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Mini Review

Lactic Acid Bacteria: Their Applications in Foods

Bintsis T*

Department of Agricultural Technology, TEI of West Macedonia, Kozani, Greece

***Corresponding author:** Bintsis T, Department of Agricultural Technology, TEI of West Macedonia, Kozani, Greece

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Abstract

Lactic acid bacteria (LAB) are a heterogeneous group of bacteria which plays a significant role in a variety of fermentation processes. They ferment food carbohydrates and produce lactic acid as the main product of fermentation.

The main application of LAB is as starter cultures, with an enormous variety of fermented dairy, meat, fish, fruit, vegetable and cereal products. Besides, LAB contribute to the flavor, texture and nutritional value of the fermented foods, and such applications as adjunct, bio-protective, probiotic cultures and various applications in food industry are discussed.

Keywords: Lactic Acid Bacteria; Applications; Fermented Foods

Introduction

Lactic acid bacteria (LAB) play an important role in food, agricultural, and clinical applications. The general description of the bacteria included in the group is gram-positive, nonsporing, nonrespiring cocci or rods, which produce lactic acid as the major end product during the fermentation of carbohydrates [1]. The common agreement is that there is a core group consisting of four genera; *Lactobacillus, Leuconostoc, Pediococcus* and *Streptococcus*. Recent taxonomic revisions have proposed several new genera and the remaining group now comprises the following: *Aerococcus, Alloiococcus, Carnobacterium, Dolosigranulum, Enterococcus, Globicatella, Lactococcus, Oenococcus, Tetragenococcus, Vagococcus*, and *Weissella* [2]. Their importance is associated mainly with their safe metabolic activity while growing in foods utilizing available sugar for the production of organic acids and other metabolites. Their common occurrence in foods along with their long-lived uses contributes to their natural acceptance as GRAS (Generally Recognized as Safe) for human consumption [3]. The EFSA's 'Panel on Biological Hazards (BIOHAZ)' has concluded that the fermenting bacteria associated with food, whether resistant to antibiotics or not with the possible exception of enterococci do not pose a clinical problem [4]. However, they can act as a reservoir for transferable resistance genes. Strains with genes transferable in such a way could inter the food chain and increase the probability of a transfer to food associated intestinal pathogenic organisms.

The three main pathways which are involved in the manufacture and development of flavour in fermented food products are 1) glycolysis (fermentation of sugars), 2) lipolysis (degradation of fat) and 3) proteolysis (degradation of proteins) [1,5-9]. Lactate is the main product generated from the metabolism of carbohydrates and a fraction of the intermediate pyruvate can alternatively be converted to diacetyl, acetoin, acetaldehyde or acetic acid (some of which can be important for typical yogurt flavours). The contribution of LAB to lipolysis is relatively little, but proteolysis is the key biochemical pathway for the development of flavour in fermented foods [10,11]. Degradation of such components can be further converted to various alcohols, aldehydes, acids, esters and sulphur compounds for specific flavour development in fermented food products [10,11].

The genetics of the LAB have been reviewed [12-18] and complete genome sequences of a great number of LAB have been published [19] since 2001, when the first genome of LAB (*Lactococcus lactis* ssp. *lactis* IL1403) was sequenced and published [20].

Applications of LAB

Starter cultures for fermented foods

Fermented foods are produced through fermentation of certain sugars by LAB and the origins of them are lost in antiquity. The most commonly LAB used, nowadays, as starter cultures in food fermentations are shown in Table 1. For a detailed classification of starter cultures see [21,41,42].

Adjunct cultures

Secondary cultures, or adjunct cultures or adjuncts, are defined as any cultures that are deliberately added at some point of the manufacture of fermented foods, but whose primary role is not acid production. Adjunct cultures are used in cheese manufacture to give back to the cheese, some of the biodiversity removed by pasteurisation, improved hygiene and the addition of defined-strain starter culture [22,43]. These are mainly non-starter LAB which they can have a significant impact on flavor and accelerate the maturation process [22-43].

