Food Bioscience 21 (2018) 34–44

Contents lists available at ScienceDirect

Food Bioscience

journal homepage: www.elsevier.com/locate/fbio

Recent developments on encapsulation of lactic acid bacteria as potential starter culture in fermented foods – A review

Digambar Kavitake[a,1], Sujatha Kandasamy[a,1], Palanisamy Bruntha Devi[b], Prathapkumar Halady Shetty[a,*]

[a] *Department of Food Science and Technology, Pondicherry University, Pondicherry 605 014, India*
[b] *Department of Microbial Biotechnology, Bharathiar University, Coimbatore 641 046, India*

ARTICLE INFO

Keywords:
Encapsulation
Lactic acid bacteria
Starter culture
Fermented foods

ABSTRACT

Fermented foods are the first processed staple human diet that have been produced and consumed since development of human civilizations. Majority of the fermented foods are made through controlled microbial growth and enzymatic conversions of major and minor food components that gain high values because of its enhanced organoleptic properties. Ease of fermentation, risk in fermentation failure and several functional properties of lactic acid bacteria makes them as suitable starter culture in production of fermented foods. The viability and stability of starter cultures in the fermented foods and gastro intestinal environment are key challenges at industrial scale. Use of encapsulated starter cultures has been considered more in the recent years, due to its improvement in survival and viability under adverse environmental conditions. This paper mainly focuses on reviewing lactic acid bacteria as functional starter cultures in fermented foods including different techniques and coating materials used for microencapsulation, factors affecting the microencapsulation, methods for evaluating the efficiency of starter cultures and future perspectives to be overcome in this area.

1. Introduction

Traditional fermented foods form an integral part of cultural heritage and diet widely consumed since ancient civilization. Since ages, this innovative practice of fermentation has extended and enriched to preserve and increase the safety of existing food resources, mainly to overcome the hidden hunger (Ray, Ghosh, Singh, & Mondal, 2016). Traditionally, many of the fermented foods are produced under spontaneous fermentation using backslopping method which involves direct addition of most dominant native microflora as selected starter culture. This technique leads to reduction in fermentation time, prevention of fermentation failure and standardization of final product. The fermented food quality depends upon the population and microbial diversity in the raw material (Tamang, Watanabe, & Holzapfel, 2016). Over the past two decades, the scientific interventions on fermented foods revealed the health-beneficial concept by the native microflora or starter culture roles in stimulating the probiotic functions, bio-availability of macro and micronutrients, production of antioxidant, anti-nutritive and anti-microbial compounds and other functional components during fermentation. This health promoting factors produce client awareness for ingesting such ancient foods on functional basis in relevant to health promotion and disease preclusion (Borresen, Henderson, Kumar, Weir, & Ryan, 2012; Marco et al., 2017).

Lactic acid bacteria (LAB) are predominant microflora present in most of the traditional fermented foods and their role in fermentation is known since ages (Anandharaj & Sivasankari, 2013). Currently, formulation of new functional starter culture of LAB that is industrially important in food safety that deal with one or more organoleptic, technological, nutritional or health benefits are being developed (Sathe & Mandal, 2016). Maintenance and viability of starter culture in fermented foods is still an immense challenge in the industrial process. At the dawn of this situation, encapsulation of starter culture provides protection to the cells and thus increases the viability of the delivered amount. For successful encapsulation of viable cells, it is important to preserve the bacterial viability under different handling processes along with the type of encapsulation material compatible with food material (Haffner, Diab, & Pasc, 2016). Fermentation using encapsulated starter culture, offers numerous advantages compared to traditional cultivations, e.g., rapid fermentation, higher cell density, enhanced tolerance of the cells towards high temperatures and toxic media, and selective removal of toxic hydrophobic substances. However, production of robust capsules capable of withstanding several months or years, of

---

[*] Corresponding author.
E-mail address: pkshalady@yahoo.co.uk (P.H. Shetty).
[1] Two authors contributed equally.

https://doi.org/10.1016/j.fbio.2017.11.003
Received 27 June 2017; Received in revised form 7 November 2017; Accepted 7 November 2017

continuous use without deterioration of cell activity or capsule characteristics, capsule size, large-scale production of capsules and economic feasibility still remain challenges for industrial application of encapsulated cells (de Prisco & Mauriello, 2016).

