FDE 437
FERMENTATION TECHNOLOGY

Instructor:

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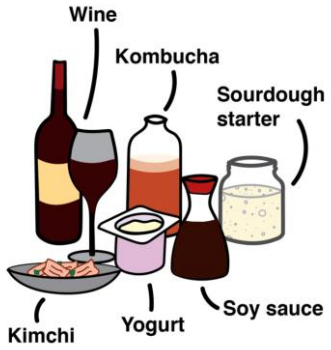


Overview of fermentation technology

- **Fermentation is one of the oldest methods of processing of food into a form that is suitable for preservation.**
- **Fermentation has been known and practiced by humankind since prehistoric times, long before the underlying scientific principles were understood.**
  - **For example, the productions of bread, beer, vinegar, yogurt, cheese, and wine were well-established technologies in ancient Egypt. It is an interesting fact that archaeological studies have revealed that bread and beer, in that order, were the two most abundant components in the diet of ancient Egyptians.**
- **The term is derived from the Latin verb *fevere* (to boil) because of the chemical change caused by microorganisms or their products in the fermenter, usually producing effervescence and heat.**
- **The fermentation process was elucidated by Louis Pasteur (1822-95) who demonstrated experimentally that fermentation is an anaerobic metabolic process of living yeast based on the transformation of glucose into ethanol. Pasteur defined it as *respiration without air*.**
- **As Louis Pasteur succinctly suggested, fermentation is "*la vie sans l'air*," or "life without air."**

Bread making as depicted on the wall of an ancient Egyptian tomb dated c. 1400 BC.

Grape treading and wine making as depicted on the walls of Nakhte's tomb, Thebes, c. 1400 BC.

Louis Pasteur

- Definition: Fermentation is the metabolic process in which carbohydrates and related compounds are oxidized with the release of energy in the absence of any external electron acceptors.

- The final electron acceptors are organic compounds produced directly from the breakdown of the carbohydrates.

- Some of the foods produced from fermentation of raw materials are pickles, olives, sausages, bread, cheese, cocoa, soy sauce, sauerkraut, pickles, beer, wine, and others.

Overview of fermentation technology

- As the most important process of food industry, **fermentation plays at least five roles in food processing**:

1. enrichment of the human dietary through development of a wide diversity of flavors, aromas, and textures in food;
2. preservation of substantial amounts of food through lactic acid, alcoholic, acetic acid, alkaline fermentations, and high salt fermentations;
3. enrichment of food substrates biologically with vitamins, protein, essential amino acids, and essential fatty acids;
4. detoxification during food fermentation processing;
5. a decrease in cooking times and fuel requirements.

Fermentation

- The word fermentation from a microbiological perspective is used to describe any biological process occurring under anaerobic conditions (absence of oxygen).

- However, many researchers use the term to describe any process that uses a microorganism to convert a particular medium into a specific product.

The Different Uses of the Word «Fermentation»

- **The first meaning relates to microbial physiology.** In strict physiological terms, fermentation is defined in microbiology as the type of metabolism of a carbon source in which energy is generated by substrate level phosphorylation and in which organic molecules function as the final electron acceptor (or as acceptors of the reducing equivalents) generated during the break-down of carbon-containing compounds or catabolism. As is well-known, when the final acceptor is an inorganic compound the process is called respiration. Respiration is referred to as aerobic if the final acceptor is oxygen and anaerobic when it is some other inorganic compound outside oxygen e.g sulphate or nitrate.

- **The second usage of the word is in industrial microbiology**, where the term 'fermentation' is any process in which micro-organisms are grown on a large scale, even if the final electron acceptor is not an organic compound (i.e. even if the growth is carried out under aerobic conditions). Thus, the production of penicillin, and the growth of yeast cells which are both highly aerobic, and the production of ethanol or alcoholic beverages which are fermentations in the physiological sense, are all referred to as fermentations.

- **The third usage concerns food**. A fermented food is one, the processing of which microorganisms play a major part. Microorganisms determine the nature of the food through producing the flavor components as well deciding the general character of the food, but microorganisms form only a small portion of the finished product by weight. Foods such as cheese, bread, and yoghurt are fermented foods.

Biochemistry of fermentation process

Microorganisms use three general processes, aerobic respiration, anaerobic respiration and fermentation, with the aim of the production of energy from sugars.

- **Aerobic cellular respiration:** Biological oxidation with **oxygen** as the final electron (H) acceptor

- **Anaerobic cellular respiration:** Biological oxido-reduction with **inorganic substances** as the final electron (H) acceptor.
  (Here, nitrate or sulfate ions act as final electron acceptor, since they do the task of oxygen in aerobic respiration, it is called anaerobic, that is, anaerobic respiration).

- **Fermentation:** Decomposition process that occurs by a biological oxido-reduction reaction in which **organic molecules** function as the final electron acceptor.

