Potential of Lactic Acid Bacteria in Human Nutrition

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ABSTRACT

Several fermented foods and beverages that incorporate lactic acid bacteria are produced throughout the world. Lactic acid bacteria (LAB) are widely distributed in nature and occur as natural microflora in many fermented foods (fermented milk, cereal fermented food, fermented fruit products, among others). Several thousand fermented foods are said to be in existence and are classified as beverages, fruits and processed foods, such as cereal, dairy food, fish, vegetables, beans, meat, starch-added crops and others. In addition to fungi and yeast LAB are also deeply related to human history and have made a great contribution to food fermentation, and to the improvement of its flavor. LAB have been, and are of interest in the promotion of good health in animals and humans. LAB may be used as probiotics, whose positive effects include: growth promotion of farm animals, protection of the host from gastrointestinal infections, alleviation of lactose intolerance, relief of constipation, anticarcinogenic, anti-cholesterolaemic and immunostimulatory effects, nutrient synthesis and bioavailability, prevention of genital and urinary tract infections. This paper reviews the potential of LAB used in several fermented food production systems and their importance (probiotic role, nutrient synthesis, immunostimulatory effect, flavour production, food protection due to bacteriocin and acid production) in human nutrition.

Keywords: bacteriocin, cereal, fermentation, fermented products, organic acids, probiotics

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INTRODUCTION

Lactic acid bacteria (LAB) have been used to ferment or culture foods for at least 4000 years. Fermented foods make up an important contribution to the human diet in many countries throughout the world; fermentation is technology which preserves food, improves its nutritional value and enhances its sensory properties (Murth and Kumar 1995; Steinkraus 1996).

Fermentation is a process dependent on the biological activity of microorganisms for production of a range of metabolites which can suppress the growth and survival of undesirable microflora in foodstuffs (Klaenhammer 1993; Soomro et al. 2002).

The most single important development permitting the formation of civilization was the ability to produce and store large quantities of food. It is beneficial to be able to store as much food as possible in order to minimize the amount of time spent gathering that food. Food fermentation has great economic value and it has been accepted that these products contribute in improving human health.

Preservation of food and beverages resulting from fermentation has been an effective form of extending the shelf-life of foods for millennia.

Alcoholic fermentations involved in wine-making and brewing are thought to have been developed during the period 2000-4000 BC by the Egyptians and Sumerians. The Egyptians also developed dough fermentations used in the production of leavened bread (Desrosier 1977).

There are many examples which report on the inhibition
of spoilage and pathogenic bacteria by LAB (Price and Lee 1970; Klaenhammer 1993).

A group of bacteria know collectively as LAB is primarily responsible for many of the microbial transformations found in the more common fermented food products: genera including Lactococcus, Lactobacillus, Enterococcus, Streptococcus, Leuconostoc, and Pediococcus generally produce lactic acid as their major end product. They are strictly obligate anaerobic and lack the ability to synthesise haem, and these requirements means that they are consequently catalase negative and lack a terminal electron transport chain (Condon 1987).

Several traditional fermented products have been documented in different African countries and include non-alcoholic beverages, alcoholic beverages, breads, pancakes, porridges, cheeses, and milks (Van der Walt 1956; Haggblade and Holzapfel 1989; Ashenafi 1990; Gorbach 1990; Dirar 1993; Mzestigye and Okurut 1995; Steinkraus 1996; Gorbach 2000; Savadogo et al. 2004).

