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Beneficial Role of Lactic Acid Bacteria in Food Preservation and Human Health: A Review

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Abstract: There is several potential health or nutritional benefits possible from some species of lactic acid bacteria. Among these are: improved nutritional value of food, control of intestinal infections, improved digestion of lactose, control of some types of cancer and control of serum cholesterol levels. Some potential benefits may result from growth and action of the bacteria during the manufacture of cultured foods. Some may result from growth and action of certain species of the lactic acid bacteria in the intestinal tract following ingestion of foods containing them. In selecting a culture to produce a specific benefit it is necessary to consider not only the wide variation among species of the lactic acid bacteria but also that among strains within a given species. The production of fermented foods is based on the use of starter cultures, for instance lactic acid bacteria that initiate rapid acidification of the raw material. Recently, new starter cultures of lactic acid bacteria with an industrially important functionality are being developed. The latter can contribute to the microbial safety or offer one or more organoleptic, technological, nutritional, or health advantages. Examples are lactic acid bacteria that produce antimicrobial substances, sugar polymers, sweeteners, aromatic compounds, vitamins, or useful enzymes, or that have probiotic properties. In the developed world, lactic acid bacteria are usually associated with fermented dairy products and the use of dairy starter cultures has become a whole industry this century. Add to this that lactic acid bacteria have been associated with beneficial health effects for many years now. Nowadays, many food products are promoted as being particularly healthy because of the characteristics of certain strains of lactic acid bacteria. Unfortunately, not all these strains have been studied carefully and therefore it might be difficult to substantiate some of the claims. Thus, there is a clear need for the critical study of the effects on health of strain selectio and quality.

Key words: Lactic acid bacteria, food preservation, human health

INTRODUCTION

Lactic Acid Bacteria (LAB) are gram positive, typically non- sporulating rod or coccus shaped. They lack catalase and strictly fermentative, producing either a mixture of lactic acid, carbon dioxide, acetic acid and/or ethanol (heterofermentation) or almost entirely lactic acid (homofermentation) as the major metabolic end-product (Rogosa, 1974; Collins and Lyne, 1984; Jay, 1986; Kandler and Weiss, 1986; Schillinger and Lucke, 1987; Priest and Campbell, 1996). Kluver divided LAB into two groups based on the end product of glucose metabolism; those that produce lactic acid as the only product of fermentation are designated

homofermentative. The homofermentative pattern is observed when glucose is metabolized but not necessarily when pentose sugars are metabolized, for some, homolactics produce acetic acids when utilizing pentose. Also the homofermentative character of homolactics may be shifted for some strains by altering cultural conditions such as glucose concentration, pH and nutrient limitation. The homolactics able to extract twice as much energy from a given quantity of glucose as are the heterolactics. These lactics that produce equal molar amounts of lactate, carbon dioxide and ethanol from hexoses are designated heterofermentative. All members of the genera *Pediococcus*, *Streptococcus*, *Lactococcus* and *Vagococcus* are homofermenters, along with some of the *lactobacilli*, while all *Leuconostoc* sp., as well as some *Lactobacilli* are heterofermenters. The heterolactics are more important than the homolactics in producing flavour and aroma components such as acetylaldehyde and diacetyl (Sharpe, 1979; Jay, 1986; Schillinger and Lucke, 1987).

LAB IN BIOCONTROL AND FERMENTATION

Biological Control of Food Borne Pathogens

Research has focused on the biological approach to the control and eradication of food borne pathogens. Scientists developed natural antimicrobial products for the biocontrol of pathogens and have exploited LAB for the competitive exclusion of pathogens and delivery of vaccines and bioactive compounds (Grasson, 2002).

LAB in Competitive Exclusion

The gastrointestinal tract of humans and animals contain a complex bacterial ecosystem. Commensal strains of LAB have a history of use with the intention of enhancing health in the form of probiotics and controlling human pathogens in farm animals. Research has demonstrated the capacity of *Lactobacillus* species to control arrangement of human pathogens including *E. coli*, *Compylobacter jejuni* and *Clostridium perfringes* (Grasson, 2002).

