COMPARISON OF THE EFFECTS OF FEEDING VARIOUS DIETARY FIBERS TO HUMANS, PIGS, AND CHICKENS

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TABLE OF CONTENTS

LIST OF TABLES

Table Page

CHAPTER II

CHAPTER III

CHAPTER IV

Table Page

CHAPTER V

CHAPTER VI

CHAPTER VII

LIST OF FIGURES

Figure Page

CHAPTER VI

CHAPTER VII

APPENDIX

CHAPTER I

THE RESEARCH PROBLEM

Introduction to Topic

> In recent years a startling new medical theory has suggested that it may be a lot simpler than we had thought to help ourselves feel better and live longer through good nutrition. Medical authorities are recommending that we eat our food 'the way God made it grow', i.e. with its skin, seeds, and natural fibrous strings as intact as possible. They say that we should take time to chew on chewy nutritious food (Anonymous, 1983).

This promotion on a package of cracked wheat dinner rolls reflects a growing recognition by the general populace of the healthful effects of the addition of more fiber to the diet. Although discussions of the importance of fiber in the human diet have been recorded since the time of Hippocrates (Trowell, 1978), only within the past few years has the term "fiber" filled scientific and popular writings on human nutrition.

Fibrous components of plants may have profound nutritional implications. Dietary fiber aids in treatment and prevention of constipation and diverticular disease (Painter et al., 1972). Inadequate fiber in the diets has been associated with appendicitis, ulcerative colitis, gall stones, hemorrhoids, varicose veins, deep vein thrombosis, pulmonary embolism, coronary heart disease, obesity,

diabetes, hiatus hernia, benign tumors, cancer of the large bowel, and about 20 other disorders (Burkitt, 1973; Trowell, 1978). Various sources of fiber alter lipid absorption, reduce the rate of carbohydrate absorption, modify bile acid and cholesterol metabolism, affect the availability of certain vitamins and minerals, and change the rate of passage of material through the gastrointestinal tract (Cummings, 1978; Heller et al., 1980). These effects of fiber can be attributed to specific physical or chemical properties of fiber including density, hydration capacity, binding properties, particle size, and fermentability (Van Soest, 1978a; Heller et al., 1980).

Claims for health benefits of dietary fiber come primarily from epidemiological studies (Burkitt, 1973; Trowell, 1972, 1978; Cummings, 1978). In population studies, additional dietary variables, activity level and life style, other environmental effects, and genetics influence results and interpretations, and prevent accurate evaluation of the specific effects of fiber consumption.

The current understanding of the physiological and nutritional mechanism involved in fiber's role in health has been summarized as follows:

> ...one of the difficulties in making recommendations relative to dietary fiber is that current knowledge does not permit an adequate definition of what dietary fiber actually is or what various forms of dietary fiber may do physiologically, and does not permit adequate measurements of the dietary fiber content of foods (Hegsted, 1982).

The reason for this level of understanding is explained by Van Soest:

> Because of the ignorance and confusion stemming from a persistent belief in the inertness and nonnutritive character of dietary fiber in human nutrition, this topic has been assigned a very low priority in the order of nutritional investigations (1978).

To evaluate the effects of dietary fiber on health, nutrition, and metabolism, long term nutrition studies involving extreme dietary modifications and frequent biochemical tests are needed. Such studies are both difficult and costly using human subjects. Furthermore, human studies seldom can control or balance genetic variation, personal habits, and environmental and social backgrounds. Finally, ethical considerations prevent researchers from using humans in studies that might be physically or emotionally harmful.

Animals are an alternative experimental model for study of nutrient requirements for all biological systems, including man. Animal models have contributed immeasurably to our knowledge of nutritional needs of humans. Researchers can control the genetics, environment, and dietary intake of animals, which increases the precision of research results. Extensive, invasive, biochemical tests can be used in animals to test nutrient requirements and interactions over many generations.

For the study of fiber, morphology and physiology of the gastrointestinal tract may alter results. The gastrointestinal tract of an ideal animal model would parallel that of humans; however, basic relationships among species should be consistent. The gastrointestinal tract of the most commonly used laboratory animals, rodents, differs markedly from the gastrointestinal tract of humans. This difference has led researchers to question the applicability to

man of results from rodent models in fiber research (Hegsted, 1977; Vahouny, 1982a). Since species vary greatly in gastrointestinal morphology and physiology, comparative experiments are needed using a variety of animals. But results must be verified using human subjects.

Research with pigs and chickens may help elucidate the effects of fiber on humans. In the following experiments, three monogastric species, pigs, chickens, and humans were used to evaluate the effect of various sources and levels of fiber in the intestinal tract.

Objectives and Hypotheses

The objectives and hypotheses tested were as follows;

Objectives

1. To investigate in humans, pigs, and chickens the digestibility of various dietary fibers, effects on passage rate in various portions of the gastrointestinal tract, and effects on breath hydrogen concentration.

2. To determine the similarity in response of the digestive tract to fiber intake among pigs, chickens and humans.

3. To determine the usefulness and reliability of breath hydrogen output for evaluating effects of fiber in the intestinal tract of pigs, chickens, and humans.

Hypotheses

H1. Dietary fibers will not differ in their digestibilities and effects on passage rates and breath hydrogen concentrations.

H2. The gastrointestinal response of one species to consumption of a particular fiber will not be similar to the response of other species.

H3. Hydrogen output will not be related to digestion of fiber fractions within the gastrointestinal tract of pigs, chickens, and humans.

Development of Experiments

A brief overview of the measurements taken on the three experimental groups, humans, pigs, and chickens follows. In the experiments using people, four dietary fibers (corn bran, oat bran, wheat bran, and citrus flour) were used to determine differences in passage rate to the large intestine after a single high fiber meal and to measure breath hydrogen concentration after consumption of various fibers. A second experiment measured breath hydrogen concentration of subjects consuming corn bran for three weeks. Fecal fiber components were measured and bowel function was monitored. With pigs, breath hydrogen concentration was measured after feeding single meals using

three dietary fibers (corn bran, wheat bran or citrus flour) or powdered milk. In a second experiment with pigs consuming corn or oat bran for two weeks, passage rate to the ileum and digestibility of fiber components were determined. A final experiment measured hydrogen concentration, total tract passage rate, fiber digestibility, and measurements on cecal and ileal contents in adult laying hens fed four dietary fibers at three different levels of fiber intake.

Format of Dissertation

Each of the five described experiments was organized as an individual manuscript for publication in the most applicable journal. The experiment described in Chapter III was written according to the Guidelines for Authors, Journal of the American Dietetics Association. Experiments described in Chapters IV and V followed the Information For Authors, American Journal of Clinical Nutrition. Experiments described in Chapters VI and VII were prepared according to the Guide for Authors for the Journal of Nutrition.

CHAPTER II

REVIEW OF LITERATURE

Fiber Definitions

Dietary fiber is a vague, encompassing term. The term "fiber" does not refer to a specific chemical material, or even to a class of materials that all have similar properties or chemical structures. Certain plant components are generally accepted as constituents of dietary fiber. Various components of dietary fiber as described biologically and chemically by Cummings (1976), Southgate (1978), Vahouny (1982b), and Van Soest (1982) are;

Cellulose: a structural polysaccharide, part of the cell wall; an unbranched polymer of glucose with B 1-4 linkages.

Hemicellulose: a structural polysaccharide, part of the cell wall; a polymer of xylose and other five carbon sugars with many side chains consisting of mainly arabinose, uronic acid, and galactose, with some glucose, rhamnose, mannose, and xylose,

Lignin: the major non-carbohydrate component of cell-wall material; a polymer of phenylpropanes.

Pectin: non-structural polysaccharide; polymers of galacturonic acid with side chains of neutral sugars such as arabinose, galactose, rhamnose, xylose and fructose.

Gums: non-structural polysaccharides; polymers of galactose, galacturonic acid, and mannose, with side chains of xylose, fucose, and galactose.

Mucilages: non-structural polysaccharides; chains of galactose-mannose, glucose-mannose, arabinose-xylose, and galacturonic acid with side chains of galactose.

Silica: a cell wall component, found at higher concentrations in grass than in legumes, and can be as high as 22 percent of the dry matter of some plant material; mineral oxide.

Various additional materials including cutin, phytates, and indigestible proteins may be associated with various fiber fractions.

Thus, dietary fiber is composed of both structural and nonstructural materials of plants.

A variety of definitions and alternative terms for dietary fiber have been proposed. Some definitions are confusing because fiber components are difficult to measure and rate and extent of digestion by microorganisms varies. Kritchevsky (1977) described dietary fiber as the material that cannot be digested by human or microflora digestive enzymes, composed of cellulose, hemicellulose, lignin, gums, and pectin. This definition is limited since most of these substances are partially fermented by microorganisms in the digestive tract of animals and man. Also, this definition, like many others, limits dietary fiber to humans or mammals, and does not consider birds and

other vertebrates, which may utilize dietary fiber similarly to mammals.

Dietary fiber has been described by various workers as plant cell wall, unavailable carbohydrate, and non-nutritive residue. None of these are ideal as they each omit an important component or characteristic of fiber (Van Soest, 1978a). Other fiber researchers feel that "fiber" is not an acceptable term for the indigestible material from plants, and have suggested and alternative term -- "plantix" (Spiller, 1978). As more information about the effects of various types of dietary fiber accumulates, new terms may become useful; currently, additional terms only add to the confusion.

Fiber Analysis

Methods for analysis of fibrous materials have led to debate over the most accurate method of fiber analysis.

Crude fiber analysis, used for over 150 years, treats materials with sulfuric acid and sodium hydroxide (Van Soest and McQueen, 1973). This method, approved by the Association of Official Analytical Chemists, greatly underestimates total indigestible components. Up to 80% of hemicellulose, 20 to 50% of cellulose, and 50 to 90% of the lignin in various foods are not included in crude fiber (Van Soest and McQueen, 1973). In 1934 Williams and Olmstead criticized the crude fiber method and suggested an alternate analytical method for measurement of hemicellulose, cellulose, and lignin in food and feces. However, little interest in fiber analysis occurred until

epidemiologic studies suggested that the incidence of certain diseases was correlated with low intake of fiber (Burkitt, 1973; Trowell, 1978; Painter et al., 1972).

Increased interest in the function of fiber in the diet led to development of more useful methods of analysis (McConnell and Eastwood, 1974). The most frequently used method of analysis for fiber today is that developed by Van Soest and published as a procedure by Goering and Van Soest (1970). This method systematically removes various dietary components.

Solubility of fiber components in detergent fiber solutions allows fiber to be separated into neutral detergent fiber (NDF), acid detergent fiber (ADF) and acid detergent lignin (ADL) fractions. Removal of cell contents with a detergent at a neutral pH leaves the plant cell walls , which consist of cellulose, hemicellulose, and lignin. Hemicellulose is removed by a detergent at an acid pH leaving ADF, which consists of cellulose and lignin (Van Soest and McQueen, 1973). Thus, NDF minus ADF estimates water insoluble hemicellulose. However, the NDF fraction contains some starch while the ADF fraction contains some hemicellulose and pectin (Van Soest, 1978b). Cellulose is removed with sulfuric acid, leaving lignin (ADL) plus ash in the residue. ADL measures lignin, some cutin, and bound nitrogen. Acid insoluble ash (AIA) is primarily silica. ADL minus AIA provides an estimate of lignin, and ADF minus ADL gives an estimate of cellulose. In another technique for determining lignin, the permanganate lignin method, lignin is removed from ADF by oxidation with a permanganate solution. This leaves cellulose and ash in the residue.

Van Soest, an analytical chemist working in the animal science field, developed the detergent fiber method to analyze forages, which contain little starch. In contrast, human foods contain high levels of starch and little fiber compared to animal feeds. These foods also may contain substantial amounts of pectins, gums, and water soluble hemicellulose. The Southgate analysis method separates fiber into lignin, cellulosic polysaccharide and non-cellulosic polysaccharide fractions, retaining pectic materials in the non-cellulosic polysaccharide fraction (Southgate, 1969, Van Soest and Robertson, 1980). However, the Southgate analysis is very time consuming, requiring six extractions with incubations requiring 2 1/2, 18, and 24 hours, including drying and ashing steps. Thus, analytical technicalities limit use of this procedure.

As an alternative, modifications have been developed for the detergent fiber method for analysis of fiber composition of human foods. Filtration of NDF is complicated by high amounts of protein, starch, or gummy materials commonly found in human foods. Special procedures for handling samples high in protein, starch or oil have been developed (Robertson and Van Soest, 1977; McQueen and Nicholson 1979; Robertson and Van Soest, 1981) and are now gaining acceptance. The American Association of Cereal Chemists has recently accepted one of these new methods, combining the NDF method with a hog pancreas amylase predigestion (Jwuang and Zabik, 1979; Brauer et al., 1981).

Comparative Anatomy

The gastrointestinal tracts of various animal species differ in gross and microscopic anatomy. Differences may affect the speed that food travels through the tract and, thereby, alter site and extent of digestion.

The sizes and volumes of gastrointestinal tracts of the human, pig, and chicken are presented in table 1. The human stomach has a capacity of about one liter. It begins to empty immediately and has emptied within two to six hours after a meal. Passage from the mouth to the large intestine of the human takes from 2.5 to 9 hours. The small intestine, about five to seven meters in length, has a mean transit time of only 17 to 28 minutes for liquids (Dillard et al., 1965) indicating that the time delay is in the stomach. The human cecum is small, and the colon is sacculated, composed of many pouch-like segments. This anatomical structure appears to be an adaptation for fermentation (Van Soest, 1982). Total tract transit time from consumption of a meal to excretion, on typical free choice diets, ranges from 20 to over 100 hours (Gear et al., 1981).

Anatomically, the size of each section of the gastrointestinal tract of the pig is comparable to that of the human. A wide range of rates of passage through various portions of the pig's gastrointestinal tract has been reported. Most of a dye marker leaves the pig's stomach, which has a capacity of about 4 liters, within three hours.

Transit time from a meal to the ileum (the distal segment of the

TABLE 1. Comparative gastrointestinal volumes and lengths.

Organ	Species		
	Human 68 kg	Pig 182 kg	Chicken 1.8 kg
Stomach	25 cm[a]		
	1 l	3-4 l[b]	
Small intestine	5-7 m[a]	12-20 m[c]	
Duodenum	25 cm	60 cm	30 cm[d]
Jejunum	2.4 m		85-120 cm
Ileum	4 m		16 cm
Cecum			
length		20-30 cm[c]	12-25 cm[e]
width		7-10 cm	
Appendix	5-20 cm[a]		
Large intestine	1.5-2 m[f]	4-5 m[c]	

[a] Basmajian, 1976.
[b] Anthony and Lewis, 1961.
[c] Dunne, 1958.
[d] Koch, 1973.
[e] Nickel et al., 1977.
[f] Anderson, 1976.

small intestine) ranges from a low of two to four hours to a high of six to nine hours (Keys and DeBarthe, 1974a). In another study, more than 70% of a marker had passed into the large intestine by five hours after a meal (Kim et al., 1978). The length of the small intestine of the adult pig ranges from about 12 to 20 meters.

Mean transit time through the large intestine has been measured at 20 to 35 hours (Clemens et al., 1975; Keys and DeBarthe, 1974; Rust, 1983). The large intestine is four to five meters in length in the pig. Like man, the pig is an omnivore, and the pig colon is sacculated suggesting a similarity of function (Van Soest, 1982).

Digesta remain in the large intestine longer than in any other part of the intestinal tract in pigs, as in humans. The large intestine is the primary organ regulating the rate of passage of dietary fiber and soluble materials (Keys and DeBarthe, 1974b). Total tract passage times were 22 to 35 hours in 82 kg pigs (Rust, 1983) and 38 to 45 hours in young growing barrows (Keys and DeBarthe, 1974b).

In general, rodents and other small mammals have a large cecum in proportion to the size of their gastrointestinal tract and the colon is unsacculated. Carnivores, which have almost no cecal capacity, also have an unsacculated colon (Van Soest, 1982).

The digestive tract of the chicken differs in several ways from the digestive tracts of pigs and humans. The first organ in the gastrointestinal tract of poultry is the crop. The crop is a non-secretory enlargement of the esophagus for food storage. Food next passes into the glandular stomach for mixing with digestive secretions. Digesta then passes into the gizzard, the muscular stomach, which thoroughly grinds particles with stone or grit. Ground

digesta passes to the small intestine, which is subdivided into duodenal, jejunal, and ileal segments. At the junction of the large and small intestine are two long ceca in which a limited amount of bacterial degradation occurs. The large intestine of the chicken is short and homologous to the rectum of mammals. The colon empties into the cloaca, where undigested material and uric acid crystals mix and are voided together (Nickel et al., 1977). Material from the colon and rectum is expelled about 10 times per day, while material from the cecum is expelled about once daily. Cecal material is more solid, darker, and more homogeneous than other fecal material (Koch, 1973). Because the colon is relatively short and less developed, intestinal passage time is faster in the chicken than in other small animals, with a retention time only one-third to one-fourth that of the mouse (Koch, 1973). The digestive efficiency of chickens, however, is similar to that of other non-ruminant animals (Sakamoto et al., 1980).

Although differences exist among these three animal species, basic similarities allow one to draw useful comparisons. Pig ileal fluid has been used to successfully predict the digestion of various feeds for the chicken (Sakamoto et al., 1980).

The pig is a convenient animal for experimental digestive research, being large enough to modify surgically and the volume of digesta in the gastrointestinal tract provides adequate material for analysis. Various sizes of pigs can be chosen to approximate the weights of humans at specific ages.

No other non-primate is more similar to humans, physiologically and anatomically, than the pig. Pigs have been used successfully in dental, renal, visual, cardiovascular, and gastric research.

Similarities in drug sensitivity and in nutritional requirements enable researchers to use pigs to test various human drugs, and evaluate human infant formulas (Pond and Houpt, 1978).

Passage Rates

Passage rate through the total tract and segments of the digestive tract are usually measured using liquid or solid dyes, markers, or particles. Transit time is the time required to pass from one point to another. The digestive tract has several distinct pools of variable size. Flow through these pools is intermittent, not constant, and any one segment or pool is seldom full. For example, after a meal, fluid will flow from a cannula in the duodenum at intervals of about 10 minutes (Rust, 1983). But longer intervals between flow pulses are observed in the ileum, and at times one may wait several hours for a sample.

Chemical and physical characteristics of dietary fiber can affect transit time through various portions of the gastrointestinal tract. Generally, increasing the level of fiber in the diet decreases the total retention time in nonruminants and in man (Kass et al., 1980; Gear et al., 1981). However, foods may affect transit time differently within various segments of the gastrointestinal tract. For example, a diet of 70% yellow dent corn traveled more quickly than a diet of 70% soft red winter wheat to the ileum of pigs, but it passed more slowly through the entire tract (Keyes and DeBarth, 1974b).

In swine, research with fluid and particulate digesta markers have indicated that liquids and small particles pass through the tract at a similar speed while particles larger than about two cm pass much more slowly (Argenzio and Southworth, 1974). This delay may occur in the stomach. The distal portion of the stomach of humans delays passage of solid particles after a meal until particles are reduced or softened. Liquids leave the stomach more rapidly than solids in both humans and pigs (Clemens et al., 1975).

The increased rate of passage with added dietary fiber is partially attributable to bulk, and grinding of fiber may alter passage rate. Although coarse particles move more slowly through parts of the digestive tract than fine particles (Van Soest, 1978b), coarse bran reduces total tract transit times more than finely ground bran (Heller et al., 1980; Kirwan et al., 1974). However, Gragert (1981) found no significant difference in passage time to the ileum in humans fed fine and coarse wheat bran. High vegetable and fruit or wheat bran diets reduce transit time and produce stools that are bulkier, wetter, and more frequent. High pectin diets also increase the wet weight of stools (Stasse-Wolthuis et al., 1980).

With chickens, high fiber diets also reduce transit time (Bayer et al., 1978). According to Patrick and Schaible (1980), other factors affecting retention time in poultry include level of intake (high intake reducing transit time), particle size (fine particles travel faster than coarse particles), and solubility (soluble constituents pass more rapidly than coarse particles).

The effect of various fibers on retention time depends on the composition of the fiber. Chemically isolated plant fibers can differ from intact dietary fiber if the physical structure and chemical linkage of fiber molecules in the plant cell wall are damaged (Van Soest, 1978b). Solka floc, an isolated cellulose, and other isolated wood fibers vary in composition and digestibility. It is difficult to interpret results from studies with such isolated materials (Van Soest and McQueen, 1973).

In humans, large quantities of high cellulose foods decrease intestinal transit time and increase fecal bulk (Eastwood, et al., 1973; Fuchs, et al., 1976), while soluble fibers, such as guar gum, delay gastric emptying and increase small intestine transit time since they form gels (Jenkins et al., 1978; Anderson and Chen, 1979). Pectin, a soluble fiber, does not appear to change transit time through the total gastrointestinal tract (Durrington et al., 1976; Stasse-Wolthuis et al., 1980).

Microbial Activity

Being resistant to animal and human digestive enzymes, fiber is available for fermentation in the intestinal tract (Hellendoorn, 1978; Van Soest, 1978a). Since naturally occurring plant fiber varies in chemical and physical composition, the extent of fermentation will vary. Pectin and galacto-oligosaccharides are readily fermented, hemicellulose is partially fermented, cellulose is only slightly fermented, and lignin is fermented the least (Williams and Olmstead,

1936, Hellendoorn, 1978). Generally, monogastric animals, including humans, hydrolyze hemicellulose more completely than cellulose, while ruminant animals digest cellulose and hemicellulose to similar degrees (Van Soest, 1978a). The human large intestine, like the rumen, is anaerobic. Anaerobic organisms of the large intestine of non-ruminant animals are similar taxonomically and nutritionally to organisms found in the rumen (Wolin, 1974).

End products of fermentation can influence the environment and function of the digestive tract (Van Soest and McQueen, 1973). Ruminant animals appear to be designed for fermentation of fiber in the gastrointestinal tract. In ruminant animals, end products of carbohydrate fermentation include acetic, propionic, butyric, succinic, and lactic acids, ethanol, hydrogen, methane, and carbon dioxide (Miller and Wolin, 1979; Wolin, 1981) plus bacterial lipids and proteins (Van Soest and McQueen, 1973). Volatile fatty acids (VFA) are extensively absorbed and catabolized by ruminant animals, horses, rats, and pigs. However, the quantitative importance of VFA that are produced in the human gastrointestinal tract as a source of energy for man has not been determined (Anderson and Chen, 1979). Since a normal western diet contains less than 3% crude fiber (Hickman, 1983), VFA from fiber would provide an insignificant amount of energy.

In non-ruminants, the microbial population of the small intestine is much less numerous and diverse than that of the large intestine and cecum. Most fermentation is assumed to occur in the large intestine

and cecum due to the greater population of microbes in that area (Hellendoorn, 1978; Levitt, 1972).

In pigs, fiber digestion begins in the stomach (Keys and DeBarthe, 1974a; Kass et al., 1980). Bacterial fermentation has been detected in the stomach of both young and adult pigs (Argenzio and Southworth, 1974). As in the colon, large particles are retained in the stomach for long periods of time allowing microbes to ferment carbohydrates (Clemens et al., 1975). Over 38% of dietary hemicellulose has disappeared from the gastrointestinal tract of pigs anterior to the large intestine, and digestion of hemicellulose continues in the large intestine. Little cellulose digestion anterior to the large intestine has been reported. However, Kass et al. (1980) found 38.8% of cellulose was digested in the small intestine of pigs with fed a corn-soy diet, and others have found 33% digestion of cellulose anterior to the large intestine (Keys and DeBarthe, 1974a). Although lignin is usually considered indigestible, digestibilities up to 52% were seen in steers fed a corn diet, and disappearance of lignin occurs in the rumen, stomach, and lower intestine (Fahey and Jung, 1983).

Since intestinal bacteria adapt to available nutrients, adaptation to digest fiber over time might be expected. Consumption of lactose for an extended time increased the volume of both the large bowel and cecum of pigs and increased lactase activity. This change is attributable to adaptation of microflora of the gastrointestinal tract to the change in diet (Rerat, 1978). Although fiber digestibility varies with age and body weight in pigs, no adaptation

in ability to digest fiber has been detected (Kass et al., 1980). However, changes in bacterial activity have been observed in humans consuming high fiber diets. In humans fed wheat bran, cabbage, or low fiber diets, changes in the proportions of VFA in feces incubated with alfalfa, bran, cabbage, or cellulose of have been observed (Ehle et al., 1982). Also, in humans, total anaerobic bacterial counts per gram of dry feces have increased when subjects consumed wheat bran (Fuchs et al., 1976).

