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Review

Application of probiotic delivery systems in meat products

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ABSTRACT

Background: In recent years, probiotic foods have received special attention. The most commonly used probiotic microorganisms are *Lactobacillus* and *Bifidobacterium*, and to a lesser degree, *Enterococcus* and *Pediococcus* due to their importance for consumer health. Probiotics have also been used as food bioprotectors.

Scopes and approach: This review addresses the potential use of different probiotic delivery strategies for use in meat products to guarantee the viability of the microorganisms throughout the different stages of processing, conservation and preparation, the aim being to obtain probiotic meat products (in some cases even combined with prebiotics) with a positive impact on consumer health.

Key findings and conclusions: In the case of meat products, these studies have mostly focused on fermented meats and, to a lesser degree, on cooked frankfurter-type products or fresh products because the processing to which they are subjected does not guarantee full viability of the microorganisms. Traditionally, starters as free cells have been used to incorporate these microorganisms into meat products. More recently, new microorganism immobilization techniques such as encapsulation have been tested. These new strategies ensure enhanced viability even in meat products subject to thermal treatment during processing or cooking.

1. Introduction

During the last several decades, a strong link has been established between nutrition and human health (Jiménez-Colmenero, Reig, & Toldrà, 2006). Today, consumer preferences are changing mainly driven by new concerns about wellbeing and a healthier lifestyle (Chen, 2011). This has led to many researches including those designed to enhance the benefits derived from the foods we consume both from a nutritional point of view and in terms of new ingredients incorporated into them with specific functions. In this regard, there has been a major increase in the number of studies conducted on probiotics in recent years. Probiotic foods mainly include fermented dairy products, vegetables, juices and meat products (Burgain, Gaiani, Linder, & Scher, 2011; Khan et al., 2011; Martins et al., 2013; Nulkaekul, Lenton, Cook, Khutoryanskiy, & Charalampopoulos, 2012; Rouhi, Sohrabvandi, & Mortazavian, 2013).

The concept of probiotics emerged from observations early in the 19th century by Russian immunologist Elie Metchnikoff who hypothesized that the long and healthy lives of Bulgarian peasants were rooted in their consumption of fermented milks containing beneficial *Lactobacillus* and its positive influence on colonic health (Dixon, 2002). Until then, microbes were known only for their negative effects commonly associated with morbidity and mortality (Douglas & Sanders, 2008). Nowadays probiotics can be defined as “live microorganisms which, when administered in adequate amounts, confer health benefits on the consumer” (FAO/WHO, 2002).

The most common probiotics used in food are from the

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Lactobacillus and *Bifidobacterium* genera, although *Enterococcus* and *Pediococcus* have also been used (Weinbreck, Bodnár, & Marco, 2010). Some of these probiotic microorganisms have also been traditionally used for bioprotectors purposes in meat products of various kinds (Bomdespacho, Cavallini, Zavarizi, Pinto, & Rossi, 2014; Chaillou et al., 2014; Sparo, Confalonieri, Urbizu, Ceci, & Bruni, 2013). As probiotic propose a wide range of these probiotics have proven clinically effective against many diseases in humans and animals. Probiotics in general can prevent gastrointestinal infections, enhance host immunity and relieve diarrhea (Douglas & Sanders, 2008). The safety assessment of probiotics for human use is discussed in a review by Sanders et al. (2010). Clinical studies have shown that some probiotics can be safely administered to immunocompromised patients without side-effects (Bernardeau, Vernoux, Henri-Dubernet & Gueguen, 2008; Sanders et al., 2010). Moreover, the literature reports few correlations between adverse events and probiotic consumption (Boyle, Robins-Browne, & Tang, 2006), and also that the risk of lactobacillemia is rare (Borriello et al., 2003). However, there is some controversy over the use of enterococci strains as probiotics or bioprotective cultures since they have been described as opportunistic pathogens (Morrison, Woodford, & Cockson, 1997). Some enterococci strains are associated with nosocomial infections and cause human diseases such as bacteremia, endocarditis or urinary tract infections, and therefore their use is not indicated in people with immunodeficiency. The main problem of enterococci use is the presence of antibiotic resistance and virulence factors, which are clearly explained in the review by Franz, Huch, Abriouel, Holzapfel, and Gálvez (2011). On the other hand, enterococci strains can bring health benefits to the host, such as immune regulation, lowering of serum cholesterol, and treatment of diarrhea, antibiotic-associated diarrhea and irritable bowel syndrome. According to Allen, Okoko, Martinez, Gregorio, and Dans (2004), *Enterococcus faecium* SF68 is one of the best documented and effective enterococci strains for use as a probiotic.

