Production and Application of Lactic Acid: A Review

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Abstract: In organic chemistry and food science, lactic acid is one of the most industrially widely used hydroxycarboxylic acids. This work focuses on the production method, fundamental properties, the reason for lactic functioning as a preservative, and various applications of lactic acid in different areas. The common pathways to produce lactic acid are microorganism fermentation and chemical synthesis. Furthermore, the acidity due to hydrogen bonding and the opposite effect of the hydroxyl group makes lactic acid a good preservative. In addition, Poly Lactic Acid (PLA) originates from lactic acid and is another promising application from industrial uses to household usage, such as food takeaway containers.

1 INTRODUCTION

Lactic acid also expressed as 2-hydroxypropanoic acid or milk acid has molecular formula of $CH_3CH(OH)COOH$ and $C_3H_6O_3$. Its molar mass is 90.078g mol^{-1}. It exists in two enantiomeric forms: L(+)-lactic acid or D(-)-lactic acid. The structures are shown in Figure 1. L-lactic acid can be used for metabolizing by the human body or animals, so it's more beneficial for organisms, while the D-lactic acid cannot be metabolized, and a large proportion of it is excreted (Dashmeet, 2018).

Lactic acid was first found by C.W.Scheele in sour milk in 1780, and Fermi successfully extracted lactic acid by fermentation in 1881, which was then used in the industrial synthesizing of lactic acid. Lactic acid exists in different fermented foods like yoghurt and butter. By 2012, the demand for lactic acid was over 259,000 metric tons per year (Castillo, 2013). The vast demand is attributed to several functions of lactic acid.

Lactic acid is widely used as a preservative to prevent food spoilage by inhibiting the growth of putrefying bacteria. When it is changed into potassium or sodium lactate, the shelf life of fish and meat can be extended by its addition. It also serves as an acidulant to add savoury flavour to pickled vegetables, beverages, and baked products. As a pH regulator, lactic acid produces chocolates and sweets to achieve the correct pH value.

The textile industry works as a mordant (fixative) to dye clothes. In addition, lactic acid can be converted to ethanol, propylene glycol, and acrylic polymers. In the pharmaceutical industry, lactic acid works as an electrolyte in implants, pills, and dialysis. In the cosmetic industry, lactic acid has the functions of brightening skin and helping remove the brown spots on the skin. The role of moisturizer due to its retaining water capacity also makes lactic acid a popular ingredient in hygiene and aesthetic products (Krishna, 2019).

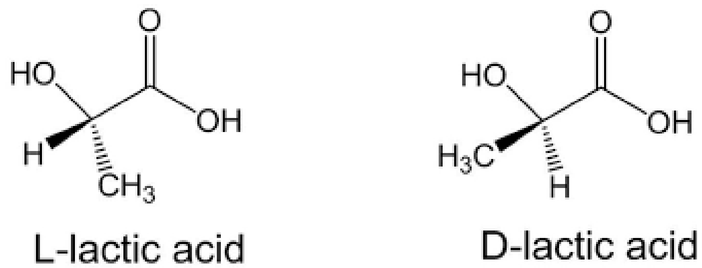

Figure 1: The structures of D(-)-lactic acid and L(+)-lactic acid (Dashmeet, 2018).

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For industrial production, there are several pathways to obtain lactic acid. The two most popular ones are fermentation and chemical synthesis (Krishna, 2019).

2 FERMENTATION FOR LACTIC ACID

Fermentation is a relatively fast and cheap way to lead one of the enantiomers of lactic acid with high yields. However, like any other fermentation process, its yield and efficiency are determined by starting raw materials, nutrients in the medium and the microorganisms used, such as bacteria type (Krishna, 2019).

There are two main patterns of lactic acid bacteria used in fermentation. The first one is heterofermentative; these organisms produce several byproducts and are, therefore, unsuitable for industrial processes. The second one is homofermentative. Those organisms only produce fewer byproducts, but the large yield of lactic acid is used in commercial production (Dashmeet, 2018).

Table 1 is a summary table of the fermentation bacteria and their respective isomer result, fermentation pattern and necessary raw materials.

The first kind of fermentation: homofermentative fermentation produces more than 85% lactic acid from glucose (Boontawan, 2010). One mole of glucose can be converted to two moles of lactic acid. The reaction process is shown by the diagram below. Step 1.

Figure 2 shows the first step of homofermentative fermentation. In step 2 shown by Figure 3, pyruvate is reduced from the aldehyde or ketone oxidation level to the alcohol oxidation level. The NADH, also known as dihydropyridine, loses one proton and becomes positively charged as NAD^+.