LAB is of interest since it promotes good health in animals and man (Gorbach 1990, 2000). Also LAB can be use as probiotics (Fuller 1989). Fuller (1989) defined a probiotic as a live microbial feed supplement beneficial to the host (man or animal) by improving the microbial balance within its body. Some of the positive effects of probiotics are: growth promotion of farm animal (Havenaar and Huis in’t Veld 1992), protection of hosts from intestinal infections (de Simone 1986; Fuller 1989; O’Sullivan et al. 1992), alleviation of lactose intolerance (Fuller 1989; Marteau et al. 1990; Sawada et al. 1990), relief of constipation (Oyetayo and Oyetayo 2005), anticancerogenenic effect (O’Sullivan et al. 1992; Isolauri 2004; Lee et al. 2004; Saikali et al. 2004; Oyetayo and Oyetayo 2005), anticholesterolastic effects (Tamme 2002; Oyetayo and Oyetayo 2005; Parvez et al. 2005), nutrient synthesis and bioavailability (Oyetayo and Oyetayo 2005), prevention of genitil and urinary tract infection (McLean and Rosenstein 2000) and immunostimulatory effects (Perdigon and Alvarez 1992; Malin et al. 1997; MacFarlane and Cummings 2002; McNaught et al. 2005).

Fermented food may have a potential for use as weaning foods if they promote organic acids such as lactic, acetic and propionic acids, produced during the fermentation process of cereal foods, and which are inhibitory of many diarrhoea-causing bacteria (Simango and Rukure 1992). Fermented foods contribute to about one third of the diet worldwide (Campbell-Platt 1994). The content and quality of cereal proteins may be improved by fermentation (Wang and Fields 1978; Cahvan et al. 1988). Natural fermentation of cereals increases their relative nutritive value and available lysine (Hamad and Fields 1979). Bacterial fermentations involving proteolytic activity are expected to increase the biological availability of essential amino acids more so than yeast fermentation which mainly degrade carbohydrate (Chaven and Kadam 1989).

This article reviews the potential of lactic acid bacteria as a result of carbohydrate fermentation.

LAB are generally described as Gram positive, non-sporing cocci or rods with lactic acid as the major product of carbohydrate fermentation.

LAB refers to a large group of beneficial bacteria that have similar properties and all produce lactic acid as and product of the fermentation process. Traditionally LAB comprise four genera Lactobacillus, Leuconostoc, Pediococcus and Streptococcus. However, several new genera have been suggested for inclusion in the group of LAB due to a recent taxonomic revision (Axelson 1998). The genus Streptococcus has been reorganized into Enterococcus, Lactococcus, Streptococcus and Yagococcus (Axelson 1998).

They are widespread in nature and are also found in our digestive systems.

LAB are all gram positive, anaerobic, microaerophilic or aero-tolerant; catalase negative; rods or cocci; most importantly they produce lactic acid as the sole major or an important product from the energy-yielding fermentation of sugars. It used to be thought that all LAB were non motile and non-sporing; although there are now the sporolactobacilli and motile organisms which are reported to otherwise fit with the LAB. They are chemo-organotrophic and grow only in complex media. Fermentable carbohydrates are used as energy source (Campbell-Platt 1994).}

**Phylogenetic relationships**

Phylogenetic relationships of LAB based on 16 S and 23 S rRNA sequence data divide the Gram positive bacteria form into two lines of descent. One phylum consists of Gram positive bacteria with a DNA base composition of less than 50 mol % guanine plus cytosine (G+C), the so-called Clostridium branch, whereas the other branch (Actinomycetes) comprises organisms with a G+C content that is higher than 50 mol %. The typical LAB, such as Carnobacterium, Lactobacillus, Lactococcus, Leuconostoc, Pediococcus and Streptococcus, have a G+C content of less than 50 mol % and belong to the Clostridium branch.

**FERMENTATION FUNCTIONS IN FOODS**

LAB are able to produce a large variety of components which contribute to the flavour, colour, texture and consistency of fermented foods (Tables 1, 2, 3).

According to Steinkraus (1995) traditional fermentation of foods (cereal, milk, fruits) serves several functions: a) Enrichment of the diet through development of a diversity of flavours, aromas and textures in food substrates; b) Preservation of substantial amounts of food through lactic acid, alcoholic, acetic acid and alkaline fermentations; c) Enrichment of food substrates biologically with protein essential amino acids essential fatty acids vitamins; d) Detoxification in cooking times and fuel requirements microbial activity in foods makes them more attractive in terms of appearance and flavours. Such foods are more appetizing and easily digestible. Fermentation improves the digestibility of the ingredients for human consumption and enhances the keeping quality and shelf life.

