Trends in Food Science & Technology 54 (2016) 17–25

Contents lists available at ScienceDirect

Trends in Food Science & Technology

journal homepage: http://www.journals.elsevier.com/trends-in-food-science-and-technology

Lactic acid bacteria as sensory biomodulators for fermented cereal-based beverages

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ARTICLE INFO

Article history:
Received 27 July 2015
Received in revised form
23 April 2016
Accepted 13 May 2016
Available online 14 May 2016

Keywords:
Lactic acid bacteria
Cereal beverages
Flavour production
Textural modification
Pyruvate metabolism

ABSTRACT

Background: Today's consumer demands functional, healthy and diversified food products that satisfy nutrition-related conditions such as food intolerances, allergies and malabsorption, and lifestyle choices, e.g. vegetarianism, veganism, low-fat or low-salt. Cereal-based beverages have been tested as *functional* and *probiotic* foods because of their nutritious and health-promoting properties, e.g. soluble fibres and phytoestrogens. A way to add functionality and improve the low organoleptic attributes of raw cereals is through fermentation using lactic acid bacteria (LAB). The use of starter cultures with known flavour- and texture-enhancing properties offers a promising tool for *in situ* product enhancement, innovation and diversification of cereal-based beverages.
Scope and approach: This review highlights studies that have principally addressed flavour and textural changes in model liquid cereal-based substrates using defined LAB starter cultures. The main biochemical mechanisms involved in the formation of compounds that play a central role in the acceptance of cereal beverages are reviewed, and possibilities for enhancing organoleptic and rheological properties are discussed.
Key findings and conclusions: Starter cultures able to release desired flavours or to positively change the food structure have been successfully used to increase the palatability of cereal beverages and replace the need for additives, i.e. flavourings, enzymes or thickeners. However, predicting the presence of organoleptically-active compounds is often a difficult task, as such compounds are affected by biological and non-biological factors. The outcomes from fermentations done with defined cereal and culture combinations could increase our understanding of which compounds are important for the final acceptance of cereal beverages, and how these components can be enhanced using different technological conditions and starter cultures.

1. Cereals as alternative substrates for functional beverages

The domestication of grains during the first agricultural revolution around 10,000 B.C. led to cereals becoming the major source of nutrients and calories for humans throughout the world (Poutanen, 2012). Even though their dietary protein and fat content is inferior compared to other staple foods, e.g. milk or legumes (Chavan, Kadam, & Beuchat, 1989), cereals are a most important source of carbohydrate and dietary fibres, and provide essential micronutrients such as minerals, vitamins, and phytochemicals (e.g. phytoestrogens and phenolic compounds) (Katina et al., 2007). Along with the traditional milk-based formulations, cereals and other food substrates (fruits, teas and vegetables) have been increasingly considered as ingredients for *functional beverages* that satisfy dietary lifestyles such as *veganism* and *allergen-free* (Corbo, Bevilacqua, Petruzzi, Casanova, & Sinigaglia, 2014). In this regard, oats have received particular research interest because of their high content in soluble fibres e.g. β-glucan, linked to health-promoting effects on diabetes and cardiovascular diseases (Angelov, Gotcheva, Kuncheva, & Hristozova, 2006; Herrera-Ponce, Nevárez-Morillón, Ortega-Rívas, Pérez-Vega, & Salmerón, 2014). Oats formed the main substrate for the first commercialised cereal-based *probiotic* beverages, Proviva® (Skane Dairy, Sweden) and Yosa® (Bioferme, Finland), which both do not contain any milk constituents (Salovaara, 1996). On a worldwide basis, maize, rice and wheat are the prevailing crops in terms of area reserved for

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http://dx.doi.org/10.1016/j.tifs.2016.05.009
0924-2244/

cereal cultivation and total cereal production (Poutanen, 2012). However, ancient and/or minor cereals, such as kamut, spelt, einkorn, millet, and sorghum, and pseudocereals, such as quinoa, amaranth, and buckwheat, have generated renewed interest, particularly in Western countries, because of their higher content in beneficial minor components (dietary fibre, resistant starch, minerals, vitamins, phenolic compounds) (Coda, Cagno, Gobbetti, & Rizzello, 2014) compared to staple grains (wheat, maize, rice), and the possibility to fulfil further dietary needs, such as low-gluten or gluten-free (Zannini, Pontonio, Waters, & Arendt, 2012).

2. LAB starter cultures for fermentation of cereal-based liquid matrices

2.1. Re-discovering fermentation

As a way to keep pace with the trends of *sustainability, naturalness* and *healthiness*, food companies have started to employ transformation practices that favour low-processing and low-energy methods (Athapol, Imran, & Kumar Anal, 2014). Fermentation has long been used as a way to naturally improve and fortify a substrate, without the need for additives or preservatives (Hugenholtz, 2013). In the interest of ease of control and reproducibility of final product qualities, the industry avails of defined starter cultures. Lactic acid bacteria (LAB) have long been used as such in many food substrates e.g. milk, meat, vegetables, and cereals, as well as being part of their indigenous microflora (Holzapfel, 1997), and many of them have been granted with the GRAS (Generally Recognized as Safe) status. The genera *Enterococcus, Lactobacillus, Lactococcus, Leuconostoc, Pediococcus, Streptococcus* and *Weissella* are naturally found on the surface of grains and in the surrounding environment (Guyot, 2012). For this reason, they often form the natural inoculum, together to fungal strains, of fermented cereal gruels commonly consumed in many rural societies worldwide (Nout, 2009). Fermentation of cereal-based beverages, as well as other food substrates, by LAB has been shown to improve protein digestibility (Holzapfel, 1997; Taylor & Taylor, 2002), increase nutritional bioavailability of minerals and other micronutrients (Agarry, Nkama, & Akoma, 2010; Greffeuille et al., 2011), prolong shelf life (Angelov et al., 2006; Gupta, Cox, & Abu-Ghannam, 2010), and finally enhance organoleptic qualities (Nionelli et al., 2014; Peyer, Zannini, Jacob, & Arendt, 2015).

