PROBIOTICS AND HUMAN HEALTH

R. HULL

Summary

Probiotics are a special class of microorganisms that can be consumed and may confer health and nutritional benefits. They offer the opportunity to improve the quality of foods and to raise the health and well-being of the consumer. Quality improvements of increased shelf-life and food safety result from the fermentative metabolism of probiotic microbes. These improvements are strain specific and are common to traditional fermented foods. The health attributes are assumed to be dependent on the probiotic microorganisms surviving and being delivered to appropriate sites of the gastrointestinal tract where they re-establish the normal intestinal microbial balance. Restoring the balance can bring about a wide variety of health and nutritional benefits including: an increased resistance to infection by pathogens including food-borne organisms, improved digestion and adsorption of nutrients in foods, enhanced immunocompetence and protection from cancers. Consumption of probiotics is low in Australia. Development of appropriate probiotic foods and products, and raising the level of consumption of probiotics should become a major strategy for health professionals and food companies.

I. INTRODUCTION

The practice of fermenting foods is widespread amongst all human populations. Many raw materials from plant and animal sources are subjected to fermentation using a wide variety of microorganisms. The microbial fermentation process changes the raw food improving food safety, shelf-life, acceptability, and nutritional value (Steinkraus 1983). For example, the process of fermenting milk to produce yoghurt increases shelf-life from a few days to several weeks. The increased shelf-life is due to the presence of organic acids and other antimicrobial substances produced during fermentation. These antimicrobial substances suppress the growth of spoilage organisms. They also suppress the growth, or may kill, food borne pathogenic organisms. For this reason fermented foods are considered safer foods than their corresponding raw materials. Many existing traditional fermented foods are equivalent to probiotic foods. In less-developed countries fermented foods remain an important part of the diet supplying a balance of macro and rnicro-nutrients as well as playing a key role in food safety. In western countries the availability of more modern systems for food preparation and preservation may account for the lower consumption of such products. Evidence is now emerging that reduced consumption of fermented foods (probiotics) may predispose individuals to those diseases of the digestive tract and associated organs that are now associated with the western diet.

II. WHAT IS A PROBIOTIC MICROORGANISM?

The term 'probiotic' has gained general acceptance to mean a live microbial food or feed supplement which beneficially affects the host by improving its intestinal microbial balance and therefore its nutritional health and well-being (Fuller 1989; Hull et al. 1992). Before discussing

Ron Hull and Associates, 8 Park Street, Mt Waverley, Victoria 3149

the relationship of probiotics to nutritional health and well-being, it is first necessary to consider in general terms the concept of intestinal microbial balance. Soon after birth the body's surfaces and cavities, including the oral cavity, the gastro-intestinal (GI) tract, and the upper respiratory tract, are colonised by a diverse collection of microorganisms. Each group of colonising microorganisms is well adapted to its specialised habitat and collectively makes up the normal microflora of the body of healthy persons. The density and types of bacterial species varies considerably between different regions of the GI tract, with the greatest density being in the oral cavity and in the large intestine. The most important factor determining the type of microorganisms present and their metabolic products is diet. For example, the intestinal microflora of breast-fed infants is made up almost entirely of friendly Bifidobacteria, whereas that of non-breast-fed infants is more diverse and the dominating microorganisms include undesirable microbes such as coliforms, Bacilli and Clostridia. The dominant bacterial species present in the major regions of the GI tract are listed in Table 1.

Table 1. The main genera of bacteria inhabiting the GI tract.

Segment	Genus	Bacterial numbers
Oral cavity	Streptococcus Veillonella Neisseria	10^5-10^9
Stomach and small intestine	Lactobacillus Streptococcus	10^1-10^4
Large intestine	Bacteroides Clostridium Eubacterium Peptococcus Bifidobacteria	10^9-10^{12}

The concept of intestinal microbial balance can be simply explained as maintenance of a normal density and composition of microflora in the GI tract. A normal microflora ensures that:

(i) Levels of pathogenic and abnormal microorganisms are kept low or are excluded.
(ii) There is suppression of abnormal microbial enzymic activity, ie enzymic formation of toxic and carcinogenic substances, particularly from nitrogen containing compounds, is kept at a low level.
(iii) There is maintenance of normal enzymic formation of end products, particularly of organic acids which reduce pH and provide an energy source for the growth, multiplication, and maintenance of normal function (eg water and electrolyte uptake from the lumen) of the epithelial cells of the large intestine. Organic acids also play a key role in suppressing pathogenic and other abnormal microorganisms.

