TYPES of FERMENTATIONS

Fermentation types are listed as follows according to the final product synthesized;

1) Lactic Acid Fermentation

2) Alcohol Fermentation

3) Propionic Acid Fermentation

4) Formic Acid Fermentation

5) Butyric Acid Fermentation

6) Methane Fermentation

1-Lactic Acid Fermentation

Lactic acid bacteria (LAB) ferment carbohydrates to lactic acid in anaerobic conditions. The enzyme used in this reaction is **lactate dehydrogenase (LDH).**

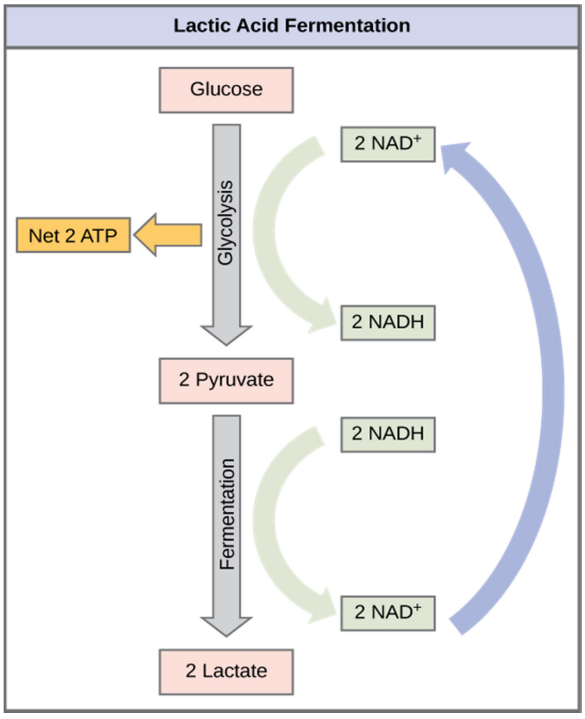

Figure 1.Diagram of Lactic acid fermentation

LAB are common to the dairy industry, and while the definition of LAB may be imprecise, it is assumed that LAB are organisms that produce lactic acid as the principle by-product of sugar fermentations. LAB may be rods or cocci, are Gram-positive and are generally more tolerant of low pH environments than are other bacteria associated with milk and dairy products.

LAB are common in nature and are often associated with plant materials.

They can also be found as part of the resident microflora of humans and other mammals (e.g., oral cavity, GI track, etc.).

LAB are most known in the dairy industry for their use in "starter" cultures and dairy fermentations. As starter cultures, they are added to milk and allowed to grow under controlled conditions in order to produce acid and/or modify the flavor and texture for the desired characteristics of a cheese or cultured product. LAB may also grow in dairy products as contaminants or under uncontrolled conditions, resulting in undesirable defects. LAB can cause milk to "sour" while some strains may produce gas in cultured products or cheese that will influence package appearance and cause product flavor defects.

The fermentation method used by animals and certain bacteria, like those in yogurt, is also lactic acid fermentation (Figure 1). This type of fermentation is used routinely in mammalian red blood cells and in skeletal muscle that has an insufficient oxygen supply to allow aerobic respiration to continue (that is, in muscles used to the point of fatigue). In muscles, lactic acid accumulation must be removed by the blood circulation and the lactate brought to the liver for further metabolism.

Lactic acid bacteria classified as homofermentative or heterofermentative based on their by-products of sugar (e.g., glucose) fermentation.

-Homofermentative LAB ferment glucose via the EMP-path, producing 99% lactic acid (primary **by-product) .**

- **Homofermentative LAB include;**

***Lactococcus* spp.** ; used in dairy starter culture applications where the rapid development of lactic acid and reduced pH is desirable.

Lactobacillus delbruckii* subsp*. bulgaricus*, *Lb. acidophilus: rod type yogurt strains ,

Streptococcus salivarius subsp. thermophilus: thermophilic and cocci type yogurt strains,

***Lb. helveticus**:* thermophilic strains that might be used in cheese

Streptococcus spp., Enterococcus, Pediococcus and *Aerococcus:* Other homofermentative cocci that might be found in milk and dairy products, but are rarely used as starter cultures include other.

-Heterofermentative LAB ferment glucose through the PP pathway to form 50% lactic acid as well as CO2 (carbon dioxide), C2H5OH (ethanol) and CH3COOH (acetic acid) as by-products.. Lactic acid and other metabolic products produced by these bacteria during fermentation provide characteristic properties to foods.

Testing for heterofermentative fermentation generally involves the detection of gas (e.g., CO2). With the exception of certain fermented milk products, heterofermentative LAB are rarely used as dairy starter cultures, although they are not uncommon in milk and dairy products. If allowed to grow to significant numbers, they can cause defects related to their acid and CO2 production, such as slits in hard cheeses or bloated packaging in other dairy products.

- **Heterofermentative LAB include;**

***Leuconostoc* spp.** (Gram-positive cocci),

***Lactobacillus brevis, Lb. fermentum,* and *Lb. reuteri* (**Gram-positive rods)

Lb. plantarum, Lb. casei* and *Lb. curvatus: "facultatively" heterofermentative Lactobacillus species, meaning they will produce CO2 and other by-products only under certain conditions or from specific substrates

The lactic acid bacteria and metabolic products used in the production of fermented dairy products are shown in the table below.