LAB as Probiotics

In discussing the importance of *Lactobacillus* species in fermented foods one also needs to consider their importance as probiotics was later defined as a live microbial feed supplement, which is beneficial to the host animal through improving its intestinal microbial balance (Steinkrause, 1995). *Lactobacillus* sp. has been used as probiotic organisms. In this case, *L. acidophilus* has been used because it was thought to be the dominant *lactobacillus* in the intestine. However, a wide range of *lactobacilli* has been used in probiotic preparations. These include: *L. delbreuckii* subsp. *bulgaricus*, *L. casei*, *L. brevis*, *L. cellobiosus*, *L. lactis*, *L. fermentum*, *L. plantarum* and *L. reuteri* (Steinkrause, 1995; Vinderola *et al.*, 2002). Metchnikoff (1908) described the beneficial effect of lactic acid bacteria on human health almost a century ago. Although, numerous studies have substantiated the findings of Metchnikoff, it has been a difficult scientific discipline to identify and prove the mode of action for probiotics (Mattila-Sandholm *et al.*, 1999; Pathmakanthan *et al.*, 2000). The pre-existing flora of the digestive tract is complex and ill-defined which makes it very difficult to determine how probiotics influence the intestinal ecosystem (Tannock, 1998; Kleessen *et al.*, 2000; Macfarlane *et al.*, 2000). The presence of microbial flora is necessary for the normal function of the digestive system. Elimination or severe perturbations of the flora leads to diarrhoea or constipation and the maintenance of a healthy bacterial flora is therefore desirable (Tannock, 1998; Pathmakanthan *et al.*, 2000). In the absence of precise models for the mode of action, a number of practical criteria for

selecting probiotic strains have been formulated (Collins *et al.*, 1998; Salminen *et al.*, 2000; Klaenhammer and Kullen, 1999; Mattila-Sandholm *et al.*, 1999). The large increase in the occurrence of allergy in the populations of the industrialized world is still largely unexplained. One of several hypotheses is the hygiene hypothesis, which explains the increase by our modern environment being too aseptic (Martinez and Holt, 1999; Van den Biggelaar *et al.*, 2000). If this is, indeed, a part of the problem, we will need to design our future fermented food or the probiotic products to contain safe microorganisms counteracting this unwanted distortion of the immune system.

LAB as Vaccine Delivery Vehicles

Commensal LAB can be exploited to deliver vaccines and other biological active material to the gastrointestinal tract. Their use in vaccine delivery is of special value in stimulating mucosal immunity that is protective at the site of pathogen entry. The advantages of LAB delivery include: ease of administration; survival in stomach acid; inherent safety; particulate nature and size for uptake by cells; economic technology in that the bacterial manufacture the vaccine or therapeutic agent (Grasson, 2002).

LAB as Beneficial Microorganisms

The LAB are important commercially in the processing of meats, alcoholic beverages and vegetables. The products include sausages, cured hams, wines, beer, fortified spirits, pickles and sauerkraut (Collins and Lyne, 1976; Sharpe, 1981; Jay, 1986; Kandler and Weiss, 1986; Hastings and Holzappel, 1987; Schillinger and Lucke, 1987; Jay, 1992). Although, LAB have beneficial effects in the food industry, they can sometimes be a nuisance as contaminants by producing off flavours (Kandler and Kunath, 1983; Aguirre and Collins, 1993; Cai *et al.*, 1998). *Lactobacillus* and *Streptococcus faecum* are beneficial microorganisms, which have been proven to replenish essential microflora and decrease the incidence of gastrointestinal disorders. Beneficial bacteria, especially *lactobacillus* sp. can produce anti- microbial substances, which have been observed to inhibit the growth of some pathogenic microorganisms. The addition of type O lactic culture may be an additional safeguard to established good manufacturing practices and Hazard Analysis and Critical Control Point (HACCP) programs in the control of growth of *E. coli* 0157:H7 in minas cheese (Saad *et al.*, 2001; Yost and Nattress, 2002). These beneficial microorganisms are most effective during periods of disease or stress and following antibiotic treatment.