Although in recent years valuable and promising research on encapsulation of LAB as starter culture has been published and commercialization of products are being made, the information exchange between industry and academia should noticeably intensify. This paper aims to give an overview of the vast encapsulation of LAB as starter culture in fermented foods on what has been done in the academia and industry scenarios in the past few years, in terms of technologies employed and research insights. Here, we discuss the materials and techniques used for encapsulation of LAB and its applications in terms of biological production processes, as well as the effect of encapsulation on cells and their viability.

2. Fermented foods

Fermented foods enrich the human diet as they offer and reserve huge amounts of nutrition in a comprehensive mixture of flavor, aroma and texture. Traditional fermentation improves the overall content or availability of amino acid, vitamins, mineral profiles and therapeutic potentialities that have profound effects directly on the consumer's health (Steinkraus, 2002). Most of the global fermented foods are known to be fermented by both functional and non-functional microorganisms that exist as native microflora in raw plant materials, containers, utensils and environment (Franz et al., 2014). These microbes alter the biochemical constituents of raw materials, thereby improving the flavor, digestibility and aroma while imparting nutritional and pharmacological values in some fermented foods that are traditionally and socially acceptable by the consumers. Most of these traditional process of preparation remains majorly secretive being passed on from generation to generation and tend to be specific for tribes and castes in different provinces while many of them are made under home scale by using back slopping (Tamang, Thapa, Tamang, Rai, & Chettri, 2015).

Each ethnic group region has its own unique food diversity and beliefs including fermented foods that symbolize their heritage, tradition, agroeconomic and socio-cultural traits of the society. Although, some fermented foods are popular as delicious daily dish and promoted globally for their functional, nutraceutical and therapeutic properties. Numerous reviews were published on the biological, chemical and nutritional components of fermented foods from countries such as Asia (Rhee, Lee, & Lee, 2011; Steinkraus, 2002; Tamang et al., 2015, 2016), Africa (Benkerroum, 2013; Chelule, Mokoena, & Gqaleni, 2010) and America (Nout, 2003; Oguntoyinbo, Tourlomousis, Gasson, & Narbad, 2011).

3. LAB as functional starter culture

LAB are a broad group of bacteria belonging to the genera (Table 1) *Bifidobacterium, Enterococcus, Lactobacillus, Leuconostoc, Lactococcus, Propionibacterium, Pediococcus, Streptococcus, Tetragenococcus*, *Vagococcus* and *Weissella* (Holzapfel & Wood, 2014; Tamang et al., 2015).

In traditional fermented foods, fermentation is mainly accomplished by the native LAB from the available resources that proceed the fermentation process in absence of an added industrial starter culture. Selective addition of starter culture to raw materials controls the overall fermentation process that mainly reduces the risk of fermentation failure and fermentation period while improving the end product value. Several functional properties of LAB have been reported widely including antioxidant activity by *Lactobacillus*, *Bifidobacteria* (Mishra et al., 2015), antimicrobial compounds from *Aerococcus, Carnobacterium, Enterococcus, Lactobacillus, Lactococcus, Leuconostoc, Pediococcus, Streptococcus, Tetragenococcus, Vagococcus* and *Weissella* (Rattanachaikunsopon & Phumkhachorn, 2010), degradation of antinutritive compounds by *Lactobacillus plantarum, L. brevis, L. curvatus* (Reale et al., 2004), fibrinolytic activity by *Vagococcus carniphilus, V. lutrae, Enterococcus faecalis, E. faecium, E. gallinarum* and *Pediococcus acidilactici* (Singh, Devi, Ahmed, & Jeyaram, 2014), peptide production by *Lactococcus sp.* and *Lactobacillus* sp. (Brown et al., 2016), poly-lactic acid by *Lactobacillus delbrueckii* and *Lactobacillus bulgaricus* (Ghaffar et al., 2014) and probiotic effects of *Lactobacillus acidophilus, L. casei, L. johnsonii, L. fermentum, L. rhamnosus, L. plantarum, L. reuteri, L. salivarius, L. paracasei, L. delbrueckii subsp. bulgaricus, Streptococcus thermophilus, Bifidobacterium lactis, B. longum* and *B. breve* etc. (Quinto et al., 2014). These properties play a major role in the selection of starter culture for the production of functional food.

