids are pectins with only a portion of the acidic groups methylated, whereas pectic acids refers to polysaccharides with no methyl groups on the carboxylic acid groups (Kertesz, 1963). Dilute aqueous solutions of isolated pectic substances gel on cooling, a property that is used extensively in jam and jelly production. Gel formation involves the intermolecular association of the galacturonan chains (Baker, 1948).

The ion-binding capacity of pectic substances is closely related to the uronic acid content, which functions as a cation-exchanger. Werch and Ivy (1941) reported that in man, pectin may be almost completely
broken down in the colon with less than 15 percent recovery in stool. Pectin is degraded by the microflora in the colon and the degradation products are largely excreted in the feces (Select Committee on GRAS Substances, 1976).

5. **Plant Gums and Mucilages**

These substances are a mixed group of complex polysaccharides which are not generally part of the plant cell wall and are essentially non-digestible by man. Gums are composed of galactans (e.g., gum arabic), glucuronomannans, galacturonorhamnans, xylans, and xyloglucans (Aspinall, 1969). Mucilages are for the most part neutral polysaccharides. Guar mucilage is isolated from ground endosperm of the legume, *Cyanopsis tetragonoloba*. It is a 1,4-α-D-galactomannan with single-unit side chains consisting of 1,6-α-D-galactose. Psyllium seed extracts are mucilages from *Plantago* sp. containing both acidic and neutral polysaccharides.

6. **Cuticular Substances**

The waxy materials secreted by the epidermal cells form a waterproof coating on the surface of stems, fruits, seeds, and leaves. While the cutins and waxes form a small proportion of the total plant lipids, they provide an extremely hydrophobic layer in the outer surface and as such are intimately associated with the plant cell wall. Cuticular substances are extremely resistant to digestion by man and behave much like lignin in impairing the digestibility of the other cell wall constituents. Waxes, which are soluble in simple solvents like benzene, include a mixture of paraffins, aliphatic acids, and alcohols. Cutin is a complex polymer of mono-, di-, tri-, and polyhydroxyl fatty acids and forms the ground substance of cuticle (Preston, 1974).

While the major constituents of dietary fiber complex are substances that may be classified as one of these six types, other materials are associated with structural and nonstructural plant cell wall material. These include cell wall bound proteins, cell wall bound minerals such as inorganic and organic silicates, and certain other essentially indigestible cell wall bound substances. In addition, the type of plant, its maturity, and the conditions of growth affect the composition and quality of what becomes "dietary fiber." The variability is exemplified by the differences between two important sources of dietary fiber: fleshy or leafy vegetables and cereal grains. The former are typically immature vegetative plant structures; the latter, mature reproductive structures. Most vegetable fiber is readily digested and contains little or no lignin or cutin. On the other hand, cereal grain fiber is less digestible and contains more lignin. The frequently used human dietary item, wheat bran, is highly lignified and nearly indigestible.
C. WATER-HOLDING CAPACITY

In addition to the usual measurement for fiber constituents, dietary fiber data could usefully include values for water-holding capacity (WHC)*. WHC varies from the lignins, which are least hygroscopic, to hemicelluloses and pectic substances which have a high WHC and readily form gels. Celluloses are not soluble in water but have some WHC.

Dietary fiber has a finite capacity to hold water when its surface and interstices are saturated with water (Eastwood and Mitchell, 1976). Any water subsequently added will be superfluous free water. WHC means the extent to which a material is capable of holding water within its interstices in the presence of adequate water. It appears that WHC of dietary fiber in the gastrointestinal tract (as measured from stool weight and consistency) varies with the sources of fiber, amount of hydration, particle size, pH of the solution, age of subject, and the effect of digestive function and bacterial degradation of fiber by the gut flora.

Table 2 gives estimates of WHC of several selected substances. On a dry weight basis, carrot pulp has considerable WHC. In the fresh raw condition, carrots are hydrated to near maximum values and as Van Soest (1976b) pointed out, one must eat several pounds of raw carrots or celery to provide the comparable dietary fiber equivalent value of a 3 ounce serving of bran cereal as based on WHC.

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*Water-Holding Capacity--Samples of fiber (~1 g) are soaked in water for 6 hours at room temperature, the slurries are then poured into tared 15 ml polypropylene tapered tubes and centrifuged at 800 G in an IEC clinical centrifuge for 30 minutes. The supernatent is poured off, the tubes drained for 15 minutes and any remaining droplets carefully removed with tissue. The tubes are then weighed, dried at 110°C overnight, reweighed and the water-holding capacity calculated as grams of water held per gram of dry weight of the sample determined (Schaller, 1977b).
percent sulfuric acid dissolves the cellulose, and the residual insoluble matter is mainly lignin (Goering and Van Soest, 1970). It has been pointed out that the low concentrations of cellulose and lignin in mixed diets can make accurate determination of these constituents difficult for such food samples (Southgate, 1976a).

McConnell and Eastwood (1974) compared the Southgate method with Van Soest's acid detergent fiber method for the determination of cellulose and lignin in some commonly eaten plant materials (Table 7). Moisture was removed from apples, cabbage, celery, and turnips by acetone and/or freeze-drying prior to analysis. Except in the case of apples, the Van Soest method gave higher values for the combined cellulose and lignin content of the products examined. The former method also gave higher values for residual lignin after removal of cellulose. The authors noted that the Southgate method was most comprehensive in that it gave values for water-soluble polysaccharides, starch, and hemicellulose in addition to cellulose and lignin, but was very time consuming.

The fractions removed and components quantified by reasonably rapid analytical methods currently available are summarized in Table 8.
E. ANALYTICAL METHODS

Several analytical methods have been developed that may be applied to the measurement of dietary fiber or dietary fiber components in foods. Total dietary fiber can be estimated by three methods: 1) the enzyme modification (Schaller, 1976) of Van Soest's neutral detergent fiber method (Goering and Van Soest, 1970), 2) Southgate's method for measuring the components of dietary fiber (Southgate, 1976a), and the method of McCance et al. (1936) for unavailable, i.e., indigestible, carbohydrate. The neutral detergent fiber method was developed to measure total plant cell wall constituents in forages. For foods, the AACC Fiber Committee (Schaller, 1976) added an initial extraction step for the removal of lipids followed by digestion with α-amylase to remove starch (Appendix A, p 59). Protein is solubilized in hot neutral detergent solution leaving a residue of plant cell wall polysaccharides and lignin. Some water soluble polysaccharides may be lost in this procedure. Southgate (1976a) states that a measurement of total dietary fiber is given by the first stages (these involve solvent extraction, starch digestion, and extraction of the residue with hot water) of his method for dietary fiber components. In the method of McCance et al. (1936) total unavailable carbohydrate, which includes lignin and hence is equivalent to dietary fiber, is determined as the residue insoluble in 80 percent ethanol after correction for the content of starch and protein in the residue. Starch was measured by takadiastase digestion and protein as total nitrogen x 6.25.

A number of analytical procedures have been developed for the fractionation of plant cell wall material into its component polysaccharides and lignin (Paesch and Tracey, 1955; Bath, 1960; Selvendran, 1975). However, no single procedure is applicable without modification to the isolation and quantitation of the polysaccharide components of all types of plant tissues. Also, the procedures are research oriented and are not easily adapted to the routine analysis of foods (Southgate, 1976a). Southgate's method, mentioned earlier, for estimating the amounts of dietary fiber components present in a sample does not isolate individual polysaccharides but gives values for them in terms of sugar components present in hydrolysates after appropriate treatments. It appears to be the most practicable procedure currently available for systematic determination of the components of dietary fiber.

Van Soest (1963b) developed a relatively simple method for the analysis of forage for cellulose and lignin. This method, called the acid-detergent fiber method, involves heating a sample with normal sulfuric acid containing cetyltrimethylammonium bromide and filtering off and washing the residue. The residue is mainly composed of cellulose and lignin and contains silica and other ash components. Treatment of the residue in 72
Table 6. Wheat flour pentosans, cellulosic material and crude fiber (percent).

<table>
<thead>
<tr>
<th>Flour type</th>
<th>Pentosans (hemicellulose)</th>
<th>Cellulosic material</th>
<th>Crude fiber</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low Extraction</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(70 percent)*</td>
<td>2.0</td>
<td>0.4</td>
<td>0.12</td>
</tr>
<tr>
<td>Brown flour</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(&lt;93 percent)*</td>
<td>4.9</td>
<td>2.8</td>
<td>1.44</td>
</tr>
<tr>
<td>(&gt;93 percent)*</td>
<td>5.2</td>
<td>3.0</td>
<td>1.60</td>
</tr>
<tr>
<td>Whole meal</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(100 percent)*</td>
<td>5.8</td>
<td>4.4</td>
<td>1.99</td>
</tr>
</tbody>
</table>

*Wheat flour extraction rate, i.e., the percentage of the grain recovered as flour.

Adapted from Fraser and Holmes (1956) and Fraser, et al. (1956).
### Table 5. Percentage fiber in selected dry foods as analyzed by three different methods.  

