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Review

Prebiotics: Present and future in food science and technology

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ABSTRACT

Because of its resident microbiota, the human colon is one of the body's most metabolically active organs. The use of diet to fortify certain gut flora components is a popular current aspect of functional food sciences and prebiotics have a significant role. Prebiotics are selectively fermented ingredients that allow specific changes, both in the composition and/or activity in the gastrointestinal microbiota that confers benefits upon host well-being and health. Improved techniques for analysis of the gut microflora, new food manufacturing biotechnologies, and increased understanding of the metabolism of prebiotic inulin and oligosaccharides by probiotics are facilitating development. Such developments are leading us to the time when we will be able to rationally develop prebiotics for specific functional properties and health outcomes. Thus, this review will focus on the progress of prebiotics in food science and technology in understanding the important role of prebiotics in health, beginning at the rationale of gut microflora and interactions with prebiotics. Furthermore, the classification criteria, food applications and safety assessment of prebiotics as food ingredient is also discussed.

Contents

1. Introduction

It is now well established that the colonic microflora has a profound influence on health (Steer, Carpenter, Tuohy, & Gibson, 2000). Consequently, there is currently a great deal of interest in the use of prebiotic as functional food ingredients to manipulate the composition of colonic microflora in order to improve health (Aryana & McGrew, 2007; Coppa, Zampini, Galeazzi, & Gabrielli, 2006; Losada & Olleros, 2002; Manning & Gibson, 2004; Rao, 2001; Rousseau, Lepargneur, Roques, Remaud-Simeon, & Paul, 2005). Thus, prebiotics, such as oligosaccharides and inulin, are defined as "nondigestible food ingredient(s) that beneficially affects host health by selectively stimulating the growth and/or activity of one or a limited number of bacteria in the colon" (Gibson & Roberfroid, 1995). This definition was updated in 2004 and prebiotics is now defined as "selectively fermented ingredients that allow specific changes, both in the composition and/or activity in the gastrointestinal microbiota that confers benefits upon host well-being and health" (Gibson, Probert, Van Loo, Rastall, & Roberfroid, 2004).

However, the effect of a prebiotic is, essentially, indirect because it selectively feeds one or a limited number of microorganisms thus causing a selective modification of the host's intestinal (especially colonic) microflora. It is not the prebiotic by itself but rather the changes induced in microflora composition that is responsible for its effects. Indeed, the most important bacterial genera targeted for selective stimulation are the indigenous bifidobacteria and lactobacilli (Teitelbaum & Walker, 2002). This clearly

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built upon the success of probiotics for microflora management approaches. Bifidobacteria are thought to stimulate the immune system, produce B vitamins, inhibit pathogen growth, reduce blood ammonia and blood cholesterol levels, and help to restore the normal flora after antibiotic therapy (Gibson & Roberfroid, 1995). Lactobacilli may aid digestion of lactose in lactose-intolerant individuals, reduce constipation and infantile diarrhoea, help resist infections such as salmonellae and help to relieve irritable bowel syndrome (Manning & Gibson, 2004). Increases in bifidobacteria and lactobacilli by prebiotics have been studied (Langlands, Hopkins, Coleman, & Cummings, 2004; Macfarlane, Macfarlane, & Cummings, 2006; Probert & Gibson, 2002).

Taking the view that positive components of the gut flora already exist in the intestinal tract, the trials are ongoing to determine the clinical benefits of prebiotic use. Intestinal disorders like ulcerative colitis and irritable bowel syndrome (IBS) are particular targets. A study shows that the modification of the intestinal microflora by prebiotics, including germinated barley food-stuff (GBF), may serve as a useful adjunct in the treatment of ulcerative colitis as well as antibiotic treatment (Fukuda et al., 2002). However, even though the treatment most widely recommended for IBS patients is an increased intake of dietary fibre, current clinical trials do not support the use of prebiotics in the treatment of an inflammatory bowel disease (Sartor, 2004). The mechanisms of action certainly need to be adequately defined, but it is becoming apparent that the modifications of intestinal flora by the ingestion of prebiotics can interact with the immunological component of the intestine, and yield not only gastrointestinal protective effects, but given the nature of the immune response of the gut associated lymphoid tissue, may yield systemic effects, that in turn may have significance in other mucosal surfaces, such as the skin and respiratory tract, thereby providing a broader systemic benefit (Saavedra & Tschernia, 2002).

Nowadays, many prebiotics are already used in a broad range of food applications (Franck, 1999). However, it is still possible to identify desirable targets for enhancement of their efficacy as prebiotics. According to the claims of the producers, these products are effective in supporting the health of human and are also safe. On the other hand, there are doubts with regard to the general concept of prebiotics and to these claims. Thus, there is clearly a need to increase our knowledge of gut microflora and interactions with prebiotics. Furthermore, a better understanding of the recent development and safety assessment of prebiotics in food science and technology is also required.