**CEREAL-BASED FERMENTED PRODUCTS (TABLE 1)**

Cereals are one of the oldest of all cultivated plants. Today, there are more than 5000 cultivars of wheat in existence and as a result wheat can be grown in a relatively wide range of climatic conditions. Cereal grains are the fruit of plants belonging to the grass family Poaceae. Cereals have a variety of uses as food. Only two cereals, wheat and rye, are suited to the preparation of leavened bread. The most general usage of cereals is in cooking, either directly in the form of grain, flour, starch, or as semolina. Another common usage of cereals is in the preparation of alcoholic drinks such as whiskey and beer, vodka, American bourbon, Japanese sake etc. A variety of unique indigenous fermented foods, other than leavened bread and alcoholic beverages are also pro-
Lactic acid bacteria in human nutrition. Savadogo et al.

Fermented food contribute to about one third of the diet worldwide (Campbell-Platt 1994). Cereals are particularly important substrates for fermented foods all over the world and are staples in the Indian subcontinent in Asia and in Africa. Fermentation causes changes in food quality indices including texture, flavor, appearance, nutrition and safety. Natural fermentation of cereals increases their relative nutritive value and available lysine (Hamad and Fields 1979).

Table 1: Some important indigenous fermented cereal products around the world (based on and modified from Soni and Sandhu 1999).

<table>
<thead>
<tr>
<th>Fermented food name</th>
<th>Country/place</th>
<th>Ingredient(s)</th>
<th>Nature of product</th>
<th>Product use</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ang-Kak (Chinese red rice)</td>
<td>China, Taiwan, Philippines, Thailand</td>
<td>Rice</td>
<td>Solid</td>
<td>Colouring other foods</td>
</tr>
<tr>
<td>Ambali</td>
<td>India</td>
<td>Millet flour</td>
<td>Semi-solid</td>
<td>All time food</td>
</tr>
<tr>
<td>Bhatura</td>
<td>India North</td>
<td>White wheat flour</td>
<td>Deep fried; bread</td>
<td>Breakfast</td>
</tr>
<tr>
<td>Fermented rice</td>
<td>India</td>
<td>Rice</td>
<td>Semi-solid</td>
<td>Breakfast</td>
</tr>
<tr>
<td>Hopper (Appa)</td>
<td>Sri Lanka</td>
<td>Rice or White wheat flour and coconut water</td>
<td>Semi-solid</td>
<td>Breakfast</td>
</tr>
<tr>
<td>Jalebie</td>
<td>India, Pakistan</td>
<td>White wheat flour</td>
<td>Deep fried; crispy pretzel</td>
<td>Confection food</td>
</tr>
<tr>
<td>Kenkey</td>
<td>Ghana</td>
<td>Maize</td>
<td>Semi-solid</td>
<td>Breakfast, lunch and supplement to fish stews</td>
</tr>
<tr>
<td>Kisra</td>
<td>Sudan</td>
<td>Sorghum flour</td>
<td>Spongy bread</td>
<td>Staple food</td>
</tr>
<tr>
<td>Kulcha</td>
<td>India (North), Pakistan</td>
<td>White wheat flour</td>
<td>Flat bread</td>
<td>Staple food</td>
</tr>
<tr>
<td>Mahewu</td>
<td>South Africa</td>
<td>Maize meal</td>
<td>Liquid</td>
<td>Beverage food</td>
</tr>
<tr>
<td>Nan</td>
<td>India (North) Pakistan, Iran, Afghanistan</td>
<td>White wheat flour</td>
<td>Flat bread</td>
<td>Staple food</td>
</tr>
<tr>
<td>Ogí</td>
<td>Nigeria</td>
<td>Maize, Millet or Sorghum</td>
<td>Semi-solid</td>
<td>Breakfast and infant food</td>
</tr>
<tr>
<td>Pozol</td>
<td>Mexico</td>
<td>White maize</td>
<td>Liquid</td>
<td>Beverage or Porridge</td>
</tr>
<tr>
<td>Puto</td>
<td>Philippines</td>
<td>Rice</td>
<td>Semi-solid</td>
<td>Breakfast and snack food</td>
</tr>
<tr>
<td>Shamsy bread</td>
<td>Egypt</td>
<td>Flour</td>
<td>Spongy bread</td>
<td>Staple food</td>
</tr>
<tr>
<td>Uji</td>
<td>Kenya, Uganda, Tanzania</td>
<td>Maize, sorghum or millet flour</td>
<td>Semi-solid</td>
<td>Breakfast and lunch</td>
</tr>
</tbody>
</table>