<table>
<thead>
<tr>
<th>Ingredients or products²</th>
<th>Insoluble hemicellulose³</th>
<th>Cellulose⁴</th>
<th>Lignin and ash</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corn bran (pericarp)⁵</td>
<td>60</td>
<td>21.2</td>
<td>0.1</td>
</tr>
<tr>
<td>Corn bran (pericarp)⁵</td>
<td>48</td>
<td>16.4</td>
<td>0.3</td>
</tr>
<tr>
<td>Corn bran (pericarp)⁶</td>
<td>30</td>
<td>12.8</td>
<td>1.2</td>
</tr>
<tr>
<td>Durum bran</td>
<td>24</td>
<td>14.1</td>
<td>2.4</td>
</tr>
<tr>
<td>Brewer's dried grain</td>
<td>25</td>
<td>16.0</td>
<td>6.9</td>
</tr>
<tr>
<td>White bran (14 mesh)</td>
<td>24</td>
<td>8.3</td>
<td>3.3</td>
</tr>
<tr>
<td>Red bran (light)</td>
<td>25</td>
<td>8.0</td>
<td>3.1</td>
</tr>
<tr>
<td>White bran (light)</td>
<td>22</td>
<td>8.4</td>
<td>3.1</td>
</tr>
<tr>
<td>Rice bran (defatted, parboiled)</td>
<td>16</td>
<td>13.3</td>
<td>10.4</td>
</tr>
<tr>
<td>Bran buds</td>
<td>15.4</td>
<td>6.9</td>
<td>2.0</td>
</tr>
<tr>
<td>All Bran®</td>
<td>17.7</td>
<td>8.0</td>
<td>2.3</td>
</tr>
<tr>
<td>Beet pulp</td>
<td>12</td>
<td>23.4</td>
<td>2.0</td>
</tr>
<tr>
<td>Carrot pulp</td>
<td>1</td>
<td>25.9</td>
<td>0.2</td>
</tr>
<tr>
<td>Citrus pulp</td>
<td>0</td>
<td>5.6</td>
<td>0</td>
</tr>
<tr>
<td>Corn grits</td>
<td>0</td>
<td>0.4</td>
<td>0.2</td>
</tr>
</tbody>
</table>

¹Does not add up to 100 percent because protein, fat, starch and other digestible constituents are not included.

²Ground to 35 mesh.

³Neutral detergent fiber analysis value using α-amylase to remove starch (Schaller, 1976) minus acid detergent fiber value (Van Soest, 1963b).

⁴Acid detergent fiber value minus lignin (Horwitz, 1975).

⁵Three samples with variable starch content.

Modified from Schaller (1977a)
Table 4. Percentage crude fiber content of selected plant materials.*

<table>
<thead>
<tr>
<th>Materials</th>
<th>Dry basis</th>
<th>Wet basis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Avicel (microcrystalline cellulose)</td>
<td>62</td>
<td>---</td>
</tr>
<tr>
<td>Alfalfa</td>
<td>28</td>
<td>---</td>
</tr>
<tr>
<td>Food grade miller's bran</td>
<td>10</td>
<td>---</td>
</tr>
<tr>
<td>Whole wheat bran (All Bran®, 100% Bran®)</td>
<td>6 - 10</td>
<td>---</td>
</tr>
<tr>
<td>Cucumber peels</td>
<td>34.1</td>
<td>2.9</td>
</tr>
<tr>
<td>Eggplant (peeled)</td>
<td>18.6</td>
<td>1.3</td>
</tr>
<tr>
<td>Lettuce</td>
<td>13</td>
<td>0.6</td>
</tr>
<tr>
<td>Celery</td>
<td>13</td>
<td>0.6</td>
</tr>
<tr>
<td>Cucumber (peeled)</td>
<td>11</td>
<td>0.4</td>
</tr>
<tr>
<td>Green beans</td>
<td>11</td>
<td>1.1</td>
</tr>
<tr>
<td>Cauliflower</td>
<td>10</td>
<td>0.9</td>
</tr>
<tr>
<td>Cabbage</td>
<td>8.4</td>
<td>0.7</td>
</tr>
<tr>
<td>Carrots</td>
<td>5.7</td>
<td>0.6</td>
</tr>
</tbody>
</table>

*Adapted from Lang and Briggs (1976) and Van Soest (1976b).
<table>
<thead>
<tr>
<th>Source</th>
<th>Products</th>
<th>Crude fiber g/30 g serving</th>
<th>Crude fiber percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rice</td>
<td>Puffed Rice®, Rice Toasties®, Rice Krinkles®, Puffa Puffa Rice®, Cocoa Krispies®, Rice Krispies®</td>
<td>0.1 - 0.5</td>
<td>0.3 - 1.7</td>
</tr>
<tr>
<td>Mixed</td>
<td>Special K®, Product 19®, Kellogg's Concentrate®, Apple Jacks®, Froot Loops®, Franken Berry®, Kaboom®, Count Chocula®, Kellogg's Country Morning®, Quaker 100% Natural Cereal®, Team Flakes®, Alpen®</td>
<td>0.1 - 0.4</td>
<td>0.3 - 1.3</td>
</tr>
<tr>
<td>Corn</td>
<td>Post Toasties®, Kellogg's Corn Flakes®, Sugar Frosted Flakes®, Sugar Pops®, Corn Total®, Trix®, Cocoa Puffs®, Country Corn Flakes®</td>
<td>0.1 - 0.2</td>
<td>0.3 - 0.7</td>
</tr>
</tbody>
</table>
Table 3. Crude fiber content of selected breakfast cereals.*

<table>
<thead>
<tr>
<th>Source</th>
<th>Products</th>
<th>Crude fiber g/30 g serving</th>
<th>Crude fiber percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Food grade miller's bran</td>
<td></td>
<td>3.0 - 3.6</td>
<td>10 - 12</td>
</tr>
<tr>
<td>Wheat bran</td>
<td>All-Bran®, Bran Buds®, 100% Bran®</td>
<td>1.8 - 2.3</td>
<td>6.0 - 7.7</td>
</tr>
<tr>
<td>Mixed</td>
<td>Familia®</td>
<td>1.1 - 1.3</td>
<td>3.7 - 4.3</td>
</tr>
<tr>
<td>Wheat bran</td>
<td>40% Bran Flakes®, Raisin Bran®</td>
<td>0.8 - 1.1</td>
<td>2.7 - 3.7</td>
</tr>
<tr>
<td>Wheat</td>
<td>Puffed Wheat®, Pep®, Sugar Smacks®, Krumbles®, Wheaties®, Total®, Buc-Wheats®, Shredded Wheat®</td>
<td>0.3 - 1.0</td>
<td>1.0 - 3.3</td>
</tr>
<tr>
<td>Cooked cereals</td>
<td>Farina®, Ralston®, Heartland®, Wheatena®, Rolled Oats®</td>
<td>0.4 - 0.7</td>
<td>1.3 - 2.3</td>
</tr>
<tr>
<td>Wheat and barley</td>
<td>Grape Nuts®, Grape Nut Flakes®</td>
<td>0.5</td>
<td>1.7</td>
</tr>
<tr>
<td>Oats</td>
<td>Oat Flakes®, Cheerios®, Lucky Charms®, Granola®, Heartland®, Life®</td>
<td>0.2 - 0.5</td>
<td>0.7 - 1.7</td>
</tr>
</tbody>
</table>

* Adapted from Anonymous (1973) and Schaller (1977c).
6. **Prepared Foods**

Processed and prepared plant products are major sources of dietary fiber in the Western world. The most commonly used sources are bran-containing cereals that provide a ready source and apparently the highest dietary fiber content of any breakfast cereals available in the United States (Table 3). In addition to wheat, oats, and corn, high fiber fractions isolated from soybean hulls can also be considered as potential high-fiber food ingredients. Their fiber content has been analysed and found to be more than 40 percent (Anonymous, 1976). It is important to note that there is a major difference between the fiber content of fleshy and leafy immature vegetables in the hydrated natural form and on a "dry basis" (Table 4). Water is the major constituent of fresh fruits and vegetables and on the weight basis, as is, they do not offer as much dietary fiber as the whole cereal grains, especially wheat bran. In addition, Table 4 illustrates the undesirability of using crude fiber values. Methylcellulose and microcrystalline cellulose are both 99 percent indigestible, yet have a crude fiber value of 62 percent. Table 5 gives the composition of some selected grain and vegetable foods supporting the general observation that the dietary fiber of cereals consists predominately of hemicelluloses while that of vegetables is primarily cellulose.

Fraser and Holmes (1956) analyzed four types of wheat flour and gave values for pentosans, cellulosic materials and crude fiber content. The data in Table 6 indicate that the usual crude fiber values are much lower than the cellulosic fraction and crude fiber values do not include the pentosan fraction. With the highest possible flour extraction of 100 percent, as whole meal, the predominant fiber component is the pentosans since these account for the major noncellulosic polysaccharides (arabinoxylans) of flour.

In summary, because of the complexity of the plant constituents and the effects of processing, it is difficult to identify specifically or to conclude which plant polysaccharide or lignin structure may be most important in dietary fiber as this complex affects gastrointestinal physiology. However, one can classify the components of fiber in the diet although the complexity of fiber source is compounded by the differences in composition from plant to plant even within the same species.
D. SOURCES OF DIETARY FIBER

The human diet includes a number of different types of plant tissues from many plants, each tissue having its own characteristic cellular structure.

1. Stem Structures

Stems contain considerable thin-walled parenchymatous tissues rich in pectic substances in the less mature stems. In mature stems, a greater degree of deposition of lignin, cork, and suberin occurs, but because most plant parts are consumed in a tender, relatively immature condition, the tissues are still only lightly lignified or suberinized.

