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Research review paper

# Biotechnological routes based on lactic acid production from biomass

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ABSTRACT

Lactic acid, the most important hydroxycarboxylic acid, is now commercially produced by the fermentation of sugars present in biomass. In addition to its use in the synthesis of biodegradable polymers, lactic acid can be regarded as a feedstock for the green chemistry of the future. Different potentially useful chemicals such as pyruvic acid, acrylic acid, 1,2-propanediol, and lactate ester can be produced from lactic acid via chemical and biotechnological routes. Here, we reviewed the current status of the production of potentially valuable chemicals from lactic acid via biotechnological routes. Although some of the reactions described in this review article are still not applicable at current stage, due to their "greener" properties, biotechnological processes for the production of lactic acid derivatives might replace the chemical routes in the future.

**Contents**

## 1. Introduction

Currently, fossil resources are used to produce the vast majority of chemicals. However, the use of fossil resources causes serious environmental problems. Discovery of new environment-friendly sources of chemicals has captured the attention of researchers. Different building-block intermediates have been produced from biomass via biotechnological routes (Corma et al., 2007).

Lactic acid (2-hydroxypropionic acid, $CH_3-CHOHCOOH$) is a naturally occurring organic acid (John et al., 2007). Owing to its versatile applications in food, pharmaceutical, textile, leather, and chemical industries, lactic acid is the most important hydroxycarboxylic acid (Datta and Henry, 2006). Because lactic acid has both carboxylic and hydroxyl groups, it can also be converted into different potentially useful chemicals such as pyruvic acid, acrylic acid, 1,2-propanediol, and lactate ester (Fan et al., 2009) (Fig. 1).

Chemical and biotechnological routes that can help transform lactic acid into valuable chemicals have been described in previous studies (Corma et al., 2007). For green production of those valuable chemicals,

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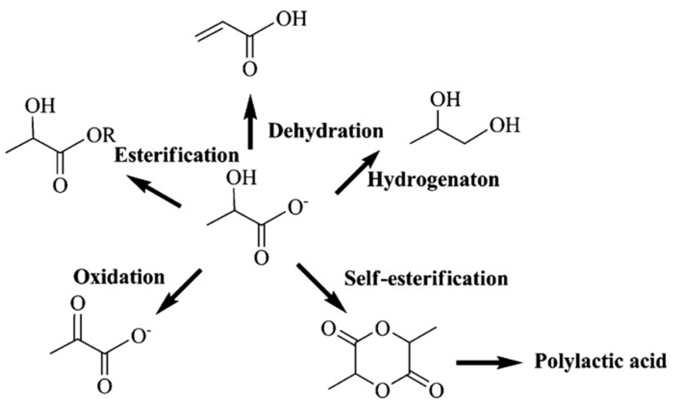

**Fig. 1.** Summary of the chemicals derived directly from lactic acid (Corma et al., 2007).

biotechnological routes are desirable. In this review, we focused our attention on biotechnological routes based on lactic acid from biomass. The drawbacks as well as improvements of the production of lactic acid derivatives via biotechnological routes were also discussed.

## 2. Fermentative production of lactic acid

Lactic acid has 2 optical isomers: L-lactic acid and D-lactic acid. Lactic acid can be produced via either chemical synthesis or microbial fermentation. Chemical synthesis of lactic acid is mainly based on the hydrolysis of lactonitrile by strong acids, and this process yields a racemic mixture of the 2 isomers (Holten et al., 1971; John et al., 2007). Other chemical routes, such as base-catalyzed degradation of sugars; oxidation of propylene glycol; reaction of acetaldehyde, carbon monoxide, and water at high temperatures and pressures; hydrolysis of chloropropionic acid; and nitric acid oxidation of propylene, are not technically and economically feasible processes for lactic acid production (Datta et al., 1995).

Compared to chemical synthesis, the biotechnological process for lactic acid production offers several advantages: low substrate costs, production temperature and energy consumption (Datta and Henry, 2006). Lactic acid-producing microorganisms use pyruvic acid as the precursor for lactic acid production. The conversion of pyruvic acid to lactic acid can be catalyzed by 2 types of enzymes: NAD-dependent L-lactate dehydrogenase and NAD-dependent D-lactate dehydrogenase (Garvie, 1980). The stereospecificity of lactic acid produced by microorganisms depends on the type of enzymes involved in the lactic acid production. Because the optical purity of lactic acid is a crucial factor in lactic acid-based industries, numerous studies have investigated the biotechnological production of optically pure lactic acid (John et al., 2007; Okano et al., 2010; Wee et al., 2006; Zhang et al., 2007; Zhao et al., 2010a, 2010b).