The surface of the crop of the chicken histologically resembles the surface of the rumen. The crop contains a bacterial population similar in type to that seen in the rumen. When material from the crop of chicks fed a high fiber diet (6% added cellulose) was incubated, lactic and acetic acid, end products of fiber fermentation, were rapidly produced (Bayer et al., 1978).

In chickens, most cellulose digestion occurs in the ceca but only a small part of the digesta passes into the ceca. With normal chickens, only 7-9% of the cellulose from normal diets was digested (Koch, 1973) and 2.3% of cellulose from sawdust (Lang and Briggs, 1976). When the ceca were removed, cellulose digestion dropped to about 1% (Koch, 1973).

The intestinal flora of chicks can be altered by changing the diet. Numbers of anaerobic bacteria in the ileum were greater with rye or pectin added to the diet. When diets contained pectin, gas production was observed, which could be inhibited by adding penicillin to the diet (Wagner and Thomas, 1978).

In the human, a limited amount of fiber digestion may occur in the small intestine. Bacteria have been isolated from human small intestinal mucosa and fluids (Clemens et al., 1975) and stomach (Gorbach et al., 1967), but fermentation in the stomach or upper small intestine is believed to be minimal in normal subjects (Sandberg et al., 1981).

Major organisms isolated from the stomach and intestine of humans include anaerobic Streptococci and Lactobacilli, Staphylococci and fungi. Genèra found in the lower tract of humans include Ruminococcus, Bacteroides, Eubacterium, Streptococcus, Fusobacterium, Coprococcus, Bifidobacterium, and Gemmiger (Bryant, 1974; Van Soest, 1982). The distal ileum contains a mixture of the microbial species present in the upper intestine and stomach and the lower intestine (Gorbach et al., 1967). Little work has been published on the metabolic characteristics of bacteria in the human intestinal tract. However, it is known that species of the Bacteroides genera ferment the hemicellulose component xylan in the gut (Salyers, 1979). This organism also ferments pectin, hemicellulose, and starch producing succinate and hydrogen gas. In the rumen, Methanobacterium ruminantium uses hydrogen gas and formate produced by other organisms to reduce carbon dioxide to methane (Wolin, 1974). Thus, methane rather than hydrogen is the end-product of fermentation in ruminant animals.

Each gram of human fecal material contains approximately 200 to 400 billion live bacterial cells (Moore and Holdeman, 1974). Bacterial populations in fecal material of subjects from various

countries differ, possibly due to diet (Finegold et al., 1974), environment, or other factors. However, when five subjects in a state training school consumed identical diets for seven months, fecal bacterial strains and numbers varied as greatly as with five subjects consuming random diets (Gorbach et al., 1967).

The response of the human gastrointestinal tract to various fermentable materials varies greatly among individuals. This difference may be due to intestinal microbial populations or eating habits. Types and amounts of fermentation end-products also vary over time and among subjects (Hellendoorn, 1978).

Site of fermentation of fiber by humans has been estimated by comparing digestion of fiber in intact and ostomized subjects. Ileostomized patients digested 15.5% of consumed cellulose and 72.5% of water insoluble hemicellulose, in contrast to 80% and 96% of cellulose and hemicellulose, respectively, with intact subjects fed the same diet. Lignin from vegetable and legume fiber was not digested (Holloway et al., 1978). Other work with ileostomized subjects showed hemicellulose digestibilities of 65% by female subjects and 83% by male subjects compared with 97% and 95% with intact female and male subjects, respectively. These results indicate that fermentation of hemicellulose can occur before material reaches the large intestine where fermentation continues (Holloway et al., 1980).

In contrast, other investigators have found less than 20% of the hemicellulose and 25% of the cellulose from bran was digested by subjects with ileostomies (Sandberg et al., 1981) compared with 50 to

54% digestion of hemicellulose in intact subjects (Heller et al, 1980). This suggests that availability may vary with fiber source. Lignin is the only plant fiber that appears to be neither digested nor fermented (Anderson and Chen, 1979). However, lignin structure may be modified during passage through the gut causing lignin to be lost from the ADL fraction (Fahey and Jung, 1983), or artifact lignin, such as Maillard products, are indigestible and may cause an apparent increase in lignin (Van Soest, 1982).

Bacterial fermentation results in production of gases. About 30 to 200 ml of gas, containing nitrogen, hydrogen, methane, and oxygen are present in the human intestinal tract. Also, carbon dioxide, hydrogen and sometimes methane are found in rectal gas (Levitt, 1971). Germ-free rats produce no hydrogen gas in the intestinal tract. Dietary antibiotics reduce gas production in the intestinal tract of non-ruminants, and newborn infants do not excrete hydrogen or methane. These observations indicate that intestinal gas arises from microbial action (Levitt, 1971; Hellendoorn, 1978; Levitt et al., 1968). Gas production, which increases with addition of fiber to the diet, is also related to large, soft stools (Hellendoorn, 1976), and gas presence may be responsible for decreased density of stools.

Gas produced during incubation of ileal fluid contained much more hydrogen (24-36%) than gas produced during incubation of colonic material (3%) from ostomized patients. When lactose was added to the digesta, 33% of the gas produced by the ileal sample was hydrogen and 42% of the gas produced by the colonic sample was hydrogen. Addition of milk resulted in gas containing 11% hydrogen from ileal and 2%

hydrogen from colonic material. Quantities of gas produced from these substances were similar for both ileal and colonic incubations (Calloway et al., 1966). Observing the time delay from consumption of beans to appearance of hydrogen in breath led some researchers to suggest that hydrogen is produced in the lower ileum of humans (Calloway, 1966). However, Levitt (1969) and Bond and Levitt (1978) reported that hydrogen gas is produced almost entirely in the large intestine, and Levitt (1972) indicated that bacterial numbers in the small intestine were too small to support extensive fermentation.

Summary

Fiber, indigestible to animal digestive enzymes, affects the gastrointestinal tract in various ways. Depending on chemical and physical characteristics, dietary fiber may have specific effects on passage time through each section of the gastrointestinal tract. This, in turn, will affect opportunity for bacterial fermentation to occur, which will affect gas and VFA production. Fiber bulk and the gas produced from fermentation will result in greater fecal volume.

CHAPTER III

BREATH HYDROGEN CONCENTRATION AND FECAL FIBER COMPOSITION FROM HUMAN SUBJECTS CONSUMING CORN BRAN

Christa F. Hanson, Esther A. Winterfeldt, and Mary Alice Kenney

Summary

Six men and six women consumed 20 gm. of neutral detergent fiber (NDF) from 23 gm. of corn bran (CB) in addition to their normal daily diets for three weeks. Hydrogen gas (H_2) in expired air was determined at 0, 4, 6, and 8 hours after breakfast on days during the first and last week of the three week CB feeding period, and at the end of a two week control period during which subjects consumed foods similar to those consumed during the fiber period but without added CB. Fecal samples were obtained from all subjects before the study began, at the end of the CB period, and at the end of the control (low fiber) period. Including CB in the diet increased H_2 concentration in expired air 8 hours after breakfast. Breath H_2 concentrations were directly related to the amount of CB consumed during the breakfast meal of the sampling day. Dry matter content of feces tended to be greater during the CB period than during the other

periods, and was significantly greater ($P<.05$) for females (36.4%) than males (27.7%) during the CB period. Neutral detergent fiber as a percent of fecal dry matter increased by 129% after addition of CB to the diet though lignin decreased by 42%. Corn bran addition to the diet increased ($P<.05$) the number of bowel movements per day by 33%. Consumption of CB apparently altered bacterial activity in the gastrointestinal tract of humans, thus increasing the concentration of H_2 in breath.

Abstract

Addition of 23 gm. corn bran to the daily diet of 12 young adults increased breath hydrogen levels, frequency of bowel movements, and the dry matter and fiber content of feces.

Introduction

Diets containing insufficient amounts of dietary fiber have been epidemiologically linked to a variety of diseases common to residents of developed countries (1, 2). Although increasing intake of dietary fiber may have positive effects on health, little is known about the effect of added fiber on the gastrointestinal tract. Effects may differ with source of dietary fiber, since fiber is composed of various proportions of cellulose, lignin, hemicellulose, pectin, gum, and mucilage.

Dietary fibers differ in fermentability and bulk characteristics. Fermentability may be the most important positive effect of fiber in

the gastrointestinal tract (3) although fermentation may cause gaseousness and flatulence in some people. Increased fecal bulk helps dilute and sweep potentially harmful substances from the gastrointestinal tract (4) and, by reducing intraluminal pressure, prevent diverticulosis (5).

Corn bran is one source of dietary fiber that has recently appeared in ready to eat cereal. Corn bran can be incorporated into a variety of foods without adversely affecting palatability or acceptance of the product (6, 7).

Corn bran is a rich source of dietary fiber (85% NDF) and is high in hemicellulose (65.8%), as measured by the detergent fiber method (8) using a modified amylase procedure for human foods (9). Bacteria in the intestinal tract of humans readily ferment xylan, a component of hemicellulose, releasing hydrogen gas (10, 11). Consequently, corn bran may be useful as a source of dietary fiber for people.

The purpose of this study was to determine the effect of adding corn fiber to the diet on H_2 concentration in expired breath, bowel function, and fiber composition of fecal material.

Methods

Six men and six women, all students or employees of Oklahoma State University were chosen from people who volunteered for the six-week trial. During the first week (pre-fiber), subjects were instructed how to record daily dietary intakes and to list number of bowel movements per day. During weeks two, three, and four of the

trial (test period), subjects consumed 23 gm. of corn bran (Staley Manufacturing Company, Decatur, IL) each day, which added 20 gm. of neutral detergent fiber (NDF) to their daily diet.

The 23 gm. of corn bran contained 15.40 gm. hemicellulose, 4.59 gm. cellulose, and 0.09 gm. lignin. The corn bran was incorporated into a variety of typically consumed foods as described by Hickman (12).

A control period lasting two weeks followed the test period. During the control period, subjects were provided with the same foods as during the test period but with no corn bran added.

To obtain breath samples, subjects inhaled deeply, held their breath for 10 seconds, and inflated a gas-tight sample bag with one expiration. This process was repeated at 0, 4, 6, and 8 hours after breakfast on test days. Plastic laminated aluminum material for the gas sample bags was obtained from Reynolds Metals, Co., Richmond, VA. Each bag was fitted with brass and plastic tubing and the edges sealed with heat and tested to be air-tight (13). All breath samples were analyzed using a gas chromatograph (Varian, model 920; Varian Associates, Walnut Creek, CA) equipped with a thermal conductivity detector and a 226 cm, 0.16 cm ID column packed with 60-80 mesh 5A molecular sieve (Supelco, Inc., Bellofonte, PA).

Breath samples were obtained from subjects on days 1, 2, or 3 of the corn bran period (T1), at the end of the corn bran period (T2), and at the end of the control period (C). Subjects ate various other foods during each test day but were asked to avoid foods, such as

milk, which are known to increase breath hydrogen excretion in certain people.

Single fecal samples were collected during the pre-fiber period (P), at the end of the test period (T2), and at the end of the control period (C). Fecal samples were sealed in plastic containers and frozen at the time of collection. At the end of the trial, fecal samples were weighed, oven dried, and ground to a fine powder. Subsamples were analyzed for fiber components (cellulose, hemicellulose, and lignin) by the detergent fiber method (8).

The influence of fiber intake on breath H_2 was determined by comparing H_2 concentrations during the control period with the mean of concentrations at the two times during the period of fiber supplementation. H_2 concentrations, changes in H_2 concentrations from fasting, fecal dry matter and fiber were analyzed by analysis of variance and Duncan's multiple range testing following procedures outlined by Snedecor and Cochran (14).

Results and Discussion

Corn bran intake during the test period averaged 4.3% of the dry matter of the diet based dietary intake records (Table 1). Crude fiber intakes were 5.1, 9.8, and 6.4 gm. for the P, T, and C periods, respectively, based on dietary recall data from the subjects (12). Addition of crude fiber from corn bran (3.5 gm.) increased crude fiber intake from 1.2 to 1.8 % of the diet ($P<.05$). This indicates that fiber as a fraction of the total diet is lower in human diets than in

typical diets for domestic nonruminant animals which contain 5 to 10% crude fiber.

Intakes of calories, fat, carbohydrate, and protein during the T and C periods were considerably higher than during P when diets were entirely self-selected. Had subjects maintained the same intakes as during P, percent crude fiber intake would have increased to 2.3% during T. However, subjects consumed these very palatable high fiber products (12) in addition to their normal diet.

Averaged across sampling times within test period, corn bran addition to the diet increased breath H_2 concentration (Table 2). To determine the relationship of breath H_2 concentrations to intake of corn bran, at time T2 half of the subjects consumed 10 gm. dietary fiber from corn bran at breakfast, while the other half consumed only 5 gm. Subjects who consumed the larger amount of corn bran in their breakfast meals at T2 had greater concentrations of breath hydrogen (9.38 vs 5.35 ppm), while the mean for T1, when all subjects consumed 10 gm. NDF in their breakfast, was 8.7 ppm. Since all subjects consumed breakfasts of similar composition on T2 except for the quantity of corn bran, this indicates that total H_2 gas excretion was related to the quantity of corn bran consumed.

Breath H_2 concentrations did not differ by sex of subject although the mean hydrogen concentration was consistently greater for males (Table 3) than for females (Table 4). In males, H_2 concentration 8 hours after breakfast was greater during T1 than C (Table 3). In females, this trend was also seen, but was not statistically significant.

Change in breath H_2 concentration from the concentration at hour 0 during T1 for all subjects was different from that at T2 and C at 6 and 8 hours after breakfast (Table 5). Before breakfast, breath H_2 concentration was higher for all subjects during T2 and C than at T1, the beginning of the fiber period. For females the zero hour measurement was lower ($P<.05$) at the end of C than the end of T.

As respiratory H_2 excretion reflects intestinal H_2 production (15), material was still apparently present in the gastrointestinal tract of subjects after the 12 hour fast. It is assumed that subjects fasted according to the experimental protocol.

Females, who had a higher fasting H_2 level at T2, consumed a higher percent of their diet as corn bran NDF than males (4.7% vs 3.1% of the diet). Adaptation to the corn bran diet may have slowed passage rate. Longer passage time with more corn bran in the diet would permit fermentable material to remain in the upper large intestine and continue to be fermented, releasing H_2 that would be detected in breath even after a 12 hour fast.

To investigate the rise in fasting breath H_2, breath samples were obtained from two subjects during T2 at 8, 10, 12, and 14 hours after breakfast. Breath H_2 rose from a mean of 5 PPM at hour 8 to a mean of 24 PPM at hour 14, seven hours after all corn bran for that day had been consumed and 14 hours after breakfast. Those two subjects had breath H_2 concentrations which on all other measurement times were well within the range observed in the other subjects. This suggests that fermentation may be prolonged with intake of corn bran.

When subjects were fed a single meal of 40 gm. of corn bran at breakfast (16), rate of passage to the large intestine decreased as measured by H_2 appearance time. In contrast, passage time to the large intestine was slowed after two weeks in pigs consuming a 20% corn bran diet (17). Gastrointestinal adaptation to fiber intake may occur over weeks or longer as bacterial activity, enzyme and hormone level, and muscle functioning respond to the change in diet.

In previous studies, corn bran did not increase H_2 when fed as part of a diet for nine days (18), or when fed as part of a single breakfast (16). However, corn bran at 60% of the diet increased H_2 expiration of pigs (19). Corn bran contains about 66% hemicellulose, and hemicellulose at a level of 10 gm. in flavored water increased H_2 in breath in humans (20).

Based on H_2 production, consumption of corn bran altered bacterial activity in the gastrointestinal tract of humans. Total H_2 concentration in breath was greater when corn bran was fed than during the control period, while total caloric intake was similar.

Composition of feces and frequency of bowel movements were changed with corn bran addition to the diet. Dry matter content of the feces was slightly (4.7%) greater during T than during the mean of P and C. NDF as a percent of dry matter in feces increased by 129%. Components of fiber changed differently, however. Hemicellulose, the major component of corn bran increased ($P<.05$) by 217%, cellulose increased ($P<.05$) by 54%, while lignin decreased ($P<.05$) by 37% (Table 6). These changes correspond to the composition of fiber from corn bran, which was 66% hemicellulose, 20% cellulose, and 0.4% lignin.

In previous studies, the fiber composition of feces also has reflected fiber composition of the diet, with fecal fiber increasing when fiber from relatively unprocessed foods such as whole wheat bread and brown rice were added to the diet (21). Digestibility of the fermentable hemicellulose fraction has been measured in various studies. Apparent digestibility of hemicellulose was 88% in a high fiber (25 gm. NDF per day) diet consisting of fruits and vegetables (22), while only 50-54% of hemicellulose was digested by subjects consuming 12 gm. cell wall from wheat bran (23). In a third study, digestibility of hemicellulose was similar for both the high and low fiber diets, but greater than the digestibility of cellulose (21). Among subjects with ileostomies, females digested 65% of the hemicellulose and males digested 83% of hemicellulose from a mixed diet. This contrasts with hemicellulose digestion by intact males and females of 97 and 95% of the hemicellulose, respectively (24).

Assuming that lignin excretion was similar during T and C, fecal excretion of dry matter was 49% greater during T than C. This means that fecal output of wet matter was 40% greater during T than C. In previous studies, total wet weight of feces increased when subjects were fed fiber. Feeding 26 gm. corn bran to subjects on a completely controlled diet increased fecal output by 100% (25). When subjects consumed 16 gm. wheat bran, fecal output increased by 63% and output of both water and solid increased though percent dry matter of the feces remained the same. Feeding 16 gm. cellulose in the same study increased fecal output by 45%, and increased the dry matter percentage of feces (26). In our study, fecal dry matter was greater ($P<.05$) for

females than males (38.0 vs 28.1%) during the corn bran period and tended to be higher for females for all periods (Table 7). No explanation for this difference is apparent.

Percent dry matter of fecal samples increased slightly after consumption of corn bran in this study. When a higher level of dietary fiber, 28 gm. from wheat bran, was fed by Cummings et al. (4), total fecal weight increased by 188% and percent solids decreased. Addition of the fecal bulking agent, ispaghula husk, to the diet also increased fecal output of both solids and water (27). Feces contained 27% dry matter for a control diet, but when nondigestible materials were fed, dry matters were 22% with wheat bran, 27% with oat bran and 22% with raffinose. Oat and wheat increased fecal output by 186% and 260%, respectively, while raffinose did not significantly increase fecal output (28). Percent dry matter in feces did not change when subjects consumed a high fruit and vegetable diet, however, fecal output increased by 135% (29).

The number of bowel movements per day increased ($P<.05$) by a mean of 33% during the high fiber period (Table 8). This is illustrated by week in figure 1. Amount of feces per bowel movement remained approximately the same, according to comments from subjects. If fecal wet matter excretion was increased by 40%, as calculated above, and frequency of bowel movements was increased by 33%, then wet matter output per bowel movement would be increased by about 5%. This difference per bowel movement probably would not be detected. This suggests that volume of feces excreted per bowel movement remained similar though individuals differed drastically ($P<.01$) in the mean

number of bowel movements per day (0.51 to 3.06) during the total 6 weeks of this experiment.

Bowel movements per day on a typical diet was 1.0 for young adults and 1.1 for elderly people (30). Frequency of bowel movements was increased with consumption of wheat bran and raffinose but increased only slightly with consumption of oat bran and gum (28). These researchers found that bowel movement frequency per day was 1.4 on the control diet vs 3.4 after wheat bran, 1.8 after oat bran, and 3.0 after raffinose. Bowel movements per day dropped to 2.3 and 1.7 when wheat and oat bran were removed from the diet (28). Number of bowel movements also increased when subjects consumed 26 gm. corn bran with a typical diet (25) or when subjects were fed a high fruit and vegetable diet (22).

The percentage of water in feces remained unchanged although total weight of feces increased when 5.4 gm. crude fiber from All-Bran was added to the diet (31). These workers also observed an increase in anaerobic bacteria numbers in feces.

The intestine may adapt both microbially and physiologically to increased fiber. Comments from subjects during the study are categorized in Table 9. An abrupt change, either an increase or a decrease in fiber intake, precipitated comments. When fiber was added to the diet, greater gas production was noted followed by a higher incidence of cramps and loose stools during the second week of high fiber intake. By the third week on corn bran, the incidence of loose stools and other intestinal upsets had begun to subside. When fiber was removed from the diet, dry stools and constipation occurred in

some subjects. To reduce the possibility of gastrointestinal discomfort, fiber should be increased slowly to the diet and added fiber should be distributed in several meals.

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Table 1. Nutrient intake of subjects

	period		
	pre-fiber	corn bran	control
males			
calories, kcal	2448	3191	3242
protein, gm	94.9	122.0	125.6
fat, gm	96.8	130.7	148.2
carbohydrate, gm	285.8$_{b}$	387.0$_{a}$	346.9$_{ab}$
crude fiber, gm	5.7^{b}	11.0^{a}	7.6^{ab}
moisture, gm	1767	1667	1879
crude fiber, %	1.2	1.7	1.2
corn bran, %		3.6	
females			
calories, kcal	1881	2227	2223
protein, gm	68.7	82.2	81.2
fat, gm	77.1	96.2	109.0
carbohydrate, gm	218.7$_{b}$	251.4$_{a}$	229.8$_{b}$
crude fiber, gm	4.6^{b}	8.5^{a}	5.3^{b}
moisture, gm	1589	1488	1464
crude fiber, %	1.3	2.0	1.3
corn bran, %		5.4	
all subjects			
calories, kcal	2165	2709	2732
protein, gm	81.8	102.1$_{ab}$	103.5$_{a}$
fat, gm	87.0^{a}	113.5^{ab}	128.6^{a}
carbohydrate, gm	252.2$_{b}$	319.2$_{a}$	293.3$_{b}$
crude fiber, gm	5.1^{b}	9.8^{a}	6.4^{b}
moisture, gm	1678	1577	1672
crude fiber, %	1.2	1.8	1.2
corn bran, %		4.3	

^{ab}Means in a row with different superscripts differ ($P<.05$).

Table 2. Breath hydrogen concentrations of subjects consuming the corn bran or control diet

period	hours after breakfast 0	4	6	8	mean
		parts per million			
corn bran	6.9	4.6[a]	10.4	10.3[a]	8.0[a]
control	8.1	1.5[b]	5.4	4.6[b]	4.9[b]

[ab]Means in a column with different superscripts differ ($P<.05$).

Table 3. Hydrogen concentration in expired breath for males

hours after breakfast	period: start of corn bran	period: end of corn bran	control
	parts per million		
0	4.0	6.5	11.1
4	4.0	7.7	1.9
6	17.2	10.2	5.7
8	15.9[a]	9.9[ab]	4.2[b]
Mean	10.3	8.6	5.7
	change in parts per million		
0 to 4 h	0.1	1.2	-9.2
0 to 6 h	13.3[a]	3.7[ab]	-5.4[b]
0 to 8 h	11.9[a]	3.5[ab]	-6.9[b]

[ab]Means in a row with different superscripts differ ($P<.05$).

Table 4. Hydrogen concentration in expired breath for females

hours after breakfast	period: start of corn bran	period: end of corn bran	control
	parts per million		
0	6.0[ab]	11.0[a]	5.1[b]
4	3.8	2.8	1.0
6	9.8	4.2	5.1
8	8.8	6.6	4.9
Mean	7.1	6.2	4.0
	change in parts per million		
0 to 4 h	-2.2	-8.2	-4.1
0 to 6 h	3.8[a]	-6.8[b]	-0.0[ab]
0 to 8 h	2.8[a]	-4.4[b]	-0.2[ab]

[ab]Means in a row with different superscripts differ ($P<.05$).

Table 5. Hydrogen concentration in expired breath for all subjects

hours after breakfast	period		
	start of corn bran	end of corn bran	control
	parts per million		
0	5.0	8.7	8.1
4	3.9	5.3	1.5
6	13.5	7.1	5.4
8	12.4[a]	8.3[ab]	4.6[b]
Mean	8.7	7.4	4.9
	change in parts per million		
0 to 4 h	-1.1	-3.5	-6.6
0 to 6 h	8.6[a]	-1.6[b]	-2.7[b]
0 to 8 h	7.4[a]	-0.5[b]	-3.5[b]

[ab]Means in a row with different superscripts differ ($P<.05$).