2. Leaf Structures

Leafy tissues have varying degrees of lignification. The outer surfaces carry a cuticular layer which is often protected by a waxy coating. In grasses, the proportions of lignified elements are often higher than in the leafy tissues of dicotyledonous plants.

3. Root Structures

Edible roots are usually harvested before any secondary thickening has occurred. Immature root structures contain relatively few lignified elements, but very mature roots may be heavily lignified.

4. Fruits

The fruits, including many so-called vegetables (cucumber, squash, and tomato) are, strictly speaking, a ripened ovary or ovaries. Fruits are either dry or fleshy when mature. A major part of fleshy fruit consists of succulent parenchyma. In dry fruits, nonsucculent and lignified sclerenchyma is present. In such fruits as the tomato and watermelon, the portion of the fruit called the placenta usually consists of soft, thin-walled parenchymal cells in which the vascular elements are lightly lignified.

5. Seeds

Seeds are well protected in most species with a seed coat which is usually impervious to water. Cells of the seed coat frequently have thick lignified and cutinized walls. In cereal grains and many seeds, the endosperm cells are packed with starch granules.
Table 2. Comparison of the water-holding capacity of selected plant materials and the dietary fibers isolated from them.\(^1\)

<table>
<thead>
<tr>
<th>Plant Material</th>
<th>Isolated dietary fiber(^2) (g/g dietary fiber)</th>
<th>Whole plant material(^3)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Measured (g/g dry weight)</td>
<td>Calculated (g/g dry weight)</td>
</tr>
<tr>
<td>White wheat bran</td>
<td>7.5</td>
<td>1.9</td>
</tr>
<tr>
<td>Red wheat bran</td>
<td>7.6</td>
<td>2.2</td>
</tr>
<tr>
<td>Rice bran</td>
<td>9.7</td>
<td>2.1</td>
</tr>
<tr>
<td>Rice bran (parboiled &amp; defatted)</td>
<td>6.9</td>
<td>4.4</td>
</tr>
<tr>
<td>Corn bran (pericarp) #2</td>
<td>5.0</td>
<td>3.1</td>
</tr>
<tr>
<td>Citrus pulp</td>
<td>21.7</td>
<td>6.6</td>
</tr>
<tr>
<td>Sugar beet pulp</td>
<td>38.1</td>
<td>4.9</td>
</tr>
<tr>
<td>Carrot pulp</td>
<td>39.0</td>
<td>29.5</td>
</tr>
<tr>
<td>Solka Floc 200(^\text{®})</td>
<td>3.4</td>
<td>3.4</td>
</tr>
<tr>
<td>White bran (14 mesh)</td>
<td>8.4</td>
<td>---</td>
</tr>
<tr>
<td>Bran Buds(^\text{®}) (14 mesh)</td>
<td>8.4</td>
<td>---</td>
</tr>
</tbody>
</table>

\(^1\) Modified from data supplied by Schaller, 1977b.
\(^2\) As determined by the enzyme modified neutral detergent fiber method (Schaller, 1976).
\(^3\) Ground to 35 mesh except as indicated otherwise.
investigations of large molecular weight complex carbohydrates which sug-
gest that persorption does occur in the vertebrate gastrointestinal system
(Grasso, 1976).

The quantitative and qualitative aspects of persorption of dietary
fiber have not been investigated thoroughly. Studies on starch and micro-
crystalline cellulose, as well as those with stained oatmeal and corn, sug-
gest that some ingested dietary fiber does pass through the wall of the
intestine by persorption. As pointed out by Grasso (1976), subtle functional
disturbances of macrophages and phagocytes might occur as a result of
long-term or lifetime ingestion and persorption of macromolecular sub-
stances in foods.

Whether partially degraded components of dietary fiber, that is,
large molecular weight substances, are absorbed by endocytotic processes
is unknown. However, any derangement of the integrity of the natural
intraluminal and mucosal defenses such as inflammation or ulceration has
been shown to increase the uptake of these large molecular weight substances
and their transport out of the cells into the systemic circulation. Even in
the abnormal gastrointestinal tract, the absorption would have little nutri-
tional significance; however, the quantities could be antigenic and biolog-
ically active (Walker and Isselbacher, 1974). There is a need to investigate
the significance of mechanisms such as persorption and endocytosis in
transport of dietary fiber and its components out of the digestive tract to
the blood and other body fluids.

The effect of dietary fiber on stool weight is well known. Thus, the
stools of rural Africans, whose diets are relatively high in plant fibers, are
about five times the weight of those from Westerners (Burkitt, 1973). Con-
sumption of bran, as an example of a good source of plant dietary fiber,
results in stools that are soft and bulky, with decreased transit time
(increased speed of emptying). Hoppert and Clark (1942) noted in human
volunteers that as much as 115 g of bran per day were tolerated as a lax-
ative. However, Eastwood et al. (1973) showed that in a group of normal
subjects the ingestion of as little as 16 g of cereal bran per day readily pro-
duced some laxation with softer and heavier stools.

An important property of bran is its ability to absorb up to three
times its weight of water. The increased fecal weight or bulk appears related
to the increase in water content of the stool. Other components of dietary
fiber such as cellulose, hemicellulose, pectic substances and gums are
efficient bulking agents showing the ability to absorb water.

Hoppert and Clark (1945) suggested a daily intake of approximately
30 g of prepared bran (equivalent to 40 mg of crude fiber per kg of body

- 30 -
Williams and Olmsted (1936b) further noted that the hemicelluloses are the most effective in increasing the stool bulk. Cellulose was less effective, although it has some capacity to hold water. However, residues high in lignin tended to be constipating. Williams and Olmsted (1936b) stated that the increased motility and decreased transit time may be due to the stimulating effect of the lower volatile fatty acids derived from bacterial action on hemicellulose and cellulose.

Additional studies are required to understand the effects of the colonic contents of man on dietary components and the influence of dietary fiber on composition, activity, and absorption of these components in the colon.

Another phenomenon that has received little or no attention is the possible persorption of dietary fiber. Volkeimer and Schulz (1968) and Volkeimer et al. (1968a, 1968b) have demonstrated that raw starch granules administered as a suspension to rats, dogs, or to young, healthy adult men are transported through the intestinal wall by a process of "persorption." In this process, solid particles are kneaded with constant regularity from the intestinal lumen into the subepithelial region by a mechanical process. The particles apparently pass through the intercellular spaces and can be demonstrated in the venous blood a few minutes later. The phenomenon of persorption is described as different from absorption because the epithelial cells do not exert an absorptive function in this process.

Pahlke and Friedrich (1974), in studies with rats, dogs, and pigs given oral doses of microcrystalline cellulose at levels of 0.5, 140, and 200 g respectively, observed particles of the material in the blood of all three species. Mean cellulose fiber lengths observed were 56.5 μ, 36 μ, and 39 μ for rats, dogs, and pigs, respectively. Maximum lengths seen were fibers 179 μ long.

Schreiber (1974) has reported the presence of dyed cellulose fibers in the blood and urine of several male and female subjects fed oatmeal containing methylene blue or creamed corn stained with basic fuchsin. He presented photographic evidence of dyed plant fibers (500 μ in length) in the venous blood at periods from 4 hours to 6 days after meal ingestion. Schreiber (1974) indicated that persorption was the probable origin of the plant material in blood and urine.

However, Ferch (1973) found no evidence of persorption in Wistar rats fed dyed microcrystalline cellulose as 50 percent of their daily diet for 30 days. Despite this negative report, there are a number of
Table 9. Average percentage disappearance during gastrointestinal passage of materials fed to three human subjects.

<table>
<thead>
<tr>
<th>Materials added to basal diet</th>
<th>Lignin</th>
<th>Cellulose</th>
<th>Hemicellulose</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wheat bran</td>
<td>10</td>
<td>30</td>
<td>35</td>
</tr>
<tr>
<td>Agar</td>
<td>--</td>
<td>--</td>
<td>60</td>
</tr>
<tr>
<td>84 percent hemicellulose</td>
<td>--</td>
<td>45</td>
<td>84</td>
</tr>
<tr>
<td>Canned peas (dried)</td>
<td>--</td>
<td>7</td>
<td>29</td>
</tr>
<tr>
<td>Cellu Flour®</td>
<td>--</td>
<td>7</td>
<td>29</td>
</tr>
<tr>
<td>79 percent cellulose</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>16 percent hemicellulose</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Modified from Williams and Olmsted (1938).
agent in connective tissue of animals and plants, and is bound in large amounts in arterial intima. Most silicon in plants is nonsilicate opaline silicic acid and is in the cell wall and a legitimate part of the fiber matrix. Rice bran is particularly high in silicic acid. This silicon compound may be important in the binding of trace elements: viz. Fe, Zn, Cu, Mg (Jones, 1977; Jones and Handreck, 1967). Large amounts of silicate-silicon (1000-25000 ppm) are present in diverse dietary fiber components such as pectins and guar gums which are active hypocholesterolemic. Schwarz (1977) concluded that silicate-silicon may be the active agent in dietary fiber that influences the development of atherosclerosis. This hypothesis remains to be studied further.