4. Encapsulation of LAB

Encapsulation process involves the entrapment of active substance into another substance wall material that produces particles in various scale. The encapsulated material is usually called as core, fill, active, internal or pay load phase, whereas the material used for encapsulation is called as coating membrane, shell, capsule, carrier material, external phase, or matrix (Burgain, Gaiani, Linder, & Scher, 2011; Fang & Bhandari, 2010). Encapsulation is intensively used in food sectors (Fig. 1) as an effective barrier for liquid and solid ingredients against several environmental (oxygen, light, free radicals etc.) parameters (Desai & Park, 2005). Encapsulation involves wide area with encapsulating material, wall material, process, functionality and properties of encapsulated systems (John, Tyagi, Brar, Surampalli, & Prévost, 2011). Based on size of the beads produced, encapsulation can be broadly classified into two types, i.e. macroencapsulation (millimeters to centimeters) and microencapsulation (1–1000 μm) (Heidebach, Först, & Kulozik, 2012). In case of macroencapsulation, bacterial cells will normally grow on the beads surface due to depletion in nutrient diffusion efficiency in depth of more than 300–500 μm as well as toxic metabolites accumulation in center of the beads. Moreover, microcapsules are reported for higher mechanically robust than macrospheres (Park & Chang, 2000). There are several factors (Fig. 2) that affect the microencapsulation effectiveness which can be further overcome by selecting proper encapsulation method, coating material and process conditions.

Different LAB were encapsulated in different polymers for different purposes such as encapsulated *Lactobacillus rhamnosus* VTT E-97800 successfully increased the shelf life to at least 18 months during deep freezing using liquid nitrogen (Mortazavian, Razavi, Ehsani, & Sohrabvandi, 2007). Yogurt produced using encapsulated starter culture (*S. thermophilus* and *Lb. delbrueckii*) influenced its sensory and flavor qualities as well as higher bacterial viability from initial to final stages of the fermentation process (Krasaekoopt, Bhandari, & Deeth, 2004). Several studies on encapsulation of LAB such as *Lactobacillus acidophilus* and *Bifidobacterium lactis* (Darukaradhya, Phillips, & Kailasapathy, 2013), *Lactococcus lactis* and *Lactobacillus paracasei* (Léonard et al., 2015), *Lactobacillus curvatus* MBSa2 (Barbosa, Todorov, Jurkiewicz, & Franco, 2015) and *Lactobacillus plantarum* (Corbo et al., 2016) were described using different coating materials with respect to their functionality, viability and application.

5. Methods of encapsulation

Encapsulation of active substances into carrier materials can be attained by several methods such as spray drying, spray chilling or spray cooling, extrusion coating, fluidized-bed coating, liposomal entrapment, lyophilization, coacervation, centrifugal suspension separation, cocrystallization, inclusion complexation and thermal gelation (Table 2) (Gibbs, Kermasha, Ali, & Mulligan, 1999; Poshadri & Kuna, 2010; Raymond, Neufeld, & Poncelet, 2004). Several factors such as physical and chemical characteristics of core and carrier/coating materials and their proposed application in food matrix influence the choice of suitable encapsulation process. Among all the techniques,