Biochemistry of fermentation process

- Microorganisms use two general processes, respiration and fermentation, with the aim of the production of energy from sugars.
- Both processes start with glycolysis but then follow different pathways.
- Under aerobic conditions, glycolysis usually functions with the respiration, which can oxidize pyruvate to carbon dioxide (CO_2) and water with large amount of ATP.
- Under anaerobic conditions, pyruvate is fermented to a wide range of fermentation products, many of which have industrial importance. In fermentation, the pyruvate is converted to various fermentation end products.
- The produced end products change depending on the microorganisms. For example, in the ethyl alcohol fermentation, first pyruvate is reduced to acetaldehyde and then acetaldehyde is converted to ethanol by yeasts. However, in lactic acid fermentation, pyruvate is converted to lactic acid as a major end product by lactic acid bacteria (LAB).

- With these decompositions, the most energy is released by aerobic respiration, then by anaerobic respiration, and the least by fermentation.

- Fermentations, according to whether the air oxygen participates in the fermentation process, they are divided into oxidative or non-oxidative fermentations.

Oxidative fermentations

*Acetic acid fermentation

*Citric acid fermentation

Non-oxidative fermentations

* Ethyl alcohol fermentation

* Lactic acid fermentation

Pasteur Effect
Crab-tree Effect

- **The Pasteur Effect:** The behavior of yeasts during aerobic and anaerobic growth led to important discoveries in microbial physiology. For example, it was observed that when yeasts were exposed to air or oxygen during fermentation, glycolytic metabolism was abruptly inhibited, a phenomenon appropriately termed the Pasteur Effect.

- Pasteur discovered that yeast produced more ethanol during anaerobic fermentative growth compared to growth under aerobic, respiring conditions (the aptly called "Pasteur effect").

- The Pasteur effect relates oxygen with the kinetics of yeast sugar catabolism and states that under anaerobic conditions, glycolysis proceeds faster than it does under aerobic conditions. Alternatively, it may be defined as a suppression of fermentation by oxygen. However, this phenomenon is only observable when glucose concentrations are low (e.g. below around ***5*** mM in ***S. cerevisiae)*** or under certain nutrient-limited conditions.

Pasteur Effect
Crab-tree Effect

- **The Crab-tree Effect: If** the concentration of available glucose is high the Pasteur effect in ***S. cerevisiae*** is no longer operable. Then the Crabtree effect comes into play.

- This phenomenon (also referred to as the glucose effect or contre-effect Pasteur) relates glucose concentration with the particular catabolic route adopted by glucose-sensitive yeasts (like ***S. cerevisiae)*** in the presence of oxygen and states that, even under aerobic conditions, fermentation predominates over respiration. Thus, even though oxygen may be present, **NADH** generated during glycolysis is mainly oxidized by fermentation, rather than by respiration.

- This phenomenon is initially described by the English biochemist Herbert Grace Crabtree (hence the name).

- The **Crabtree effect** describes the observation that respiration is frequently inhibited when high concentrations of glucose or fructose are added to the culture medium - a phenomenon observed in numerous cell types, particularly in proliferating cells, not only tumor cells but also bacteria and yeast.

- **The Pasteur effect (suppression of glycolysis by oxygen) is the converse of the Crabtree effect (suppression of respiration by high concentration of glucose or fructose).**

- In the most general sense, the Crabtree effect describes the phenomenon of metabolic competition between fermentation (substrate-level phosphorylation) and aerobic metabolism of glucose via the tricarboxylic acid (TCA) cycle and the electron transport chain observed aerobically in the presence of high, external glucose concentrations. Thus, a Crabtree effect is similar to well-known Pasteur effect, the only difference being that fermentation is induced not by lack of oxygen but by excess of glucose.

Fermented Foods

- Fermented foods are defined as "foods or beverages produced through controlled microbial growth, and the conversion of food components through enzymatic action".

- Fermented foods are defined as 'those foods that have been subjected to the action of microorganisms or enzymes so that desirable biochemical changes cause significant modification in the food'.

  (The processes may make the foods more nutritious or digestible, or may make them safer or tastier, or some or all of these).

Fermented Foods

- Many foods have historically undergone fermentation, including meat and fish, dairy, vegetables, soybeans, other legumes, cereals and fruits.

- There are several variables in the fermentation process including the microorganisms, the nutritional ingredients and the environmental conditions, giving rise to thousands of different variations of fermented foods.

- Historically, food fermentation was performed as a method of preservation, as the generation of antimicrobial metabolites (e.g., organic acids, ethanol and bacteriocins) reduces the risk of contamination with pathogenic microorganisms. Fermentation is also used to enhance the organoleptic properties (e.g., taste and texture), with some foods, such as olives, being inedible without fermentation that removes bitter phenolic compounds.

Definitions of fermented foods

- van Veen (1957) defined **fermented foods** as «**foods that are fermented till at least one of the constituents has been subjected to the action of microorganisms for a period, so that the final products have often undergone considerable changes in chemical composition and other aspects due to microbial and enzymatic changes**».

- Steinkraus (1994, 1996) defined **indigenous fermented foods** as «**foods where microorganisms bring about some biochemical changes in the substrates during fermentation, such as the enrichment of the human diet through the development of a wide variety of flavors, aromas, and textures in foods; the preservation of foods through lactic acid, and alcoholic, acetic acid, and alkaline fermentations; the enrichment of food substrates biologically with proteins, essential amino acids, essential fatty acids, and vitamins; the detoxification of undesirable compounds; and the decrease in cooking times and fuel requirements**». Late Prof. Steinkraus used the word "indigenous" for every fermented food he mentioned in his books and publications.