Extracellular polysaccharides (EPSs) are produced by a variety of bacteria and are present as capsular polysaccharides bound to the cell surface, or are released into the growth medium [44]. These polymers play a major role in the production of yogurt, cheese, fermented cream and milk-based desserts [45] where they contribute to texture, mouth-feel, taste perception and stability of the final products. In addition, it has been suggested that these EPSs or fermented milks containing these EPSs are active as prebiotics [46], cholesterol-lowering [47] and immunomodulants [48]. EPS-producing strains of *Streptococcus thermophilus* and *Lactobacillus delbreuckii* ssp. *bulgaricus* have been shown to enhance the texture and viscosity of yogurt and to reduce syneresis [49].

For the production of wine, LAB are involved in the malolactic fermentation, that is a secondary fermentation, which involves the conversion of L-malate to L-lactate and CO_2 *via* malate decarboxylase, also known as the malolactic enzyme, resulting in a reduction of wine

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Table 1: Lactic acid bacteria used as starter cultures in the production of some fermented food products.

Product	Genera of LAB[1]	References
	Dairy products	
Cheese (Mesophilic starter)	*Lc. lactis* ssp. *lactis*	[22]
	Lc. lactis ssp. *cremoris*	
	Lc. lactis ssp. *lactis* var. *diacetylactis*	
	Leuc. mesenteroides ssp. *cremoris*	
Cheese (Thermophilic starter)	*S. thermoplillus*	[22]
	Lb. delbrueckii ssp. *bulgaricus*	
	Lb. helveticus	
	Lb. delbrueckii ssp. *lactis*	
Cheese (Mixed starter)	*Lc. lactis* ssp. *lactis*	[22]
	Lc. lactis ssp. *cremoris*	
	S. thermoplillus	
Yogurt	*Lb. delbrueckii* ssp. *bulgaricus, S. thermophilus*	[22]
Fermented milks	*Lb. delbrueckii* ssp. *bulgaricus, S. thermophilus Lb. casei, Lb. acidophilus, Lb. rhamnosus, Lb. johnsonii*	[22]
Yakult	*Lb. casei* ssp. *casei*	[2]
Acidophilus milk	*Lb. Acidophilus*	[22]
Butter and buttermilk	*Lc. lactis* ssp. *lactis, Lc. lactis* ssp. *lactis* var. *diacetylactis, Lc. lactis* ssp. *cremoris, Leuc. menesteroides* ssp. *cremoris*	[22]
Kefir	*Lb. kefir, Lb. kefiranofacies, Lb. brevis, Lb. plantarum, Lb. paracasei* spp. *paracasei, Lc. lactis* spp. *lactis, Leuc. mesenteroides*	[23]
Trahanas	*Lc. lactis* ssp. *lactis, Lc. lactis* ssp. *lactis* var. *diacetylactis, Leuc. menesteroides* ssp. *cremoris, Lb. delbrueckii* ssp. *lactis, Lb. casei, Lb. delbrueckii* ssp. *bulgaricus and Lb. Acidophilus*	[24]
	Fermented meat products	
Dry sausages	*Lb. sakei*, *Lb. curvatus*, *Lb. plantarum*, *Lb. pentosus*, *Lb. casei*, *P. pentosaceous*, *P. acidilactici*	[25,26]
Salami Milano	*Lb. sakei, Lb. plantarum*	[26]
Salame Piacentino	*Lb. acidophilus, Lb. helveticus, Lb. sakei, Lb. antri, Lb. oris, Lb. vaginalis, Lb. brevis, Lb. panis, Lb. versmoldensis, Lb. zeae, Lb. curvatus, Lb. paralimentarius, Lb. frumenti, Lb. plantarum, Lb. graminis, Lb. reuteri*	[27]
Greek dry fermented sausages	*Lb. sakei, Lb. plantarum, Lb. curvatus, Lb. pentosus, Lc. lactis ssp. lactis, W. hellenica, W. paramesenteroides, W. viridescens, W. minor*	[27]
Chrorizo	*Lb. brevis, Lb. curvatus, Lb. sakei, Lc. lactis, P. acidilactici, P. pentosaceus, Leuc. mesenteroides*	[27]
	Fermented fish products	
Thai fish	*Lb. plantarum, Lb. reuteri*	[28]
	Pickled fruits and vegetables	
Cabbage (Sauerkraut)	*Leuc. mesenteroides, Lb. plantarum, Lb. brevis, Lb. fermentum*	[29]
Cucumber	*Lb. brevis, Lb. plantarum, Lb. pentosus, Lb. acidophilus, Lb. fermentum, Leuc. Mesenteroides*	[30,31]
Olives	*Lb. brevis, Lb. plantarum, Lb. pentosus*	[32,33]
	Fermented cereal products	
Sourdough	*Lb. brevis, Lb. hilgardii*	[34,35]
	Lb. sanfransiscensis, Lb. farciminis, Lb. fermentum, Lb. brevis, Lb. plantarum, Lb. amylovorus, Lb. reuteri, Lb. pontis, Lb. panis, Lb. alimentarius, W. cibaria	
Kimchi	*Leuc. mesenteroides, Lb. plantarum, W. kimchii* sp. nov., *Lb. kimchi, Lb. sakei, W. koreensis*	[36,37,38]
Bushera	*Lb. plantarum, Lb. paracasei* ssp. *paracasei, Lb. fermentum, Lb. brevis, Lb. delbrueckii* ssp. *delbrueckii, S. thermophilus*	[39]
Pozol	*Leuc. mesenteroides, Lb. plantarum, Lb. confusus, Lc. lactis, Lc. raffinolactis*	[40]