Table 6. Fiber components of fecal samples

	period		
	pre-fiber	corn bran	control
hemicellulose	percentage of dry matter		
males	8.6[b]	23.4[ae]	11.7[b]
females	8.3[b]	32.3[ad]	6.5[b]
total	8.5[b]	27.9[a]	9.1[b]
cellulose			
males	8.1	10.2	7.5
females	5.5[b]	9.9[a]	5.0[b]
total	6.8[b]	10.0[a]	6.3[b]
lignin			
males	6.9[a]	4.1[b]	5.7[ab]
females	7.0[a]	4.0[b]	6.5[a]
total	7.0[a]	4.1[b]	6.1[a]
ADF			
males	15.4	14.4	12.9
females	13.0	17.4	14.2
total	14.2	15.9	13.6
NDF			
males	24.1[b]	40.8[a]	25.9[b]
females	21.3[b]	46.7[a]	19.4[b]
total	22.7[b]	43.8[a]	22.7[b]

[ab] Means in a row with different superscripts differ ($P<.01$).

[de] Means in a column within a fiber fraction with different superscripts differ ($P<.05$).

Table 7. Dry matter content of fecal samples

sex	period		
	pre-fiber	corn bran	control
	percent of wet matter		
males	27.7	28.1[b]	27.2[d]
females	36.1	38.0[a]	35.1[c]
total	31.9	33.1	31.2

[ab]Means in a column with different superscripts differ ($P<.03$).

[cd]Means in a column with different superscripts differ ($P<.06$).

Table 8. Bowel movements per day

	period		
sex	pre-fiber	corn bran	control
males	1.2^{b}	1.9^{a}	1.5^{ab}
females	1.4^{ab}	1.7^{a}	1.3^{b}
total	1.3^{b}	1.8^{a}	1.4^{b}

^{ab}Means in a row with different superscripts differ ($P<.05$).

Table 9. Comments concerning intestinal action by subjects

week	diet	stool consistency		intestinal			stool size	
		loose	constipated	gas	noise	cramps	large	small
		number of subject comments						
1	pre-fiber	2	0	0	0	0	0	0
2	test	2	0	8	2	2	1	0
3	test	6	0	7	0	7	0	0
4	test	0	3	5	0	5	1	1
5	control	1	2	0	0	0	1	1
6	control	2	4	1	0	0	0	0

Legend for Figure

FIG. 1. Bowel movement frequency of male and female subjects for each week of the experiment.

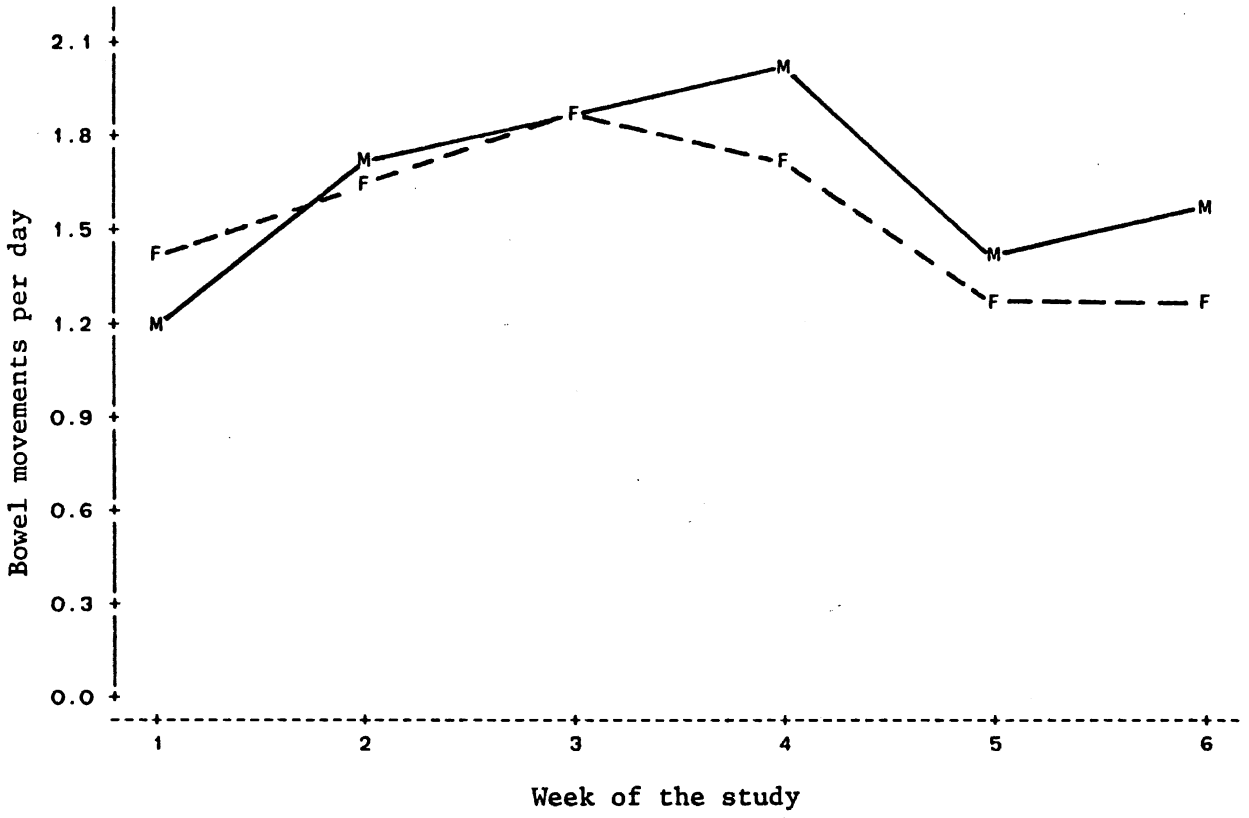

Fig 1. Bowel movement frequency

CHAPTER IV

DIETARY FIBER EFFECTS ON PASSAGE RATE AND BREATH HYDROGEN

Christa F. Hanson and Esther A. Winterfeldt

Abstract

Fermentation of fiber and passage to the large intestine were monitored by measuring hydrogen gas (H_2) concentration in expired breath. Following the consumption of a standardized dinner and a 14 hour overnight fast, 5 human subjects consumed meals containing no added fiber or 40 g (26% of DM of meal) of wheat bran (WB), corn bran (CB), oat bran (OB), or citrus flour (CF) replacing white flour in a 5X5 latin square with one treatment per week. Breath samples were obtained at 30 min intervals for 9 hours after the test meals. Peak H_2 concentrations (25 to 39 ppm) were greater with OB than WB ($P<.05$), with no differences between other fiber sources and the basal (no fiber) meal. Mean H_2 concentration (ppm), averaged over the 9 hour test period, ranged from 7.5 (CB) to 12.0 (OB). Mean H_2 concentration increased with addition of OB, CF, or WB to the diet but decreased with addition of CB. The gel-like fibers (OB and CF) resulted in greater H_2 concentration than the particulate fibers (WB

and CB). H_2 concentration increased more rapidly following consumption of the wheat bran than of the other test meals. Times to highest H_2 peaks were 4.7 h (WB), 5.6 h (CB), 6.2 h (OB), 6.4 h (CF), and 8.2 h (basal). Time to reach 5 and 10 ppm followed the same order, indicating that passage rate to the large intestine was accelerated by the addition of dietary fiber. Results suggest that the consumption of particulate fibers (WB and CB) increased speed of passage to the large intestine more than gel-like fibers (OB and CF).

Key terms: breath hydrogen, fiber, passage time, wheat bran, corn bran, citrus flour, oat bran

Introduction

Epidemiological studies have indicated that the consumption of dietary fiber may prevent various degenerative diseases common to Western countries where very low fiber diets are consumed (1, 2). Dietary fibers, which differ in physical and chemical characteristics may differ in their effects on the gastrointestinal tract (3). Interactions between intestinal bacteria and fiber may cause additional important effects (4, 5). During fermentation of fiber in the lower intestine, bacteria produce hydrogen gas which is partially absorbed and excreted through the lungs (6). Hydrogen gas producing organisms which ferment various fiber fractions have been identified in the human intestinal tract (7).

Bacterial fermentation of fiber results in a measurable change in breath hydrogen, and fiber consumption appears to change passage time through the gastrointestinal tract. In subjects fed single doses of purified fibers in flavored water, breath hydrogen increased after consumption of 10 g of hemicellulose and raffinose but not after consumption of 20 g of cellulose, pectin, or lignin (8). Breath H_2 concentrations increased proportionately to wheat bran intake in human subjects (9). This suggests that breath H_2 excretion varies with fiber source and level. Persons consuming xylan and pectin diets produced higher concentrations of breath H_2 gas than those consuming cellulose, corn bran or a control diet in a study in which subjects consumed the test fiber for 9 days (10).

The time at which concentration of breath H_2 rises after a meal has been used as an indicator of passage time to the lower ileum (11, 12). Transit time was delayed by consumption of water suspensions of guar, tragacanth, and pectin, while methylcellulose had no effect, and bran shortened transit time compared to the control diet (13). In elderly women, wheat bran and raffinose meals produced a rise in breath H_2 starting 2-3 hours after a test meal, while oat bran, oat gum and control meals did not increase breath H_2 until 4, 5, and 5 hours after the meal, respectively (12).

Although passage time through the entire tract may be affected by particle size of fiber (14), particle size of wheat bran (coarse vs. fine) had no significant effect on time of breath H_2 increase after meals (15).

The objective of this study was to measure 1) the effect of various fibers on the concentration of hydrogen gas excreted and 2) passage time through the stomach and small intestine as measured by time of increase in H_2 concentrations.

Methods

Five human subjects, three males and two females (26 to 41 years of age) were selected from employees at Oklahoma State University to participate in the five week study. The volunteers had no known gastrointestinal disorders and had no history of adverse effects due to consumption of high fiber foods. Mean height and weight were 1.70 m and 58.6 kg for female subjects and 1.78 m and 73.6 kg for the male subjects.

Each subject consumed one test meal on the same day each week with the treatment order following a latin square experimental design. On the day before the test day, subjects were provided with a 700 kcal dinner consisting of chopped beef with gravy, whipped potatoes, peas and carrots, and mixed fruit cobbler. The meal provided 42 g protein, 49 g carbohydrate, and 37 g fat. No other food or beverage except water was consumed until the testing period began. The test period was started the following morning, 14 hours after consumption of the dinner. The first breath sample was collected immediately before consumption of the test meal. Expired air at this and at subsequent sampling times was collected in three-liter, gas-tight laminated aluminum (Reynolds Metals Co., Richmond, VA) sample bags.

Subjects stood, inhaled deeply, waited 10 seconds, and blew into the bag via 0.6 cm tygon tubing. Breath samples were analyzed within 30 min of collection using a gas chromatograph (Varian, model 920; Varian Associates, Walnut Creek, CA) equipped with a thermal conductivity detector and a 336 cm, 0.16 cm ID column packed with 60-80 mesh 5A molecular sieve (Supelco, Inc., Bellofonte, PA).

Following collection of the fasting breath sample, subjects were provided with four hot pancakes with syrup. The pancakes were prepared with either 1) all purpose white flour, 2) oat bran (Quaker Oats Co., Barrington, IL), 3) corn bran (Staley Manufacturing Co., Decatur, IL), 4) citrus flour (Ben Hill Griffin, Inc., Frostproof, FL), or 5) wheat bran (Shawnee Mills, Shawnee, OK) substituted for 50% of the white flour. Composition of the high fiber pancakes, on a dry matter basis, were; test fiber, 40 g; white wheat flour, 40 g; baking powder, 1.6 g; baking soda, 2.8 g; egg, 13 g. Pancakes were served with 1/4 cup corn syrup based imitation maple syrup (55.4 g dry matter).

Fiber constituted 40% of the test pancake (dry matter basis) and 26% of the total meal dry matter. The fiber composition of the test materials analyzed by the detergent fiber method (16) is presented in table 1. Corn bran, oat bran, and wheat bran were used in cooking as received. Since the citrus flour had a bitter flavor, it was extracted with ethyl ether to remove the objectionable compounds. Wheat bran appeared to have the largest particle size, oat and corn bran were similar and intermediate and citrus flour had the smallest particle size.

Breath samples were collected every 30 min for nine hours following consumption of the test breakfast. Four hours after breakfast, each subject ate a sandwich made from two slices of commercial white bread with the crust removed and two ounces of pre-cooked lean ham. Subjects ate no other food but were allowed water during the nine hour period. Analysis of variance and Duncan's multiple range testing followed procedures outlined by Snedecor and Cochran (17).

Results

Concentrations of H_2 in breath samples were analyzed at 30 min intervals (table 2). Mean H_2 concentration for the nine hour test period tended to increase with substitution of oat bran, citrus flour, or wheat bran for white flour in the control diet (12.0, 10.6, 10.3, and 9.5 ppm, respectively), and decreased with addition of corn bran (7.5 ppm). These differences proved significant at certain times.

As illustrated in figures 1 through 5, breath H_2 concentrations generally rose 2.5 to 4.5 h after the test and control meals and either remained high or subsided. Peak H_2 concentrations were greater with oat bran than wheat bran, with no differences between other fiber sources and the control (no fiber) meal (footnote, table 3).

H_2 concentration increased more rapidly following consumption of the wheat bran than of the other test meals. Time to reach 5 ppm, 10 ppm, and the highest H_2 value for each subject was, from fastest

to slowest, wheat bran, corn bran, oat bran, citrus flour, and basal (table 5). The control diet, at 8.2 h, took 3.5 h longer to reach maximum H_2 gas concentration than wheat bran, and nearly two hours longer than citrus flour, the slowest fiber diet. These results indicate that passage rate to the lower intestine was accelerated by the addition of all dietary fiber sources tested. The consumption of the particulate fibers (wheat bran and corn bran) increased speed of passage to the large intestine more than the gel-like fibers (oat bran and citrus flour).

Comments by the test subjects indicated that gaseousness or fullness was not related more to one fiber source than another. Several subjects indicated that wheat bran and corn bran consumption produced feelings of gaseousness approximately 3 to 4 hours after consumption, while citrus and oat pancakes produced feelings of gaseousness about 9 hours after breakfast. One subject complained of digestive upset and diarrhea the day following consumption of the oat bran, while two other subjects indicated that the oat pancakes were not as filling as the other fiber sources. No subject had any negative comments about the control diet.

Discussion

The four types of dietary fiber used in this study differed in their chemical composition and in their effects on H_2 gas concentration in breath. Consumption of pancakes containing oat and citrus resulted in greater H_2 concentrations than the wheat bran,

while the corn bran pancakes resulted in a lower mean H_2 concentration than the control diet. Citrus flour is high in pectin while oat contains gums and mucilages, which have similar properties to pectins (18, 19). These fiber components are more fermentable than cell wall materials.

Corn bran, high in hemicellulose, increased breath H_2 in pigs when fed at 60% of the diet (20). Tadesse and Eastwood found that feeding 10 g of purified hemicellulose in flavored water to human subjects increased H_2 while feeding 20 g of lignin, pectin, or cellulose did not (8). In this study, consumption of 40 g of corn bran (26 g hemicellulose) resulted in lower H_2 concentration compared to consumption of the control meal. Similar findings were reported by Marthinsen and Fleming when they fed corn bran as part of the daily diet to human subjects (10). They also observed that pectin increased H_2 concentration in breath. Measurement of H_2 gas concentration from chickens after consumption of high fiber diets for 14 days showed higher concentrations of H_2 from birds fed the oat and citrus diets than from those fed the corn or wheat diets (21).

Patterns of breath H_2 concentrations differed markedly with fiber source. This bacterial response to consumption of fiber may be partially dependent on both physical and chemical structure of the fiber (22, 23) and rate of passage through the gastrointestinal tract (24). Rate of fermentation depends on the ability of bacteria to infiltrate particles and solubilize fermentable carbohydrate. Extent of fermentation may be altered by residence time in some sections of the gastrointestinal tract. Persistently high H_2 values may reflect

prolonged fermentation due to continued availability of fermentable carbohydrate. Fibers that provide little fermentable material or pass rapidly through the lower intestine would not result in continued H_2 expiration. The greater the intestinal residence time, the greater the amount of fiber fermentation possible. However, added fiber may attract water and accelerate passage rate as well.

In humans, a feeling of fullness, which might be provided by a fiber with a very slow passage time, may decrease food intake and thereby assist in weight control programs. In this study, slow passage appeared to be related to increased fermentation and accompanying gas production, which may cause discomfort in certain individuals. In contrast, fast passage results in discomfort due to increased intestinal motility in other individuals.

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TABLE 1

Composition of fiber sources (%)

Source	Hemicellulose[1]	Cellulose[2]	Lignin[3]
Wheat bran	35.0	9.7	2.57
Citrus flour	<1.0	21.9	0.66
Corn bran	65.8	19.6	0.37
Oat bran	17.5	0.9	1.49

[1] NDF minus ADF [2] ADF minus lignin [3] Permanganate lignin

TABLE 2

Mean hydrogen concentration in breath at 30 minute intervals.

Time after meal,	Fiber source				
	Control	Corn	Oat	Wheat	Citrus
Hours			PPM		
0	.7	1.2	.9	.5	.0
.5	.5	.0	2.9	.2	1.4
1	.0	2.7	4.4	2.3	0.8
1.5	1.3	2.8	4.0	6.5	1.0
2	1.4	4.7	3.7	7.1	1.1
2.5	$.9^{b}$	4.6^{ab}	4.0^{ab}	11.1^{a1}	4.2^{ab}
3	$.0^{b}$	5.6^{b}	4.3^{b}	18.6^{a}	3.7^{b}
3.5	$.0^{b}$	3.8^{b}	7.4^{b}	16.5^{a}	7.2^{b}
4	3.7^{b}	4.6^{b}	13.2^{a}	12.9^{a}	8.4^{ab}
4.5	5.2^{b}	19.8^{a}	16.9^{ab}	23.7^{a}	23.2^{a}
5	6.8	22.2	24.0	19.3	18.8
5.5	12.8^{ab}	8.9^{b}	18.4^{ab}	18.4^{ab}	22.0^{a}
6	13.8^{ab}	5.2^{b}	18.9^{a}	14.0^{ab}	17.1^{a}
6.5	21.5	8.9	15.5	8.7	17.4
7	23.5^{a}	8.4^{ab}	18.3^{ab}	5.7^{b}	15.9^{ab}
7.5	17.8^{a}	5.6^{b}	14.9^{ab}	6.5^{b}	11.0^{ab}
8	19.1^{a}	4.7^{ab}	15.2^{ab}	3.3^{b}	11.7^{ab}
8.5	21.2	4.3	18.2	5.6	13.5
9	22.8^{a}	13.1^{ab}	11.6^{ab}	4.7^{b}	12.0^{ab}

^{ab} Means in a row with different superscript letters differ ($P<.05$).
^{1} Underlined means differ from control means ($P<.05$).

TABLE 3

Mean passage time estimate in hours

Fiber source	Hours to reach breath hydrogen of		
	5 ppm	10 ppm	Peak[1]
Wheat	2.3^{c}	2.6^{b}	4.7^{b}
Corn	2.8^{bc}	3.2^{b}	5.6^{b}
Oat	3.2^{bc}	3.7^{b}	6.2^{b}
Citrus	4.0^{ab}	4.4^{ab}	6.4^{ab}
Control	4.6^{a}	5.7^{a}	8.2^{a}

[1] Peak H_2 concentrations (ppm) were: wheat 25.3^{b}, corn 29.4^{ab}, oat 39.0^{a}, citrus 26.9^{ab}, and control 32.8^{ab}.

^{ab} Means in a column with different superscripts differ ($P<.05$).

Legends for Figures

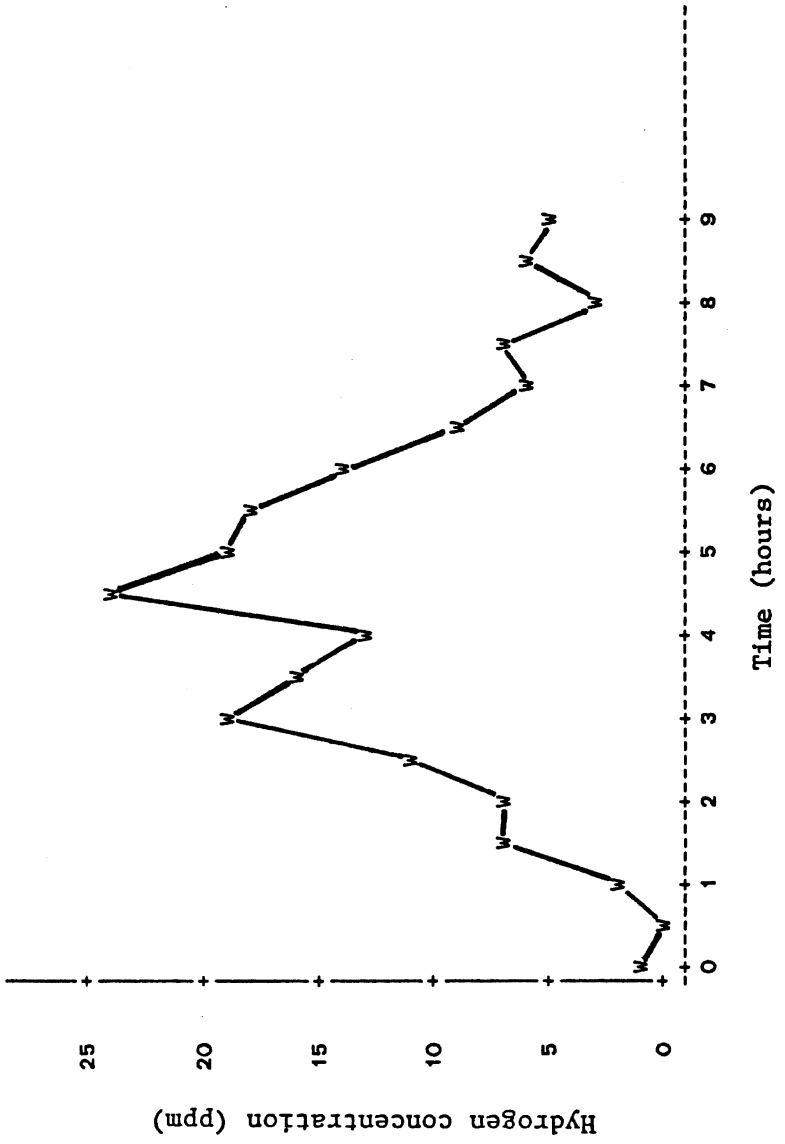
FIG. 1. Mean breath hydrogen concentration (ppm) for subjects consuming wheat bran.

FIG. 2. Mean breath hydrogen concentration (ppm) for subjects consuming corn bran.

FIG. 3. Mean breath hydrogen concentration (ppm) for subjects consuming oat bran.

FIG. 4. Mean breath hydrogen concentration (ppm) for subjects consuming citrus flour.

FIG. 5. Mean breath hydrogen concentration (ppm) for subjects consuming control diet.