The favourable macro- and micronutrients profile present in cereals have made them an excellent candidate for LAB fermentation (Blandino, Al-Aseeri, Pandiella, Cantero, & Webb, 2003), providing the necessary carbohydrates, amino acids, peptides, nucleotides, vitamins, minerals, and fatty acids for their growth (Endo & Dicks, 2014). The bioavailability of nutrients that are usually bound as reserve molecules in the form of starch and proteins can be enhanced with the addition of malted cereals, either directly or by adding to the pool of hydrolytic enzymes with e.g. amylases, glucanases and peptidases (Gupta, Abu-Ghannam, & Gallaghar, 2010; Nionelli et al., 2014). Charalampopoulos, Pandiella, and Webb (2002) reported that the significant higher levels of fermentable sugars in form of glucose, fructose, maltose and sucrose (ca. 15 g/l) and free amino nitrogen (80 mg/l) of a liquid barley malt medium were among the main reasons for the better growth of the LAB on this medium compared to raw barley and raw wheat media (ca. 3–4 g/l and 15–27 mg/l, respectively). Similarly, Herrera-Ponce et al. (2014) documented that *Lactobacillus* strains could adapt faster and entering the exponential growth phase sooner when inoculated in germinated or malted oats media compared to simple raw oats.

2.2. LAB fermentation for sensory improvement in cereal-based beverages

Raw cereals carry very low levels of organoleptic-active compounds, and in this form, give flat, “green” and unpleasant odours and flavours (Zhou, Robards, Glennie-Holmes, & Helliwell, 1999). The bitterness and astringency carried by certain phenolic compounds found in the outer layers of whole grains can also lead to poor acceptance (Heiniö, Kaukovirta-Norja, & Poutanen, 2011). Together with other preparation steps such as boiling, toasting, and roasting (Coda, Rizzello, Trani, & Gobbetti, 2011), fermentation has been used to improve sensorial and textural properties of liquid cereal substrates. The fermentation of an oat-based substrate with a *Lb. plantarum* strain for the production of a yogurt-like functional beverage improved the sensorial characteristics by changing the earthy and raw notes of the untreated oat flakes into dairy notes and a pleasant sourness (Nionelli et al., 2014).

Investigation on flavour and sensorial changes due to LAB fermentation in liquid cereal substrates have been initially done in relation to off-flavour formation, unwanted acidification, hazes and sediments during microbial spoilage in beer (Bokulich & Bamforth, 2013). More recently, research has concentrated on the flavour and textural changes caused by the deliberate inoculation of LAB starter cultures as only inoculum in cereal beverages (Table 1). These studies have been mainly carried out during the development of potentially *probiotic* cereal beverages (Coda et al., 2011; Salmerón, Thomas, & Pandiella, 2014), or for quality improvement of traditional cereal-based fermented beverages (Blandino et al., 2003). Tropical fermented drinks are often affected by texture and flavour inconsistencies caused by the spontaneous, mixed microbiota found as inoculum during such fermentations (Nout, 2009). In an attempt to guarantee product safety and functionality of these products, without changing the sensorial characteristics, researchers have tried to replace the natural “*backslop*” cultures with defined cultures of single or mixed LAB. Agarry et al. (2010) replaced the natural inoculum used for the production of *Kunun-zaki*, a spontaneously fermented non-alcoholic beverage traditionally produced in Nigeria, with a simpler starter culture comprising three dominant LAB species found during natural fermentation, namely *Lb. plantarum*, *Lb. fermentum* and *L. lactis*. While the nutritional value could be increased by improving mineral bioavailability, the use of these defined starter cultures also led to a product with better appearance, aroma, taste and acceptability than the control sample. When the natural inoculum in *Gowé* beverage was replaced with individual LAB cultures of *Lb. fermentum* L025 and *W. confusa* L015, acidification of the substrate was obtained faster, helping the inhibition of growth of pathogens, while sensorial scores were comparable to the traditional beverage (Vieira-Dalodé, 2008). Nonetheless, similar attempts have also reported unsatisfactory sensorial results, obtaining products with a simpler or different sensorial profile than the original ones (Onyango, Bley, Raddatz, & Henle, 2004). In this regard, the exclusion of yeast from the original starter culture have caused the loss of important flavour-active metabolites, especially higher alcohols and esters (Muyanja, Narvhus, & Langsrud, 2012).

The majority of work done on novel liquid cereal-based fermented products has chosen *Lb. plantarum* as starter culture because robust under conditions of low pH (Charalampopoulos et al., 2002), which gives this strain a competitive advantage against other autochthonous microorganisms present on the grains, and able to deliver a pleasant organoleptic profile in the form of “dairy”-related flavours (e.g. diacetyl, acetoin, acetaldehyde) (Prado, Parada, Pandey, & Soccol, 2008; Salmerón, Thomas, & Pandiella, 2015). However, a defined strain does not preclude the release of specific flavours when inoculated in different cereal