Figure 4 shows the second kind of fermentation: heterofermentative fermentation produces only 50% lactic acid and large quantity of ethanol, and carbon dioxide. With the help of bacteria, 1 mole of glucose can be converted to 1 mole of lactic acid, 1 mole of ethanol, and 1 mole of carbon dioxide (Boontawan, 2010).

3 INDUSTRIAL WAY OF SYNTHESIZING LACTIC ACID (DRAW DETAILED SCHEME)

The industrial process for commercial production is

Table 1: Characteristics of selected bacteria and molds of interest in lactic acid production (Dashmeet, 2018).

Microorganism	Lactic acid isomer	Fermentation pattern	Raw material
Bacteria: *Lactobacillus amylophilus*	L (-)	Homofermentative	Starch
L. amylovorus	DL	Homofermentative	Starch
L. casei subsp. Rhamnosus (L. delbueckii NRRL B-445)	L (+)	Facultative heterofermentative	Glucose, sucrose (molasses)
L. delbueckii subsp. bulgaricus	D (-)	Homofermentative	Cheese whey and permeate (Lactose)
L. helviticus	DL	Homofermentative	Cheese whey and permeate (Lactose)
Molds: *Rhizopus arrhizus* *R. oryzae*	L (+) L (+)	Homofermentative Homofermentative	Glucose, starch Glucose, starch

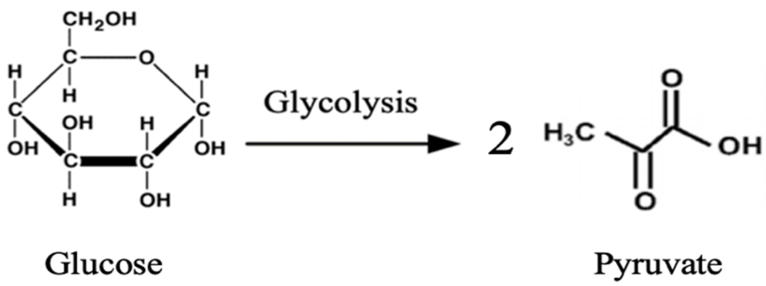

Figure 2: First step of homofermentative fermentation.

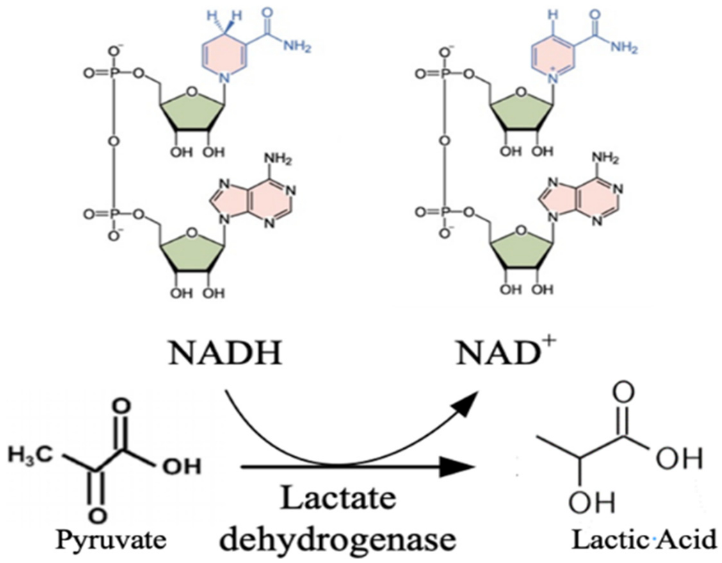

Figure 3: Second step of homofermentative fermentation.

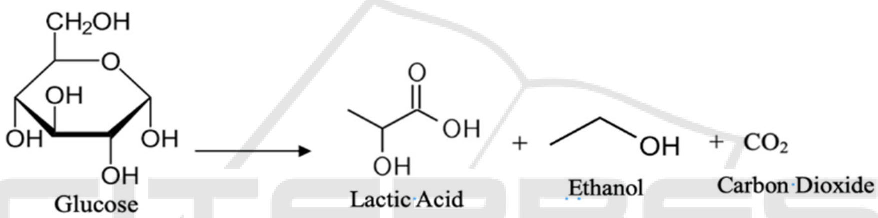

Figure 4: Heterofermentative fermentation.

also based on chemical synthesis. The starting material is lactonitrile produced by acetaldehyde and hydrogen cyanide. The reaction should be conducted in liquid phase under high atmospheric pressures. The crude lactonitrile is then purified by distillation. After that, concentrated HCl or H_2SO_4 is used to hydrolyze the lactic acid to produce ammonium salt and lactic acid. As methyl lactate is easier to purify through distillation, the product lactic acid is then esterified with methanol. After distilling, methyl lactate is hydrolyzed by water under an acid catalyst to produce purer lactic acid and methanol. Unlike the fermentation process, the chemical synthesis method would produce a mixture of DL-lactic acid. The process is presented in Figure 6 and Figure 7. (Boontawan, 2010).