Hydrogen concentration (ppm)
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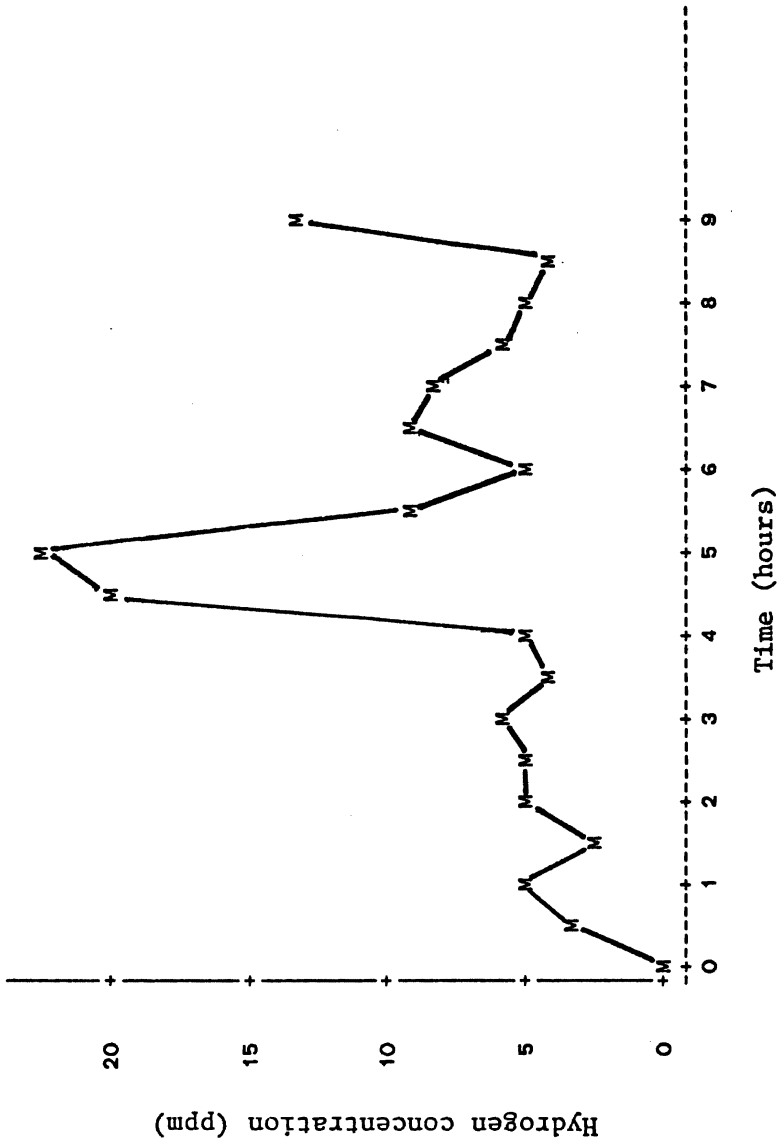
Time (hours)


Hydrogen concentration (ppm)
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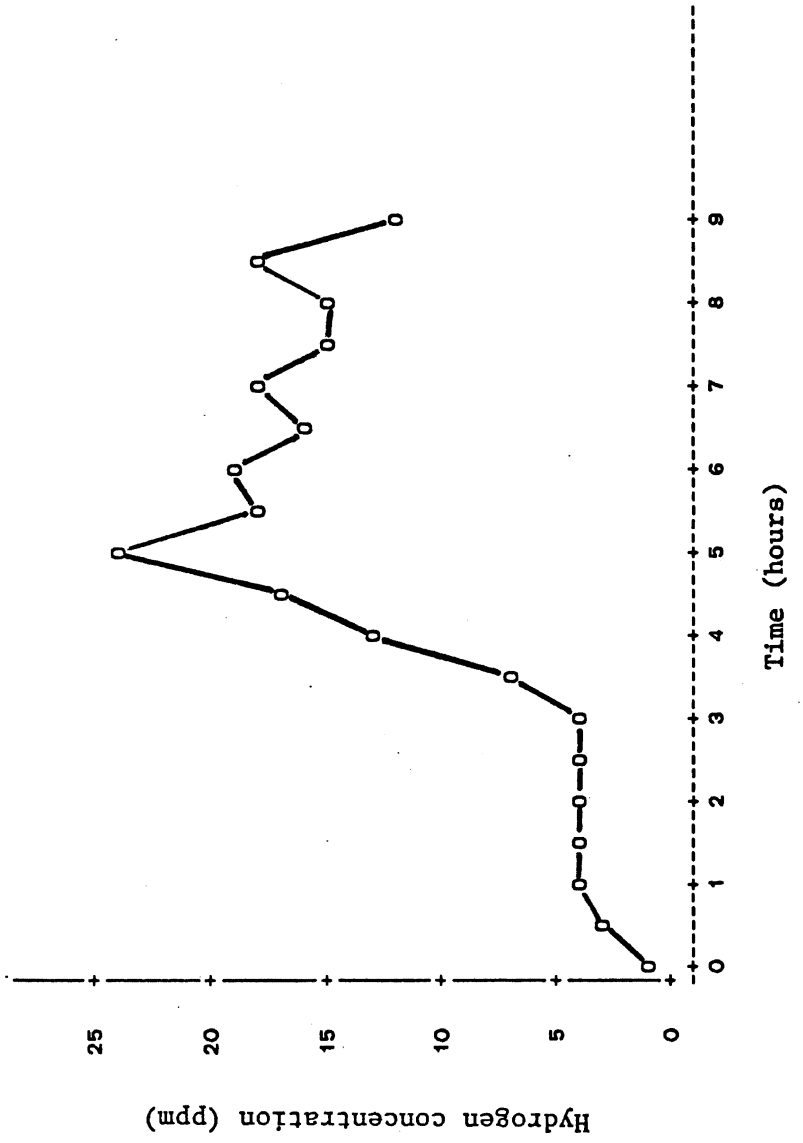
0 1 2 3 4 5 6 7 8 9
Time (hours)


Hydrogen concentration (ppm)
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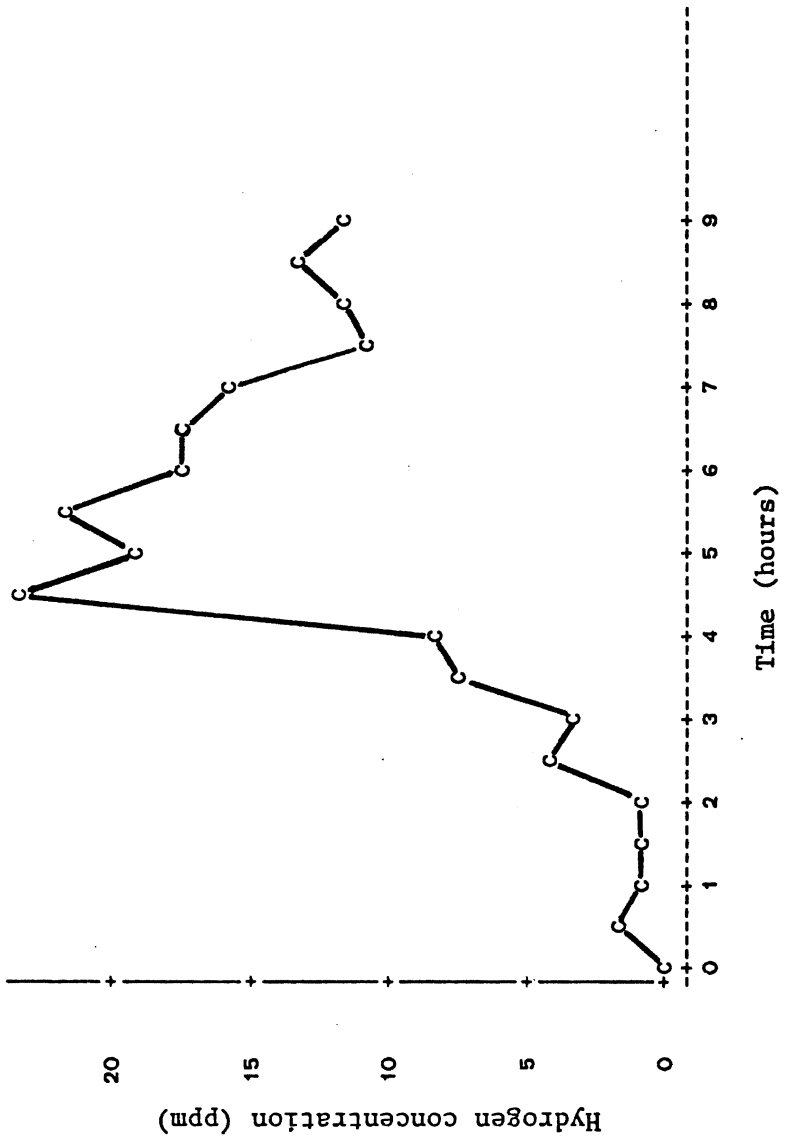
Time (hours)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Time (hours)
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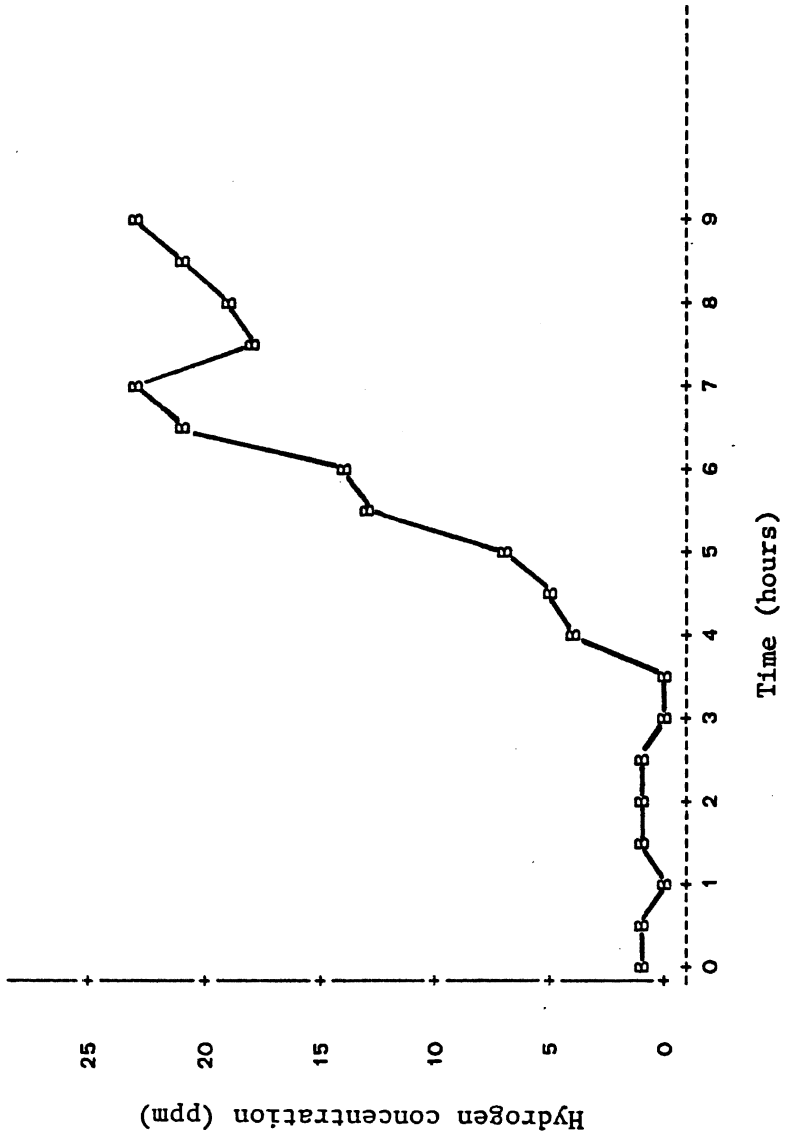
Hydrogen concentration (ppm)
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0 1 2 3 4 5 6 7 8 9
Time (hours)

CHAPTER V

BREATH HYDROGEN FROM PIGS INGESTING FIBER

Christa F. Hanson and Esther A. Winterfeldt

Abstract

The breath hydrogen test, a detection method for carbohydrate malabsorption, monitors hydrogen gas production by intestinal bacteria. It also may be useful for monitoring microbial fermentation of fiber. Two Yorkshire barrows (65 kg) were fasted 12 h and fed meals with or without addition of corn bran, wheat bran, citrus flour, or powdered milk. Breath samples were obtained at intervals from -1 to 12 hours post-prandially. Hydrogen concentration in expired air, averaged across post-prandial h three to seven, was less when pigs were fasted than when fed a normal swine ration (2.3 vs 11.4 ppm). Adding wheat bran, corn bran, or powdered milk to the diet increased hydrogen concentration in expired air ($P<.01$). Means for hydrogen concentration were increased above basal by 2.0, 4.5, 6.5, and 8.2 ppm for every 100 g added citrus flour, wheat bran, corn bran, and powdered milk. Citrus flour, wheat bran, and corn bran contained, respectively, hemicellulose at <1%, 35%, and 66%; cellulose at 22%, 10%, and 20%; and lignin at 0.7%, 2.6% and 0.4% of dry matter. Breath

hydrogen concentrations were poorly correlated with cellulose and lignin but highly correlated with hemicellulose intake. Results suggest that gaseous hydrogen may be derived from hemicellulose reaching the large intestine, and breath hydrogen tests detect both fiber and lactose fermentation in the large intestine.

Key terms: hydrogen gas, fiber, pigs, intestinal bacteria, hemicellulose

Introduction

Fibrous components of plants have several important nutritional impacts. Dietary fiber may aid in relief from constipation and diverticular disease, and may help prevent hemorrhoids, varicose veins, cardiovascular disease, and certain types of cancer (1, 2). Various sources of fiber will alter lipid absorption, reduce the rate of carbohydrate absorption, modify bile acid and cholesterol metabolism, affect the availability of certain vitamins and minerals, and change the rate of passage of material through the gastrointestinal tract (3, 4). These effects of fiber can be attributed to specific physical or chemical properties of fiber, including density, hydration capacity, binding properties, and fermentability (5).

Claims for health benefits of dietary fiber come primarily from epidemiological studies (2, 6). In population studies, additional dietary variables, activity level and life style, other environmental

effects, and genetics may influence results and interpretations and prevent accurate evaluation of the specific effects of fiber consumption (7).

Many animal models provide alternate approaches to study of nutrient needs and interactions for man. In the study of fiber, however, differences among species in morphology and physiology of the gastrointestinal tract may alter results. For results to apply to humans, the gastrointestinal tract of animal models should be similar to that of humans. The gastrointestinal tract of rodents, the most commonly used laboratory animals, differs markedly from the gastrointestinal tract of humans. This difference has made researchers question the applicability to man of results of fiber research with rodent models (7, 8).

Pigs appear physiologically and anatomically more similar to humans than most other non-primate animals. They have been used successfully in dental, renal, visual, cardiovascular, and gastric research. Similarities of sensitivity and nutritional requirements of the pig to those of man enable researchers to use pigs to test various drugs, and to use young pigs to evaluate formulas for human infants (9). Anatomically, the size of each section of the gastrointestinal tract of the pig is comparable to that of the human, and like man, the pig is an omnivore. The pig's colon is sacculated like that of man, suggesting a similarity of function (10). In both man and the pig, digesta remain in the large intestine longer than in any other part of the intestinal tract (11). The pig is a convenient animal for

experimental digestive research. Pigs are large enough to modify surgically and the volume of digesta in the gastrointestinal tract provides adequate material for sampling. Pigs have weight ranges similar to humans of various ages and genetic backgrounds.

In this study, the response of pigs to various types of fiber was evaluated using the breath hydrogen test for carbohydrate malabsorption. The breath hydrogen test is a sensitive and accurate test that has been used successfully to monitor lactose intolerance in humans. This method, which is simple, non-invasive, and acceptable to human subjects, has been employed in a large number of experiments using humans (12). It is potentially useful for the investigation of effects of fiber in the intestinal tract. The test is based on several premises. First, hydrogen gas in the intestinal tract is assumed to arise from microbial fermentation. Hydrogen then passes into the bloodstream quickly and is expired via the lungs. Thereby, breath hydrogen concentrations rapidly reflect changes in bacterial metabolism in the gastrointestinal tract. These changes may be due to dietary changes (13). Consequently, the amount of hydrogen expired increases as the amount of fermentable material reaching the colon increases. Hydrogen expiration ceases when no fermentable material is available in the colon or large intestine (14).

Methods

Two Yorkshire barrows, weighing 65 kg, were selected from the Animal Science herd of Specific Pathogen Free pigs. The pigs, housed

in separate pens, were fed twice daily, and had free access to water throughout the study. Test materials included wheat bran (Shawnee Mills, Shawnee, OK), corn bran (Staley Manufacturing Co., Decatur, IL), citrus flour (Ben Hill Griffin, Inc, Frostproof, FL), and Camelot nonfat dry milk (C & M Marketing Co., Livonia, MI).

Fiber fractions were quantitated as outlined by Goering and Van Soest (15). Results are presented in Table 1. Physical characteristics of the fiber sources differed. Citrus flour was finely ground, the corn bran consisted of small particles and wheat bran ranged in size from powdery particles to particles larger than 2 mm in diameter. All test materials were produced for human consumption.

Each meal consisted of 750 g of dry diet. The basal portion of the diet consisted of, in percent; ground corn grain, 76; soybean meal, 21; dicalcium phosphate, 1.5; calcium carbonate, .75; NaCl, .50; vitamin-trace mineral premix, 0.25; chlortetracycline, 0.1. Test fiber sources replaced 60% of the basal diet or dry powdered milk replaced 36% of the basal diet. Water was added to test meals to speed consumption of feed. The meals were consumed within 20 min after feeding. Pigs were fasted for at least 12 h prior to each test meal. Breath samples were obtained immediately before and periodically after consumption of the test meal.

To collect breath samples, a face mask was devised, which covered the pig's nose and mouth. A one-way valve in the mask directed expired air into airtight aluminum bags. A plastic laminated aluminum

material (Reynolds Metals Co., Richmond, VA) was used for construction of these bags.

Pigs responded well to this testing method after an initial training period. During sampling, pigs were restrained only with a sliding panel, which prevented them from backing away from the face mask. This procedure insured a snug fit of the mask for collecting the breath samples.

All breath samples were analyzed within four h after collection using a gas chromatograph (Varian, model 920: Varian Associates, Walnut Creek, CA) equipped with a thermal conductivity detector and a 336 cm 0.16 cm ID column packed with 60-80 mesh 5A molecular sieve (Supelco, Inc., Bellofonte, PA). No hydrogen gas was detected in air from either the analytical laboratory or the animal room.

To determine the repeatability of the sampling technique, consecutive samples of breath were taken at 2 min intervals at three different times after a meal of corn plus soybean meal. Samples proved repeatable (within 3 ppm) in hydrogen concentration (Figure 1). Analysis of variance for the completely randomized design followed procedures outlined by Snedecor and Cochran (16).

Results

The breath hydrogen concentrations over a 24 h time period when pigs consumed the control (corn-soy) meal is shown by the dashed line in Figure 2. The pigs had been fasted approximately 12 to 15 h before feeding at time zero. Breath hydrogen concentration was near zero

before feeding and began to rise about 3 h after pigs were fed. Hydrogen concentration peaked 5 to 7 h after pigs were fed. After 8 h, hydrogen concentration fell below 10 ppm, and after 18 h, hydrogen concentration was below 5 ppm. In lactose intolerance research with humans, a breath hydrogen concentration exceeding 20 ppm after consumption of milk indicates lactose intolerance (17). This level also may be useful as an index of bacterial activity after consumption of fiber.

After feeding the pigs a meal containing fiber, breath hydrogen increased and peaked between three and seven h after consumption of the test meal (Figure 2). For comparison of fiber sources in subsequent trials, hydrogen concentrations in breath samples obtained from three to seven h after feeding were averaged. Test diets were fed to pigs in a random order.

The mean hydrogen gas concentration in breath between three and seven h after feeding was less when pigs were fasted than when pigs were fed the corn-soy ration (2.3 vs. 11.4 ppm). Adding wheat bran, corn bran, or powdered milk to the diet increased ($P<.05$) hydrogen concentration above that observed when pigs were fed the basal diet. The hourly hydrogen concentrations from three to seven h after feeding, per 100 g of test product added to the diet, are presented in Figure 3. The three to seven h period average, expressed as ppm of hydrogen per 100 g of test material substituted for basal diet is shown in Table 2.

The increase in hydrogen concentration with citrus flour was not significant, but feeding of wheat bran, corn bran, or powdered milk increased hydrogen concentration in breath ($P<.01$). The high level of hydrogen from the ingestion of lactose presumably reflects malabsorption of lactose by these pigs.

The chemical composition of the test fiber materials is shown in Table 1. Corn bran contained the greatest amount of cell wall material, most of which was hemicellulose. Wheat bran had approximately half as much hemicellulose and cellulose as corn bran, but about five times as much lignin. Citrus flour was low in hemicellulose, but had similar amounts of cellulose and lignin as the other fiber sources. The non-sequential NDF, ADF method of fiber analysis used may have underestimated the amount of fiber (pectin) in the citrus product since this procedure extracts soluble pectic materials, which would be found in a citrus product and comprise a portion of the dietary fiber.

Breath hydrogen concentrations were poorly correlated with cellulose and lignin intake ($r=-0.149$; $r=-0.105$ with $N = 3$) but correlated highly ($r=.99$; $P<.015$) with hemicellulose intake.

Discussion

The amount and type of fiber fed to pigs altered the amounts of hydrogen found in breath. Breath hydrogen response was related most closely to the amount of hemicellulose fed. This finding agrees with results of certain other research with humans. Tadesse and Eastwood

(18) found that breath hydrogen increased after consumption of hemicellulose and raffinose but not after consumption of cellulose, pectin, or lignin.

Breath hydrogen response to consumption of fiber may be partially dependent on physical and chemical structure of the fiber (18, 19, 20). Differences between fiber components in their effect on the intestinal flora may be limited by the ability of bacteria to infiltrate particles and solubilize fermentable structures. Furthermore, added fiber may reduce residence time in the gastrointestinal tract. In general, the greater the intestinal residence time, the greater the degree of fiber fermentation possible.

In humans, hydrogen production is directly proportional to the quality of nonabsorbable carbohydrates available to colonic bacteria (21). Breath hydrogen excretion is responsive to consumption of food and follows a uniform excretion pattern (13). Since hydrogen is produced during bacterial fermentation of fiber, the breath hydrogen test appears useful to study fermentation of fiber in the intestinal tract of pigs. Pigs consumed large amounts of fiber at one time, without the necessity of food preparation required in human experiments.

Breath hydrogen tests appear to detect both fiber and lactose fermentation in the large intestine of pigs and humans. Since dietary fiber sources differ in the amount of hydrogen that is generated, the nutritive value and degree of digestibility of dietary fiber probably differs depending on chemical composition and physical structure of

fiber. Whether the desired components of fiber are the same or different from the components that increase hydrogen production in the colon must be resolved by further research.

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TABLE 1

Composition of fiber sources (%)

Source	Hemicellulose*	Cellulose+	Lignin#
Wheat bran	35.0	9.7	2.57
Citrus flour	<1.0	21.9	0.66
Corn bran	65.8	19.6	0.37

* NDF minus ADF + ADF minus lignin # Permanganate lignin

TABLE 2

Hydrogen response to consumption of test materials

Test material	Change in H_2 concentration (ppm) per 100 gm test material
Corn bran	6.5*
Wheat bran	4.5*
Citrus flour	2.0
Powdered milk	8.2*

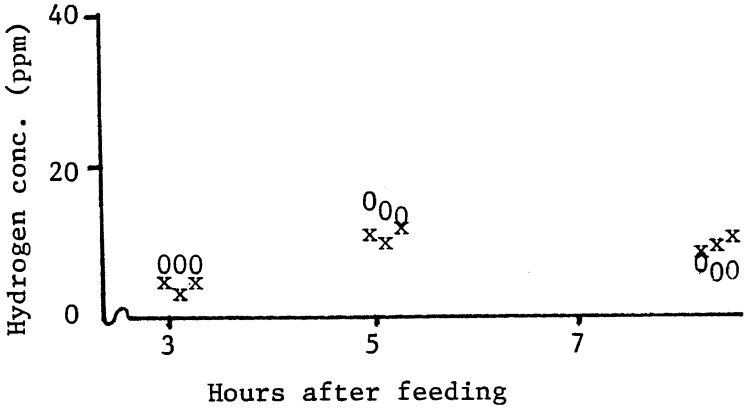
* Greater than basal (corn-soy) diet ($P<.01$).