B. GASTROINTESTINAL ASPECTS

The major impact of dietary fiber is on the colonic portion of the gastrointestinal tract. The colon primarily has two important functions: (1) to conserve the intestinal contents and (2) to act as a reservoir. It is well known that the colon contributes to the enterohepatic circulation of bile acids (Mitchell and Eastwood, 1976). As a reservoir, the colon contains electrolytes, microbes, unabsorbed dietary residues, shed epithelial cells, bile acids, and organic and inorganic materials.

Human colonic bacteria can digest plant fiber both in vitro and in vivo (Hungate, 1976). Most herbivorous vertebrates make use of the microbial ability to digest resistant plant components for which the animals have no effective enzymes. Nonruminants, whose post-acid fermentation is of the cecal-colonic type, can utilize their own enzymes to break down the easily digestible parts of the food. Certain amounts of resistant carbohydrates are then fermented by cecal-colonic microbes to reduce the total undigested fecal material.

Williams and Olmsted (1936b), in studies of adults, determined the capability of gut flora to digest various fibrous materials by assessing the relative disappearance of hemicelluloses, cellulose, pectins, and lignins. The microflora of the colon was able to digest hemicelluloses and pectic substances to a significant extent, cellulose to a limited extent, but virtually no lignin was digested. When there was a high percentage of lignin in the residue (e.g., wheat bran), less hemicellulose and cellulose disappeared from the gut. Table 9, adapted from Williams and Olmsted (1936b), shows relative disappearance of four materials fed to three human subjects during gastrointestinal passage. The analysis of stools for lignin, cellulose, and hemicellulose revealed that a remarkably high percentage of these residues disappeared during their passage through the human gut.
A well documented review by Story and Kritchevsky (1976) noted that orally ingested pectin and vegetable gums may show a hypocholesterolemic effect in animals such as the rat, chick, and rabbit. Some of the pectins did not produce this effect, and there was no uniformity among the species studied. Generally speaking, bran ingestion has little or no effect on the blood cholesterol level of man (Connell et al., 1975; Eastwood, 1969; Heaton and Pomare, 1974; Jenkins et al., 1975). However, pectin and guar gum are reported to be effective in lowering serum cholesterol (Jenkins et al., 1975; Keys et al., 1961). Truswell and Kay (1975) noted that the addition of "wholemeal" bread and unprocessed wheat bran in baked goods did not lower plasma cholesterol or triglycerides after a three week trial in adult volunteers, but citrus pectin (15 g per day) did produce a 15 percent reduction of plasma cholesterol. Keys et al. (1961) reported a 5 percent reduction in serum cholesterol in human subjects given 15 g of pectin daily for three weeks.

On the other hand, Raymond et al. (1976) reported no changes in plasma lipid levels, lipoprotein distribution, or cholesterol absorption when 60 g of neutral detergent fiber was provided daily with muffins. This intake contained 39 g of hemicellulose, 14 g of cellulose, 5 g of lignin, and 2 g of pectic substances. The subjects were given a low cholesterol diet (no eggs) for eight weeks followed by eight weeks on a daily diet containing 1000 mg cholesterol provided by eggs. During the first four weeks of each period, the diets were devoid of fiber and during the last four weeks were high in fiber. With the exception of fiber and cholesterol content, all four diets were identical and contained similar sources of calories as follows: protein, 15 percent; carbohydrate, 45 percent; and fat, 40 percent. Fiber ingestion significantly reduced the transit times in both periods (59 to 35 hours and 66 to 40 hours, respectively. Fiber significantly increased the wet and dry weight of the stool in both cholesterol-free and high-cholesterol diets. Raymond et al. (1976) concluded that one cannot substantiate the epidemiological data of beneficial effects of fiber ingestion from data on people ingesting high-fiber diets as being related to fiber alone. He noted that African native diets are low in fat, low in cholesterol, low in meat, low in refined carbohydrates in addition to having a low calorie density.

It is apparent that further work is necessary to elucidate and document the effect of high-fiber diets on cholesterol and bile acid levels of human subjects consuming "western type" diets before conclusive statements can be made on this subject.

Schwarz (1977) hypothesized that the presence of silicon could account for the hypocholesterolemic and bile-acid-binding action of several types of dietary fiber. Silicon is apparently involved in several biological activities; thus, it is essential for growth of chickens, is a cross-linking
III. BIOCHEMICAL AND METABOLIC ASPECTS OF DIETARY FIBER

A. BIOCHEMICAL ASPECTS

It is not sufficient to consider the biochemistry of each of the components of dietary fiber individually because in the gastrointestinal tract, the degradation of each type of substance affects the metabolism of the others (Southgate, 1973, 1976b; Van Soest and McQueen, 1973). In addition, the various components are modified by activities of the gastrointestinal enzymes, hormones, pH changes as well as the health or disease status of the subject. Physiological effects of dietary fiber components are known to differ, for example, the costiveness of lignin, the bulking effect of hemi-celluloses, and the near indigestibility of highly lignified cereal fibers.

The intermolecular bonding among the constituents of the cell wall involving covalent and hydrogen bonding may be a significant factor (Gaillard and Richards, 1975). The exact nature and extent of these linkages are highly variable among different plants and are not well established. However, it has been shown that lignin in the cell wall limits the enzymatic degradation of cellulose because of complex bonding between lignin and cellulose (Dekker and Richards, 1973a, 1973b). More recent views on the chemistry of the plant cell wall indicate that some of the isolated components may be artifacts, resulting from the action of the reagents used in fractionation of the plant tissue; thus their physicochemical status in situ may be entirely different (Spiller and Amen, 1976).

The effects of fiber from diverse origin on the cholesterol and bile acid absorption of animals and man are controversial. There is considerable confusion regarding the hypocholesterolemic effects of fiber because the experimental conclusions drawn seem to vary with the animals, the diet, the length of the study, the type and amount of fiber used, the frequency of dietary administration, and the influence of dietary parameters other than fiber intake.

Cholesterol metabolism is vital to many tissues of the body and the major catabolic products of cholesterol metabolism are the bile salts. Bile contains cholesterol, bile salts, and phospholipids in a delicate balance and any substantial changes in the proportion of these three components may produce gallstones. Recent epidemiological reports (Burkitt, 1973; Cleave, 1974; Cummings, 1973; Trowell, 1972b) indicated that rural African natives on a high-fiber diet were free from atherosclerotic heart disease and gallstones. These reports stimulated considerable interest in the effect of dietary fiber on cholesterol and bile acid absorption and excretion.
Table 8. Chemical definition of fiber components.

<table>
<thead>
<tr>
<th>Name</th>
<th>Fraction removed by extraction during analysis (soluble fraction)</th>
<th>Fiber components quantified by the assay (undigested)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crude fiber</td>
<td>Approximately 80 percent lignin</td>
<td>20 percent total lignin</td>
</tr>
<tr>
<td></td>
<td>Approximately 85 percent hemicellulose</td>
<td>15 percent total hemicellulose</td>
</tr>
<tr>
<td></td>
<td>Approximately 20 to 60 percent cellulose</td>
<td>50 to 80 percent total cellulose</td>
</tr>
<tr>
<td>Neutral Detergent Fiber</td>
<td>Cellular constituents: starches, sugars, fat, soluble nitrogen compounds, soluble minerals</td>
<td>Cell wall constituents: hemicellulose cellulose, lignin, bound nitrogen (proteins), cutin, silica</td>
</tr>
<tr>
<td>(total cell wall)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Acid Detergent Fiber</td>
<td>Solubilizes same as neutral detergent plus hemicellulose</td>
<td>Same as neutral detergent fiber, except hemicellulose is solubilized</td>
</tr>
<tr>
<td>Lignin (72 percent sulfuric acid)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>a. run on permanganate lignin residue</td>
<td>Cellulose</td>
<td>Cutin, silica</td>
</tr>
<tr>
<td>b. run on acid detergent fiber residue</td>
<td>Cellulose</td>
<td>Lignin, insoluble nitrogen compounds, cutin, silica</td>
</tr>
<tr>
<td>Lignin (permanganate)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>run on acid detergent fiber residue</td>
<td>Lignin, acid detergent fiber, nitrogen compounds</td>
<td>Cellulose, cutin, silica (dark specks in residue indicate significant cutin levels)</td>
</tr>
<tr>
<td>Acid Detergent Fiber Nitrogen</td>
<td></td>
<td></td>
</tr>
<tr>
<td>run on acid detergent fiber residue</td>
<td>When compared to total protein result, is a measure of percent protein bound in the cell and unavailable due to artifact lignification or heat damage</td>
<td></td>
</tr>
<tr>
<td>Acid Detergent Fiber Ash</td>
<td></td>
<td></td>
</tr>
<tr>
<td>run on any residue containing silica¹</td>
<td>All components volatilized by ignition</td>
<td>Silica</td>
</tr>
</tbody>
</table>

¹(sic)
Copied from vol. 2, no. 1, 1977 of etc. a newsletter published by Research 900° (a division of Ralston Purina Company).
Table 7. Comparisons of cellulose and lignin estimations (percent dry weight) by the Van Soest and Southgate methods.¹

<table>
<thead>
<tr>
<th>Food</th>
<th>Van Soest Method</th>
<th>Southgate Method</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Acid detergent</td>
<td>Cellulose and</td>
</tr>
<tr>
<td></td>
<td>fiber</td>
<td>lignin</td>
</tr>
<tr>
<td>AD apple²</td>
<td>31.9</td>
<td>21.4</td>
</tr>
<tr>
<td>AD cabbage</td>
<td>27.1</td>
<td>29.0</td>
</tr>
<tr>
<td>AD celery</td>
<td>28.2</td>
<td>33.3</td>
</tr>
<tr>
<td>FD celery³</td>
<td>22.2</td>
<td>24.3</td>
</tr>
<tr>
<td>AD turnip</td>
<td>27.4</td>
<td>29.0</td>
</tr>
<tr>
<td>W. Aust. wheat</td>
<td>12.7</td>
<td>15.9</td>
</tr>
<tr>
<td>French wheat bran</td>
<td>13.3</td>
<td>15.7</td>
</tr>
</tbody>
</table>

¹ Adapted from McConnell and Eastwood (1974).
² AD = acetone dried.
³ FD = freeze dried.
weight) for optimum intake of bulk-forming foods of the wheat bran class. They indicated that the laxative properties of foods should be evaluated on the basis of their physiological results and not on the basis of their crude fiber content. The inadequacy of using crude fiber values is well established. Dietary fiber values should be developed for commonly used human food material, for example by the use of the AACC Enzyme Modified Neutral Detergent Fiber Method or other accepted modifications (Appendix A, p 59). This compilation should be further amplified by actual human data on optimum laxative quantities and the effect of various parameters such as source, degree of drying, particle size, and influence of cooking.

