Dietary Fibers and Their Effects on Human Digestive Health

David C. Hernot, PhD and George C. Fahey, Jr., PhD - University of Illinois at Urbana-Champaign

Introduction

The human colon contains 400-500 species of bacteria that result in significant fermentation of substrates traveling through the gastrointestinal system. It was previously believed that the main function of the human colon was water and electrolyte reabsorption; however, it is now known that the lower gastrointestinal tract and its resident microflora affect the host in many significant ways. Particularly, the colonic microflora participate in the causation and prevention of various diseases. This is accomplished through the biotransformation of ingested and endogenous compounds to derivatives that are either beneficial or detrimental (1). Dietary fibers can alter the composition of the colonic microflora by affecting the balance between beneficial and detrimental bacterial species.

Colonic Bacteria: A Symbiotic Relationship with the Host

The large bowel is highly populated with anaerobic bacteria, containing approximately 10^{11} viable bacteria in each gram of contents. The indigenous microbial population has a symbiotic relationship with the host and plays a crucial role in the development of the immune system and pathogenic colonization resistance. Short-chain fatty acids (SCFA) such as acetate, propionate and butyrate are the main end-products of bacterial fermentation of organic matter that reaches the colon. These SCFA are the main energy source for colonocytes; in particular, butyrate is the preferred energy substrate of colonic epithelium (2) and may account for up to 70% of its total energy consumption (3). Recent reports also suggest that commensal bacteria (i.e., beneficial bacteria) may modulate expression of genes involved with several important intestinal functions (4).

The diet can have a dramatic effect on the microbial population in the colon. For example, high protein intake increases amino acid flow to the colon and provides more substrates for pathogenic species. Alternatively, certain dietary fibers beneficially affect host health by selectively stimulating the growth and/or activity of one or a limited number of beneficial bacteria in the colon (5). Examples of beneficial types of bacteria include bifidobacteria, lactobacilli and eubacteria. Staphylococci, clostridia and veillonella are considered to be harmful, while streptococcus, E. coli and bacteroides are more neutral types of bacteria.

Dietary Fiber

According to the proposed definition from the Institute of Medicine, *dietary fiber* consists of plant carbohydrates and lignin that are largely intact in the plant matrix and are not digested or absorbed by the human small intestine (6). Dietary fiber also includes naturally occurring non-digestible oligosaccharides (NDO) and resistant starches (RS) that occur naturally in plants or are created during normal processing. In contrast, synthetically manufactured oligosaccharides or RS, naturally occurring polysaccharides or oligosaccharides that are isolated, extracted or modified by chemical or enzymatic reactions, are considered to be sources of *functional fiber* according to the Institute of Medicine (6). Animal-derived, non-digestible carbohydrates found in connective tissue may also be considered functional fibers.

Historically, dietary fibers have been classified as either *soluble* or *insoluble* in order to distinguish those that modulate gastric and small bowel function (soluble) from those that contribute to fecal bulk (insoluble). However, the physico-chemical properties, *viscosity* and *fermentability*, have been recommended as possibly more meaningful labels, as they may provide a better indication of the physiological responses resulting from fiber ingestion.

Dietary Fiber: Viscosity and Fermentability

It has long been recognized that dietary fiber influences intestinal function by altering water content, viscosity and microbial mass of intestinal contents. In other words, many of the health benefits of consuming dietary fiber are due to its *fermentability* and *viscosity*.

Fiber Viscosity

High fiber intake reduces transit time, increases fecal weight and improves laxation. These effects, along with dilution of intestinal contents, are believed to reduce the risk of colon cancer. Increased bulk in the colon also decreases intracolonic pressure, leading to decreased risk of diverticular disease (7). Epidemiological research has suggested that dietary fiber intake is negatively associated with the formation of adenomatous polyps, a precancerous lesion (8). Furthermore, viscous fibers are thought to reduce the risk of developing cardiovascular disease. Research suggests that consumption of viscous dietary fibers may result in reduced blood cholesterol concentrations and decreased hypertension (9). Viscous fibers play a role in reducing the risk of type 2 diabetes mellitus by reducing glycemic responses to meals while increasing insulin sensitivity. These fiber types beneficially affect fasting glucose concentrations, postprandial glucose response, urinary glucose excretion and glycosylated hemoglobin concentrations (HbA1c) in blood (10, 11). Slowed stomach emptying resulting from the consumption of viscous fibers also may induce a short-term increase in satiety, which may decrease food intake and nutrient absorption and may facilitate weight control (12).

Fiber Fermentability

Although the beneficial effects of fiber viscosity are primarily associated with the stomach and small intestine, the benefits of fermentable fibers are primarily associated with colonic health. Examples include NDO and RS, which can be important substrates for the dense population of bacterial species residing in the large bowel.

As fermentative substrates, NDO can act as prebiotics. Prebiotics are defined as indigestible food ingredients that positively affect the host by selectively increasing beneficial colonic bacteria to create a healthier gut environment (12). Prebiotic NDO are fermented in the colon, where they selectively stimulate health-promoting bacterial populations. This selective stimulation occurs because NDO are readily fermented by beneficial types of colonic bacteria, and are not extensively used by potentially pathogenic bacterial species. In addition to their ability to create a more favorable colonic bacterial population, prebiotic NDO also may optimize stool characteristics. The active fermentation of carbohydrates, such as NDO, reduces fecal ammonia, indole and phenol concentrations (13), compounds that have been implicated as the major malodorous components of feces (14) and as toxins or co-carcinogens (15). In addition to the potential benefits, it is important to note that, at very high levels of intake, many NDO can result in loosely formed stools, flatulence and abdominal pain. These effects vary among individuals and across different levels of intake due to differences in individual tolerance.