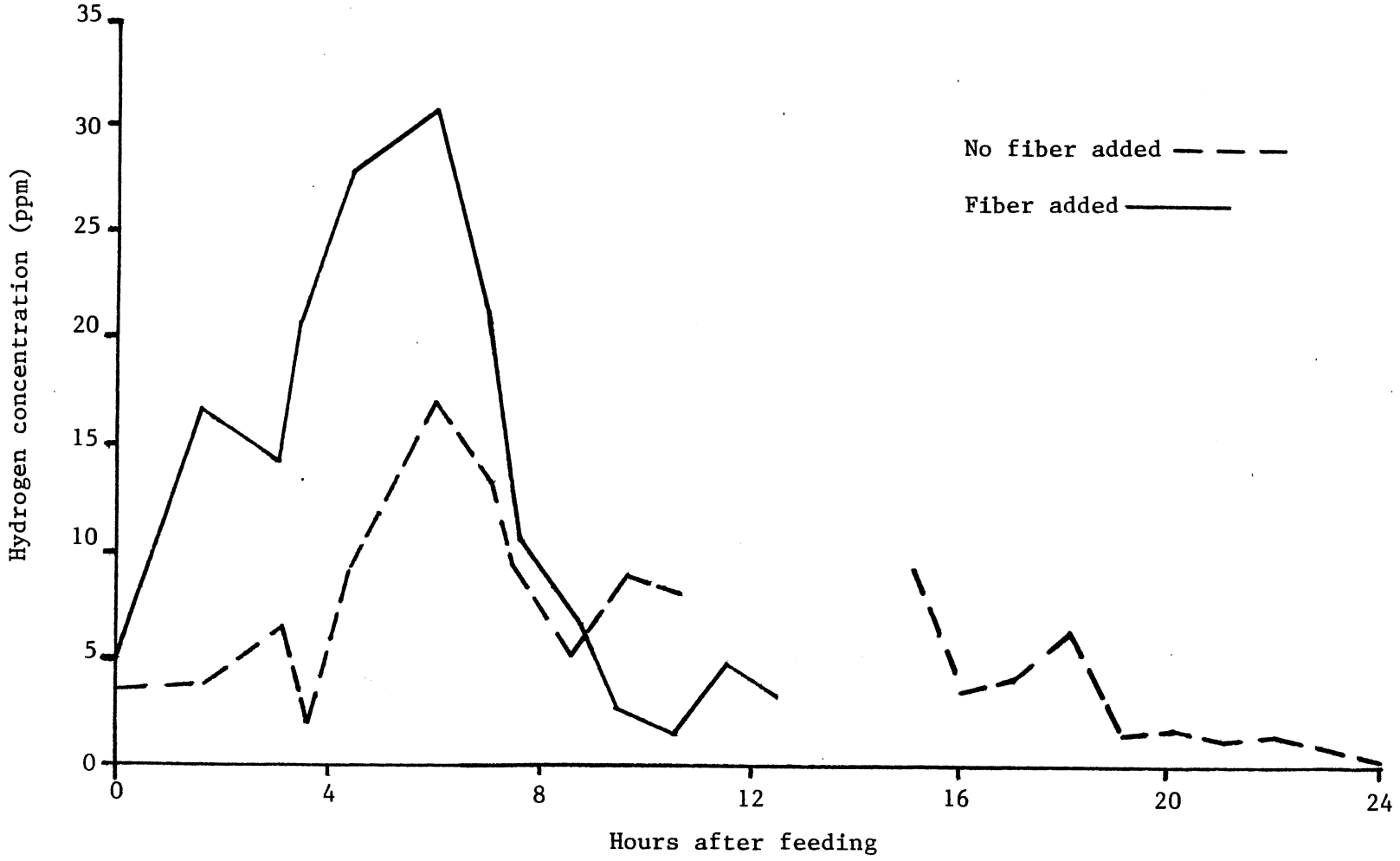
Legends for Figures

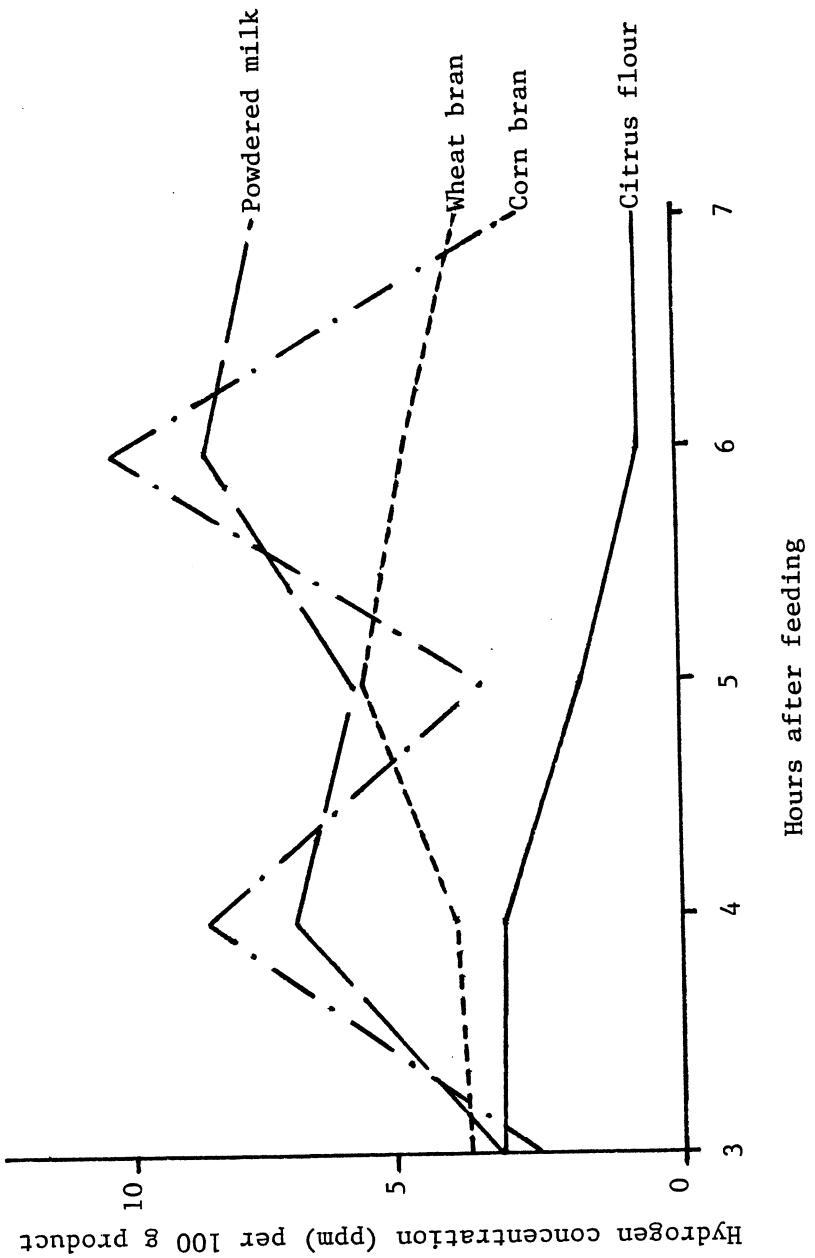
FIG. 1. Repeatability of sampling and analysis. Three consecutive samples taken from pig A (x) and pig B (o) at 3, 5, and 7.5 h after a corn-soy meal.

FIG. 2. Breath hydrogen concentration over 24 h from pigs fed 750 gm corn-soy or 450 gm wheat bran plus 300 gm corn-soy.

FIG. 3. Average breath hydrogen concentration from hours three to seven for each diet.


40
20
0
Hydrogen conc. (ppm)
3
5
7
Hours after feeding


35
30
25
20
15
10
5
0
Hydrogen concentration (ppm)
No fiber added
Fiber added
0
4
8
12
16
20
24
Hours after feeding


Powdered milk
Wheat bran
Corn bran
Citrus flour
10
5
0
3
4
5
6
7
Hydrogen concentration (ppm) per 100 g product
Hours after feeding

CHAPTER VI

PASSAGE TIME AND DIGESTIBILITY MEASUREMENTS IN PIGS FED OAT OR CORN BRAN

Christa F. Hanson, Esther A. Winterfeldt, and Charles V. Maxwell

Abstract

Five 110 kg ileally cannulated Yorkshire barrows were fed diets containing 20% corn bran, 40% oat bran, or a corn-soy control diet with two weeks on each diet. Ileal samples were collected and passage times to the ileum measured three times (days 1, 6, and 13) during each of the three periods. Fecal samples were collected daily. Dry matter and fiber content were measured and pre-ileal and total tract digestibilities were determined. After one week of feeding diets containing added fiber, dry matter content of feces stabilized at about 34% for corn, 36% for oat and 37% for the basal diet. Rate of passage of ferric oxide to the ileum changed with adaptation to the diet, and after six days tended to be slowed with corn fiber and speeded with oat. Hemicellulose content of ileal and fecal dry matter increased with corn bran or oat bran in the diet. Cellulose in ileal dry matter but not in fecal dry matter was increased with added corn

bran. This may reflect digestion of cellulose from corn bran in the cecum and large intestine. Percent lignin in ileal and fecal dry matter was increased ($P<.05$) when oat bran was fed. Results suggest that the gastrointestinal tract of pigs adjusts both in rate of passage and composition of feces to dietary fiber after a period of about one week. The percentage of dietary hemicellulose digested ahead of the cecum and in the total tract for corn bran diet was 41.0 and 86.8 compared with 45.8 and 93.7 for the oat bran diet. Comparable figures for cellulose were 38.4 and 87.4, and 14.4 and 77.9, respectively, for the corn and oat diets. These values indicate that about half of the hemicellulose digestion and about two-thirds of the cellulose digestion occurred in the cecum and large intestine. Oat bran, the fiber source containing the greater amount of non-cell wall fiber, accelerated passage to the ileum the most, while fecal fiber and moisture were increased more with corn bran, the fiber source higher in hemicellulose and cellulose.

Introduction

Fiber, being resistant to animal and human digestive enzymes, is available for fermentation by bacteria in the gastrointestinal tract (1, 2). Since naturally occurring plant fiber varies in chemical and physical composition, the degree of fermentation will vary (3, 4). Generally, hemicellulose is fermented more extensively than cellulose in nonruminants (5), while ruminant animals digest hemicellulose and cellulose to similar degrees (6). However, the monogastric large

intestine, like the rumen, is anaerobic, and the anaerobic bacteria present are similar in both the ruminant and monogastric animal (7).

In pigs, digestion of fiber begins in the stomach (8). Over 38% of dietary hemicellulose disappeared from the gastrointestinal tract of pigs anterior to the large intestine and digestion of hemicellulose continued in the large intestine (9). Cellulose digestion by pigs of similar weights, however, varied considerably (10).

Since intestinal bacteria can adapt to available nutrients, adaptation to digest more fiber over time might be expected. The microflora of the pig adapts to lactose ingestion with increased lactase activity. Capacity and volume of the large bowel and cecum also increased (4). As pigs increased in body weight, digestibility of crude fiber increased, and pigs more than 180 kg digested crude fiber more fully than did pigs less than 100 kg (11). However, Kass et al. (9) detected no adaptation in ability to digest fiber after feeding a high fiber diet for several months. Some researchers have indicated that digestion of cellulose in the pig occurs only by bacterial fermentation in the lower tract (9); however, cellulose disappearance prior to the large intestine has been reported (12). The extent of cellulose fermentation is affected by the type of cellulose present and pH of the medium, with an optimal pH for fermentation about 7.0 (11).

Increasing the percentage of fiber in the diet usually speeds passage rate through the total tract and increases fecal volume in nonruminants and humans (9, 13). Yet, various fibers may affect

transit time differently. High cellulose material appear to speed transit time, while soluble fiber may slow passage time (1). Faster passage could decrease the amount of time available for digestion and could cancel the effect of an increased fermentation rate.

The objective of this experiment was to measure in pigs the site and extent of fiber digestion, fecal composition, passage time to the ileum, and adaptation to consumption of diets supplemented with oat and corn bran.

Methods

Five 110 kg Yorkshire barrows were selected from the Animal Science Specific Pathogen Free herd and fitted with cannulas about 15 cm from the cecum. The T cannulas were constructed from polyethylene tubing fused with cyclohexanone. Pigs were housed in individual pens and were fed each day at 8 am and 5 pm. Water was available at all times and 1 l of water was mixed with each meal. Diets consisted of a basal corn-soy diet without added antibiotics, or this diet with fiber from one of two sources replacing a portion of the basal diet. Oat bran (Quaker Oats Co., Barrington, IL) was added at a level of 40% or corn bran (Staley Manufacturing Co., Decatur, IL) was added at 20% of the diet. The three diets were fed to the five pigs in a Youden square design with a single treatment sequence (control to oat bran to corn bran).

All diets contained 0.15% chromic oxide for quantitating digesta passage. The fiber composition of the oat and corn brans were

analyzed by the detergent method (14), with the feed components analyzed using the amylase modification of McQueen and Nicholson (15). Table 1 lists fiber composition and basal feed components.

Passage time from the mouth to ileum was measured on days 1, 6, and 13 of each period. To measure passage time, each pig received 5 gm of ferric oxide with its 8 am meal and passage time was calculated as the time from initiation of the meal to the time at which ferric oxide first colored the fluid leaving the ileal cannula. Ileal samples were collected and analyzed for dry matter and fiber components and for chromium (16). Daily ileal flow and fecal output were calculated from the chromic oxide concentration of feed and samples from various points in the digestive tract, and digestibilities were calculated for each nutrient from the dietary intakes and the amount of nutrient passing a given point.

Fecal samples were collected daily for dry matter determination and were pooled from days 12 through 14 for measurement of fiber composition and estimation of digestibility. Results were analyzed using analysis of variance and means were compared using Duncan's multiple range test (17).

Results

Dry matter content of feces changed rapidly and widely during the first week after a dietary change. After stabilizing, feces from pigs fed the control diet were driest while feces of pigs fed the corn bran diet were wettest (figure 1). The mean dry matter percent of samples

from days 8 through 14 was greater ($P<.05$) for feces of pigs fed the control diet (37.9%) than for pigs fed the corn diet (34.3%). Total fiber content of ileal fluid during collections on days 6 and 13 of each period was greater for pigs consuming corn bran than for pigs consuming either the oat bran or the control diet (table 2). Residual fiber from the previous period added variation to composition of samples taken on day 1.

Hemicellulose content of ileal dry matter was greater for pigs fed corn bran than those fed the oat bran diet. Cellulose tended to be increased slightly with corn bran and decreased slightly with oat bran feeding. Lignin was greater when oat was fed than when regular feed or corn bran was fed. These changes generally reflected the fiber composition of the diet. However, lignin content of ileal fluid was greater when corn bran was fed than might be expected, since corn bran contained less lignin than the basal feed.

Concentrations of NDF and hemicellulose in feces were higher when pigs consumed corn bran while fecal ADF and lignin levels were higher with pigs consuming oat bran (table 3).

Tabular values present transit times to the ileum (table 4). In discussion, the terminology of speed of passage through the tract rather than time for passage will be used to avoid confusion between rate of passage and transit time. Speed of passage changes inversely to transit time. The more descriptive adjectives of slowed or speeded passage will be used. Passage time to the ileum on day 1 appeared to be influenced by the diet consumed during the previous period.

Switching from the control diet to oat bran appeared to slow passage rate on day 1 but speeded passage by day 13. Passage with oat bran consumption tended to be speeded from day 1 to day 6 and speeded further from day 6 to day 13. Switching from oat bran to corn bran slightly slowed passage rate. Passage to the ileum slowed further over time for pigs consuming corn bran. Passage was significantly slower for pigs consuming corn bran than for pigs consuming oat by day 13. Switching from corn bran to the control diet initially slowed speed of passage; then passage speeded, but the rate stabilized by day 6. Results suggest that pigs adjusted more rapidly to the control diet than to diets containing fiber.

Digestibilities of fiber fractions are listed in table 5. Addition of fiber to the diet depressed total digestibility both to the ileum and through the entire tract (tables 6 and 7) as might be expected when a less digestible fiber is added to a highly digestible diet. Apparent digestibilities of both dry matter and fiber were depressed by addition of fiber to the diet.

Corn bran consumption decreased pre-ileal and total tract dry matter digestion. No apparent adaptation to diets was observed based on ileal digestibilities, however bacterial adaptation may have influenced post-ileal digestion during the trial. Liquid passage from the ileum of pigs fed corn bran almost tripled with time on the diet while no change was apparent with the oat or control diet over time. Relative to liquid passage, dry matter passage changed little with diet or time on a diet.

Corn bran altered physical characteristics of ileal material. When corn bran was fed, ileal chyme was more granular and clogged the cannula openings readily, occasionally forcing the cannula out of the intestine. Ileal fluid of pigs fed corn bran also appeared to have a large quantity of free liquid present.

Pigs fed oat bran had ileal chyme with greater gelling and foaming. In some pigs, the ileal fluid was a foamy mass with many gas bubbles, while in others the fluid was more stringy and gummy. In either case, little free liquid was present. Moisture content of the ileal chyme from pigs fed oat bran, however, was not greatly altered.

Physical characteristics of feces changed as pigs were switched to different diets. Oat bran diets resulted in feces with a more gummy texture while adding corn bran to diets resulted in feces that broke apart more easily.

After pigs had been fed high fiber diets for four weeks, an abrupt switch to the normal, lower fiber diet resulted in production of small, round feces (similar to normal sheep or rabbit feces). This observation indicates that the switch from high fiber back to a "normal" level of fiber also affects the function of the intestinal tract.

Discussion

Addition of fiber to the diet depressed digestibilities of dry matter and fiber fractions. These results agree with those of Kass et al. (9), Rust (18), and Collings et al. (19).

Patients with an ileal fistula (an ileostomy) have been used to study the extent of fiber digestion anterior to the cecum and large intestine. Digestibilities of 65% and 83% of consumed hemicellulose have been reported for male and female ileostomy subjects. This compared with 97% and 95% digestibilities for intact males and females (20). Other researchers have found between 0 and 21% of ingested hemicellulose from wheat bran was digested by subjects with ileostomies (21) compared to 50 to 54% for intact subjects (13). In this study, hemicellulose digestion prior to the ileum ranged from 41 to 54% following adaptation. Total tract digestion of hemicellulose was 87 to 94%. At both sites, hemicellulose from corn bran was less digested than hemicellulose from the oat bran or control diet.

Cellulose has generally proven less digestible than hemicellulose in monogastric animals. Cellulose digestion by ileostomy subjects consuming a mixed diet high in fruits and vegetables was only 15.5% (22). This compared with 77.6% for intact subjects consuming the same diet. In another report, between 0 and 26% of ingested cellulose was digested by ileostomy subjects consuming a high wheat bran diet (21) compared with digestibilities of 6 to 23% in intact subjects (13).

In this trial, 14 to 38% of the dietary cellulose was digested prior to the large intestine and digestion in the total tract reached 78 to 87%. The oat bran diet had the lowest pre- and post-ileal digestion values. Keys and Debarthe (12) found cellulose from coastal bermuda grass was 33% digested anterior to the large intestine of pigs, and Kass et al. (9) found 38.8% of cellulose was digested in

the small intestine of pigs fed a control diet. Results of these studies all indicate that cellulose, in addition to hemicellulose, is partially fermented prior to entering the large intestine in pigs as well as humans. Site of such fermentation has not been established.

In this study, animal feed did not contain antibiotics. Greater bacterial activity and fermentation of fibrous components may have been due to this formulation. Lignin digestibilities may be inflated due to the method of analysis, using sulfuric acid, which may not penetrate insoluble lumps in feed (23) and will not solubilize Maillard reaction products (3). Also, modification of lignin structure in the stomach and lower intestinal tract may reduce recovery in fecal samples (24).

Although particulate fibers have generally speeded passage through the total tract (9), in this study the corn bran diet slowed passage. Passage to the ileum was slowed in pigs fed diets supplemented with cottonseed hulls or corn silage but was not changed by feeding alfalfa hay in a trial by Rust (18). However, passage through the total tract was speeded by feeding these fibers. Also, in the pig, wheat traveled slower than corn to the ileum, but faster through the total tract (25).

In chickens, corn bran slowed passage when fed at 20% of the diet, but speeded passage at 40% of the diet compared to the control, low fiber diet (26). In humans, guar gum slowed passage to the ileum, while bran speeded passage to the ileum (27). Citrus flour and oat

bran also slowed passage to the ileum compared to corn and wheat bran (28).

Effects of fiber in the gastrointestinal tract are incompletely understood. Certain types of adaptation are apparent. Mechanical or osmotic changes may alter water content of feces. Changing from a high to a normal level of fiber produced feces in pigs that were higher in dry matter and which appeared abnormally dry. This same diet caused no adverse effect on appearance of feces before the animal was adapted to the high fiber diet. When human subjects who had been fed corn bran for three weeks were switched to a "normal" diet, many subjects complained of constipation and related discomfort (29). This suggests that variability in dietary fiber level may cause both adaptation and "de-adaptation" problems. Such changes may be responsible for certain common intestinal maladies of man.

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Table 1. Fiber composition of feed components.

Diet	Fiber fraction				
	NDF	Hemicellulose	ADF	Cellulose	Lignin
			percent		
Corn bran	79.6	59.7	19.9	19.0	0.82
Oat bran	18.2	15.3	2.9	0.92	1.84
Control[1]	12.6	11.7	4.9	3.79	0.91

[1] Consisted of, in percent; ground corn grain, 76; soybean meal, 21; dicalcium phosphate, 1.5; calcium carbonate, .75; NaCl, .50; vitamin-trace mineral premix, .25, to provide, in mg per kg diet: retinyl acetate (100 IU/mg), 44; cholecalciferol (250 IU/mg), 1.8; DL-a-tocopherol acetate, 11.1; d-pantothenic acid, 22; niacin, 30; riboflavin, 4.4; cobalamine, .022; choline chloride, 440; zinc, 0.1; iron, 0.1; manganese, .03; copper, .011; iodine, .0001.

Table 2. Fiber composition of ileal dry matter at various times of adaptation.

Component	Diet	Day of measurement 1	6	13	mean
		percent			
NDF	Corn	53.6[a]	57.0[a]	49.3[a]	53.4[a]
	Oat	39.0[b]	38.0[b]	34.0[b]	36.8[b]
	Control	41.6[ab]	32.6[b]	36.1[b]	36.8[b]
ADF	Corn	14.5	15.0[a]	14.0	14.5[a]
	Oat	13.0	12.7[ab]	11.6	12.4[b]
	Control	12.6	11.0[b]	12.2	11.9[b]
Lignin	Corn	1.99[b]	2.62	2.72[b]	2.36[b]
	Oat	3.89[a]	3.07	4.16[a]	3.69[a]
	Control	1.82[b]	2.32	2.01[b]	2.05[b]
Hemicellulose	Corn	39.1[a]	42.1[a]	35.3[a]	38.9[a]
	Oat	25.9[b]	25.3[b]	22.3[b]	24.4[b]
	Control	28.9[b]	21.6[b]	23.3[b]	24.8[b]
Cellulose	Corn	11.7[a]	12.4[a]	10.9[a]	11.7[a]
	Oat	8.2[b]	9.1[b]	6.5[b]	7.9[b]
	Control	9.7[ab]	7.3[b]	8.7[ab]	8.6[b]
Total fiber[1]	Corn	52.8[a]	57.2[a]	48.9[a]	52.9[a]
	Oat	38.0[b]	37.5[b]	32.9[b]	36.0[b]
	Control	40.4[ab]	31.2[b]	34.7[b]	35.4[b]

[ab] Means in a column within a fiber component with different superscripts differ ($P<.05$).

[1] Sum of hemicellulose, cellulose and lignin.

Table 3. Fiber composition of fecal dry matter with various diets.

Diet	Fiber fraction				
	NDF	Hemicellulose	ADF	Cellulose	Lignin
	percent				
Corn bran	35.4[a]	21.7[a]	13.8[ab]	6.1	5.6[b]
Oat bran	23.7[b]	8.0[b]	15.8[a]	5.3	8.1[a]
Control	22.0[b]	9.1[b]	12.9[b]	6.0	4.6[b]

[ab] Means in a column with different superscripts differ ($P<.05$).

Table 4. Passage time of color marker to terminal ileum.

Diet	Adaptation time, days 1	6	13
	Passage time, minutes		
Corn	131[bel]	152[ed]	185[ad]
Oat bran	175[abe]	149[e]	104[bd]
Control	208[ae]	133[d]	136[abd]

[1] Means in a column with different superscripts (a,b) differ ($P<.05$) and means in a row with different superscripts (d,e) differ ($P<.05$).

Table 5. Digestion of fiber fractions to the ileum and in the total tract of pigs.

Diet	Day	Fiber fraction		
		Hemicellulose	Cellulose	Lignin
		Digested prior to the ileum, %		
Corn bran	1	31.1	30.3^{b}	9.2^{b}
Corn bran	6	3.6^{c}	4.9^{b}	-39.2^{b}
Corn bran	13	41.0	38.4	-18.3^{b}
Oat bran	1	41.4^{b}	-1.2^{b}	-0.9^{a}
Oat bran	6	44.9^{b}	-5.5^{b}	24.8^{b}
Oat bran	13	45.8	14.4	-15.8^{b}
Control	1	18.8^{a}	2.8^{a}	30.0^{a}
Control	6	62.1^{a}	52.3^{a}	37.9^{a}
Control	13	53.9	37.3	40.9^{a}
		Digested in the total tract, %		
Corn bran	13	86.8^{b}	87.4^{a}	12.6^{c}
Oat bran	13	93.7^{a}	77.9^{b}	31.7^{b}
Control	13	92.5^{a}	82.3^{b}	46.9^{a}

^{a,b,c} Means with different superscripts for different fiber sources within a day and sampling site differ ($P<.05$).

Table 6. Digestion of dry matter, organic matter and ash to the ileum and in the total tract of pigs.

Diet	Day	Component		
		Dry matter	Organic matter	Ash
		Digested prior to the ileum, %		
Corn bran	1	55.4[b]	59.5[b]	-37.9
Corn bran	6	42.5[b]	47.2[b]	-64.1
Corn bran	13	57.8[b]	62.8[b]	-54.0
Oat bran	1	64.5[a]	68.9[a]	-31.8
Oat bran	6	66.3[ab]	69.8[ab]	-11.1
Oat bran	13	61.6[ab]	66.2[ab]	-39.5
Control	1	63.3[a]	66.7[a]	-7.1
Control	6	72.7[a]	76.9[a]	-13.3
Control	13	70.5[a]	74.4[a]	-8.9
		Digested in the total tract, %		
Corn bran	13	84.7[b]	86.3[b]	49.1[a]
Oat bran	13	88.1[a]	90.4[a]	39.3[b]
Control	13	88.3[a]	90.7[a]	40.6[b]

[a,b] Means with different superscripts for different fiber sources within a day and sampling site differ ($P<.05$).