Table 2: Some important indigenous fermented legume products around the world (based on and modified from Soni and Sandhu 1999).

<table>
<thead>
<tr>
<th>Fermented food name</th>
<th>Country/place</th>
<th>Ingredient(s)</th>
<th>Nature of product</th>
<th>Product use</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bhallae</td>
<td>India</td>
<td>Black gram</td>
<td>Deep fried patties</td>
<td>Snack after soaking in curd, water</td>
</tr>
<tr>
<td>Chee-fan</td>
<td>China</td>
<td>Soybean, whey curd</td>
<td>Solid</td>
<td>Eaten fresh, cheese-like</td>
</tr>
<tr>
<td>Docuwadwara</td>
<td>West Africa, Nigeria</td>
<td>African locust bean</td>
<td>Solid</td>
<td>Eaten fresh, supplement to soups, stews</td>
</tr>
<tr>
<td>Khaman</td>
<td>Western India</td>
<td>Bengali gram</td>
<td>Spongy cake</td>
<td>Breakfast food</td>
</tr>
<tr>
<td>Kenina</td>
<td>Nepal, Sikkim, Darjeeling, District of West Bengal in India</td>
<td>Soybeans</td>
<td>Solid</td>
<td>Snack</td>
</tr>
<tr>
<td>Ketjap</td>
<td>Indonesia</td>
<td>Black soybeans</td>
<td>Syrup</td>
<td>Seasoning agent</td>
</tr>
<tr>
<td>Meitanza</td>
<td>China, Taiwan</td>
<td>Soybean cake</td>
<td>Solid</td>
<td>Fried in oil or cooked with vegetables</td>
</tr>
<tr>
<td>Meju</td>
<td>Korea</td>
<td>Soybeans</td>
<td>Paste</td>
<td>Seasoning agent</td>
</tr>
<tr>
<td>Miso</td>
<td>Japan, China</td>
<td>Soybeans/soybeans and rice</td>
<td>Paste</td>
<td>Soup base, seasoning agent</td>
</tr>
<tr>
<td>Natto</td>
<td>Northern Japan</td>
<td>Soybeans</td>
<td>Solid</td>
<td>Roasted or fried in oil used as a meat substitute</td>
</tr>
<tr>
<td>Oncom</td>
<td>Indonesia</td>
<td>Peanut press cake</td>
<td>Solid</td>
<td>Roasted or fried in oil used as a meat substitute</td>
</tr>
<tr>
<td>Papadam</td>
<td>India</td>
<td>Black gram and spices</td>
<td>Circular tortilla like wafers</td>
<td>Condiment</td>
</tr>
<tr>
<td>Soybean milk</td>
<td>China, Japan</td>
<td>Soybeans</td>
<td>Liquid</td>
<td>Drink</td>
</tr>
<tr>
<td>Sufa</td>
<td>China, Taiwan</td>
<td>Soybean, whey curd</td>
<td>Solid</td>
<td>Soybean cheese, condiment</td>
</tr>
<tr>
<td>Soy sauce</td>
<td>Japan, China, Philippines</td>
<td>Soybeans/soybeans and wheat</td>
<td>Liquid fish, cereals and vegetables</td>
<td>Seasoning agent for meat</td>
</tr>
<tr>
<td>Tempch</td>
<td>Indonesia and its vicinity</td>
<td>Soybeans</td>
<td>Solid</td>
<td>Fried in oil, roasted or used as meat substitute in soup</td>
</tr>
<tr>
<td>Vadai</td>
<td>India</td>
<td>Black gram</td>
<td>Deep fried patties</td>
<td>Snack</td>
</tr>
<tr>
<td>Warries</td>
<td>Northern India</td>
<td>Black gram and spices</td>
<td>Ball like, hollow, brittle</td>
<td>Spicy condiment eaten with vegetables, legumes, rice</td>
</tr>
</tbody>
</table>