Many everyday activities can upset this state of normal balance and include diet (particularly in infancy and old age), stress, alcohol, and antibiotic and chemotherapy treatments. Probiotic microorganisms that have commonly been used in foods, food supplements and in animal probiotics are derived from the normal inhabitants of the GI tract. They mainly belong to the group of bacteria known as lactic acid bacteria. However, other bacteria, yeasts and fungi are finding applications in probiotic products. Some common characteristics of these microorganisms are: they produce organic acids (mainly L-lactic or acetic), they use carbohydrates and complex sugars as a major energy source, and they are anaerobes or microaerophilic.

III. WHAT IS A PROBIOTIC FOOD?

Probiotic foods are foods which contain live probiotic microorganisms that have grown in the food producing a fermented product ('fermented' probiotic food), or have been added to the food without noticeably changing its organoleptic properties ('non-fermented' probiotic food). Special food ingredients (eg. oligosaccharides) which stimulate probiotic microorganisms in vivo, are being incorporated in probiotic foods. These substances are referred to as prebiotics. An essential feature of a probiotic food is that it must contain living microorganisms in appreciable numbers. The food system, production, processing, and storage conditions may all adversely affect the viability of probiotic microorganisms in the product and subsequently their ability to survive, multiply, and colonise the GI tract. The marketing of probiotic products that contain no or very low levels of probiotic microbes (Rettger et al. 1935; Brennan et al. 1983; Anon 1992) can be expected to continue to generate scepticism about the probiotic principle. In some countries manufacturers of acidophilus and bifidus yoghurts have adopted minimum standards for viability of 1-10 million viable organisms per gram of product. In USA, manufacturers of powdered probiotic supplements specify the density of viable organisms at the use by date (eg guaranteed two billion viable organisms).

(a) Probiotic capsules, tablets, and powders

In Australia an estimated 10,000 kg of probiotic tablets, capsules, and powders are sold annually through heath food stores, supermarkets, and pharmacies. Of the approximately 30 brands, more than half contain only one strain, either Lactobacillus or Bifidobacteria. Others contain up to nine different strains. Most products are milk-based, containing between 10^9 10^{10} organisms/g, and are prepared by spray drying or freeze drying.

(b) Probiotic dairy foods

In the last five years there has been a dramatic increase in Australia and the Western world in the number of dairy products containing probiotic organisms. The main group is yoghurts and almost all manufacturers now retail products with *Lactobacillus acidophilus* and/or *Bifidobacteria.* Over the last decade yoghurt consumption has increased by 60%. In that period the use of probiotic cultures has grown from being insignificant to approximately 20% of the total product. The use of probiotics in yoghurts will continue to increase in the western world.

Incorporation of probiotic cultures in cheese, butter, cream, and icecream has occurred in Europe and USA. The efficacy of these products depends upon freshness and the level of probiotic bacteria. Freshly prepared products are most effective and with typical shelf-life in Australian yoghurts of four to six weeks, consumers should select the freshest products for the best results. Experience at CSIRO indicated that the combination of *L. acidophilis* and *Bifidobacteria* is more effective in products with only one strain. Individuals with an intolerance to bovine milk can select probiotic yoghurts made from sheeps' or goats' milk, or alternatively yoghurts made from grain legumes (eg soy or lupin).

(c) Other probiotic foods

Although milk has been the major raw material for probiotic foods in the western world, other raw materials are now being used. These include milks from soy and other grain legumes, and products from fruits and vegetables.

IV. WHAT ARE THE BENEFITS OF PROBIOTIC FOODS?

Probiotic foods offer potential health benefits as well as improving the quality and nutritive value of foods.

(a) Quality and nutritive value

In common with traditional fermented foods the quality, nutritive properties, and the acceptability of raw materials can be improved by the fermentation process of the starter or the probiotic microorganisms. Both the texture and flavour of raw materials can be significantly improved during fermentation making the food more acceptable to the consumer. Levels of food components with adverse effects, such as oligosaccharides, lactose, phytic acid, and proteins difficult to digest, can be reduced during fermentation minimising food intolerance and allergies. Levels of amino acids and vitamins (eg the B group) as well as protein and fat digestibility can be increased by fermentation improving the nutritive value of the food. Sugars and other spoilage promoting components of foods are removed during fermentation increasing shelf-life and food safety. These improvements to the quality and nutritive value of fermented probiotic foods are dependent upon the food system and the characteristics of the strain of microorganism used, and are common to traditional fermented foods (Steinkraus 1983; Rasic and Kurmann 1980; Ishibasi and Shimamura 1993). A good probiotic microorganism will be effective in bringing about these changes. However, some strains of the same species are known to be neutral or negative with respect to producing these improvements in foods. Some negative changes include the removal of vitamins and the production of substances with adverse physiological effects (eg biogenic amines).