In a recent study of fruits and vegetables, Kelsay et al. (1977) compared two diets in 12 men 37-58 years of age for a period of four weeks each, in a crossover design. One diet contained fruits and vegetables and the Neutral Detergent Fiber (NDF) content was 20 g per day. The control diet contained no fruits and vegetables and the NDF was 3.6 g. Neither diet contained whole grain cereals or legumes. The carbohydrate, fat, and protein content of each diet supplied 50, 37, and 13 percent of the calories, respectively. According to the findings, fruits and vegetables providing approximately 16 g of NDF per day can effectively produce softer stools, increase fecal lipid excretion, decrease transit time, and increase dry and wet fecal weight.

Transit time or the time taken for passage of material ingested by mouth to the anus is related to dietary fiber's ability to produce large bulky stools. Apparently rural Africans who have a high-fiber diet not only produce bulky stools but have a shorter transit time--30 hours in contrast to the 48 or more hours for North Europeans and North Americans (Burkitt et al., 1972).

Payler et al. (1975) studied the effect of wheat bran on intestinal transit time. These studies on adolescent male subjects confirmed that 20 g of bran daily accelerated slow intestinal transit (changed from 2.75 days to 0.9 days) and also slowed fast transit time. Components of the bran used were identified as cellulose, 6 percent; hemicellulose, 23 percent; and lignin, 4 percent. In a crossover study in adults using bran with 7.3 percent crude fiber, results indicated that fine bran is not as effective as coarse bran in decreasing transit times; however, fine bran was effective if given in large enough amounts.

Cummings et al. (1976) reviewed methods for measurements of the mean transit time (MTT) of dietary residue through the human gut. They introduced a new method for measuring MTT by giving a constant number of radiopaque pellets each day to healthy volunteers regularly over a number of weeks (MTT-C) and also by giving single doses of pellets (MTT-S) and recording the number of pellets excreted daily. A continuous record of
MTT-C was obtained which showed wide variations from week-to-week even on controlled dietary intakes. Using the single dose technique, the study showed that the MTT-S was more accurate for large groups than the arbitrarily standardized 80 percent transit time technique of Hinton et al. (1969). The MTT-C was developed as an alternative for many transit time measurement techniques which were difficult to conduct, often inaccurate, and subject to the day-to-day variations in bowel habit.

Cummings et al. (1976) also noted by using the continuous recording of MTT-C in man that fiber was not the only factor influencing the passage of food residue through the intestinal tract, because even when the subjects were on a metabolically-controlled diet with a constant fiber intake, wide variations in MTT-C occurred. In thirteen subjects, Cummings et al. (1976) found that the MTT-C (in days) for those on an ad libitum diet averaged $2.3 \pm 0.06$; those on the standard diet, $2.4 \pm 0.17$; while those on a high-fiber diet (36 g of dietary fiber) averaged $1.6 \pm 0.05$.

Although considerable research has been done on the effects of dietary fiber, most of it has been on wheat bran cereal. Wheat bran has been shown to increase stool weight, reduce gastrointestinal transit time, modify the nature of feces and reduce irregularly elevated colonic intraluminal pressure. Although the effects of increased dietary fiber have been documented, the physiological mechanisms are not well understood and will require further studies.

Ershoff (1960; 1974) and Ershoff and Marshall (1975) have shown that alfalfa meal (20 percent in the diet) can protect immature rats against the growth-retardant effects of various non-ionic surfactant-agents such as Myrij® and Tween®. However, alfalfa did not protect the rats against Span 20®. In addition to alfalfa, Ershoff (1974) showed that purified cellulose, rye grass, fescue grass, oat grass, orchard grass, as well as carrageenan and sodium alginate, each had a significant action in protecting the animals from the toxic effects of Tween 60®. The significance of these findings for man remains unclear.

Cyclamate, which is a highly polar compound, is not readily absorbed when given orally to immature rats. Ershoff (1972) and Ershoff and Marshall (1975) noted that immature rats fed a stock diet plus sodium cyclamate at levels of 2.5 to 10 percent of the diet experienced little adverse effect on weight gain. However, when comparable levels of cyclamate were fed in a purified diet without fiber, there was a significant retardation of growth proportional to the amount ingested. Lack of weight gains was counteracted by adding various fiber-containing material at a 10 percent level in the diet. The active plant fiber-containing material tested was blond psyllium seed powder. Also effective in promoting normal weight gain with 5 percent
sodium cyclamate in the diet were sources of dietary fiber such as 10 per-
cent blond psyllium husk, 20 percent carrot root powder, and 10 percent
gum karaya. It is not known whether the protective action of the dietary
fiber in the cyclamate fed rats was due to the water-holding properties of
the fiber, to absorption of the cyclamate, or both.

C. UNTOWARD EFFECTS

Generally speaking, most clinical reports on dietary fiber are con-
cerned with the influence of the lack of fiber in the diet on health and disease.
However, there are several articles which discuss the potential side effects
of usual or unusual dietary fiber intakes.

Southgate et al. (1976) noted an increased excretion of most inor-
ganic dietary constituents, particularly sodium and phosphorus, when 10-15
g of dietary fiber were added in the form of wheat bran biscuits. In addition,
the authors noted that supplemental fiber was unlikely to reduce significantly
the caloric intake in the management of obesity.

Phytic acid (inositol hexaphosphate) is associated with protein
present in seeds. Usually it occurs as the calcium, magnesium, and potas-
sium salts (phytin). For example, in wheat, phytic acid is present in the
aleurone layer of grain and up to 90 percent of the total phosphate is present
as phytate (MacMasters et al., 1971). Because phytates are in the aleurone
layer which is removed as part of bran during the milling process, phytates
are typically found in bran and wholemeal flour but not in white flour.

Reinhold et al. (1973, 1975) and Russell et al. (1976) suggested that
the metabolic effects of the decreased availability of calcium, zinc, and
iron may be related to the combined action of the phytate and undigestible
fiber present in large amounts in high-fiber Iranian breads (1.6 to 4.2 per-
cent fiber--dry weight). Of the two substances, fiber appears to be the
more important combining agent. However, the authors noted that the high-
fiber Iranian breads did not interfere with folic acid absorption by the small
intestine.

Subsequent studies by Reinhold et al. (1976) reported the difference
in mineral absorption between Bazari bread (80 to 90 percent extraction flour)
and white bread made with low extraction flour (70 percent extraction flour).
White bread used clinically in a 20 day period permitted good absorption of
mineral elements whereas high-fiber wheat bread increased the fecal bulk
and the excretion of calcium, zinc, and phosphorus, inducing a negative
balance of these minerals. The authors concluded that the fiber of wheat
bread was responsible for the metal binding, that cellulose interfered with absorption of zinc, and that absorption interference was not due to the phytate content. This is remarkable because the Bazari bread contained more zinc, calcium, magnesium, and phosphorus than white bread—yet negative balance existed.

On the other hand, Branch et al. (1975) reported binding of calcium by dietary fiber due to the effect of noncellulosic polysaccharides of the plant cell wall. Foods containing high proportions of uronic acids within their noncellulosic fraction seem able to bind more dietary calcium. Free-land and her co-workers (1977) reported lower borderline zinc levels in saliva (130 ppm) from 70 vegetarian subjects than from 40 nonvegetarian controls. The authors suggested that the high-fiber and phytate content of the vegetarian diet may lead to a decrease in the available zinc and result in suboptimal zinc status.

However, a moderate increase in dietary fiber does not appear to impair the zinc or copper balance of human subjects. Sanstead et al. (1977) fed four male volunteers three types of bread with increased NDF content for 30 day periods and determined zinc and copper balance. The three bread formulations contained 30 g of soft white wheat bran (48 percent NDF), 30 g of corn bran (87 percent NDF) or 30 g of soybean hulls (90 percent NDF). Using a crossover design after a 30 day period and holding body weight constant for the 30 day test period, the authors found that zinc and copper intakes ranged from 12.6 to 16.6 and 0.85 to 1.50 mg per day, respectively. Zinc balance was positive in 5 of 6 basal, 3 of 4 wheat bran, and 4 of 4 corn bran test periods. Copper balance was positive in 2 of 6 basal and 2 of 4 wheat bran periods. No relationship between dietary fiber and fecal zinc or copper was observed under these experimental conditions.