4 LACTIC ACID AS A PRESERVATIVE

The growth of bacteria and its releasing of mycotoxin in food are main factors causing food spoilage and food poisoning. Lactic acid can permeate into the membrane of the bacteria, reducing the intracellular pH, to kill the food spoilage bacteria such as Enterobacteriaceae and Pseudomonadaceae. (Nasrollahzadeh, 2022)

It is more acidic than another organic acid in households: acetic acid. Lactic acid has pKa value of 3.86, due to the existence of hydrogen bonding and the polar effect of hydroxyl group.

In Figure 7, there are two attraction forces from O to the H in the bottom right. Shown in the right part of the diagram, H is relatively more electronegative than O, so the O atom will make the H atom more positive. The proton boxed is therefore more acidic. In addition, hydroxyl OH is an electronegative functional group, so it will further pull the electrons far away from the middle H as lactic acid has two hydroxyl group, which results in the polar effect.

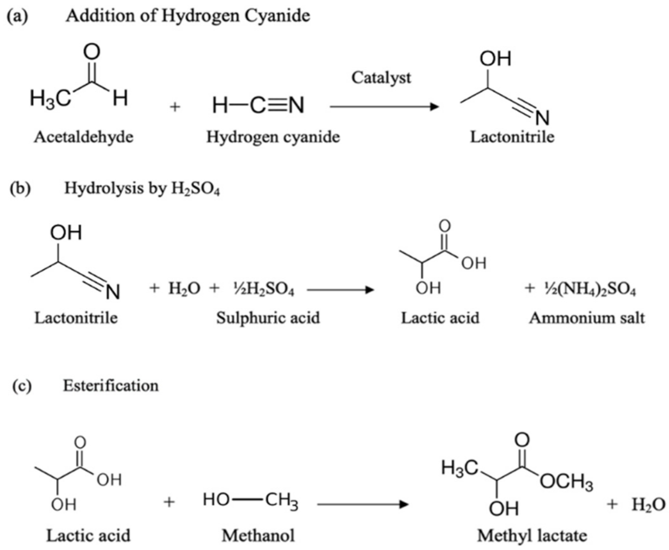

Figure 5: Step (a)(b) and(c) of chemical synthesis.

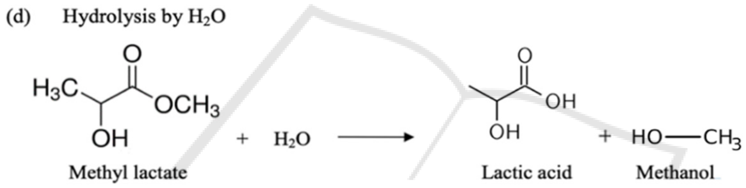

Figure 6: Step(d) of chemical synthesis

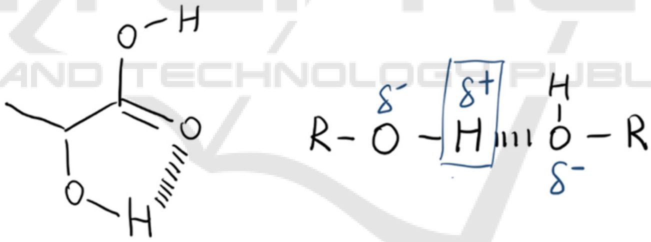

Figure 7: Lactic acid with hydrogen bonding.

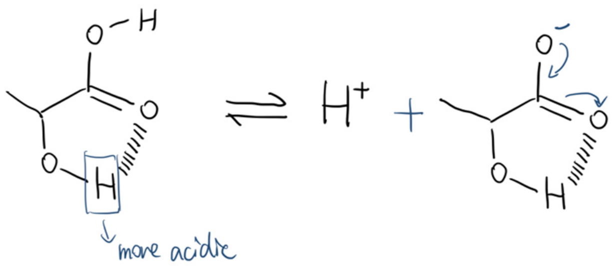

Figure 8: Formula showing resonance form of lactic acid.