(b) Health benefits

Consumption of probiotic foods has long been observed to produce health benefits particularly in correcting GI tract disorders. These benefits can be attributed to improved intestinal microbial balance. In the treatment of disease, efficacy of probiotics is critically dependent upon 'delivering' viable probiotic microorganisms and their metabolic products to the infected site so that the intestinal microbial balance can be restored. Factors important in delivering probiotics include the characteristics of the food system (diet and probiotic preparation and administration system) and the characteristics of the probiotic strains (Rettger 1935; Rasic and Kurmann 1980; Ishibashi and Shimamura 1993). Combinations of strains and species can be more effective than single strains. For example, a strain of *L. acidophilus* was ineffective in treating chronic diarrhoea in foals, yet the same strain in combination with *Bifidobacterium bifidus* was effective in treating 80% of cases (Roberts and Hull, unpublished data). Similarly, the combination of *Streptococcus salivarious* subspecies *thermophilus* and *Bifidobacterium bifidum* in infant formula was highly effective in reducing the incidence of acute diarrhoea and rotavirus shedding in infants in the hospital setting (Saavedra et al. 1994).

Health benefits attributed to probiotics include:

(i) Alleviation of intestinal disorders such as constipation and diarrhoea caused by infection by pathogenic organisms, antibiotics, or chemotherapy. The main factors producing this result are the reduction of pH and redox potential (Eh), organic acids, hydrogen peroxide, diacetyl, and bacteriocins. These factors also maintain a strong infection-preventing effect and are well documented (Rettger 1935; Rasic and Kurmann 1980; Ishibashi and Shimamura 1993; Saavedra et al. 1994; Luo et al. 1994).

(ii) Stimulation of the immune systems. Indigenous intestinal bacteria such as lactobacilli have been shown to translocate via the gut-associated lymphatic tissue to the spleen or other sites and stimulate Phagocytosis and promote immuno-competence (Ma et al. 1990).

(iii) Anti-tumour effects are reported due to inactivation or inhibition of carcinogenic compounds in the GI tract by reduction of intestinal bacterial enzyme activities such as

β-gluconidase, azoreductase, and nitroreductase which activate carcinogens by converting procarcinogens to proximal carcinogens (Gorbach & Goldin, 1990).

(iv) Reduced production of toxic end products such as ammonia, phenols, and other metabolites of protein known to influence liver cirrhosis. These effects are well documented (Rasic and Kurmann 1980).

There are differing opinions among workers in the field in relation to the efficacy of probiotics (Hoover 1993). Efficacy has been typically reported to be around 60 - 70% (Rettger 1935; Rasic and Kurmann 1980; Ishibashi and Shimamura 1993). In studies reporting low efficacy, little attention has been paid to ensuring effective delivery of the probiotic. This has been in part due to the difficulties associated in studying probiotics in vivo and intestinal microbial balance. There is now strong scientific interest in probiotics following on the commercial success of probiotics in countries like Japan. The availability of new molecular probes and protein profiling techniques greatly improve individual strain identification. The quantification of probiotics in vivo will facilitate scientific progress. The outcome should be an enhanced understanding of the interaction between the host and the probiotic microbes and improved probiotic foods and products. Disorders of the GI tract have emerged as a primary disease and with an ageing population, Australia faces an increase in demand for the effective treatment of these disorders. This has highlighted awareness of the importance of probiotic foods which have the potential to maintain health of the GI system. Research on probiotics in Australia is proceeding on topics such as controlling gastritis caused by *Helicobacter pylori,* and is also an important part of a new Cooperative Research Centre for Food Industry Innovation. The latter aims to provide a coordinated research, development and education program to provide novel food ingredients based on microorganisms.