[1]*Lc. Lactococcus*, *Lb. Lactobacillus*, *Leuc. Leuconostoc*, *P. Pediococcus*, *S. Streptococcus*, *W. Weissella*

acidity, providing microbiological stabilization and modifications of wine aroma [50,51].

Bio-protective cultures

Certain LAB has been found to produce bacteriocins, namely, polypeptides synthesized ribosomally by bacteria that can have a bacteriocidal or bacteriostatic effect on other bacteria [52,53]. In general, bacteriocins lead to cell death by inhibiting cell wall biosynthesis or by disrupting the membrane through pore formation [54]. Bacteriocins are therefore important in food fermentations where they can prevent food spoilage or the inhibition of food pathogens. The best known bacteriocin is nisin, which has gained widespread application in the food industry and is used as a food additive in at least 50 countries, particularly in processed cheese, dairy products and canned foods [55]. Examples of useful bacteriocins produced by LAB are lacticin 3147 [56-59] from lactococci, macedovicin from *Streptococcus* macedonicus ACA-DC 198 [60,61], reuterin from Lactobacillus reuteri [62], sakacin M from Lactobacillus sake 148 [63] curvacin A, curvaticin L442 and lactocin AL705 from Lactobacillus curvatus LTH1174 [64], pediocin PA-1/AcH from Pediococcus acidilactici [65], plantaricins (A, EF and JK) from *Lactobacillus* plantarum [65]. The above bacteriocins have proved effective in many food systems for the control of food spoilage or pathogenic bacteria.

Antifungal activities of LAB have been reported [66-68]. In addition, LAB strains also have the ability to reduce fungal mycotoxins, either by producing anti-mycotoxinogenic metabolites, or by absorbing them [68].

For LAB to be used as bio-protective starter cultures, they must possess a range of physical and biochemical characteristics, and most importantly, the ability to achieve growth and sufficient production of antimicrobial metabolites, which must be demonstrated in the specific food environment.

Probiotic cultures

LAB is considered as a major group of probiotic bacteria [69,70]; probiotic has been defined by Fuller [71] as "a live microbial feed supplement which beneficially affects the host animal by improving its intestinal microbial balance". Salminen et al. [72] proposed that probiotics are microbial cell preparations or components of microbial cells that have a beneficial effect on the health and well-being of the host. *Lactobacillus acidophilus, Lactobacillus casei, Lb. reuteri, Lactobacillus rhamnosus* and *Lb. plantarum* are the most used LAB in functional foods containing probiotics [73,74]. In addition, LAB, as part of gut microbiota ferments various substrates such as biogenic amines and allergenic compounds into short-chain fatty acids and other organic acids and gases [75].

Conclusion

LABS are the most commonly used microorganisms for the fermentation and preservation of foods. Bacterial cultures with specific traits have been developed during the last 17 years, since the discovery of the complete genome sequence of Lc. *lactis* ssp. lactis IL1403 and a variety of commercial starter, functional, bio-protective and probiotic cultures with desirable properties have marketed. Advances in the genetics, molecular biology, physiology, and biochemistry of LAB have provided new insights and applications for these bacteria. Food industry is now capable of producing standardized, safe and nutritious products with different flavours, sometimes with special health-promoting properties.

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