Guthrie and Robinson (1976) studied the effect of dietary fiber in coarse wheat bran in women 20 to 28 years of age. Stool weight increased upon addition of 14 g of bran daily after a 3 week control period, but stool weights returned to control period level by the 4th week of bran consumption. There were no changes in the balance of manganese, copper, and zinc after 28 days on bran. Serum levels of triglycerides remained unchanged while serum cholesterol levels increased significantly.

It should be noted that Reinhold et al. (1973) measured the zinc balance immediately after the change in diet whereas Guthrie and Robinson (1976) allowed a 3 week adaption before the study period.

Recently, Moynahan (1977) reviewed some of the nutritional hazards of a high-fiber diet. Several possible problems were postulated: phytate supposedly chelates iron, zinc, and calcium resulting in adult osteomalacia (Ca), anemia (Fe), delayed puberty (Zn), retarded growth (Zn and Ca),
and short stature (Zn and Ca). Moynahan (1977) contended that it is important to include adequate amounts of calcium, zinc, and iron in diets with increased fiber.

In rats, Harland et al. (1977) reported that feeding wheat bran and its fractions significantly lowered blood glucose, increased body weight, and increased serum cholesterol. Groups of 10 weanling male rats were given diets with 10 percent fiber for two 5 week periods. There were no significant differences in the serum triglyceride levels or in tibia zinc. However, kidney zinc levels were significantly higher in the group fed wheat bran extract than in the group receiving no bran, wheat bran, water-extracted freeze-dried wheat bran, freeze-dried water-extract, or in the group receiving the two extracts of wheat bran recombined.

Stiles (1976) considered the effect of fiber on the availability of minerals and suggested that further research be done on the rates of passage through segments of the gastrointestinal tract, intestinal sites of mineral absorption, degradation of fiber along the gut, pH alterations, turnover rates of intestinal mucosal cells, and influence of microflora on mineral availability. Existing data are conflicting and no firm conclusion can be made at this time.

Other possible untoward effects of dietary fiber ingestion that have been suggested are volvulus and intussusception. These may be related to excessive consumption of vegetable roughage (Burkitt et al., 1963). Painter (1971) has reviewed the question of psyllium seed preparations and synthetic methylcellulose products that have been implicated in intestinal obstruction. It appears that rarely have wheat bran or natural gum products been involved in so-called bolus obstruction.

Recently, some attention has been given to possible persorption of dietary fiber (See p 29). From the toxicological standpoint, persorption is of interest since this phenomenon involves the passage of particulate matter through the intestinal wall directly to the blood or lymph. Grasso (1976) has indicated concern about the possible long-term toxic effects of the uptake of small amounts of various particulate matter from food.

The effects attributed to high-fiber intake of rural Africans have not been evaluated in relation to other aspects of their total diet, including fluid intake. Fiber in the diet influences absorption, transit time, nutrient energy intake, trace minerals, and the bacterial flora. The diverse foods usually consumed by various ethnic groups in the United States are not the same as those eaten by rural Africans (Walker, 1976). It does not necessarily follow that the apparently innocuous intake of large amounts of dietary fiber by the rural African is the best diet for those in the United States. Moderate
consumption of bran cereal or a modest increase in the intake of vegetables and fruits is not likely to be harmful. However, among the aged, altered physiologic situations often exist, and the physician and dietitian must appraise the individual patient's condition. In addition, the question of persorption of dietary fiber components should be considered especially in conditions where the intestinal mucosae may be eroded, inflamed or involved in marked hypermotility.
IV. DIETARY FIBER AND DISEASES

A. SUBSTANTIATED USES

Many diseases have been cited during the last decade as resulting from inadequate fiber consumption (Burkitt and Trowell, 1975). Currently there are only one or two clinical conditions in which increasing fiber in the diet has recognized medical value. An extensive literature has accumulated in the last decade on the value of increased dietary fiber in reducing not only the intraluminal pressure and transit time but also other manifestations of patients with diverticular diseases (Painter and Truelove, 1964; Eastwood et al., 1976). In diverticular diseases, the intraluminal pressures are high with a prolonged transit time. Painter and Truelove (1964) have provided well-documented evidence that dietary fiber in the form of bran is preferred over the so-called low-residue diet. Bran diets can reduce both the intraluminal pressure and transit time in the patients. However, it should be noted that because increased fiber in the diet may be of therapeutic value, this does not necessarily suggest an etiological role of low-fiber diets in the development of the disease.

Brodribb (1977) reported on the therapeutic value of increasing daily dietary fiber intake (6.7 g) in diverticular disease over 3 months in a double-blind controlled trial of 18 patients. Significantly greater symptomatic relief was obtained by those on a high-fiber regimen than those in the control group despite the high initial placebo effect. It was noted that a high-fiber diet takes several months or more to produce the maximum therapeutic response.

There appears to be positive therapeutic value of increased dietary fiber in atonic constipation and in hemorrhoidal conditions. Increased dietary fiber provides bulk and gentle laxation in constipation, and soft stools ease the discomfort of hemorrhoids.

Recent reports of Anderson (1977), Jenkins et al. (1976a) and Kiehm et al. (1976) have given indications that high dietary fiber (guar and pectin) or high polysaccharide diets (limited in fat and simple sugars) may allow mild diabetics to reduce their insulin requirements or decrease the oral antidiabetic medication needs. These early studies require confirmation with known types of dietary fiber.
B. UNSUBSTANTIATED USES

During the last decade, many diseases and disorders of the Western World have been attributed in large part to inadequate dietary fiber intake. Such diseases and conditions as appendicitis, hiatus hernia, varicose veins, diabetes, obesity, hypercholesterolemia, coronary artery disease, and colon-rectal carcinoma have been ascribed to dietary fiber deficiency. These conclusions are based primarily on epidemiological studies that compare diseases and dietary habits of rural African natives with those of urbanized Africans, North Americans, and North Europeans (Burkitt and Trowell, 1975; Walker, 1976).

In a worldwide epidemiological survey, the diseases of native Japanese, Issei and Nisei generations in Hawaii and the mainland United States have been cited as evidence for the far-reaching effect of dietary fiber depletion (Mendeloff, 1976). However, there are no conclusive clinical studies that effectively delineate the cause and effect relationship between these diseases and low intake of dietary fiber.

The nutritional significance of adding α-cellulose to bread is not known although claims have been made for decreased calories and increased fiber content (Titcomb and Juers, 1976).

Mitchell and Eastwood (1976) discuss in detail the controversial question of dietary fiber and colonic cancer as well as the role of fiber in altering bile acid and cholesterol metabolism. They conclude that more intensive investigations are necessary to elucidate the cause and effect aspects of these clinical conditions.

C. HOSPITAL AND CLINIC USE OF DIETARY FIBER

As a portion of this study, it was of interest to determine the use of dietary fiber in diets prepared for patient use. A letter (Appendix B, p 68) was sent to 240 hospitals and clinics throughout the United States requesting information from dietitians on the availability of preprinted diet sheets, preparation of diets with modified fiber content, and use of terminology related to diets with altered fiber content.

A total of 128 responses (53 percent) was received which included diet sheets, dietary instructional aids, and information on use of fiber in diets. The most frequently mentioned terms were "High Fiber Diet" and "Increased Residue Diet." A majority of hospitals (61/86) reported
infrequent requests from medical staff for high-fiber diets. When requests were made, dietary items such as bran cereals, fresh and dried fruits, whole grain cereals and breads, as well as vegetables and salads were specified. In general, most hospital dietitians appear to have a cautious position, waiting for professional organizations to adopt policies regarding high-fiber diets. Details of the information provided in response to the letter are presented in Appendix B, p 66.
V. CONCLUSIONS

- There are few controlled clinical studies delineating the nutritional or therapeutic significance of increasing the level of dietary fiber in man. Epidemiological data suggesting therapeutic or prophylactic value of "high-fiber" diets are based on inadequate data for promotion of increased dietary fiber as an important factor in prevention or mitigation of various chronic diseases.

- The need for more acceptable laboratory analytical methods for characterization of "dietary fiber complex" is now recognized and improvements in methodology are being established. A compilation of the diversity of fiber types and dietary fiber values for various human food materials would contribute to the understanding of the nutritional significance of dietary fiber in health and disease.

- Based on the findings of European and American investigators, there appears to be positive value of increased dietary fiber in diverticular diseases, and such a regimen has been accepted as appropriate in modern clinical practice.

- The value of increasing dietary fiber intake in treating atomic constipation and hemorrhoids has been recognized for many years. The amount of dietary fiber intake requires individual adjustment to balance gastrointestinal discomfort and bulk against clinical tolerance which may develop over long time periods.

- The role of dietary fiber in susceptibility to, prevention of, or beneficial effects related to diabetes, atherosclerosis, cancer, appendicitis, duodenal ulcer, ischemic heart disease, cholecystitis, ulcerative colitis, Crohn's disease, varicose veins, deep vein thrombosis, and hiatus hernia remains to be established.

- Additional studies are necessary to elucidate and document the effects of high-fiber diets on cholesterol and bile acid absorption and excretion in man before conclusive statements on this subject can be made.