V. SAFETY AND REGULATORY ASPECTS

It has been generally assumed that lactic acid bacteria used as probiotics and starter cultures are non-pathogenic and harmless to the host. However, recent reports indicate that some strains of lactic acid bacteria may be opportunistic pathogens (Aguire and Collins 1993), causing bacteraemia, meningitis, or endocarditis. Enterococci present the major cause for concern, but some strains of Leuconostoc, Pediococci, and Lactobacilli were also found to be opportunistic pathogens. Havenaar and Veld (1992) recommend that probiotic strains, 'be harmless to the host: there must be no local or general pathogenic, allergic, or mutagenic / carcinogenic reactions provoked by the microorganism itself, its fermentation products, or its cell components after death of the bacteria'. These would appear to be prudent precautions. Other precautions currently followed by the manufacturers of starter cultures used as processing aids in the production of fermented foods should also apply to probiotics. These include defined metabolic characteristics and freedom from contaminating organisms.

VI. THE IMPORTANCE OF PROBIOTICS IN THE DIET

Traditional diets contain moderate levels of naturally fermented foods which are consumed fresh. These fresh foods contain very high levels of live probiotic microorganisms. Therefore, a traditional diet will continually add large numbers of probiotic organisms to the GI tract. In Australia, in line with other western countries, the consumption of freshly fermented foods has been declining and it is low compared to our Asian neighbours. For example, consumption of fermented foods in Australia, Japan, Korea, and Thailand is approximately 30, 71, 100, and 300 g per day per person (Hull, unpublished data). In Australia the incidence of degenerative disease is high, with hospital admissions for GI tract diseases now ranked as number one (13.4% of hospital admissions in 1990) (ABS 1989/90)).

The potential for probiotic foods to reduce the incidence of GI tract diseases in Australia is considerable. However, the strong flavours and aromas of fermented foods are not well accepted by people in the western world. Because of this, non-fermented or part-fermented probiotic foods may need to be developed to supply this market. Considerable developmental work will be needed to ensure that the new probiotic foods will be both stable and effective. This work will require cooperative research and development between food microbiologists, food technologists, and health professionals.

REFERENCES

AUSTRALIAN BUREAU OF STATISTICS (1989/90). 'National Health Survey. Summary of Results'. Catalogue No. 4364.0, Table 22.

ANON. (1992). Choice Magazine. 11: 32.

AQUIRE, M.and COLLINS, M.D. (1993). J. Applied Bacteriology 75: 95.

BRENNAN, M., WANISMAIL, B.and RAY, B. (1993). J. Food Protection 46: 887.

FULLER, R. (1989). J. Applied Bacteriology 66: 365.

FULLER, R. (1992). In 'Lactic Acid Bacteria in Health and Disease', Vol 1, p.171, ed B. Wood. (Elsevier Applied Science: London).

GORBACH, S.L.and GOLDIN, B.R. (1990). J. National Cancer Institute 64: 263.

HAVENAAR, R., VELD, J.and JOS, H.J. (1992). In 'Lactic Acid Bacteria in Health and Disease', Vol 1, p.151, ed B. Wood. (Elsevier Applied Science: London).

HOOVER, D.G. (1993). Food Technology 45: 120.

HULL, R.R., CONWAY, P.L. and EVANS, A.J. (1992). Food Australia 44: 112.

ISHIBASHI, N. and SHIMAMURA, S. (1993). Food Technology 45: 128.

LUO, F., LAMBERT, J.R., HULL, R.R. and MIDOLO, P.D. (1994). American J. Gastroenterology 89: 1395.

MA, L., DEITCH, E., STEFFEN, E. and BERG, R. (1990). Current Microbiology 20: 177.

RASIC, J.L. and KURMANN, J.A. (1983). In 'Bifidobacteria and Their Role: Microbiological. Nutritional, Physiological, Medical and Technological Aspects and Bibliography', Experientic, Supp. 39, (Bikhauser Verlag, Serves: Basel).

RETTGER, L.F., LEVY, M.N., WEINSTEIN, L. and WEISS, J.E. (1935). 'Lactobacillus acidophilus and its Therapeutic Application', (New Haven Uni Press: London).

ROBERTS, A. and HULL, R.R. (unpublished data).

SAAVEDRA, J.M., BAUMAN, N.A., OUNG, I., PERMAN, J.A. and YOLKEN, R.H. (1994). Lancet 344: 1046.

STEINKRAUS, K.H. (1983). 'Handbook of Indigenous Fermented Foods', (Marcel Dekker: New York).