2. The rationale for the use of prebiotics

Functionally, the human colon undertakes a number of important physiological activities (Fooks, Fuller, & Gibson, 1999). However, another extremely significant metabolic trait is mediated by gut bacteria (Bullock, Booth, & Gibson, 2004). The human embryo is virtually sterile, but at birth microbial colonisation of the gastrointestinal tract occurs, with the neonate receiving an inoculum from the birth canal (Fuller, 1991). During the acquisition period, some bacteria transiently colonise the gut whilst others survive and grow to form the indigenous microflora (Zetterström, Bennett, & Nord, 1994). Microorganisms occur along the whole length of the human alimentary tract with population numbers and species distribution characteristic of particular regions of the gut (Macfarlane & Macfarlane, 1997). The movement of digesta through the stomach and small intestine is rapid (ca. 4–6 h), when compared with a typical colonic transit time of around 48–70 h for adults (Macfarlane & Gibson, 1994). This allows the establishment of a complex and relatively stable bacterial community in the large intestine. The near neutral pH and the relatively low absorptive state of the colon further encourage extensive microbial colonisation and growth (O'Sullivan, 1996). Through the microflora, the colon is capable of exhibiting complex hydrolytic digestive functions (Cummings & Macfarlane, 1991). This involves the breakdown of dietary components, principally complex carbohydrates, but also some proteins, that are not hydrolysed nor absorbed in the upper digestive tract.

From another point of view, predominant growth substrates for gut bacteria are of dietary origin and consist of foodstuffs that have not been absorbed in the upper gastrointestinal tract (Fooks et al., 1999). The colonic microflora also derive substrates for growth from the diet (e.g. nondigestible oligosaccharides, dietary fibre, and undigested protein reaching the colon) and from endogenous sources such as mucin, the main glycoprotein constituent of the mucus which lines the walls of the gastrointestinal tract. Thus, any foodstuff that reaches the colon, e.g. nondigestible carbohydrates, some peptides and proteins, as well as certain lipids, is a candidate prebiotic according to the above prebiotics definition. Moreover, certain nondigestible carbohydrates seem authentic prebiotics. However, most of the interest in the development of prebiotics is aimed at nondigestible oligosaccharides (Mussatto & Mancilha, 2007). The premise behind prebiotics is therefore to stimulate certain indigenous bacteria resident in the gut rather than introducing exogenous species as is the case with probiotics. Ingesting a diet containing nondigestible carbohydrates that are selectively fermented by indigenous beneficial bacteria is the prebiotic principle.

3. Prebiotics in food science and technology

3.1. Criteria of prebiotics

In very general terms, intestinal bacteria can be divided on the basis of whether they can exert health promoting, benign or potentially harmful activities in their host (Gibson & Roberfroid, 1995). This leads towards a consideration of factors that may influence the flora composition in a manner than can impact upon health. The stimulated bacteria should be of a beneficial nature, namely bifidobacteria and lactobacilli (Gibson & Collins, 1999). To have these effects, prebiotics must be able to withstand digestive processes before they reach the colon and preferably persist throughout the large intestine such that benefits are apparent distally (Gibson et al., 2004). Resistance to digestive processes as the criteria includes prebiotic resistance to gastric acidity, hydrolysis by mammalian enzymes, and gastrointestinal absorption. Both *in vitro* and *in vivo* methods are available to demonstrate this resistance in the candidate prebiotic (Ellegard, Andersson, & Bosaeus, 1997; Molis et al., 1996).

Criteria which allow the classification of a food ingredient as a prebiotic also include selective fermentation by potentially beneficial bacteria in the colon. Disappearance of the candidate prebiotic is quantified as a function of time using standard chemical, physicochemical, or enzymatic methods using batch and continuous culture fermentation systems (Gmeiner et al., 2000). *In vivo* fermentation of nondigestible carbohydrates can be studied in laboratory and companion animals, livestock, and humans (Biedrzycka & Bielecka, 2004; Christl, Murgatroyd, Gibson, & Cummings, 1992).

Furthermore, selective stimulation of the growth and/or activity of intestinal bacteria potentially associated with health and well-being has been required as one of the criteria (Fooks et al., 1999). As defined by Huebner, Wehling, and Hutkins (2007), the prebiotic activity reflects the ability of a given substrate to support the growth of an organism relative to other organisms and relative to growth on a nonprebiotic substrate, such as glucose. Therefore,