Figure 8 illustrates the resonance form when the lactic acid loses a proton. The negative charge can either stay on the top O atom or come down as a double bond and push the electron to the left O atom. The two resonance forms also help the negative charge to spread over the conjugate base of lactic acid, making it more stable. Therefore, it further lowers the pKa of lactic acid.

As the growth of bacteria is inhibited by the acidic environment, lactic acid functions as a good inhibitor.

Along with its flavouring function and little smell, lactic acid outstands among a series of organic acids and becomes a popular food preservative (Nasrollahzadeh, 2022).

5 OTHER APPLICATIONS OF LACTIC ACID

Lactic acid can serve as a starting material and involves in numerous reactions. Table 2 is a summary table of different kinds of reactions.

The most common reaction involving lactic acid is to produce lactide, which can be further transformed into poly lactic acid (PLA). PLA is a biodegradable plastic and is applied in daily life as food packages, containers, trash bags, protective clothing, etc. The full application is shown by Table 3 (Södergård, 2002).

Table 2: Reactions and chemical produced involving lactic acid (Krishna, 2019).

Reaction	Chemical produced
Hydrogenation	Propylene oxide
Decarboxylation	Acetaldehyde
Dehydration	Acrylic acid
Reduction	Propanoic acid
Condensation	2,3-pentanedione
Self-esterification	Dilactide

Jem and Tan use a diagram (Figure 9) to illustrate two pathways from lactic acid to PLA. One is through condensation, depolymerization, and ring opening polymerization. The other one involves only azeotropic dehydrative condensation (Jem, 2020).

Table 3: Polymers types and their applications (Jem and Tan).

Lactide	Polymers	Applications
L-lactide	L-lactide for producing PLLA	Membranes and films for medical applications and 3D printing for prosthesis
D-lactide	D-lactide for producing PDLA	Hydrogel and particles for drug delivery
L-lactide	L-lactide with PEG	Medical applications, drug vehicles, nanoparticles loaded with bioactive compounds, treatment for cancer and infections
D-lactide	D-lactide with PEG	Biochemical device and packaging
L-lactide	L-lactide with poly (trimethylene carbonate)	Biodegradable elastomeric scaffold for vascular engineering
L-lactide	L-lactide with PCL	Absorbable suture medical application due to good tensile properties Packaging application thanks to tunable barrier properties
L-lactide/ D-lactide	Lactide with lignin	Bio-based composite materials
L-lactide/ DL-lactide	L-lactide with ε-caprolactone and hydroxyapatite	Composite materials for bone reconstruction
L-lactide	L-lactide with hydroxyapatite	Composite scaffolds for bone tissue engineering
L-lactide	L-lactide, glycolide, butyl succinate/citrate	Bioabsorbable block copolymers for tissue engineering
L-lactide	L-lactide with PGA	Smart polymer used as drug delivery device

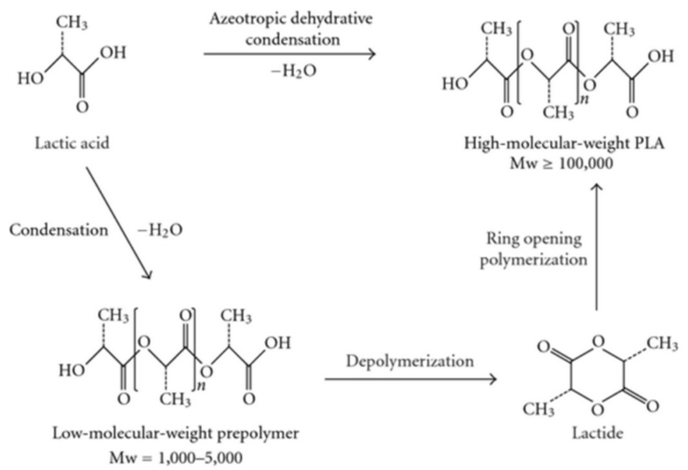

Figure 9: Reactions of converting lactic acid into PLA.

6 CONCLUSION

Lactic acid is widely used in the food, textile, pharmaceutical, and cosmetic industry as a preservative, flavouring agent, pH regulator and moisturizer. It can be obtained through chemical synthesis or biological fermentation as a functional organic compound. The selection of a certain enantiomer of lactic acid is possible in fermentation by choosing different types of bacteria. Lactic acid can also be a starting material to produce PLA, a promising bio-degradable plastic waiting for further study.

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