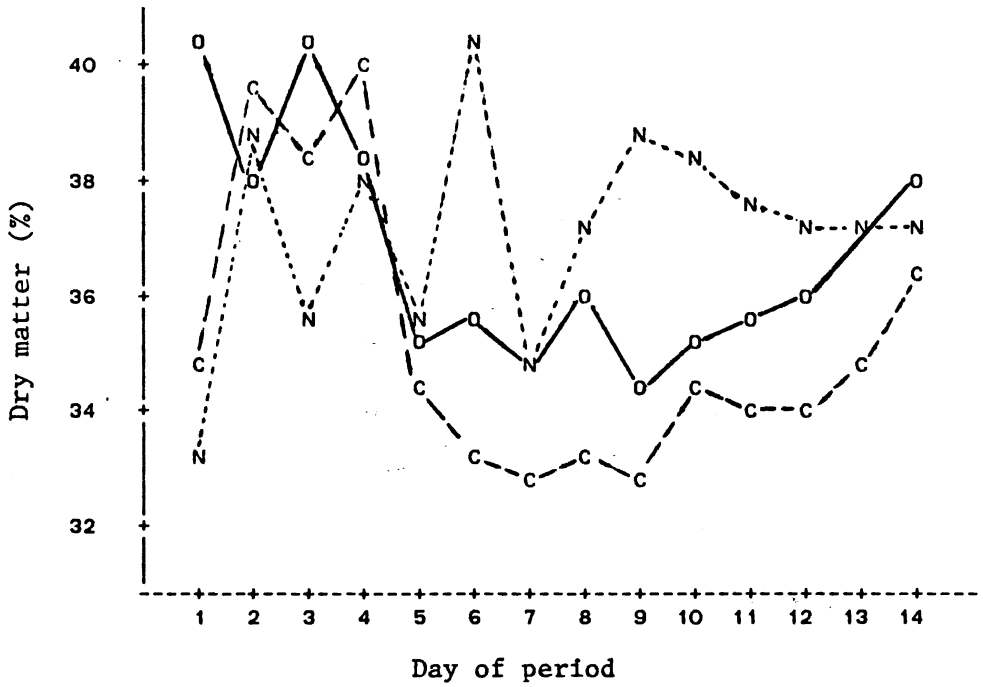
Table 7. Ileal and fecal dry matter and daily passage of wet and dry material.

Diet	Day	Component: Dry matter	Component: Dry matter	Component: Wet matter
		%	gm/day	gm/day
		Measured at the ileum		
Corn bran	1	11.2	816[a]	7450
Corn bran	6	10.8	1052[a]	10260[a]
Corn bran	13	4.2[c]	771[a]	19660[a]
Oat bran	1	9.8	655[b]	6720
Oat bran	6	13.7[b]	621[ab]	5230[b]
Oat bran	13	9.5[b]	708[ab]	8000[b]
Control	1	12.3	670[b]	5200
Control	6	9.2[a]	499[b]	5590[b]
Control	13	10.4[a]	538[b]	5200[b]
		Measured in feces		
Corn bran	13	34.0[b]	279[a]	822[a]
Oat bran	13	35.4[ab]	219[b]	620[b]
Control	13	37.6[a]	213[b]	571[b]

[a,b] Means with different superscripts for different fiber sources within a day and sampling site differ ($P<.05$).

Legend for Figure

FIG. 1. Dry matter in feces each day of period by fiber source. C = corn bran diet; O = oat bran diet; N = control (no added fiber). Mean percent dry matters for days 8-14 were: control, 37.3; oat, 35.6; corn, 34.3; with corn significantly ($P<.05$) wetter than control.


Dry matter (%)
40
38
36
34
32
1
2
3
4
5
6
7
8
9
10
11
12
13
14
Day of period

CHAPTER VII

DIETARY FIBER EFFECTS ON FEED INTAKE, PASSAGE RATE, HYDROGEN PRODUCTION, AND INTESTINAL MEASUREMENTS IN LAYING HENS

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Abstract

Corn bran, wheat bran, oat bran, or citrus flour displaced cornstarch at levels of 10, 20, or 40% of a semipurified diet fed to 65 two-year-old laying hens. As the level of fiber in the diet increased, intake of feed, amount of digesta in both the small intestine and cecum, passage rate, and hydrogen gas concentration increased, while with added fiber, digestibility declined. All fiber sources expanded the small intestine similarly. However, cecal expansion was greater with oat fiber than with other fiber sources ($P<.05$). Hydrogen production was greater with oat and citrus fiber than with corn and wheat bran in the diet. Digestibility with added corn bran was lower than with other added fiber sources. With the exception of citrus flour, hydrogen production was related to the volume of material in the cecum. Chickens fed the wheat diet ate more

feed and had the most stable weight, while chickens fed the citrus diet had the lowest intake, the greatest weight loss, and the longest passage time. One could speculate that greater water-holding capacity of the citrus fiber, due to presence of pectin, and a physiological limit to the volume of the small intestine may be responsible for these differences.

Key terms: fiber, passage rate, hydrogen production, bran, citrus flour, digestibility

Introduction

Fibrous components of plants may have several important effects on health. Dietary fiber may alter passage rate of material through the gastrointestinal tract, affect the size of certain sections of the digestive tract, and alter bacterial proliferation and products of bacterial action (1-3). In humans, foods which contain large quantities of insoluble fibrous material, such as wheat bran, decrease intestinal passage rate and increase fecal bulk compared to low fiber diets. Soluble fibers, such as guar gum, may delay gastric emptying and increase small intestine transit time (4). Pectin, a soluble fiber, does not appear to change transit time through the total tract (5, 6).

Factors affecting passage rate in poultry include level of intake (high intakes reduce transit time), particle size (fine particles travel faster than coarse particles), solubility (soluble constituents

pass more rapidly than coarse particles)(7); and fiber may speed (8) or slow (7) passage rate.

Studies of the effect of fiber on intake and growth have been inconclusive. Bran addition has both increased growth rate in some trials (9) and decreased feed intake and growth rate in others (10). Oat hulls and alfalfa meal increased feed consumption of laying hens (11), while pectin addition caused loss of weight in hens (12) and diarrhea and depressed growth in chicks (11).

The objective of this study was to determine the effect of four sources and three levels of fiber used in human diets on intake, performance, and gastrointestinal tract characteristics of laying hens.

Methods

Sixty-five White Leghorn laying hens (2 years of age), were fed a semipurified diet (table 1) with corn bran (Staley Manufacturing Company, Decatur, IL), wheat bran (Shawnee Mills, Shawnee, OK), oat bran (Quaker Oat Company, Barrington, IL), or citrus flour (Ben Hill Griffin, Inc., Frostproof, FL) displacing corn starch at levels of 10, 20, or 40% of the diet. Composition of these test fibers was quantitated as outlined by Goering and Van Soest (13) and is presented in table 2. Five birds were fed each level of fiber and five birds were fed a diet with no fiber added (control diet). Birds were housed individually in cages with separate waterers and feeders, and allowed

to eat ad libitum throughout the trial. The 65 birds were randomly assigned to the 13 diets.

Birds were selected from a flock of 252 based on similarity of feed intake and quality of egg shells when fed the OSU poultry ration, which is based on ground corn. Average intake of the selected birds was 126 g per day (range = 110 to 145 g). Birds were fed the semipurified diet for 10 days prior to the measurements of feed intake, passage rate, hydrogen production, and intestinal tract characteristics. Birds were weighed at the start and the end of the 14 day trial. Passage rate was determined by dosing each bird with a #3 gelatin capsule filled with ferric oxide and recording the time of first appearance of marker in feces. This procedure allowed passage time to be determined in birds consuming little feed and did not require birds to be fasted prior to dosing with marker. Passage rate was determined on days one and eight of the trial.

Total hydrogen (H_2) expired was determined by placing birds in a sealed chamber. The glass chamber was 30 cm high and 30 cm in diameter (19.2 l) with a glass lid fitted with two serum stoppers. The chamber was made gas tight by sealing the stoppers and rim with vacuum grease. After a bird had been in the chamber for 45 min, two 60 ml samples of gas were obtained using gas tight syringes via the serum stoppers. Gas samples were measured immediately by gas chromatography. Hydrogen gas concentration was determined using a gas chromatograph (Varian, model 920; Varian Associates, Walnut Creek, CA) equipped with a thermal conductivity detector and a 336 cm, 0.16 cm ID

column packed with 60-80 mesh 5A molecular sieve (Supelco Inc., Bellofonte, PA). Gas samples were obtained between 14 and 24 days after the birds were first fed the test diets. H_2 measurements were taken on 49 birds with similar numbers of birds taken from each treatment. Only birds that consumed more than 50 g of feed were used for measurements of digestibility, digestible dry matter intake, fecal dry matter percent, and hydrogen production.

Digestibilities were measured using total fecal output for three days. Fiber content of feces from two birds from each treatment was analyzed using the method of Goering and Van Soest (13).

At the end of the testing period (after 24 days on the test diet) two birds from each diet were asphyxiated using CO_2, and the small intestine and ceca were immediately removed, measured, and weighed. The contents were squeezed out of both the small intestine and ceca and weighed. The cecal and small intestinal contents were dried and reweighed. Analysis of variance for the 3 by 4 factorial design and means comparisons by Duncan's multiple range test followed procedures outlined by Snedecor and Cochran (14). Linear and quadratic effects were determined using a GLM statistical program (15). Means for the basal diet are included in tables but were not compared statistically with other means. Main effects are presented in tables but are discussed only when interaction of fiber source and fiber level were nonsignificant ($P>.05$).

Results

The main effects of fiber source and fiber level in the diet are summarized in tables 3 and 4, and specific effects of fiber are graphed individually and will be discussed separately. Values are presented for all birds measured, but not all measurements were obtained from all birds.

Feed intake was greatly affected by level of fiber in the diet. Averaged across fiber source, feed intake increased ($P<.05$) linearly with percentage of fiber added to the diet (table 3), however interactions between fiber source and level were apparent (figure 1). With more citrus flour added to the diet, feed intake decreased. Intake of feed was also influenced by source of fiber. Birds fed wheat bran consumed more feed ($P<.05$) than birds fed the citrus diet (table 4). Weight loss and egg production generally reflected amounts of energy consumed.

Times for ferric oxide to pass from mouth to feces for the birds fed various sources and levels of fiber are shown in figure 2. Averaged across source of fiber, passage rate was faster for birds fed 40% fiber than those fed 20% fiber diets. However, the passage time of birds fed 40% fiber was only slightly shorter than that of birds fed the control diet (with no added fiber).

Passage time was increased when 10% fiber from any source was added to the control diet (figure 2) and continued to increase for oat, corn, and citrus at the 20% level. With 40% fiber in the diet, passage time was reduced (table 3). In contrast, wheat bran reduced passage time at all levels above 10%. Averaged across fiber source,

mean passage time was greater for birds fed the citrus diet than for those fed the oat diet (table 4).

Hydrogen concentration (ppm) after 45 min of collection in the gas tight chamber for birds on various treatments is presented in tables 3 and 4. To adjust for differences in feed intake, this also is expressed as hydrogen per 100 g feed consumed (HPFC). These values are presented in tables 3 and 4 and in figure 3. Averaged across fiber sources, HPFC increased linearly with fiber added to the diet. Averaged across levels of fiber, HPFC was greater for citrus and oat than for wheat and corn. However, a fiber source by fiber level interaction was detected. This interaction is due to continued increase of HPFC with level of fiber from oat bran and citrus flour and a slight decrease in HPFC with higher dietary levels of corn and wheat bran.

Wet weight of material in the ceca increased linearly with fiber level of the diet. Wet weight, dry weight, and amount of water in the small intestine plus ceca were not significantly altered by fiber sources (table 4) although the wet weight tended to be greatest with birds fed oat bran and least with birds fed the citrus flour diet. The heaviest cecal contents on both a wet and dry weight basis were found in birds fed oat bran (figures 4, 5). The amount of water in the cecum was greater ($P<.05$) with the oat diet than either the citrus or corn diets (figure 6). As fiber percentage in the diet increased, digestibility of dry matter decreased and fecal dry matter decreased. Dry matter content of feces was greater with corn bran than with other

fibers and digestibility was lowest with this fiber source, as well. Digestibility of NDF, ADF, hemicellulose, and lignin also decreased with addition of fiber to the diet (table 5). Apparent fiber digestibilities are biased downward by unavoidable contamination of fecal material with feather particles and scaly integument. Shedding of this material was particularly high in these older birds. As fiber increased, fecal wet and dry weight output increased significantly. Compositions of fecal fiber by diet are shown in table 6. Dry matter digestibility was greater in chickens consuming the oat bran diet than the other fiber diets and least in those birds consuming the corn bran diet. Hemicellulose digestibility ranged from 94.9% in chickens consuming the oat bran diet to 10.8% in chickens consuming the citrus flour diet. Although main effects differ statistically, interactions between cellulose level and fiber source, and ADF level and fiber source were significant. Interactions also were observed for NDF, ADF, hemicellulose, and lignin content of fecal dry matter. Graphs 7 through 14 present digestibilities for the various fibers for the three levels in the diet.

Discussion

Addition of fiber to the diet altered the caloric density and the ratio of other nutrients to metabolizable energy. However, birds had free access to feed and could consume feed to meet their caloric needs. Calculated daily intakes of digestible dry matter for the 10, 20 and 40% fiber diets were 41.4, 41.8, and 37.4 g (table 3)

indicating that feed intake more than compensated for the decreased digestibility. As level of fiber increased, intake increased, and the amount of solids, liquids, and total digesta in both the intestine and ceca increased. However, there appeared to be a limit to the expansion of the tract, and at the highest fiber intake, rate of passage through the tract was accelerated, perhaps due to lack of capacity for further expansion of the intestinal tract. As weight of material in the cecum increased, H_2 production also increased. This result agrees with other research, which indicates that most fiber digestion occurs in the cecum of chickens (16).

Comparing results across fiber sources reveals that all fiber sources expanded the small intestine to similar volumes, however, cecal expansion differed among fiber sources.

H_2 production appears related to amount of wet and dry material in the ceca. With fermentation in the ceca, one would expect H_2 production. Cecal expansion may be due to the amount of fermentable material reaching the cecum and the amount of fermentation occurring in that organ (17). Results with citrus flour appear to be an exception to this idea, possibly due to its high pectin content. With citrus flour, H_2 production may be occurring in parts of the tract other than the cecum (18). In humans, breath H_2 increases after consumption of hemicellulose and raffinose, but not after consumption of cellulose , pectin, or lignin (19). Results of this study indicate that different factors are involved in the chicken, since the lowest H_2 levels occurred with the highest hemicellulose diets.

Water holding capacity may have limited intake of the citrus diet since the ratio of water to dry matter in the small intestine plus cecum was greater than with other fiber sources. This effect may be one of the reasons for the low intake and high weight loss often observed in chickens with diets containing high levels of pectin.

Results indicate that dietary fiber sources differ in their effects on intake, weight loss, egg production, hydrogen gas production, passage rate, and cecal volume. In general, higher levels of the fiber sources in the diet increased intake, hydrogen production, and cecal content wet and dry weight, and decreased weight loss and digestibility. Passage time increased with lower levels but decreased with higher levels of added fiber sources. These effects did not appear to relate to cell wall composition of fiber sources. For example, oat bran, with the lowest cell wall content, resulted in the highest hydrogen production and similar passage rates as products containing more cell wall materials. Both fiber source (or fiber composition) and level of fiber alter intake and digestive properties of a particular diet.

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TABLE 1

Composition of diets

Ingredient	%
Cornstarch[1]	25-65
Fiber source[2]	0-40
Meat meal[3]	30
Mineral mix[4]	5
Vitamin mix[5]	0.2

[1] Scrivner, Inc., Oklahoma City, OK.

[2] Fiber substituted for cornstarch at 10, 20 or 40% of diet.

[3] Southwest Recyclers, Inc., Oklahoma City, OK.

[4] In g per 100 kg diet: $Ca_3(PO_4)_2$, 850; KH_2PO_4, 1050; NaCl, 800; $CaCO_3$, 1900; Fe gluconate, 52; $MgSO_4$, 250; $MnSO_4$, 20; KI, 1; $CuSO_4$, 1.28; $ZnCO_3$, 10; $Na_2MoO_2 . 2H_2O$, 1.

[5] In mg per kilogram diet: retinyl acetate (100 IU/mg), 75.2; cholecalciferol (250 IU/mg), 10.6; DL-a-tocopherol acetate, 24; cobalamine, .007; riboflavin, 4.4; niacin, 14; Ca d-pantothenate, 15.3; choline chloride, 406; menadione sodium metabisulfite, 1.7; folic acid, 0.9; pyridoxine hydrochloride, 2.1; thiamine mononitrate, 1.9; d-biotin, 0.08. Supplied by Hoffman LaRoche, Dallas, TX.

TABLE 2

Composition of fiber sources (%)

Fiber source	Hemicellulose[1]	Cellulose[2]	Lignin[3]
Wheat bran	25.6	8.1	3.08
Citrus flour	8.2	16.2	1.70
Corn bran	59.7	19.0	0.82
Oat bran	18.2	0.9	1.84
Control feed	5.1	0.4	1.00

[1] NDF minus ADF [2] ADF minus lignin [3] Acid lignin

TABLE 3

Effects of fiber level on intake, performance, and intestinal measurements

Measurement	Fiber Level in Diet (%)				
	0	10	20	40	SE
		All birds[1]			
Feed Intake, g/day	29.4	28.9[c2]	50.4[b2]	68.8[a2]	6.1L[3]
Weight Loss, g/day	15.9	18.9[b]	8.8[a]	9.8[a]	2.7Q[4]
Eggs, no./wk	0	0.1[b]	0.5[ab]	0.95[a]	.20L
Passage time, min.	294	336[ab]	365[a]	286[b]	18.4
		Birds consuming > 50 gm feed/day[5]			
Feed Intake, g/day	51.2	55.6	64.9	72.0	5.8
Dry matter digest. %	79.6	73.7[a]	64.8[b]	53.4[c]	1.26
Digestible DM intake, g	40.7	41.4	41.8	37.4	4.09
Feces, dry matter, %	37.5	38.6[a]	37.1[ab]	32.5[b]	1.6
Hydrogen produced ppm per bird (45 min)	3.7	4.9[b]	16.6[b]	47.1[a]	9.7L
100g feed	4.6	7.7[b]	18.9[b]	61.0[a]	9.7L
		Two birds per fiber source and level[6]			
Small Intestinal contents					
Wet Weight, g	10.6	14.2	22.6	26.2	4.9
Dry Weight, g	1.91	3.28	5.20	5.82	1.3
Water, g	8.64	11.0	17.4	20.3	3.7
Cecal contents					
Wet Weight, g	1.51	1.44[b]	2.22[ab]	3.84[a]	.60L
Dry Weight, g	0.26	0.36[b]	0.58[b]	0.89[a]	.11
Water. g	1.50	1.60	1.95	2.94	.64
Intestinal plus cecal contents					
Wet weight, g	12.1	15.7	25.7	30.0	5.4Q
Dry weight, g	3.02	4.22	5.67	6.72	1.8
Water, g	13.3	14.1	21.0	23.3	5.2

[1] N = 5, 20, 20, and 20 for 0, 10, 20, and 40% fiber, respectively.
[2] Means in a row with different superscript letters differ (P<.05).
[3] Linear effect of added fiber (P<.05).
[4] Quadratic effect of added fiber (P<.05).
[5] N = 4, 10, 15 and 19 for 0, 10, 20 and 40% fiber, respectively.
[6] N = 2, 8, 8, and 8 for 0, 10, 20 and 40% fiber, respectively.

TABLE 4

Effects of fiber source on intake, performance, and intestinal measurements

Measurement	Fiber Source in Diet				
	Citrus	Corn	Oat	Wheat	SE
		All birds[1]			
Feed Intake, g/day	29.1[b2]	48.4[ab]	46.8[ab]	66.5[a]	7.1
Weight Loss, g/day	20.4[b]	10.6[a]	10.4[a]	10.7[a]	3.1
Eggs, no./wk	0.1[b]	0.2[b]	0.3[b]	1.3[a]	.23
Passage time, min.	379[a]	322[ab]	308[b]	316[ab]	21.5
	Birds consuming > 50 gm feed/day[3]				
Feed Intake, g/day	59.9[ab]	71.2[ab]	52.4[b]	74.4[a]	6.8
Dry matter digest. %	63.6[b]	51.0[c]	70.7[a]	65.1[b]	1.5
Digestible DM intake, g/day	38.0	34.6	37.6	47.7	4.81
Feces, dry matter, %	31.1[b]	43.1[a]	32.8[b]	34.7[b]	1.8
Hydrogen prod. ppm per					
bird (45 min)	46.9[a]	8.7[b]	45.3[a]	11.2[b]	12.2
100g feed	64.1[a]	10.0[b]	57.3[a]	12.6[b]	12.9
	Two birds per fiber source and level[4]				
Small intestinal contents					
Wet Weight, g	20.1	22.8	22.9	21.1	5.8
Dry Weight, g	4.06	5.98	4.79	4.69	1.5
Water, g	16.0	16.8	18.1	16.4	4.3
Cecal contents					
Wet Weight, g	1.71[b]	1.72[b]	4.43[a]	2.39[b]	.72
Dry Weight, g	0.31[b]	.56[b]	1.30[a]	.53[ab]	.12
Water. g	1.40[b]	1.87[b]	3.96[a]	2.00[ab]	.68
Intestinal plus cecal contents					
Wet weight, g	21.8	25.7	27.3	23.5	6.3
Dry weight, g	4.37	7.22	6.98	5.52	2.1
Water, g	17.4	22.6	25.2	19.0	5.7

[1] N = 15 for each fiber source.
[2] Means in a row with different superscript letters differ ($P<.05$).
[3] N = 8, 11, 13, and 12 for citrus, corn, oat, and wheat, respectively.
[4] N = 6 for each fiber source.

TABLE 5

Effects of fiber level on composition of feces and digestibility.

Component	Fiber Level in Diet (%)				
	0	10	20	40	SE[1]
Fecal composition, %					
NDF	22.0	25.1^{c}_{b}	28.2^{b}	33.9^{a}	0.69
Hemicellulose	11.0	9.9^{b}	11.3^{b}	15.4^{a}	0.86
ADF	11.0	15.2^{b}	16.8^{ab}	18.5^{a}	0.58
Cellulose	4.80	8.89^{c}_{b}	11.51^{b}	13.34^{a}	0.11
Lignin	2.90	3.49^{b}	3.15^{ab}	3.00^{a}	0.15
Digestibilities, %					
NDF	32.6	40.2^{a}	30.3^{ab}	16.7^{b}	4.87
Hemicellulose	51.0	69.6^{a}	73.2^{a}	-12.5^{b}	26.1
ADF	-9.7	-13.0^{a}	-38.5^{ab}	-47.4^{b}	9.84
Cellulose	-164.7	-87.0^{a}	-170.9^{b}	-157.2^{b}	20.97
Lignin	37.0	18.3	15.8	-2.0	7.27
Fecal output, g/day					
Wet weight	27.5	38.4^{c}	62.8^{b}	104.5^{a}	7.69
Dry weight	10.5	14.2^{c}	23.1^{b}	34.6^{a}	2.32

[1] Standard error of the mean, N = 8 for diets with added fiber.
[2] Means in a row with different superscript letters differ ($P<.05$).

TABLE 6

Effects of fiber source on composition of feces and digestibility.

Component	Fiber source in diet					
	None	Citrus	Corn	Oat	Wheat	SE[1]
Feces composition, %						
NDF	22.0	17.9[c2]	47.5[a]	18.6[c]	32.2[b]	0.80
Hemicellulose	11.0	-0.8[c]	32.1[a]	1.4[c]	16.1[b]	0.99
ADF	11.0	18.7[a]	15.4[b]	17.2[ab]	16.2[b]	0.68
Cellulose	4.80	13.56[a]	10.68[b]	10.67[b]	10.17[b]	0.66
Lignin	2.90	2.60[b]	2.78[b]	3.73[a]	3.73[a]	0.17
Digestibilities, %						
NDF	32.7	29.2[b]	11.2[b]	48.3[a]	27.6[b]	5.62
Hemicellulose	51.0	10.8	18.9	94.9	49.0	30.1
ADF	-9.7	0.8[a]	-9.7[a]	-101.3[b]	-21.6[a]	11.3
Cellulose	-164.7	-26.5[a]	-9.0[a]	-461.6[b]	-56.3[a]	24.2
Lignin	37.0	23.4[a]	-14.8[b]	14.5[a]	19.7[a]	8.39
Fecal output, g/day						
Wet weight, g	27.5	75.1[a]	90.1[a]	45.8[b]	80.6[a]	9.05
Dry weight, g	10.5	21.9[bc]	36.6[a]	14.8[c]	26.6[b]	2.73

[1] Standard error of the mean, N = 6 for diets with added fiber.
[2] Means in a row with different superscript letters differ ($P<.05$).