Table 3: Some important indigenous fermented legume-cereal products around the world (based on and modified from Soni and Sandhu 1999).

<table>
<thead>
<tr>
<th>Fermented food name</th>
<th>Country/place</th>
<th>Ingredient(s)</th>
<th>Nature of product</th>
<th>Product use</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dhokia</td>
<td>Western India</td>
<td>Rice, Bengal gram</td>
<td>Spongy cake</td>
<td>Condiment</td>
</tr>
<tr>
<td>Dosa</td>
<td>Southern India</td>
<td>Rice, black gram</td>
<td>Spongy, pancake</td>
<td>Condiment</td>
</tr>
<tr>
<td>Hama natto</td>
<td>Japan</td>
<td>Wheat flour, whole soybeans</td>
<td>Raisin-like, soft</td>
<td>Flavouring agent for meat and fish, eaten as snack</td>
</tr>
<tr>
<td>Idli</td>
<td>Southern India</td>
<td>Rice, black gram</td>
<td>Spongy</td>
<td>Breakfast food</td>
</tr>
<tr>
<td>Kecap</td>
<td>Indonesia and vicinity</td>
<td>Soybeans, whey, soybeans</td>
<td>Liquid</td>
<td>Condiment, seasoning agent</td>
</tr>
<tr>
<td>Tao-si</td>
<td>Philippines</td>
<td>Wheat flour, soybeans</td>
<td>Semi-solid</td>
<td>Seasoning agent</td>
</tr>
<tr>
<td>Tootjo</td>
<td>East Indies</td>
<td>Roasted wheat, Meal or glutinous rice, soybeans</td>
<td>Semi-solid</td>
<td>Condiment</td>
</tr>
</tbody>
</table>
ca, where cooling facilities are not readily available, fer-
mentation provides a cheap but effective form of food pre-
servation (Hesseltine and Wang 1979; Umoh and Field

In Africa most fermented foods are based on cereals. Most of these fermentations are spontaneous, and involve LAB, yeasts or a mixture of these as the functional micro-
organisms. A wide range of cereal-based fermented foods exists such as amam in Benin (Hounhouigan et al. 1991), kenkey in Ghana, poto-poto in Congo (Blandino et al. 2003), ogi and kworum-zaki in Nigeria (Oyewole 1997), injera in Ethiopia, uji and togwa in Tanzania, kisra in Sudan (Tom-
kins et al. 1988).

Ogi
Porridge prepared from fermented maize, sorghum or millet in West Africa. Microbiological and nutritional studies of ogi (Odunfa 1985) showed that the LAB Lb plantarum, ae-
robic bacteria Corynebacterium and Aerobacter, the yeasts Candida mycoderma, Saccharomyces cerevisiae and Rhodo-
torula and moulds Cephalosporium, Fusarium, Asper-
gillus and Penicillium are the major organisms responsible for the fermentation and nutritional improvement of ogi. Odunfa (1985) determined that Lb plantarum was the pre-
dominant organism in the fermentation responsible for lactic acid production.

Traditional preparation of ogi involves soaking of corn kernels in water for 1 to 3 days followed by wet milling and sieving to remove bran, hulls and germ. The pomace is re-
tained on the sieve and later discarded as animal feed while
the filtrate is fermented (for 2 to 3 days) to yield ogi, which is a sour, white, starchy sediment.