Importance of LAB and their Effect on Human Health

Of interest is the role of LAB in the treatment of people suffering with tumors and immune compromised subjects. The evidence that LAB can stimulate the immune system is remarkable and fascinating in it and opens many questions about mechanisms and effective utilization. If this potential is supported in practice, then there are many components to conventional therapies. This may include cost effectively due to their ease of products derived from LAB seem to have relatively low toxicity compared to other treatments (Wood, 1992).

Lactic Acid Bacteria and Other Effects on the Immune System

The LAB are present in the intestine of most animals. The beneficial role played by this microorganism in humans and animals, including the effect on the immune system has been extensively reported (Perdigon *et al.*, 2001). The LAB are present in many foods and are frequently used as probiotics to improve some biological functions in the host. Through

different mechanisms they send signals to active immune cells. Thus the knowledge of the normal intestinal microflora, the contribution of LAB and their role in the numerous functions in the digestive tract as well as the functioning of the mucosal immune system. In the selection of LAB by their immune stimulatory capacity, it helps to know not only the effect which they have on the mucosal immune system, but the specific use to which these oral vaccine vectors are being put (Perdigon *et al.*, 2001).

LAB as Starter Culture

Lactic Acid Bacteria (LAB) are the most important bacteria used in food fermentations. Apart from general demands for starter cultures from the view of safety, technological effectiveness and economics, numerous specific aspects have to be considered when selecting strains for the different food fermentations. Therefore, selection criteria for LAB depend on the type and the desired characteristics of the final product, the desired metabolic activities, the characteristics of the raw materials and the applied technology. A starter culture can be defined as a microbial preparation of large numbers of cells of at least one microorganism to be added to a raw material to produce a fermented food by accelerating and steering its fermentation process. The group of Lactic Acid Bacteria (LAB) occupies a central role in these processes and has a long and safe history of application and consumption in the production of fermented foods and beverages (Caplice and Fitzgerald, 1999; Ray, 1992; Wood, 1997; Wood and Holzapfel, 1995) (Table 1). They cause rapid acidification of the raw material through the production of organic acids, mainly lactic acid. Also, their production of acetic acid, ethanol, aroma compounds, bacteriocins, exopolysaccharides and several enzymes is of importance. In this way they enhance shelf life and microbial safety, improve

