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Research review paper

Towards lactic acid bacteria-based biorefineries

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ABSTRACT

Lactic acid bacteria (LAB) have long been used in industrial applications mainly as starters for food fermentation or as biocontrol agents or as probiotics. However, LAB possess several characteristics that render them among the most promising candidates for use in future biorefineries in converting plant-derived biomass—either from dedicated crops or from municipal/industrial solid wastes—into biofuels and high value-added products. Lactic acid, their main fermentation product, is an attractive building block extensively used by the chemical industry, owing to the potential for production of polylactides as biodegradable and biocompatible plastic alternative to polymers derived from petrochemicals. LA is but one of many high-value compounds which can be produced by LAB fermentation, which also include biofuels such as ethanol and butanol, biodegradable plastic polymers, exopolysaccharides, antimicrobial agents, health-promoting substances and nutraceuticals. Furthermore, several LAB strains have ascertained probiotic properties, and their biomass can be considered a high-value product. The present contribution aims to provide an extensive overview of the main industrial applications of LAB and future perspectives concerning their utilization in biorefineries. Strategies will be described in detail for developing LAB strains with broader substrate metabolic capacity for fermentation of cheaper biomass.

Contents

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Introduction

Lactic acid bacteria (LAB) include a wide group of Gram-positive fermenting bacteria which are generally non-sporulating and non-motile. They comprise both cocci and bacilli belonging to *Carnobacterium*, *Enterococcus* (*Ent.*), *Lactobacillus* (*Lb.*), *Lactococcus* (*Lc.*), *Leuconostoc* (*Leu.*), *Oenococcus*, *Pediococcus* (*Ped.*), *Streptococcus* (*Str.*), *Tetragenococcus*, *Vagococcus* and *Weissella* genera (Hofvendahl and Hahn-Hägerdal, 2000).

LAB are among the most promising microorganisms for biorefineries converting waste biomasses into industrially important products (Berlec and Strukelj, 2009). Currently, the main application of LAB in industrial processes is as food starters (e.g., for dairy products, pickles, meat and wine) (Papagianni, 2012). However, several physiological characteristics of the LAB render these bacteria highly suitable for much wider industrial application:

i) Except for some pathogenic streptococci strains, LAB are considered GRAS (generally regarded as safe);
ii) LAB are robust organisms already adapted to stress conditions in industrial processes, since they generally show high acid tolerance (they can survive at pH 5 and lower) and broad optimal growth temperatures (ranging from 20 to 45 °C, depending on the genus and strain) (Hofvendahl and Hahn-Hägerdal, 2000);
iii) LAB are able to metabolize numerous mono- (both hexose and pentose) and di-saccharides (Kandler, 1983);
iv) LAB naturally produce many metabolites with confirmed applications in both the food and non-food industries (Fig. 1), such as: antimicrobial molecules (e.g., bacteriocins) (Settanni and Corsetti, 2008); food aromas and flavors (e.g., diacetyl and acetaldehyde) (Papagianni, 2012); food complements (e.g., vitamins) (Sybesma et al., 2004); food texturing agents (e.g., exopolysaccharides) (Chapot-Chartier et al., 2011); sweeteners (e.g., mannitol) (Hugenholtz et al., 2011); nutraceutical molecules, e.g., γ-aminobutyric acid (GABA) opioid peptides and seleno-metabolites (Lamberti et al., 2011; Mazzoli, 2014; Mazzoli et al., 2010); bulk chemicals (e.g., lactic acid and ethanol) with applications for plastic polymeric manufacturing, e.g., polylactic acid (PLA) or polyethylene terephthalate (PET), respectively (Madhavan Nampoothiri et al., 2010; Singh and Ray, 2007) or as solvents or biofuels (e.g., ethyl lactate, ethanol) (Ohara, 2003); as well as biodegradable plastics (i.e., polyhydroxyalkanoates, PHA) (Aslim et al., 1998).

Although it is not within the scope of this review, it is worth mentioning LAB properties as extensively used probiotics (Lamberti et al., 2011; Settanni and Moschetti, 2010).

Depending on which metabolic pathway(s) is (are) used by a LAB strain to catabolize sugars, a given strain can show either homo-, hetero- or mixed acid fermentation phenotype. Homofermentation virtually produces lactic acid (LA) as the sole end product. Sugars are

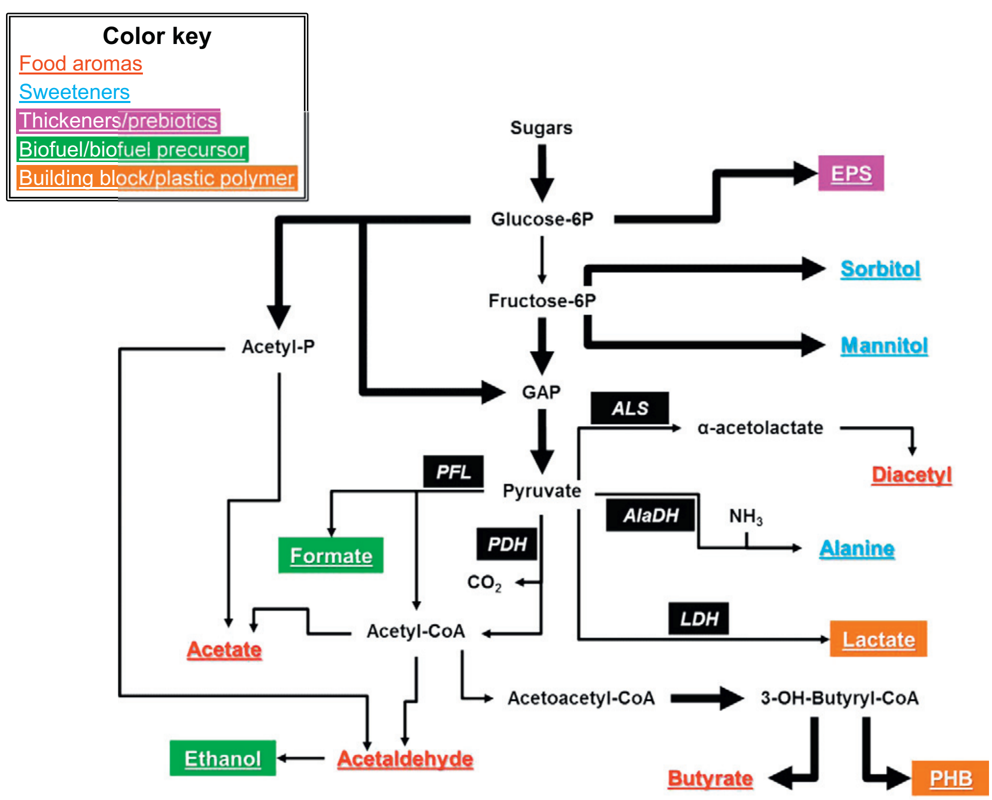

Fig. 1. Schematic overview of the metabolic pathways enabling LAB to produce some of the most industrially desired molecules by sugar fermentation. Thin arrows stand for single enzymatic reactions, while thick arrows stands for multiple reaction pathways. AlaDH, alanine dehydrogenase; ALS, α-acetolactate synthase; EPS, exopolysaccharides; GAP, glyceraldehyde-3-phosphate; LDH, lactate dehydrogenase; PDH, pyruvate dehydrogenase; PFL, pyruvate-formiate lyase; PHB, polyhydroxybutyrate.