Tempe kedele
A fermented product of Indonesia which is prepared by in-
cubating the soaked soybeans in a warm place, and is are
knitted into a compact cake by a fibrous mould mycelium for 1 to 3 days (Hesseltine 1965). Tempe kedele is a white, mould-covered cake produced by fungal fermentation of dehulled, hydrated, and partially cooked soybean cotyle-
dons.

The essential steps in the production of tempe are: cleaning the soybeans, hydration and acid fermentation, dehulling dry or following hydration, partial cooking, draining, cooling, surface drying, placing the soybean cotyle-
dons in suitable fermentation containers, inoculating with tempe mould (Aspergillus niger, Mucor javanicus, Mucor-
russ, Rhizopus achlamydoxporus), incubating until the cotyle-
dons are completely covered with mould mycelium, harvest-
ing and selling, cooking for consumption.

Traditionally, the inoculated cotyledons are then wrap-
ed in small packets using wilted banana or other large leaves and are incubated in a warm place for two or three days.

Natto, tu-si, tao-si, tnu-a-nao
Fermented whole soybeans are known as natto in Japan, tu-
si in China, tao-si in The Philippines and tnu-a-nao in Thai-
lnd (Hesseltine and Wang 1979; Reddy et al. 1982).

Natto is a Japanese original and traditional food. Natto is a fermented food made of soybeans and is rich in vege-
table protein (Table 2).

Kenkey
Kenkey is a fermented maize dough which is consumed in Ghana. During the production of Kenkey dough is divided into
 two parts: one part “the aflata” is cooked into a thick porridge, while the other uncooked part is later mixed with “aflata”. The resulting mixture is moulded into balls and wrapped in dried maize husk or plantain leaves, after which it is steamed. Dough is fermented for 72 hours. Microbial

studies of kenkey production by Jespersen et al. (1994) highlighted the significance of yeasts and moulds in the pro-
duction of this fermented maize dough. A mixed flora con-
sisting of Candida, Saccharomyces, Penicillium, Aspergillus and Fusarium species were found to be the dominance mi-
croorganisms during the preparation of this food product. Halim et al. (1993) concluded that a homogenous group of obligatorily heterofermentation lactobacilli related to Lacto-
bacillus fermentum and Lactobacillus reuteri play a domi-
nant role during kenkey production (Table 1).

LAB AS PROBIOTICS

Definition
The term “probioitc” has been given many meanings, but it now generally recognized as a fermented dairy product con-
taining live LAB that have been specially selected to pro-
vide specific health benefits (Fuller 1989). Most probiotic products contain bacteria from the genera Lactobacillus or Bifidobacterium. Probiotic products should be safe, effective, and should maintain their effectiveness and potency until they are consumed (Scheerenmeir and de Vrese 2001). Probiotics are usually defined as microbial food supple-
ments with beneficial effects on the consumers. Recent sci-
entific investigation has supported the important role of pro-
biotics as a part of a healthy diet for human as well as for animals and may be an avenue to provide a safe, cost-effective, and natural approach that adds a barrier against mi-
crobial infection.

Functions of probiotics
Reported functions of probiotics as a part of a healthy diet include: a) Providing support to the immune system (Malin
et al. 1997; MacFarlane and Cummings 2002; McNaught et al. 2005); b) Maintaining a healthy gut flora to provide in-
creased resistance to disease (Naidu et al. 1999; Parvez et al. 2006); c) Reducing lactose intolerance (Fernandes et al. 1987; Marteau et al. 1990); d) May assist in preventing some cancers (Reddy et al. 1973; Isolauri 2004; Lee et al. 2004; Saikali et al. 2004); e) May reduce cholesterol for some individuals (Lin et al. 1989; Taranto et al. 1998).