Studies have reported the ability of some probiotic strains such as *Bifidobacterium longum* B6, *B. longum* ATCC 15708 and *Bifidobacterium animalis* DN-173010 to reduce lactose intolerance by increasing production of the enzyme ß-galactosidase (He et al., 2008; Jiang, Mustapha, & Savaiano, 1996). A reduction in the symptoms of inflammatory bowel disease (Chron's disease and Ulcerative colitis) is related to consumption of fermented milk containing *Bifidobacterium bifidum* Yakult, *Bifidobacterium breve* Yakult, and *Lactobacillus acidophilus* YIT 0168 (Ishikawa et al., 2003; Kato et al., 2004). Probiotics can also be helpful in preventing and treating some types of cancer. Studies have shown that the risk of colon cancer is reduced by consuming yoghurt containing *B. longum* 913 and *Lb. acidophilus* 145 (Oberreuther-Moschner, Jahreis, Rechkemmer, & Pool-Zobel, 2004) and anti-tumor activity was observed in *Escherichia coli* Nissle 1917 strains (Stritzker et al., 2007). Probiotic mechanisms of action are likely due to many factors and related to activity against pathogenic microorganisms including the secretion of antimicrobial substances, competitive adherence to the mucosa and epithelium, strengthening of the gut epithelial barrier and modulation of the immune system (Bermudez-Brito, Plaza-Díaz, Muñoz-Quezada, Gómez-Llorente, & Gil, 2012).

The health benefits of probiotics depend on many factors associated to the microorganism (genus, species, strain etc.) and the product (processing, temperature, pH, a_w etc.). However, the beneficial effects of probiotics not only depend on the right strain of microorganism but also on a minimum level of viability. The level of probiotic necessary to bring about positive effects is still unknown and varies in different studies and standards (Rouhi et al., 2013). The higher the level of probiotic microorganisms in food the better, however, there is a degree of consensus that the minimum probiotic concentration in food should be between 10^6 and 10^7 CFU/g or CFU/ml at the moment of consumption (Nulkaekul et al., 2012). However, consumption of high viable counts of probiotics does not guarantee the same survival rate after the arrival of the cells in the intestine (Iravani, Korbekandi, & Mirmohammadi, 2015). The probiotic must also survive the upper gastrointestinal tract (GIT) (gastric acid and bile) so that it can adhere to intestinal mucosa and competitively eliminate pathogens and maintain viability (Sharma & Devi, 2014).

Over the last ten years, meat products have generally been related to health problems such as coronary diseases, hypertension, cancer, etc. (Jiménez-Colmenero et al., 2006). However, meat and meat products are an important group of highly nutritious foods forming part of the diet of many consumers around the world. Meat products are an important source of a wide range of nutrients and contribute a considerable proportion of the dietary intake of various nutrients that are essential for optimal growth and development. In recent years, major efforts have been made to develop meat-based functional foods using strategies related to increasing the presence of beneficial compounds and limiting those with negative health implications. These are based on approaches that basically affect animal production practices (genetic and nutritional) and meat processing systems (reformulation processes) (Olmedilla-Alonso, Jiménez-Colmenero, & Sánchez-Muniz, 2013). A number of approaches can be used to remove, reduce, increase, add and/or replace different functional ingredients as, for example, probiotic microorganisms.

A variety of probiotic meat products have been prepared with most of the focus on fermented meat products as these provide a more appropriate environment (no heat treatment) for the viability of microorganisms (Table 1). Studies using probiotic microorganisms in other types of meat products such as cooked meat sausages and fresh ground or raw meat are still scarce mainly because of the processing required for these products such as heating, the use of additives (sodium chloride, sodium nitrite, etc.) and consume conditions. Some of these probiotic microorganisms have also been used in these meat products as bioprotectors against pathogenic strains (Table 1). The meat industry is now focusing on producing meat products with potential health benefits by using probiotic microorganisms. To that end, they are searching for delivery strategies to incorporate microorganisms that are able to protect them from harsh environments and storage conditions, limiting the effect of factors that tend to decrease or eliminate the viability of microorganisms in food (Anal & Stevens, 2005; Burgain et al., 2011). Overcoming these difficulties has opened up new challenges for meat research and industry. Although there are various reviews of probiotics in meat products (De Vuyst, Falony, & Leroy, 2008; Khan et al., 2011; Kolozyn-Krajewska & Dolatowski, 2012; Rouhi et al., 2013; Työppönen, Petäjä, & Mattilaa-Sandholm, 2003), they focus on fermented products and/or without giving special consideration to incorporation strategies.

The aim of this review is to give an overview of the different probiotic delivery strategies and their incorporation and behavior of probiotics in different meat matrices. These strategies, based mainly on encapsulation and/or entrapping in gelled dispersions, are designed to enhance viability during manufacture, storage, cooking and gastrointestinal stages with the aim of obtaining healthy meat products. We also review the control of probiotic microorganisms in meat products and the current state of probiotic meat products.

2. Delivery systems for probiotics

Traditionally, probiotics have been added to food as free cells