- Few clinical studies related to pediatric use of dietary fiber have been reported and there are no clinical indications for increasing dietary fiber in infant feeding.
• The overenthusiastic use of dietary fiber may produce a negative mineral balance or possible gastrointestinal dysfunction in the presence of anatomic pathology of the intestinal tract.

• There seems little scientific justification for significantly increasing the fiber content of the American diet except in cases where medical considerations suggest such alterations are desirable. Currently, physicians and hospital dietitians seem to have developed a reasoned approach to dietary fiber intake based on use of commonly available high-fiber food items such as whole grain and wheat bran cereals and baked goods in addition to fruits and vegetables.

• Development of well-characterized food fiber sources would permit the conduct of controlled comparative clinical studies. This is an essential requirement before the nutritional and therapeutic significance of dietary fiber can be established.
VI. SUGGESTIONS FOR FUTURE CONSIDERATIONS

The American Association of Cereal Chemists has characterized a selected reference sample of white wheat bran with an analytical profile. For clinical studies of the value of high-fiber diets, fresh and dried fruits and vegetables should be characterized by dietary fiber values. It is recognized that fruits or vegetables from diverse sources, with variations in species and soil conditions, may present nonuniform products; dietary fiber values should be established for these common foods.

More controlled and objective clinical studies should be conducted with dietary fiber components and dietary fiber from various sources in human subjects to evaluate such physiologic parameters as transit time, stool bulk, and water-holding capacity in addition to such measurable biochemical factors as cholesterol, divalent metals, and nutrients. The influence of high-fiber diets on mineral absorption and the influence of microflora on mineral availability should be given consideration in future research studies.

Dietary fiber values in place of crude fiber values should be developed and published in a journal of wide circulation to make more meaningful data available to research workers, clinicians, dietitians, and nutritionists.

Any addition of various dietary fiber isolates to processed foods should be preceded by adequate clinical studies in man to provide evidence of effectiveness and freedom from side-effects such as fecal loss of mineral elements and nutrients.

It is suggested that the Enzyme-Modified Neutral Detergent Fiber method as proposed by the AACC could be considered as a pioneer method in the development of methodology adapted to the analyses of other food-stuffs commonly used in the United States diet.
VII. REFERENCES CITED


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VIII. STUDY PARTICIPANTS

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Clare Monahan
Typist

Lee C. Rogers
Literature Retrieval/Technical Report Specialist

Jeanne L. Schachter
Secretary

Evelyn C. Volkman
Assistant to the Director

Michael J. Wade, Ph.D.
Research Associate
IX. APPENDIX

A. AMERICAN ASSOCIATION OF CEREAL CHEMISTS (AACC)
CERTIFIED FOOD GRADE WHEAT BRAN*

Analytical data for the official AACC Certified Food Grade Wheat Bran R07-3691 are summarized below. These values, as is basis, are the average of duplicate analyses.

The various analyses were divided among the following laboratories unless otherwise noted: Doty Laboratories, Inc., 1435 Clay Street, North Kansas City, Missouri 64116; Ingman Laboratories, Inc., 324 South Fourth Avenue, Minneapolis, Minnesota 55415; Medallion Laboratories, 9000 Plymouth Avenue, North, Minneapolis, Minnesota 55427; and Research 900, 900 Checkerboard Square, St. Louis, Missouri 63188.

The bran was made from a commercial blend of white wheats (87.3 percent soft white and 12.7 percent club white), taken after the fifth break roll over a 22 wire to a bran duster with a 1250 microscreen. The bran was immediately sent through an enzyme deactivation steamer with a residence time of about thirty seconds, exiting at 213-215°F, and 17.2 percent moisture, and into an insulated screw conveyer which holds the hot bran for about 1.5 minutes. The bran was dried to 10.4 percent moisture and sacked into "scotchguard" three layer paper, one-layer 2 mil polyethylene bags. The bran is being held at 0°F in Minneapolis.

Requests for samples and information should be made to the AACC headquarters.** Bran is available at $2.00/lb. in 2.5 lb. quantities or at $1.50/lb. in 30 lb. bags, plus shipping costs.

*Reproduced as received from D. Schaller, Chairman, Subcommittee on Methodology, AACC Food Fiber Committee, 1976.

**American Association of Cereal Chemists
3340 Pilot Knob Road
St. Paul, Minnesota 55121
<table>
<thead>
<tr>
<th>Assay</th>
<th>Value (as is basis)</th>
<th>Method ¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crude Fiber</td>
<td>8.91%</td>
<td>AOAC-7.050-7.054</td>
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<tr>
<td>Protein</td>
<td>14.3%</td>
<td>AACC-46-10</td>
</tr>
<tr>
<td>Moisture</td>
<td>10.4%</td>
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<tr>
<td>Fat (Acid Hydrolysis)</td>
<td>5.22%</td>
<td>AOAC-7.047</td>
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<tr>
<td>Ash</td>
<td>5.12%</td>
<td>AACC-08-01</td>
</tr>
<tr>
<td>Aerobic Plate Count</td>
<td>16,000/g</td>
<td>AACC-42-11</td>
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<tr>
<td>Acid Detergent Fiber</td>
<td>11.9%</td>
<td>AOAC-7.055-7.057</td>
</tr>
<tr>
<td>Neutral Detergent Fiber</td>
<td>40.2%</td>
<td>See Below ²</td>
</tr>
<tr>
<td>Lignin</td>
<td>3.2%</td>
<td>AOAC-7.058</td>
</tr>
<tr>
<td>Pectin</td>
<td>3.0%</td>
<td>See Below ³</td>
</tr>
<tr>
<td>Water Holding Capacity</td>
<td>9.5 g/g</td>
<td>See Below ⁴</td>
</tr>
<tr>
<td>Cutin</td>
<td>0%</td>
<td>USDA Handbook No. 379 pp. 9-11</td>
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<tr>
<td>Thiamine (B₁)</td>
<td>0.78 mg/100g</td>
<td>AOAC-43.024-43.030</td>
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<tr>
<td>Riboflavin (B₂)</td>
<td>0.39 mg/100g</td>
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<tr>
<td>Niacin</td>
<td>20.9 mg/100g</td>
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<tr>
<td>Pyridoxine (B₆)</td>
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<tr>
<td>Folic Acid</td>
<td>0.12 mg/100g</td>
<td>JAOAC, 48(6), 1230 (1965)</td>
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<tr>
<td>Pantothenic Acid</td>
<td>2.48 mg/100g</td>
<td>AOAC-43.130-43.138</td>
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<tr>
<td>Vitamin E</td>
<td>2.69 mg/100g</td>
<td>Gas Chromatography ⁵</td>
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<tr>
<td>Assay</td>
<td>Value (as is basis)</td>
<td>Method*</td>
</tr>
<tr>
<td>-----------------</td>
<td>---------------------</td>
<td>---------</td>
</tr>
<tr>
<td>Choline</td>
<td>228 mg/100g</td>
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<tr>
<td>Aluminum</td>
<td>5.0 ppm</td>
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<tr>
<td>Arsenic</td>
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<tr>
<td>Barium</td>
<td>45.07 ppm</td>
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</tr>
<tr>
<td>Boron</td>
<td>4.5 ppm</td>
<td>APhA NF, 13th ed.</td>
</tr>
<tr>
<td>Cadmium</td>
<td>2.8 ppm</td>
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</tr>
<tr>
<td>Calcium</td>
<td>0.12%</td>
<td>AACC-40-21</td>
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<tr>
<td>Cobalt</td>
<td>39.2 ppm</td>
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</tr>
<tr>
<td>Copper</td>
<td>15.6 ppm</td>
<td>AACC-40-70</td>
</tr>
<tr>
<td>Iron</td>
<td>122 ppm</td>
<td>AACC-40-70</td>
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<tr>
<td>Lead</td>
<td>2.3 ppm</td>
<td>AACC-40-70</td>
</tr>
<tr>
<td>Magnesium</td>
<td>0.43%</td>
<td>AACC-40-70</td>
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<tr>
<td>Manganese</td>
<td>80.0 ppm</td>
<td>AACC-40-70</td>
</tr>
<tr>
<td>Mercury</td>
<td>0.002 ppm</td>
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<tr>
<td>Phosphorus</td>
<td>1.04%</td>
<td>AOAC-7.103</td>
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<tr>
<td>Potassium</td>
<td>1.38%</td>
<td>AACC-40-70</td>
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<tr>
<td>Selenium</td>
<td>0.1 ppm</td>
<td>See Below*</td>
</tr>
<tr>
<td>Sodium</td>
<td>0.10%</td>
<td>AACC-40-70</td>
</tr>
<tr>
<td>Zinc</td>
<td>54.5 ppm</td>
<td>AACC-40-70</td>
</tr>
<tr>
<td>Damaged Starch</td>
<td>3.74%</td>
<td>AACC-76-30A</td>
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</table>
## AACC CERTIFIED FOOD GRADE WHEAT BRAN, R07-3691 (continued)