There are 2 bottlenecks in the biotechnological production of optically pure lactic acid. One bottleneck is the substrate cost because of the addition of sugars as carbon sources. This problem can be resolved through fermentative production of lactic acid from cheap materials. As shown in Table 1, many cheap, renewable raw materials such as molasses, starch, lignocellulose, and wastes from agricultural and agro-industrial residues have been used as substrates for lactic acid fermentation. However, most starchy and lignocellulose materials must be pretreated by physicochemical and enzymatic methods because lactic acid-fermenting microorganisms cannot directly use those materials (Okano et al., 2010). Improvement of the efficacy of these microorganisms through gene modification is an essential and interesting method that has been extensively studied. For detailed discussions of recent research on lactic acid production by genetically modified microorganisms from renewable resources, a review article by the Okano group (2010) can be referred to.

The other bottleneck for lactic acid production is the operating cost. For example, sterilization is necessary for fermentative production of lactic acid. Microorganisms, with an optimal fermentation temperature of 30–42 °C, are usually used for industrial applications (John et al., 2007). Therefore, it is difficult to avoid contamination if the medium is not sterilized. Nonsterilized fermentative production of L-lactic acid by a newly isolated thermophilic strain, *Bacillus* sp. 2–6, has been recently reported (Qin et al., 2009). High yield (97.3%), productivity (4.37 g/[l h]), and optical purity of L-lactic acid (99.4%) were obtained in batch and fed-batch open fermentations (Qin et al., 2009). Practically, nonsterilization means eliminating the need for sterilization equipments, reducing energy consumption, and lowering labor cost.

The separation and purification processes after fermentation also elevate the cost of lactic acid production. Owing to the inhibitory effects of low pH on cell growth and lactic acid production, $CaCO_3$ must be added to maintain a constant pH. This requires processing for

**Table 1**
Comparison of lactic acid production from renewable raw materials by different organisms[a].

| Organism | Substrate | Lactic acid | | | | Reference |
|---|---|---|---|---|---|---|
| | | Concentration (g/l) | Yield (g/g) | Productivity (g/l/h) | Type | |
| *Enterococcus faecalis* RKY1 | Corn starch | 129.9 | 1.04 | 1.5 | L | (Wee et al., 2008) |
| | Tapioca starch | 126.7 | 1.01 | 1.5 | L | |
| | Potato starch | 123.3 | 0.99 | 1.7 | L | |
| | Wheat starch | 123.2 | 0.99 | 1.4 | L | |
| *Lactobacillus rhamnosus* strain CASL | Cassava powder | 175.4 | 0.71 | 1.8 | L | (Wang et al., 2010a) |
| *Lactobacillus pentosus* | Trimming vine shoots | 24.0 | 0.76 | 0.51 | L | (Moldes et al., 2006) |
| *Bacillus coagulan* strains 36D1 | Paper sludge | 92.0 | 0.77 | 0.96 | L | (Budhavaram and Fan, 2009) |
| *Lactobacillus delbrueckii* IFO 3202 | Rice bran | 28.0 | 0.78 | 0.28 | L | (Tanaka et al., 2006) |
| *Lactobacillus delbrueckii* mutant Uc-3 | Molasses | 166 | 0.87 | 4.2 | L | (Dumbrepatil et al., 2008) |
| *Lactobacillus rhamnosus* ATCC 7469 | | 73.0 | 0.97 | 2.9 | L | (Marques et al., 2008) |
| *Lactobacillus delbrueckii* Uc-3 | Cellobiose and cellotriose | 90.0 | 0.90 | 2.3 | L | (Adsul et al., 2007) |
| *Lactobacillus* sp. RKY2 | Lignocellulosic hydrolysates | 27.0 | 0.90 | 6.7 | L | (Wee and Ryu, 2009) |
| *Lactococcus lactis* IO-1 | Sugar cane bagasse | 10.9 | 0.36 | 0.17 | L | (Laopaiboon et al., 2010) |
| *Lactobacillus rhamnosus* CECT-288 | Apple pomace | 32.5 | 0.88 | 5.4 | L | (Gullon et al., 2008) |
| *Lactobacillus bifermentans* | Wheat bran hydrolysate | 62.8 | 0.83 | 1.2 | L | (Givry et al., 2008) |
| *Bacillus* sp. strain | Corncob molasses | 74.7 | 0.50 | 0.38 | L | (Wang et al., 2010b) |
| *Bacillus coagulans* DSM 2314 | Lime-treated wheat straw | 40.7 | 0.43 | | L | (Maas et al., 2008) |
| *Lactobacillus rhamnosus* CECT-288 | Cellulosic biosludges | 42 | 0.38 | 0.87 | L | (Romani et al., 2008) |
| *Lactobacillus delbrueckii* | Sugarcane juice | 118 | 0.95 | 1.7 | D | (Calabia and Tokiwa, 2007) |
| *Sporolactobacillus* sp. CASD | Peanut meal, glucose | 207 | 0.93 | 3.8 | D | (Wang et al., 2011) |

[a] For detailed discussion of the other researches on lactic acid production from renewable raw materials before 2006, review written by the groups of John et al. (2007), can be consulted.