Table 1: Fermented foods and beverages and their associated lactic acid bacteria

Types of fermented products	Lactic acid bacteria
Dairy products	
Hard cheeses without eyes	<i>L. lactis</i> subsp. <i>lactis</i> , <i>L. lactis</i> subsp. <i>cremoris</i>
Cheeses with small eyes	<i>L. lactis</i> subsp. <i>lactis</i> , <i>L. lactis</i> subsp. <i>lactis</i> var. <i>diacetylactis</i> , <i>L. lactis</i> subsp. <i>cremoris</i> , <i>Leuc. mesenteroides</i> subsp. <i>cremoris</i>
Swiss- and Italian-type cheeses	<i>Lb. delbrueckii</i> subsp. <i>lactis</i> , <i>Lb. helveticus</i> , <i>Lb. casei</i> , <i>Lb. delbrueckii</i> subsp. <i>bulgaricus</i> , <i>S. thermophilus</i>
Butter and buttermilk	<i>L. lactis</i> subsp. <i>lactis</i> , <i>L. lactis</i> subsp. <i>lactis</i> var. <i>diacetylactis</i> , <i>L. lactis</i> subsp. <i>cremoris</i> , <i>Leuc. mesenteroides</i> subsp. <i>cremoris</i>
Yoghurt	<i>Lb. delbrueckii</i> subsp. <i>bulgaricus</i> , <i>S. thermophilus</i>
Fermented, probiotic milk	<i>Lb. casei</i> , <i>Lb. acidophilus</i> , <i>Lb. rhamnosus</i> , <i>Lb. johnsonii</i> , <i>B. lactis</i> , <i>B. bifidum</i> , <i>B. breve</i>
Kefir	<i>Lb. kefir</i> , <i>Lb. kefiranoformis</i> , <i>Lb. brevis</i>
Fermented meats	
Fermented sausage (Europe)	<i>Lb. sakei</i> , <i>Lb. curvatus</i>
Fermented sausage (USA)	<i>P. acidilactici</i> , <i>P. pentosaceus</i>
Fermented fish products	<i>Lb. alimentarius</i> , <i>C. piscicola</i>
Fermented vegetables	
Sauerkraut	<i>Leuc. mesenteroides</i> , <i>Lb. plantarum</i> , <i>P. acidilactici</i>
Pickles	<i>Leuc. mesenteroides</i> , <i>P. cerevisiae</i> , <i>Lb. brevis</i> , <i>Lb. plantarum</i>
Fermented olives	<i>Leuc. mesenteroides</i> , <i>Lb. pentosus</i> , <i>Lb. plantarum</i> , <i>P. acidilactici</i> , <i>P. pentosaceus</i> , <i>Lb. plantarum</i> , <i>Lb. fermentum</i>
Fermented vegetables soy sauce	<i>T. halophilus</i>
Fermented cereals	
Sourdough	<i>Lb. sanfransiscensis</i> , <i>Lb. farciminis</i> , <i>Lb. fermentum</i> , <i>Lb. brevis</i> , <i>Lb. plantarum</i> , <i>Lb. amylovorus</i> , <i>Lb. reuteri</i> , <i>Lb. pontis</i> , <i>Lb. panis</i> , <i>Lb. alimentarius</i> , <i>W. cibaria</i>
Alcoholic beverages	
Wine (malolactic fermentation)	<i>O. oeni</i>
Rice wine	<i>Lb. sakei</i>

B: *Bifidobacterium*, C: *Carnobacterium*, L: *Lactococcus*, Lb: *Lactobacillus*, Leuc: *Leuconostoc*, O: *Oenococcus*, P: *Pediococcus*, S: *Streptococcus*, T: *Tetragenococcus*, W: *Weissella*

texture and contribute to the pleasant sensory profile of the end product. The earliest production of fermented foods was based on spontaneous fermentation due to the development of the microflora naturally present in the raw material. The quality of the end product was dependent on the microbial load and spectrum of the raw material. Spontaneous fermentation was optimized through back-slopping, i.e., inoculation of the raw material with a small quantity of a previously performed successful fermentation. Hence, back-slopping results in dominance of the best adapted strains. It represents a way, be it unconsciously, of using a selected starter culture to shorten the fermentation process and to reduce the risk of fermentation failure. Back-slopping is still in use, for instance in the production of sauerkraut and sourdough and particularly for products for which the microbial ecology and the precise role of successions in microbial population are not well known (Harris, 1998). Today, the production of fermented foods and beverages through spontaneous fermentation and back-slopping represents a cheap and reliable preservation method in less developed countries, whereas in Western countries the large-scale production of fermented foods has become an important branch of the food industry. Moreover, the Western consumer appreciates traditionally fermented products for their outstanding gastronomic qualities. The direct addition of selected starter cultures to raw materials has been a breakthrough in the processing of fermented foods, resulting in a high degree of control over the fermentation process and standardization of the end product. Strains with the proper physiological and metabolic features were isolated from natural habitats or from successfully fermented products (Oberman and Libudzisz, 1998). However, some disadvantages have to be considered. In general, the initial selection of commercial starter cultures did not occur in a rational way, but was based on rapid acidification and phage resistance. These starters are not very flexible with regard to the desired properties and functionality of the end product. Originally, industrial starter cultures were maintained by daily propagation. Later, they became available as frozen concentrates and dried or lyophilized preparations, produced on an industrial scale, some of them allowing direct vat inoculation (Sandine, 1996). Because the original starter cultures were mixtures of several undefined microbes, the daily propagation probably led to shifts of the ecosystem resulting in the disappearance of certain strains. Moreover, some important metabolic traits in LAB are plasmid-encoded and there is a risk that they are lost during propagation. It is further likely that loss of genetic material occurred due to adaptation to the food matrix. The biodiversity of commercial starters has therefore become limited. This often leads to a loss of the uniqueness of the original product and the loss of the characteristics that have made the product popular (Caplice and Fitzgerald, 1999). In contrast, the fermentation of traditional fermented foods is frequently caused by natural, wild-type LAB that originate from the raw material, the process apparatus, or the environment and that initiate the fermentation process in the absence of an added commercial starter (Bocker *et al.*, 1995; Weerkamp *et al.*, 1996). Moreover, many traditional products obtain their flavour intensity from the Non-Starter Lactic Acid Bacteria (NSLAB), which are not part of the normal starter flora but develop in the product, particularly during maturation, as a secondary flora (Beresford *et al.*, 2001). Pure cultures isolated from complex ecosystems of traditionally fermented foods exhibit a diversity of metabolic activities that diverge strongly from the ones of comparable strains used as industrial bulk starters (Klijn *et al.*, 1995). These include differences in growth rate and competitive growth behavior in mixed cultures, adaptation to a particular substrate or raw material, antimicrobial properties and flavour, aroma and quality attributes. Wild strains need to withstand the competition of other microorganisms to survive in their hostile natural environment, so that they often produce antimicrobials such as bacteriocins (Ayad *et al.*, 2002). In addition, they are more dependent