<table>
<thead>
<tr>
<th>Assay</th>
<th>Value (as is basis)</th>
<th>Method^a</th>
</tr>
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<tbody>
<tr>
<td>Total Starch</td>
<td>17.4%</td>
<td>AOAC-14.031</td>
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<tr>
<td>Total Sugar As Invert</td>
<td>7.04%</td>
<td>AOAC-7.066</td>
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<tr>
<td>Pentosan</td>
<td>22.1%</td>
<td>See Below^b</td>
</tr>
<tr>
<td>Phytic Acid</td>
<td>3.36%</td>
<td>See Below^c</td>
</tr>
<tr>
<td>β-Sitosterol</td>
<td>123 mg/100g</td>
<td>Gas Chromatography^d</td>
</tr>
<tr>
<td>Campesterol</td>
<td>68.8 mg/100g</td>
<td>Gas Chromatography^d</td>
</tr>
<tr>
<td>Stigmasterol</td>
<td>11.2 mg/100g</td>
<td>Gas Chromatography^d</td>
</tr>
<tr>
<td>Aflatoxin</td>
<td>&lt;10 ppb</td>
<td>JAOAC 56(4), 803 (1973)</td>
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<tr>
<td>Sanitation^d</td>
<td>0</td>
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<tr>
<td>Pesticides, Phosphorus</td>
<td>&lt;0.005 ppm</td>
<td>AOAC-29. -</td>
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<tr>
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<td></td>
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<tr>
<td>Pesticides, Chlorine</td>
<td>&lt;0.02 ppm</td>
<td>See Below^k</td>
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<td>Containing</td>
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### Particle Size^e

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
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<tbody>
<tr>
<td>ON US#10</td>
<td>1%</td>
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<tr>
<td>#12</td>
<td>2%</td>
<td></td>
</tr>
<tr>
<td>#14</td>
<td>5%</td>
<td></td>
</tr>
<tr>
<td>#16</td>
<td>11%</td>
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</tr>
<tr>
<td>#18</td>
<td>13%</td>
<td></td>
</tr>
<tr>
<td>#20</td>
<td>9%</td>
<td></td>
</tr>
<tr>
<td>#30</td>
<td>33%</td>
<td></td>
</tr>
<tr>
<td>#40</td>
<td>17%</td>
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<tr>
<td>#50</td>
<td>8%</td>
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<td>#70</td>
<td>Trace</td>
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</tr>
<tr>
<td>Thru #70</td>
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</tbody>
</table>

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AACC CERTIFIED FOOD GRADE WHEAT BRAN, R07-3691 (continued)


\(^d\) Water-Holding-Capacity of the NDF fraction. By Kellogg Company, Battle Creek, Michigan.

\(^e\) Method by Medallion Laboratories, Minneapolis, Minnesota.


\(^i\) Modified method by Research 900, St. Louis, Missouri. Adapted from: Biochem. Z. 64, 422 (1914).

\(^j\) Whole insects, insect fragments, whole larvae, larva fragments, rodent hairs, rodent excretion fragments, other contaminants.

\(^k\) Modified method by Research 900, St. Louis, Missouri.
Enzyme modified--NDF Method (Neutral-Detergent Fiber)

Analysis for Insoluble Dietary Fiber

The first part of the analysis for insoluble dietary fiber is outlined from pages 5, 6, and 8 of "Forage Fiber Analyses" by H.K. Goering and P.J. Van Soest, United States Department of Agriculture, Agricultural Handbook #379. The analysis utilizes the standard crude fiber refluxing apparatus.

Procedure:

1) Prepare the Neutral-detergent solution:

Distilled water 1 liter
Sodium lauryl sulfate, USP 30.00 g
Disodium ethylenediaminetetraacetic acid 18.61 g
dihydrate, reagent grade
Sodium borate decahydrate, reagent grade 6.81 g
Disodium hydrogen phosphate, anhydrous, 4.56 g
reagent grade
2-ethoxyethanol (ethylene glycol monoethyl 10 ml
ether), purified grade

(if necessary, adjust pH between 6.9 and 7.1)

2) Grind the sample to pass a 20-30 mesh screen (1 mm), extract with acetone if the fat content is >10% and weigh 1.0 g of the air dried sample into a beaker of the crude fiber refluxing apparatus.

3) Add, in order, 100 ml room temperature neutral-detergent solution, 2 ml decahydro-naphthalene, reagent grade, and 0.5 g sodium sulfite, anhydrous, reagent grade.

4) Heat to boiling in 5-10 minutes and reduce heat to maintain even boiling for 60 minutes timed from the onset of boiling.

5) Add a 2-4 g pad of fine glass wool to the top of a coarse glass frit (40 μ pore size) filter¹, tare the filter, filter the neutral-detergent residue with suction and wash the residue with at least 200 ml of hot distilled water.
6) Prepare the enzyme solution by suspending 2.5% wt/vol of \( \alpha \)-amylase (Sigma A6880\(^2\)) in 0.1M phosphate buffer (pH 7); centrifuge; then filter through a coarse sintered glass filter funnel.

7) Add enough enzyme solution to the filtered neutral-detergent residue to more than cover the sample and filter a small amount through to displace wash water.

8) Plug the bottom of the filter and add several drops of toluene.

9) Hold at 37°C for 18 hours (overnight).

10) Filter; wash with distilled water, then acetone; dry at 110°C, cool and weigh.

11) Report \( \frac{\text{wt. filter + residue} - \text{wt. filter}}{\text{wt. original sample}} \times 100 \) as percent neutral detergent fiber.

\footnote{\begin{itemize} \item 60 ml filter funnel, coarse frit (ASTM 40-60 \( \mu \)) Pyrex No. 36060 or equivalent. \item \( \alpha \)-amylase Type VI-A #A6880 from hog pancreas. Sigma Chemical Company P.O. Box 14508 St. Louis, Missouri 63178}
B. CLINIC AND HOSPITAL UTILIZATION OF DIETARY FIBER

Analysis of 128 responses from dietitians who answered a questionnaire survey of 240 United States clinics and hospitals concerning their use of dietary fiber.

<table>
<thead>
<tr>
<th>Responses</th>
<th>Total</th>
<th>Term Applied</th>
<th>Total</th>
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</thead>
<tbody>
<tr>
<td>Sent diet sheet</td>
<td>34</td>
<td>High or Increased Fiber Diet</td>
<td>65</td>
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<tr>
<td>Sent instruction sheet</td>
<td>44</td>
<td>High or Increased Residue</td>
<td>33</td>
</tr>
<tr>
<td>and/or booklet</td>
<td></td>
<td>Diet</td>
<td></td>
</tr>
<tr>
<td>Sent both</td>
<td>9</td>
<td>High or Increased Roughage</td>
<td>28</td>
</tr>
<tr>
<td>Sent letter only</td>
<td>41</td>
<td>High or Increased Bulk</td>
<td>14</td>
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<tr>
<td></td>
<td></td>
<td>Dietary Fiber</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Crude Fiber</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>High Cellulose</td>
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<td>Fiber Modifications</td>
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<table>
<thead>
<tr>
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<th>Item Added to Diet</th>
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<tr>
<td>Frequency of Use</td>
<td>Total</td>
<td>Item Added to Diet</td>
<td>Total</td>
</tr>
<tr>
<td>Infrequent, few, minimal</td>
<td>42</td>
<td>All-Bran, 100% Bran, Bran, Whole Bran, Unprocessed or Coarse Bran</td>
<td>48</td>
</tr>
<tr>
<td>1-2 per month</td>
<td>19</td>
<td>Fruits (including Dried Fruits)</td>
<td>43</td>
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<tr>
<td>3-6 per month</td>
<td>8</td>
<td>Whole Grain Breads and Cereals, High Fiber Bread</td>
<td>36</td>
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<tr>
<td>6-15 per month</td>
<td>9</td>
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<tr>
<td>15-20 per month</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>24 per month</td>
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<tr>
<td>28 per month</td>
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<td>96 per month</td>
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<td>Vegetables</td>
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<td>Salads</td>
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<td>Fluid Intake</td>
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<td></td>
<td></td>
<td>Nuts and Popcorn</td>
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<td>Milk</td>
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Dietary Fiber Survey (continued)

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<th>Indications</th>
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<td>Diverticulosis</td>
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<td>Constipation</td>
<td>Intestinal Disorders</td>
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<td>Constipation (Hemodialysis and Psychiatric Patients)</td>
<td>Spastic Colitis</td>
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<td>Irritable Bowel Syndrome</td>
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<td>Cardiac Diets</td>
<td>Renal Diseases</td>
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<td>Colostomy</td>
<td>Hemorrhoids</td>
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<td>Ileostomy</td>
<td>Pressure Disorders</td>
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<tr>
<td>Ambulatory Care</td>
<td>Obesity</td>
<td>1</td>
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<tr>
<td></td>
<td>Hyperlipidemia</td>
<td>1</td>
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</table>
Dear Madam:

The Life Sciences Research Office of the Federation of American Societies for Experimental Biology is under contract with the Department of Health, Education and Welfare to review the subject of "Dietary Fiber and Refined Carbohydrates in Health and Disease" for the Associate Director for Nutrition and Consumer Sciences - Food and Drug Administration.

We are interested in learning whether or not your hospital provides a pre-printed diet sheet or suggested diet for a "High Fiber Diet." If you do have them, we would appreciate receiving two copies. If there are any special instruction sheets or booklets provided by either the Diet Department or the Medical Department, kindly send two copies if available.

How frequently do the medical or surgical staff members request "High Fiber" or "High Roughage" diets?

In the event your hospital does not provide a special High Fiber diet sheet, what items do you specifically add to the regular diet?

Thank you for your assistance.

Sincerely yours,

K.K. Kimura, M.D., F.A.C.P.
Medical Consultant
Life Sciences Research Office