- Campbell-Platt (1987, 1994) defined **fermented foods** as «**those foods that have been subjected to the action of microorganisms or enzymes so that desirable biochemical changes cause significant modification to the food**».

- Holzapfel (1997) described **fermented foods** as «**palatable and wholesome foods prepared from raw or heated raw materials by microbial fermentation**». Traditionally, by trial and error, skills have been developed to control technical parameters during fermentation. Inoculation of raw materials with a residue of a previous batch, that is, a backslopping, accelerated the initial fermentation phase and controlled desirable changes.

Properties of Fermented Foods

Properties of fermented foods

- Enhanced preservation
- Enhanced nutritional value
- Enhanced functionality
- Enhanced organoleptic properties
- Uniqueness
- Increased economic value

Types of fermented foods

Classification of fermented foods:

Global fermented foods are classified into nine major groups on the basis of substrates (raw materials) used from plant/animal sources:

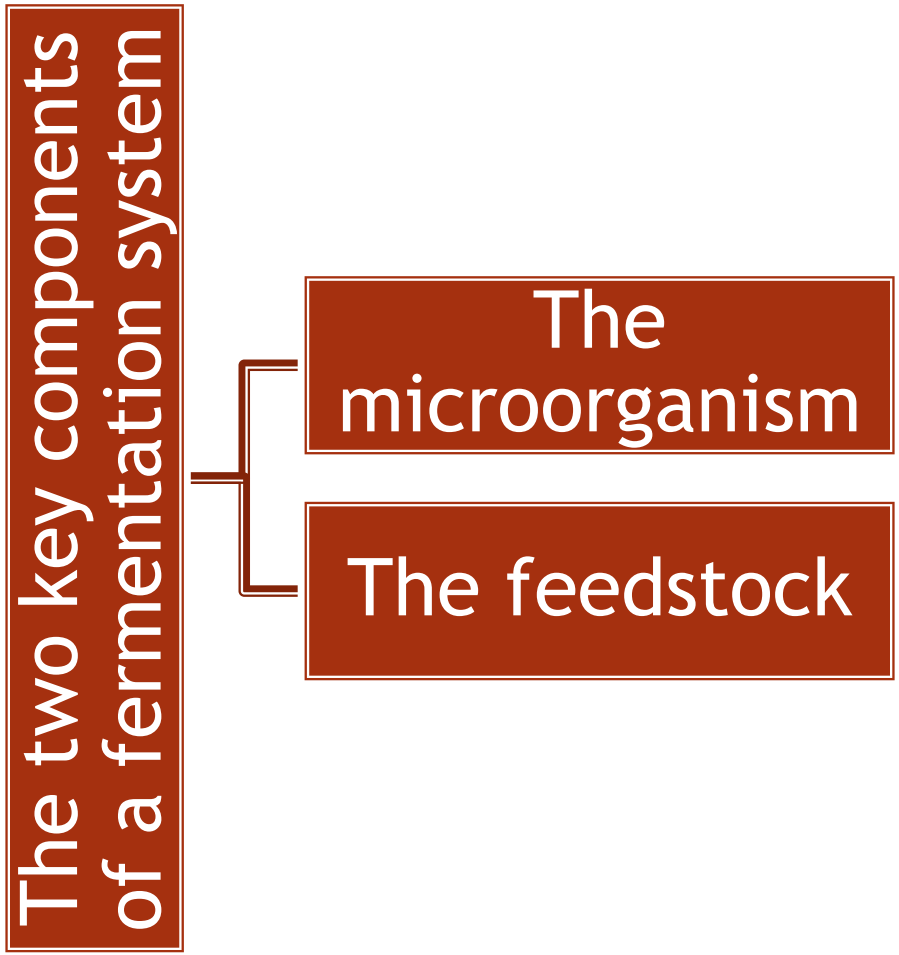
(1) fermented cereals
(2) fermented vegetables and bamboo shoots
(3) fermented legumes
(4) fermented roots/tubers
(5) fermented milk products
(6) fermented and preserved meat products
(7) fermented, dried and smoked fish products
(8) miscellaneous fermented products
(9) alcoholic beverages

Fermented Foods

- Traditional Food Fermentations
- Industrial Food Fermentations

Three ways to initiate/start food fermentations

1. Spontaneous fermentation
2. Backslopping
3. Addition of Starter cultures


The two key components of a fermentation system
The microorganism
The feedstock

Role of microorganisms in the fermentation process

(1) preservation of food through formation of inhibitory metabolites like organic acids, ethanol, bacteriocins, etc.,

(2) improvement of food safety via pathogens inhibition or by the removal of toxic compounds,

(3) enrichment of foods with vitamins, protein, minerals, essential amino acids and essential fatty acids,

(4) enrichment of products with a wide diversity of phenolic compounds that improves flavors, aromas and textures, and

(5) expansion of the diet for more diversity.