on their own biosynthetic capacity than industrial strains and harbour more amino acid converting enzymes that play a key role in flavour formation. Such findings underline the importance of the Designation of Protected Origin (DPO) of many of these products, which is crucial from an economical point of view since they contribute to the survival of small-scale fermentation plants in a world of ongoing globalization. A recent trend exists in the isolation of wild-type strains from traditional products to be used as starter cultures in food fermentation (Beukes *et al.*, 2001; De Vuyst *et al.*, 2002; Hebert *et al.*, 2000). Many indigenous cereal fermentations involve the combine action of bacteria and yeast. *L. fermentum* and *L. amylovorus* have been suggested to be the predominating microorganisms during fermentation of sorghum dough in Sudanese Kisra (Asmahan and Muna, 2009), also the use of *Lactobacillus* starter in sorghum flour fermentation decreased the traditional fermentation time from 19 to 6 h, the thing that might contribute, in no small way, in encouraging the production and development of more sorghum based products. Using yeast during *Lactobacillus* fermentation of sorghum has, furtherly, shortened the fermentation time to 4 h. The pH was decreased to 3.7 (Asmahan, 2007). Indigenous fermented food represents a unique source for future application in food technology. Little or no scientific information on lactic acid bacteria in certain indigenous, fermented sorghum products in Africa, Kisra is a prime example of such a product.

CONCLUSIONS

Lactic acid bacteria (LAB) have health-promoting attributes, including antimutagenic and anticarcinogenic activities, hypocholesterolemic properties and antagonistic actions that can restrain intestinal and food borne pathogens and immune modulation effects. The LAB have been reported to improve gastrointestinal health. Furthermore, LAB and their fermented products can effectively enhance the integrity of the gastric mucosa. Many reports suggest that LAB and their fermented products have protective effects against mucosal injury in the stomach.

The LABS are typically involved in a large number of spontaneous food fermentations but they are also closely associated with the human environment. Food fermentations have a great economic value and it has been accepted that these products contribute in improving human health. The LABS have contributed in the increased volume of fermented foods world wide especially in foods containing probiotics or health promoting bacteria. Bacteriocins produced by LAB are the subject of intense research because of their antibacterial activity against food borne bacteria. Further studies should be focused on the mechanisms of action of LAB within the gastro intestinal tract and in the immune system which stimulate the *in vivo* immunity effects. Furthermore, genetic engineering of already identified probiotics and those newly discovered to make them more efficacious should be pursued.

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