Legends for Figures

FIG. 1. Feed intake by laying hens fed various fiber sources and levels (B = no added fiber; O = oat bran; C = corn bran; W = wheat bran; I = citrus flour).

FIG. 2. Passage rate in laying hens fed various fiber sources and levels (B = no added fiber; O = oat bran; C = corn bran; W = wheat bran; I = citrus flour).

FIG. 3. Hydrogen production by laying hens fed various fiber sources and levels (B = no added fiber; O = oat bran; C = corn bran; W = wheat bran; I = citrus flour).

FIG. 4. Wet weight of cecal contents of laying hens fed various fiber sources and levels (B = no added fiber; O = oat bran; C = corn bran; W = wheat bran; I = citrus flour).

FIG. 5. Dry weight of cecal contents of laying hens fed various fiber sources and levels (B = no added fiber; O = oat bran; C = corn bran; W = wheat bran; I = citrus flour).

FIG. 6. Water contents of the ceca of laying hens fed various fiber sources and levels (B = no added fiber; O = oat bran; C = corn bran; W = wheat bran; I = citrus flour).

FIG. 7. Dry matter digestibility (%) by laying hens fed various fiber sources and levels (B = no added fiber; O = oat bran; C = corn bran; W = wheat bran; I = citrus flour).

FIG. 8. Wet fecal output (gm. per day) by laying hens fed various fiber sources and levels (B = no added fiber; O = oat bran; C = corn bran; W = wheat bran; I = citrus flour).

FIG. 9. Fecal dry matter output (gm. per day) by laying hens fed various fiber sources and levels (B = no added fiber; O = oat bran; C = corn bran; W = wheat bran; I = citrus flour).

FIG. 10. Neutral detergent fiber (NDF) digestion (%) by laying hens fed various fiber sources and levels (B = no added fiber; O = oat bran; C = corn bran; W = wheat bran; I = citrus flour).

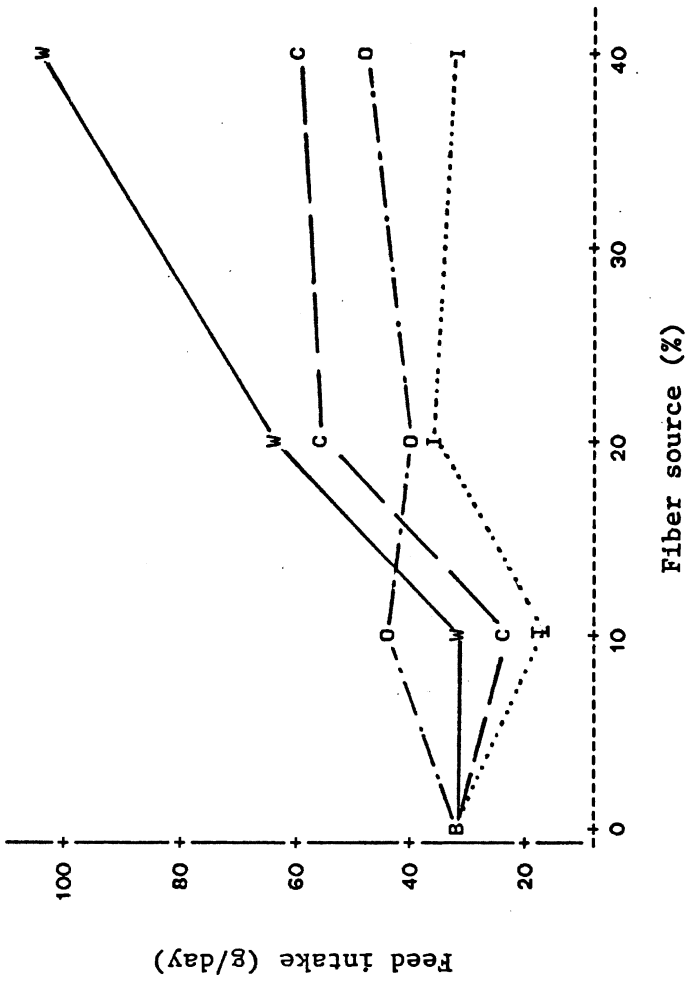
FIG. 11. Acid detergent fiber (ADF) digestion (%) by laying hens fed various fiber sources and levels (B = no added fiber; O = oat bran; C = corn bran; W = wheat bran; I = citrus flour).

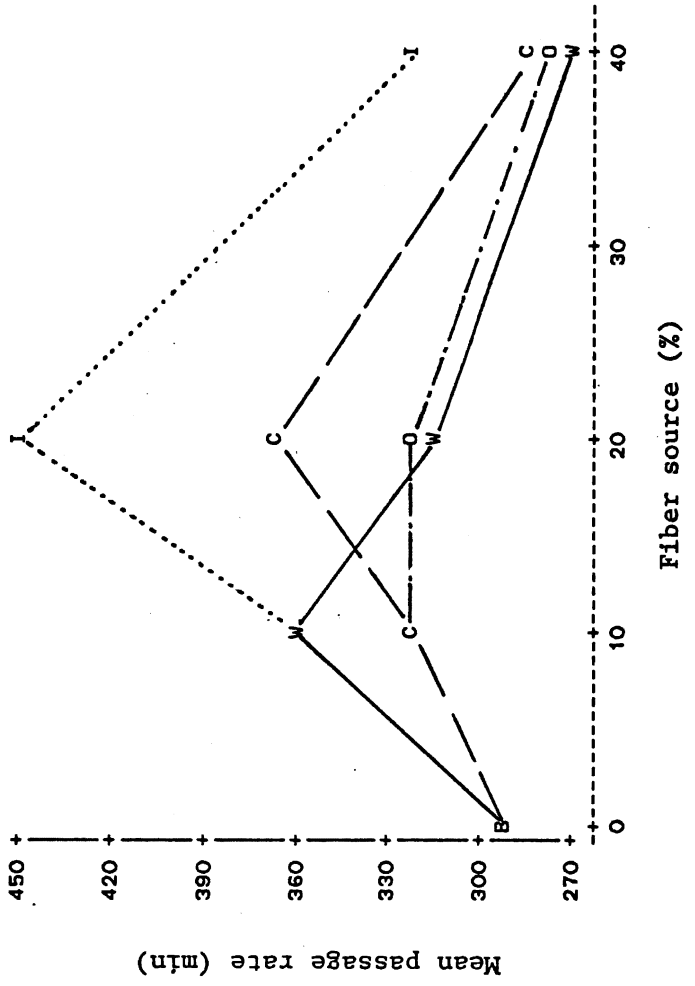
FIG. 12. Hemicellulose digestion (%) by laying hens fed various fiber sources and levels (B = no added fiber; O = oat bran; C = corn bran; W

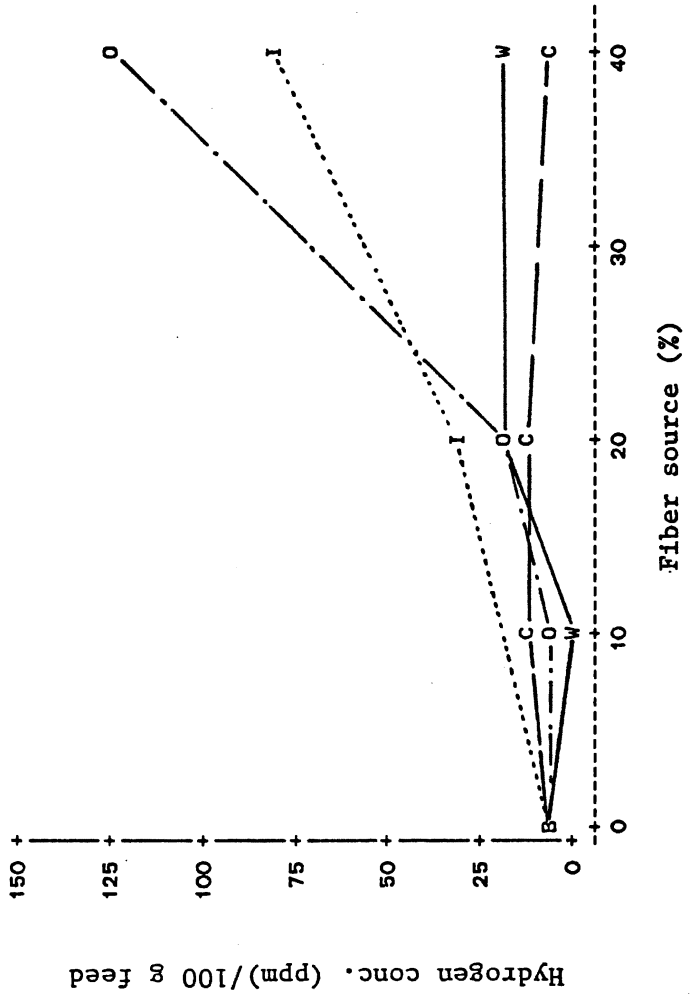
= wheat bran; I = citrus flour).

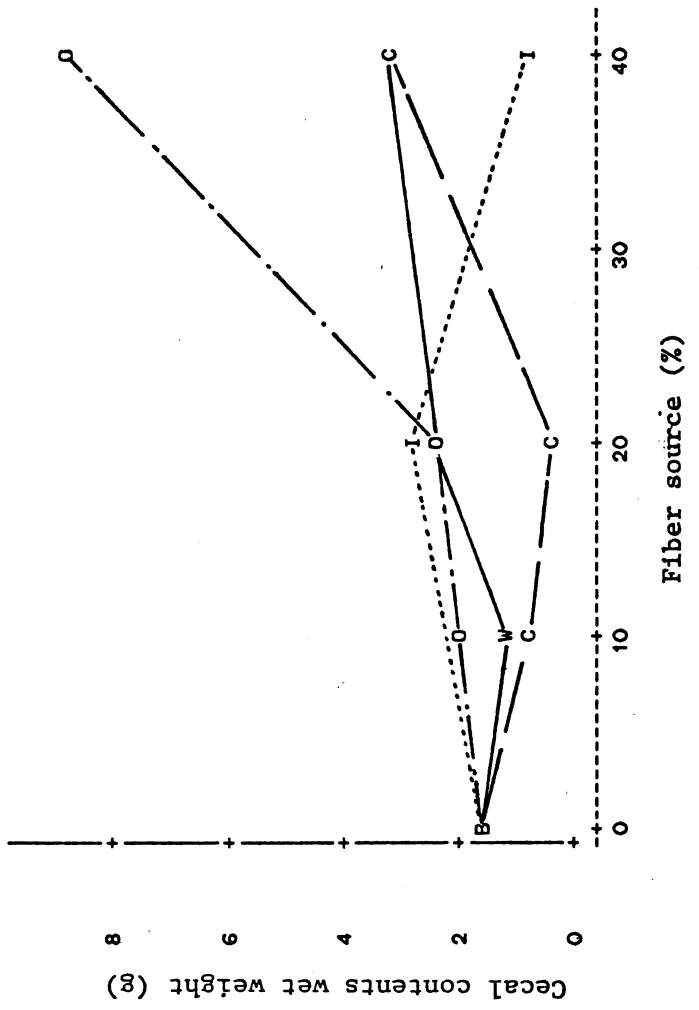
FIG. 13. Cellulose digestion (%) by laying hens fed various fiber sources and levels (B = no added fiber; O = oat bran; C = corn bran; W = wheat bran; I = citrus flour).

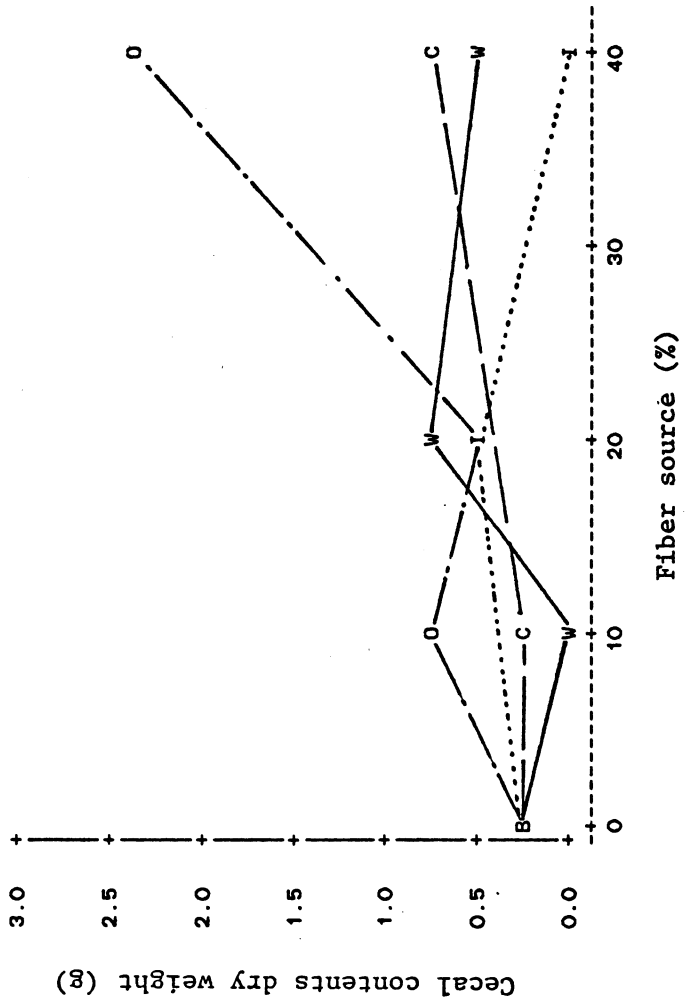
FIG. 14. Lignin digestion (%) by laying hens fed various fiber sources and levels (B = no added fiber; O = oat bran; C = corn bran; W = wheat bran; I = citrus flour).

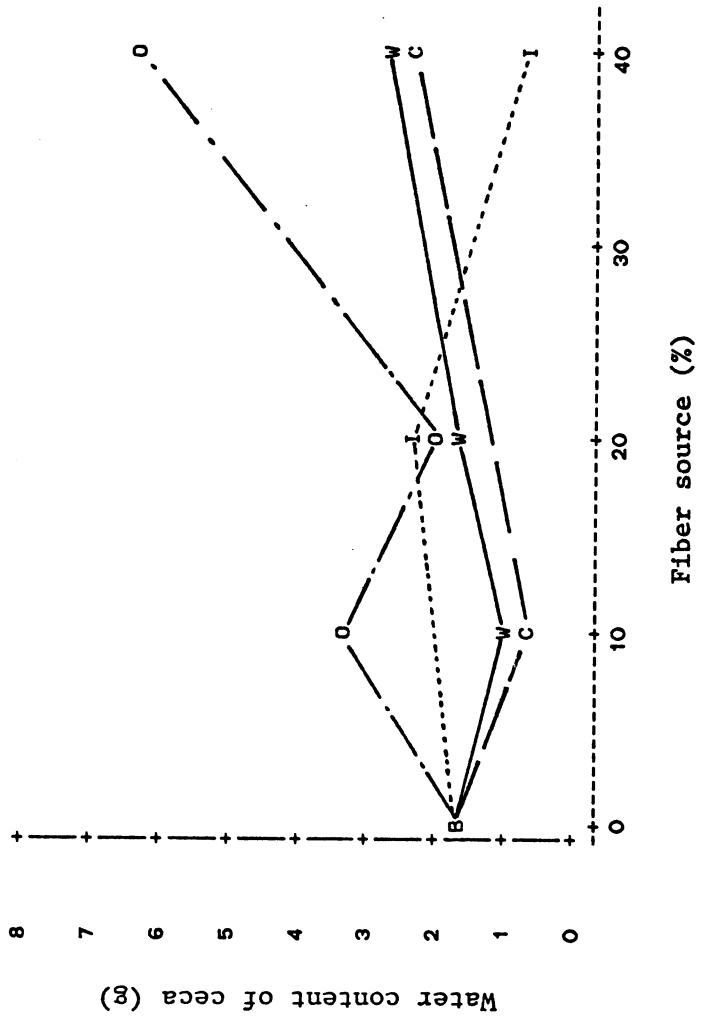

Feed intake (g/day)
100
80
60
40
20
0
10
20
30
40
Fiber source (%)
W
C
O
I
B

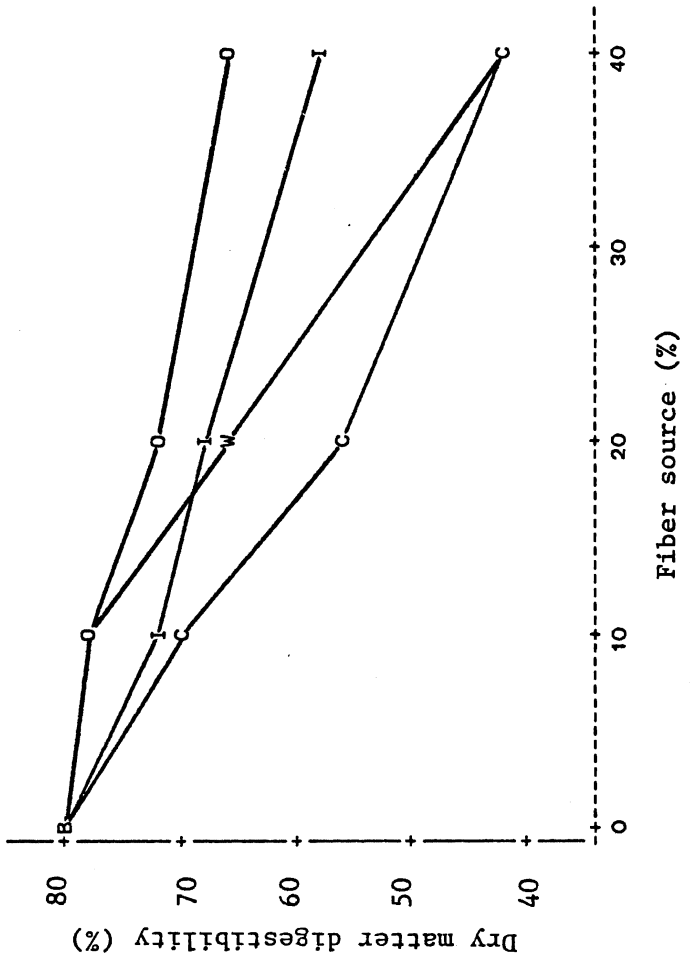

Mean passage rate (min)
450
420
390
360
330
300
270
0
10
20
30
40
Fiber source (%)
I
I
C
C
O
O
W
W
B

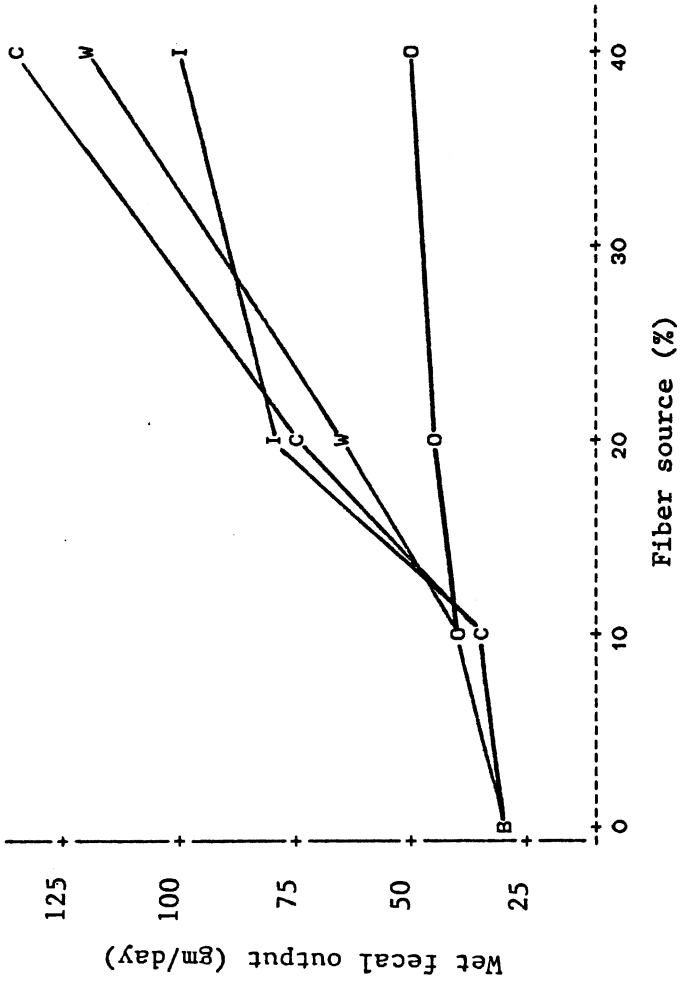

Hydrogen conc. (ppm)/100 g feed
150
125
100
75
50
25
0
0
10
20
30
40
Fiber source (%)
O
I
W
C
B

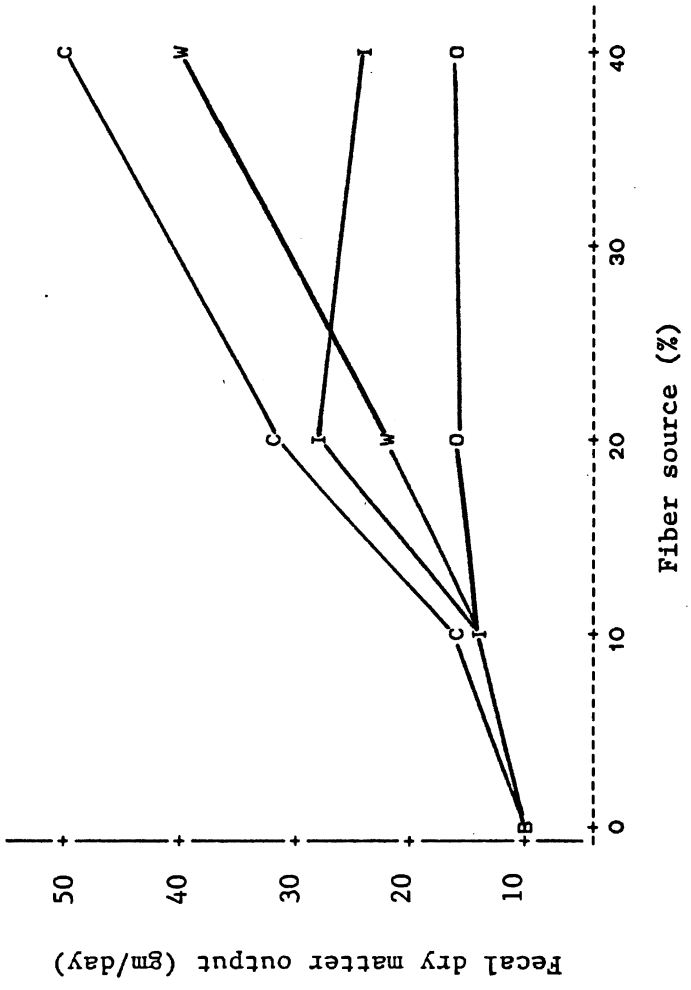

Cecal contents wet weight (g)
0
2
4
6
8
Fiber source (%)
0
10
20
30
40
B
W
C
O
I
C
O
I
C
O