The roles of probiotic bacteria in dairy fermentations is to assist in: a) the preservation of milk by the generation of lactic acid and possibly antimicrobial compounds (Parvez et al. 2006); b) the production of flavour compounds (e.g., acetalddehyde in yoghurt and cheese) and other metabolites (e.g., extracellular polysaccharides) that will provide a pro-
duct with the organoleptic properties desired by the consu-
mer (Parvez et al. 2006); c) to improve the nutritional value of food, as in, for example, the release of free amino acids or the synthesis of vitamins (Parvez et al. 2006); d) the pro-
vision of special therapeutic or prophylactic properties (Reddy et al. 1973; Fernandes et al. 1987; Gilliland 1990; O’Sullivan et al. 1992) and control of serum cholesterol le-
vels (Lin et al. 1989).

For centuries folklore has suggested that fermented dairy products containing probiotic cultures are healthful. Recent controlled scientific investigation has supported some of these traditional views, suggesting the value of pro-
biotics as part of a healthy diet. The ability of probiotic bac-
teria to support the immune system could be important to el-
derly or other people with a compromised immune function (Oyetayo and Oyetayo 2005).

ANTIMICROBIAL COMPOUNDS PRODUCED BY LAB

Bacteriocin classification
LAB involved in the fermentation of a range of milk, meat, cereal and vegetable foods (Mckay and Baldwin 1990; Goldberg and Williams 1991). The antimicrobial com-
ounds produced by LAB, the bacteriocins, can inhibit the
growth of pathogenic bacteria which possibly contaminants in the fermented products (Raccach et al. 1979; Smith and Palumbo 1983; Cintas et al. 1998).

Bacteriocins can be divided into three main groups as follows, based on the groupings proposed by Klaenhammer (1993):

- **Class I**: the lantibiotic family; these are generally small bacteriocins composed of one or two peptides of approximately 3 kDa. An unusual feature of this group is that they are post-translationally modified to contain lanthionine β-methylanthionine and dehydrated amino acids, while at least two members of this group also contain γ-alanine (Skauen et al. 1994; Rayan et al. 1999).

- **Class II**: small non-modified peptides; these are generally small unmodified of <5 kDa, which are subdivided into two groups. The first (class IIA) are the *Listeria*-active peptides which are characterized by a YNGGU N-terminus. As in the lantibiotic family, some class II bacteriocins are composed of two separate peptides and are referred to as the classIB type. The two component non-modified bacteriocins include lactacin F (Muriana and Klaenhammer 1991) and lactococcin G (Nissen-Meyer et al. 1992).

- **Class III**: large heat-labile proteins, this class III bacteriocins are the least well-characterized group and consist of heat-labile proteins which are generally >30 kDa.

### Organic acids

The levels and types of organic acids produced during the fermentation process depend on the species of organisms, culture composition and growth conditions (Lindgren and Dobrogosz 1990). The antimicrobial effect of organic acids lies in the reduction of pH, as well as the undissociated form, and it is toxic to many bacteria, fungi and yeasts.

Acetic and propionic acids produced by LAB strains interact with cell membranes and cause intracellular acidify-

Lactic acid is the major metabolite of LAB fermentation. At a low pH, a large amount of lactic acid is in the un-
dissociated form, and it is toxic to many bacteria, fungi and yeasts.

Acetic and propionic acids produced by LAB strains interact with cell membranes and cause intracellular acidification and protein denaturation (Huang et al. 1986). Acetic and propionic acids are more antimicrobially effective than lactic acid due to their pH higher value (lactic acid 3.08; acetic acid 4.75; propionic acid 4.87).

### Hydrogen peroxide and carbon dioxide

The antimicrobial effect of hydrogen peroxide (H₂O₂) may result from the peroxidation of membrane lipids thus the increased membrane permeability (Kong and Davison 1980).

Carbon dioxide plays a role in creating an anaerobic environment which inhibits enzymatic decarboxylations, and accumulation of CO₂ in the membrane lipid bilayer may cause a dysfunction in permeability (Eklandt 1984).

### CONCLUSION

Traditional fermentations are likely to remain an important part of the global food supply; many may evolve into fermentations involving the use of starter cultures, enzyme additives and controlled environmental conditions, and others may benefit.

Dairy foods fermented by LAB have long been held in special favor as safe and nutritious foods that may also eli-

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**REFERENCES**


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