Fermented dairy products	**Microorganisms**	**Final metabolites**
Yogurt	*Lactobacillus bulgaricus*	Lactic acid
	Streptococcus thermophilus	Lactic acid
Kefir	*Lactobacillus bulgaricus*	Lactic acid
	Lactobacillus casei	Lactic acid
	Lactobacillus brevis	Lactic acid, acetic acid, ethyl alcohol, CO_2
	Streptococcus lactis	Lactic acid, acetic acid, diacetyl, CO_2
Kımız	*Lactobacillus bulgaricus*	Lactic acid
	Lactobacillus casei	Lactic acid
	Streptococcus lactis	Lactic acid, acetic acid, diacetyl, CO_2
Butter	*Streptococcus cremoris*	Lactic acid, diacetyl
	Leuconostoc citrovorum	Acetoin, diacetyl
	Leuconostoc dextranicum	Acetoin, diacetyl
	Streptococcus lactis	Lactic acid, acetic acid, diacetyl, CO_2
Cheese	*Streptococcus cremoris*	Lactic acid, diacetyl
	Lactobacillus casei	Lactic acid
	Leuconostoc citrovorum	Acetoin, diacetyl
	Propionibacterium shermanii	Propionic acid, acetic acid, CO_2

2-Alcohol Fermentation

Another familiar fermentation process is **alcohol fermentation** (Figure 2) that produces ethanol, an alcohol (because of this, this kind of fermentation is also sometimes known as **ethanol fermentation**). There are two main reactions in alcohol fermentation.

The first reaction is catalyzed by **pyruvate decarboxylase**, a cytoplasmic enzyme, with a coenzyme of thiamine pyrophosphate (TPP, derived from vitamin B1 and also called thiamine). **A carboxyl group is removed from pyruvic acid, releasing carbon dioxide as a gas. The loss of carbon dioxide reduces the size of the molecule by one carbon, making acetaldehyde.**

The second reaction is catalyzed by **alcohol dehydrogenase to oxidize NADH to NAD^+ and reduce acetaldehyde to ethanol. The fermentation of pyruvic acid by yeast produces the ethanol found in alcoholic beverages.**

Many microorganism species, especially some yeast species including the Saccharomyces spp. ferment carbohydrates to ethanol and CO2 under anaerobic conditions. The breakdown of glucose into ethanol and CO2 by yeasts takes place via the FDP-pathway.

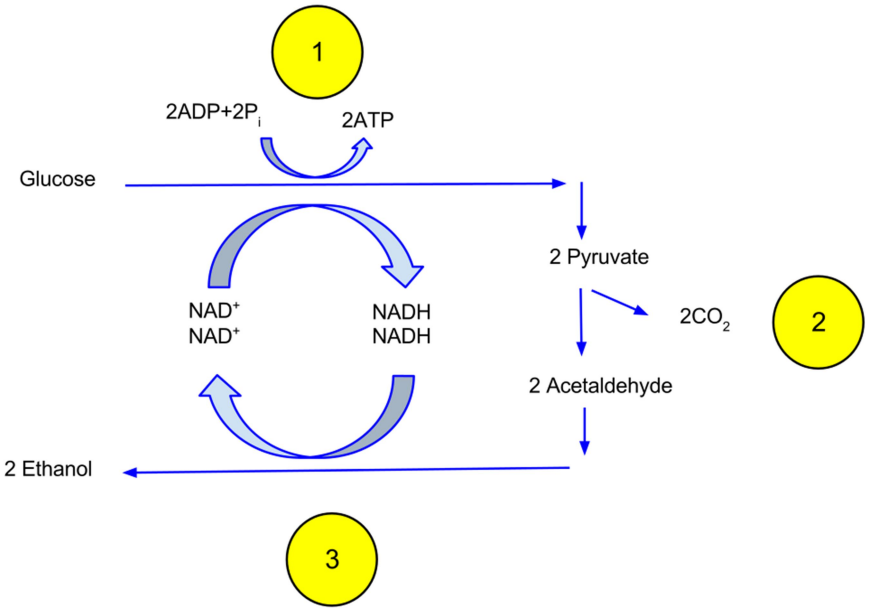

Figure 2. Diagram of alcohol fermentation

Yeasts are used in the synthesis of some biotechnological products as the following:

Fermented Products	**Yeast type**	**Final metabolite**
Bread	*Saccharomyces cerevisiae*	Ethyl alcohol, CO_2
Boza	*Saccharomyces carlsbergenensis*	Ethyl alcohol, CO_2
Beer	*Saccharomyces carlsbergenensis*	Ethyl alcohol, CO_2
Wine	*Saccharomyces ellipsoides*	Ethyl alcohol, CO_2

3) Propionic Acid Fermentation

Propionibacterium type bacteria first convert pyruvate to lactic acid and then synthesize propionic acid from lactic acid. The most important propionic bacteria isPropionibacterium shermanii.

$2CH_3CHOH\text{-}COOH \longrightarrow 2CH_3CH_2COOH \longrightarrow CH_3COOH + CO_2 + H_2O$

Some propionic acid bacteria degrade propionic acid to alcohol.

$CH_3CHOH\text{-}COOH + 2H_2 \longrightarrow CH_3CH_2CH_2OH + H_2O$

4) Formic Acid Fermentation

Enterobacteriaceae and Bacillus bacteria convert sugars into formic acid, acetic acid, succinic acid, lactic acid, ethanol, glycerin, acetone, 3,3 butanediol and CO2.

5) Butyric Acid Fermentation

Clostridium tyrobutyricum ferments carbohydrates and converts them into butyric acid, acetic acid and CO2.

$4C_6H_{12}O_6 \longrightarrow 4\,CH_3CH_2COOH + 2CH_3COOH + 8CO_2 + 8H_2$

Most of the Clostridium bacteria are primarily produce butanol, ethanol, acetone and isoproponal other than butyric acid.

6) Methane Fermentation

Methane bacteria (Methanobacterium) are anaerobic microorganisms. These bacteria are found in ruminant rumen, swamps and sewage sludge. These bacteria convert organic acids (especially CH3COOH, CO2, CO, H2) into methane gas.

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https://foodsafety.foodscience.cornell.edu/