Resistant starch is defined as starch that escapes digestion in the small intestine of humans and provides a source of fermentable substrate for cecal and colonic microflora (16). Anaerobic fermentation leads to the production of SCFA that provide additional energy to the colonic cells of the host. The stimulation of bifidobacteria and lactobacilli in the gut by substrates such as RS has been hypothesized to be important in the suppression of pathogenic bacteria (17). Among other positive attributes (e.g., reduced glucose and insulin responses to meals, reduced availability of calories, promotion of bowel health, increased fecal output and production of SCFA and decreased concentrations of secondary bile acids in the large bowel), RS selectively encourages growth of both indigenous and introduced (i.e., dietary) probiotic bacteria in a variety of ways, including enhancement of the rate of microbial growth and an ability to affect type and quantity of fermentation end-products produced (18). It also has been suggested that RS may have a positive impact on bacterially-induced diseases found higher in the gastrointestinal tract, such as dental caries and stomach ulcers (19).

Conclusion

Great strides continue to be made in determining the specific functions of dietary fibers, such as NDO and RS, for humans. Future research efforts will further define the effects of various NDO and RS on fermentation, microbial populations, cell growth and differentiation, and immune and systemic responses. It is important to understand the relationships between dietary fibers, functional fibers, prebiotics, NDO, RS and the colonic microbial ecology of humans. Such relationships should provide guidelines for formulation of diets that contain the optimal quantity and sources of dietary fibers, functional fibers, NDO and RS to support digestive health. It also is possible that dietary fibers, dietary fiber blends, prebiotics, prebiotic combinations or prebiotic/probiotic blends (symbiotics) might be defined for application in infant, elderly and/or clinical nutrition.

Key Points

- Many of the health benefits of consuming dietary fiber are due to its fermentability and viscosity.
- Prebiotic fibers are fermentable in the colon and act to increase the amount of healthy bacteria.
- Prebiotic fibers can be incorporated into an individual's daily fiber requirements.
- Prebiotic fibers can be found naturally in whole grains and cereals.
- Prebiotic functional fibers (e.g., inulin) are often added to various food products.

References

1. Mitsuoka T. Bifidobacteria and their role in human health. *J Indust Microbiol.* 1990; 6:263-8.
2. Roediger WEW. Utilization of nutrients by isolated epithelial cells of the rat colon. *Gastroenterology.* 1982; 83:424-9.
3. Roediger WEW. Role of anaerobic bacteria in the metabolic welfare of the colonic mucosa in man. *Gut.* 1980; 21:793-8.
4. Hooper LV, Wong HH, Thelin A et al. Molecular analysis of commensal host-microbial relationships in the intestine. *Science.* 2001; 291:881-4.
5. Gibson GR, Roberfroid MB. Dietary modulation of the human colonic microbiota; introducing the concept of probiotics. *J Nutr.* 1995; 125:1401-12.
6. Institute of Medicine. Proposed definition of dietary fiber. *A Report of the Panel on the Definition of Dietary Fiber and the Standing Committee on the Scientific Evaluation of Dietary Reference Intakes, Food and Nutrition Board.* Washington, DC: National Academy Press, 2001.
7. Brodribb AJM, Humphreys DM. Diverticular disease: Three studies. Part II – Treatment with bran. *Br Med J.* 1976; 1:425-8.
8. Giovannucci E, Stampfer MJ, Colditz G et al. Relationship of diet to risk of colorectal adenoma in men. *J Natl Cancer Inst.* 1992; 84:91-8.
9. Ascherio A, Rimm EB, Giovannucci EL et al. A prospective study of nutritional factors and hypertension among US men. *Circulation.* 1992; 86:1475-84.
10. Hoffmann CR, Fineberg SE, Howey DC et al. Short term effects of a high-fiber, high-carbohydrate diet in very obese diabetic individuals. *Diab Care.* 1982; 5:605-11.
11. Peterson DB, Ellis PR, Baylis JM et al. Low dose guar in a novel food product: Improved metabolic control in noninsulin-dependent diabetes. *Diab Med.* 1987; 4:111-15.
12. Roberfroid M. Dietary fiber, inulin and oligofructose: A review comparing their physiological effects. *Crit Rev Food Sci Nutr.* 1993; 33:103-48.
13. Cummings J, Macfarlane G. The control and consequences of bacterial fermentation in the human colon. *J Appl Bacteriol.* 1991; 70:443-59.
14. O'Neill D, Phillips V. A review of the control of odour nuisance from livestock buildings: Part 3. Properties of the odorous substances which have been identified in livestock wastes or in the air around them. *J Agric Eng Res.* 1992; 53:23-50.
15. Rao A, Koo M. Effect of oral administration of bifidobacteria and neosugar on plasma ammonia concentration in CF_1 mice. *Int J Food Sci Nutr.* 1992; 43:9-17.
16. Cummings JH, Englyst HN. Fermentation in the human large intestine and the available substrates. *Am J Clin Nutr.* 1987; 45:1243-55.
17. Gibson GR, Wang X. Regulatory effects of bifidobacteria on the growth of other colonic bacteria. *J Appl Bacteriol.* 1994; 77:412-20.
18. Brown IL, McNaught KJ, Andrews D, Morita T. Resistant starch: Plant breeding, applications development and commercial use. In: *Advanced Dietary Fibre Technology*, McCleary BV, Prosky L (ed). Oxford, UK: Blackwell Science Ltd, 2001; 401-12.
19. Bird AR, Trimble RP, Illman RJ, Topping DL. Starches, resistant starches, the gut microflora and human health. *Curr Iss Intest Microbiol.* 2000; 1:25-37.