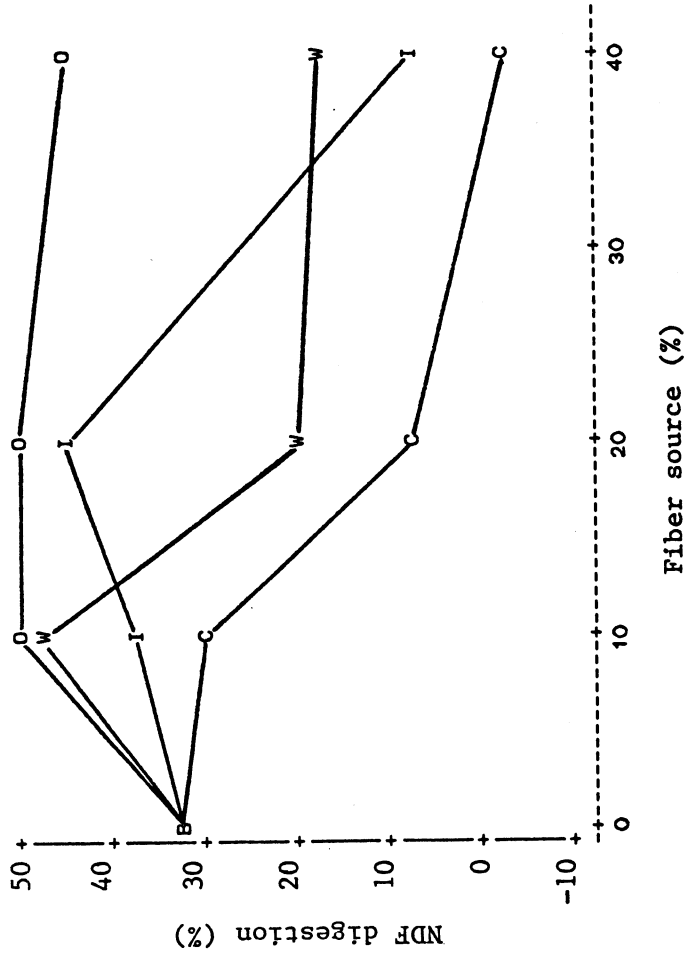

Cecal contents dry weight (g)
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0
10
20
30
40
Fiber source (%)
O
C
W
T
B

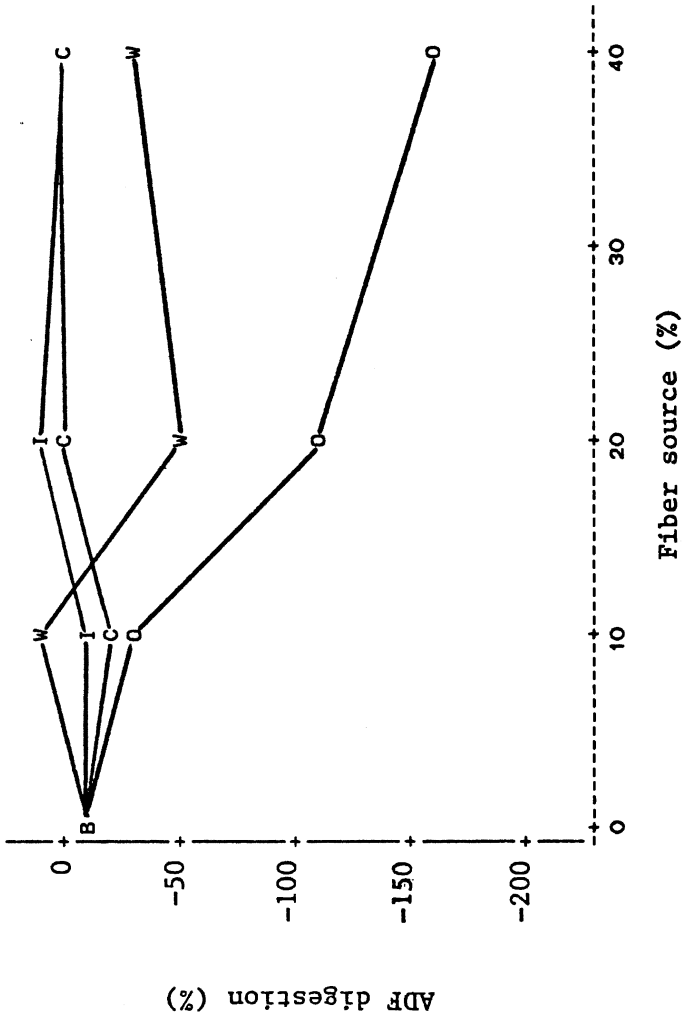

Water content of ceca (g)
0
1
2
3
4
5
6
7
8
Fiber source (%)
0
10
20
30
40
O
W
C
I
B

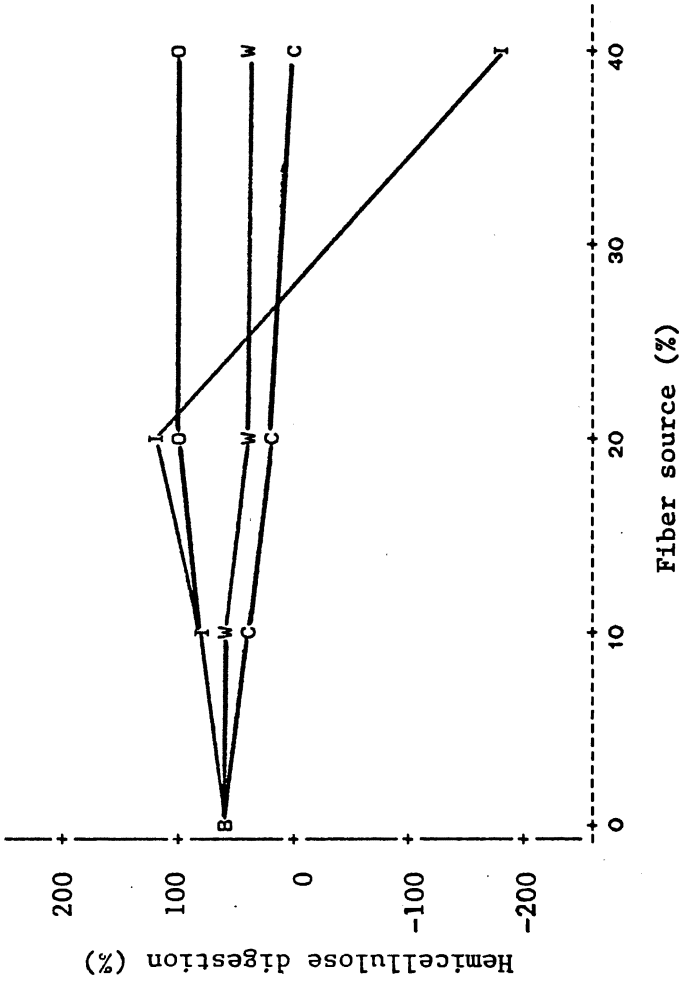

Dry matter digestibility (%)
80
70
60
50
40
Fiber source (%)
0
10
20
30
40
B
O
I
C
O
I
W
C
O
I
C

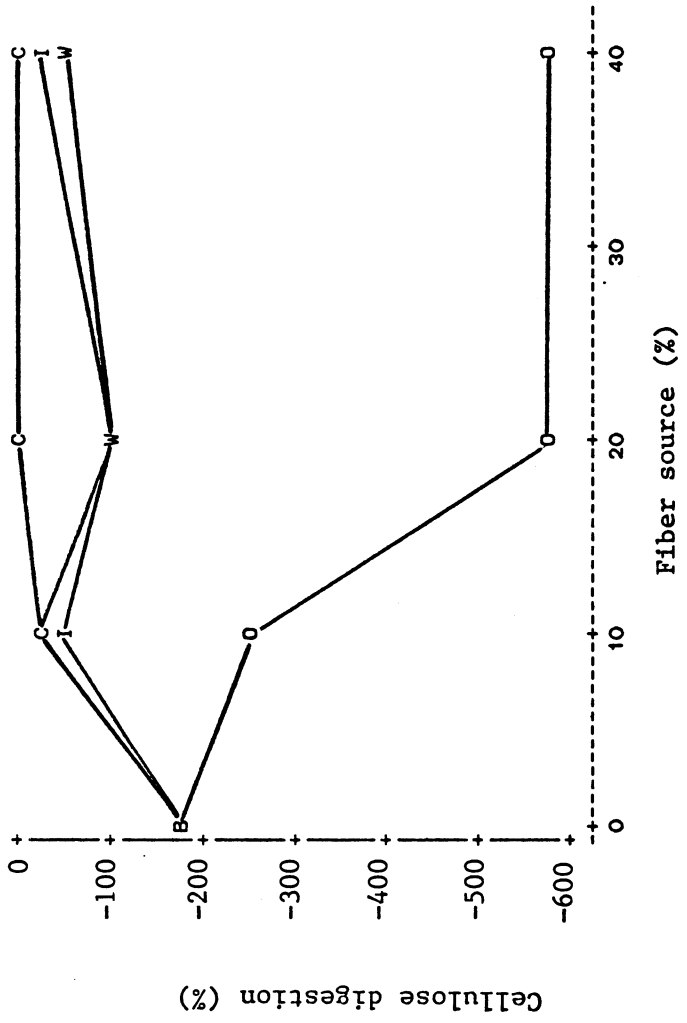

Wet fecal output (gm/day)
125
100
75
50
25
0
10
20
30
40
Fiber source (%)
C
W
I
O
B

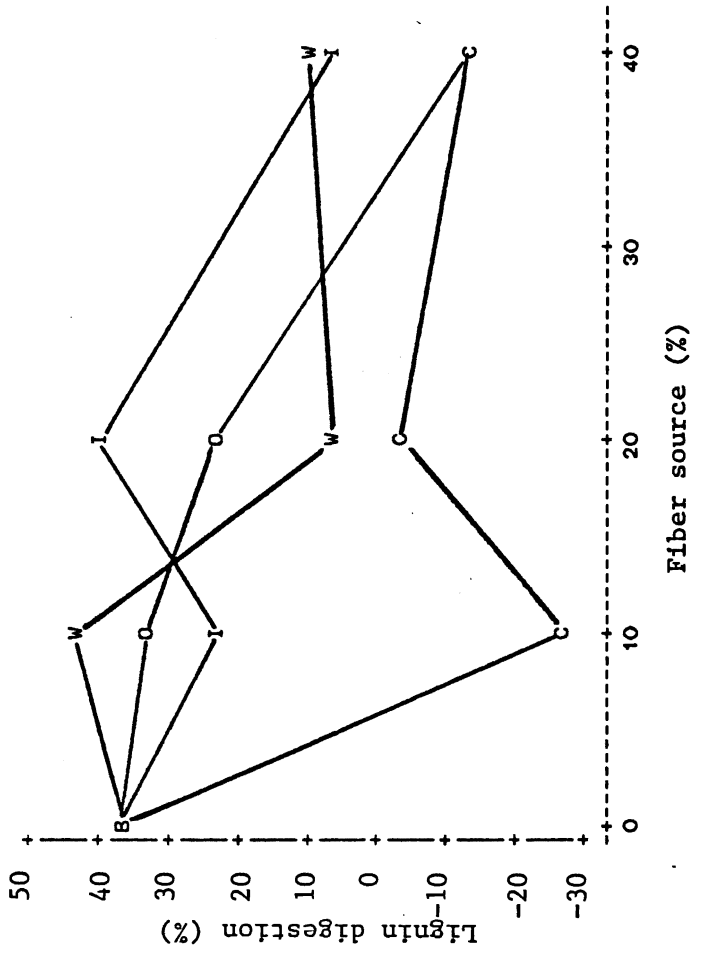

Fecal dry matter output (gm/day)
50
40
30
20
10
Fiber source (%)
0
10
20
30
40
B
C
W
I
O


NDF digestion (%)
50
40
30
20
10
0
-10
Fiber source (%)
0
10
20
30
40
O
W
I
C
B


ADF digestion (%)
0
-50
-100
-150
-200
0
10
20
30
40
Fiber source (%)
B
W
I
C
O
W
I
C
O
C
W
O


Hemicellulose digestion (%)
200
100
0
-100
-200
Fiber source (%)
0
10
20
30
40
O
W
C
I
B


Cellulose digestion (%)
0
-100
-200
-300
-400
-500
-600
0
10
20
30
40
Fiber source (%)
C
I
W
O
B


Lignin digestion (%)
50
40
30
20
10
0
-10
-20
-30
Fiber source (%)
0
10
20
30
40
B
W
O
I
C

CHAPTER VIII

SUMMARY AND RECOMMENDATIONS

Summary

This dissertation evaluated the effects of feeding four sources of dietary fiber, oat bran, corn bran, wheat bran, and citrus flour at various levels, to humans, chickens, and pigs. Effects on digestibility, passage time through the entire tract and to the large intestine, and hydrogen gas concentration were measured.

Three objectives and hypotheses related to the planned experiments were made prior to the start of the experiments and are listed in the introduction of this dissertation. Each will be addressed individually; then other general conclusions and recommendations will be discussed.

Hypothesis one stated that dietary fibers will not differ in their digestibilities and effects on passage rate and breath hydrogen concentrations.

Large differences were found between the dietary fibers used in the preceding experiments on both passage rate through the entire tract in chickens (chapter VII) (corn traveled faster than oat, wheat, or citrus), passage rate to the large intestine of human subjects

(chapter IV) (wheat traveled faster than citrus), and passage rate to the ileum of pigs (chapter VI) (oat traveled faster than corn). In human subjects consuming high fiber breakfasts (chapter IV), hydrogen concentration after consumption of oat bran was significantly greater than after consumption of wheat bran. Hydrogen concentrations for chickens (chapter VII) fed oat and citrus were significantly greater than hydrogen concentrations of chickens consuming corn and wheat bran. The breath hydrogen concentration of pigs (chapter V) consuming corn and wheat were significantly greater than that of pigs consuming the control diet. Digestibility of fiber diets varied greatly, with dry matter digestion lower in pigs fed a corn bran supplemented diet (chapter VI) than in pigs fed an oat bran supplemented diet. In chickens (chapter VII), dry matter digestibility was significantly less with the corn bran diet than with either citrus flour, oat, or wheat bran diets. Based on these results, the first null hypothesis is rejected.

Hypothesis two stated that the three test species will not respond similarly to a given fiber source.

Chickens, pigs, and humans responded very similarly to some fiber sources but differently to others and fiber sources differed in their effects. Chickens (chapter (VI) and humans (chapter IV) had similar hydrogen gas concentration responses to added fiber. Hydrogen gas was increased with oat significantly more than wheat for both groups. Pigs (chapter V) and humans (chapter III) both had a rise in breath hydrogen concentration after consuming corn bran, which was

significantly greater than the breath hydrogen response to the control diet.

Measurement of fiber in feces showed similar trends in humans (chapter III) pigs (chapter VI) and chickens (chapter VII). The fiber composition of the diet was reflected in the fiber composition of feces, with a corn bran diet resulting in significantly more hemicellulose in feces than other fiber sources, while oat consumption resulted in significantly increased concentrations of lignin.

In both pigs (chapter VI) and chickens (chapter VII) total dry matter digestibility was significantly lower when fed corn bran diets than when fed oat bran diets.

Passage rate to the ileum of pigs (chapter VI) was speeded by consumption of oat bran and slowed by consumption of corn bran, with oat bran and corn bran being significantly different. In chickens (chapter VII) passage time also was significantly speeded by consumption of oat bran, but response to oat bran was not significantly different from response to corn bran.

Hypothesis two must be rejected because there was a general similarity of response to ingestion of fiber by all species tested.

Hypothesis three stated that hydrogen concentration will not be related to digestion of fiber fractions within the gastrointestinal tract of animals and humans. Consumption of oat bran and citrus flour, which contain large quantities of highly fermentable material, resulted in greater hydrogen gas concentrations than wheat or corn when fed to humans (chapter IV) or to chickens (chapter VII), with oat

bran resulting in significantly greater hydrogen concentrations than wheat in both groups. Corn bran consumption significantly increased hydrogen concentration compared to the control diet in pigs (chapter V). Corn bran also significantly increased mean breath hydrogen concentrations in human subjects (chapter III) compared to the control diet. Corn bran contains a large percentage of hemicellulose, which is highly fermentable in humans and pigs. Pigs (chapter VI) digested over three-fourths of the hemicellulose in corn bran supplemented meals.

In both humans and pigs, hydrogen gas concentration began to rise two to four hours after consumption of the high fiber meal, about the time that material would reach the beginning of the large intestine where substantial fermentation occurs. Thus hypothesis three must be rejected since hydrogen output was related to extent of digestion of fiber in humans, pigs, and chickens.

This series of experiments helped verify the use of animals in human nutrition work. When human subjects were switched from a high corn bran diet to a control diet (chapter III) several subjects complained of constipation. This could not be verified by any measurements that were part of the study. A similar experiment was conducted feeding pigs corn bran at a higher level than could be fed to the human subjects. When the pigs were switched from a corn bran diet to a control diet, feces became significantly drier. Great variability in dry matter of feces was observed for about one week after each dietary fiber change and fecal appearance was greatly

altered. Thus, the pig experiment supported the subjective comments from the human subjects.

An interesting phenomenon, perhaps associated with the change in percent water in feces with consumption of corn bran, was the quantity of wet matter passing through the ileum of pigs (chapter VI). Wet matter passage nearly tripled from day 1 to day 13 for pigs consuming corn bran, though dry matter passage did not increase. Fecal wet matter was also increased but only slightly. Thus, a huge amount of water was apparently being reabsorbed in the colon of pigs consuming corn bran. A sudden switch to a different diet could require a period of readaptation to different quantities of liquid flow to the colon.

Expired hydrogen concentrations were changed by feeding fiber to pigs, chickens, and humans. However, responses varied considerably between fiber sources and experiments. Pigs fed fibers at a level of 60% of the total meal (450 grams of dietary fiber; chapter V) exhibited a breath hydrogen response completely different (increased with corn, no increase with citrus) from that of people consuming fiber at 26% of the total meal (40 grams of dietary fiber) (increase with citrus, no increase with corn), or chickens (chapter VII) consuming fiber at 40% of the total diet (increase with citrus, no increase with corn). However, both pigs (chapter V) and humans (chapter III) exhibited a rise in breath hydrogen levels when consuming corn bran. Research by others has had similarly conflicting results.

Fiber fermentation is affected by several factors including speed of passage through the tract and chemical composition of the fiber sources, which affect ability of bacteria to infiltrate and ferment the fiber structure. Apparently, fiber fermentation is also affected by the level of fiber in the diet, by the proportion of fiber to other meal constituents, and by the composition of other meal constituents. Fiber may dilute material in the intestinal tract and influence composition and metabolic activity of intestinal flora. Fiber may gel and surround various dietary components making them less digestible or may retain dietary components in various parts of the digestive tract where they can be more completely digested.

Thus interaction between fiber source, fiber levels, other dietary components, and gastrointestinal and physiological condition will influence the specific effect of adding fiber to the diet.

Recommendations for Further Research

The response of humans and animals to consumption of various fibers is highly variable. Repeatable results may be difficult to achieve without large numbers of subjects and well controlled experiments. Subtle, yet perhaps physiologically significant differences in fermentability and passage time can be detected between fiber sources and levels. Many legal and ethical obstacles prevent extensive, detailed experiments using human subjects. Lack of standardization of fiber sources and methods of investigation must be taken into account when comparing data from various studies. Sources

of fiber vary and fiber may have undergone different types of processing prior to use, which may affect its action in the gastrointestinal tract.

People add fiber to their diets in a variety of ways: adding some to each meal and snacks throughout the day; adding a large quantity to a single meal, such as bran cereal for breakfast; or providing a purified fiber to be consumed alone, such as mucilose flakes. Each of these methods will affect gastrointestinal function differently depending on the specific characteristics of the fiber source, and its interactions with other food constituents.

Bacterial activity may be affected by size of meal and time between meals. If fibrous components remain in various parts of the gastrointestinal tract for extended periods of time, bacterial growth and fermentation may be greatly altered compared to consumption of a highly digestible low residue diet, which is quickly absorbed and leaves the gut nearly empty for several hours until the next meal. Apparently, switching from one type of diet to another (low to high or high to low fiber) has profound effects on the gastrointestinal tract, producing cramps, gas, and alterations in bowel movements. Of interest are the specific actions within the gastrointestinal tract (hormonal, physical, or chemical) that are altered when one switches the diet. Extensive work needs to be done on the effect of processing of various types of fibrous foods, comparing the cooked, raw or processed forms. In addition, interactions of fibrous foods with well digested foods in various proportions need investigation. For

example, a high fat diet tends to slow passage from the stomach while some fibers speed passage through various sections of the gastrointestinal tract. Fat and fiber combinations may have interesting effects on passage rate through the stomach and intestinal tract, and profoundly change digestion of fat or effects of fiber.

In vitro work measuring fiber digestion when incubated with fluid from the stomach, duodenum, ileum, cecum, and large intestine would help explain the action of bacteria from various portions of the gastrointestinal tract. Samples of fluid could be obtained from human ileostomy and colostomy subjects, from cannulated animals, and from meat packing plants.

Difficulties in fiber analysis still remain. Additional modifications for analysis of various fibers are needed since the chemical characteristics of fiber sources differ. The more time consuming methods, which measure various sugars, may be more accurate for analysis of high starch foods than the detergent method, or a combination of methods may be appropriate.

Finally, work with animal models is essential to ascertain the effects of fiber in the diet without the additional confusing effects of genetics, environment, stress, and activity level encountered when using human subjects. Animal studies can provide invaluable information to the human nutritionist. The scope of nutrition experimentation using animals is limited only by the resources and ideas of the researcher.

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APPENDIX

Legend for Figure

FIG. 1. Gas chromatographic profile.

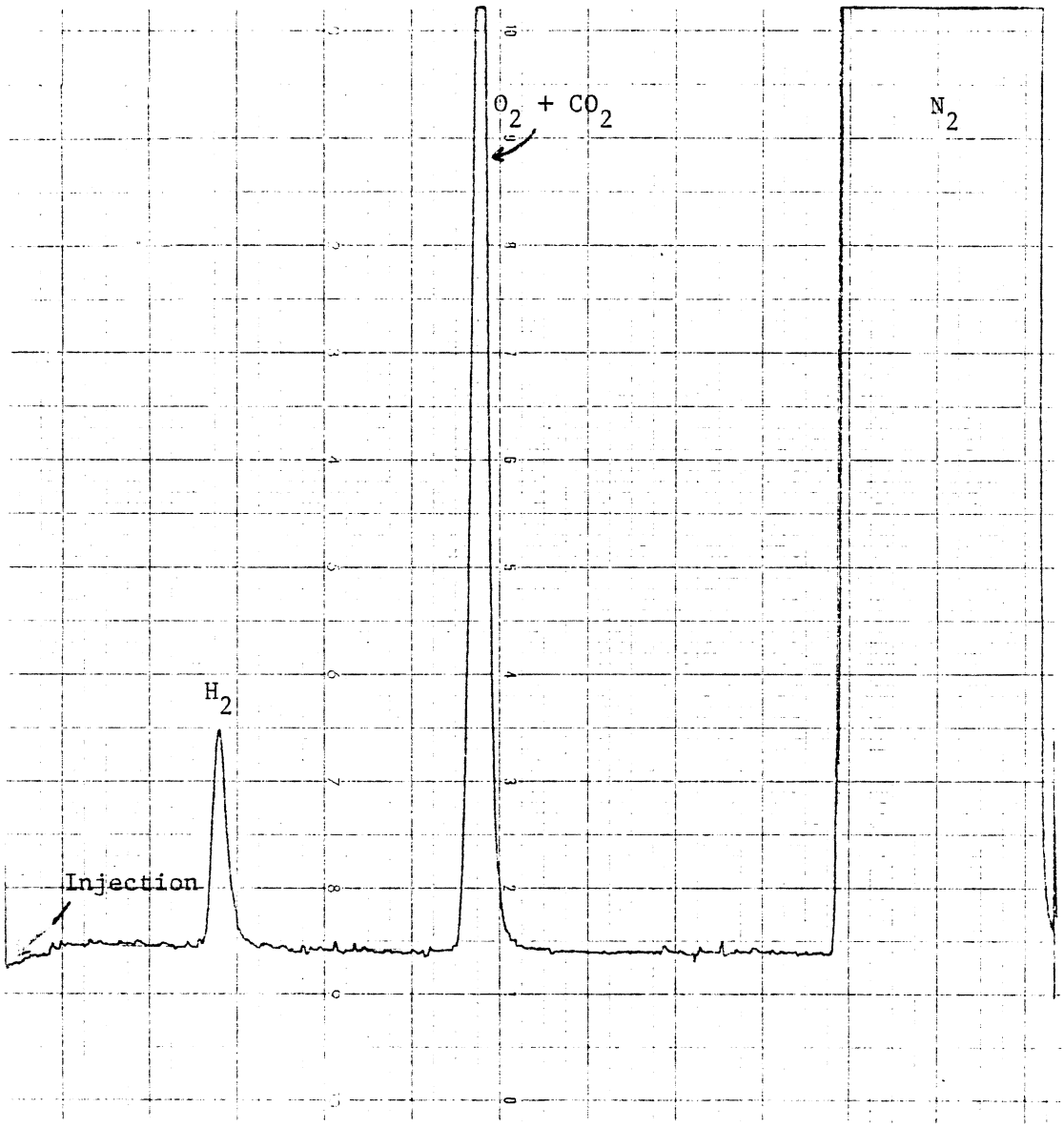

Figure 1. Gas Chromatographic Profile

VITA

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