Lesson Plan: Introduction to Fermented Foods and Beverages

Grade Level: High School Chemistry

Lesson Duration: 90 minutes

Lesson Objectives

By the end of the lesson, students will be able to:

- Students will be able to describe fermentation
- Students will be able to identify fermented foods and beverages
- Students will be able to discuss the broad types of microorganisms involved in fermentation
- Students should be able to describe how fermentation modifies food

Background and Introduction

Fermentation, in simple terms, is the microbial breakdown of complex molecules—primarily sugars such as glucose, sucrose, lactose, and maltose—into simpler organic compounds to generate energy. During this process, microorganisms convert sugars into organic acids (mainly lactic acid, acetic acid, and formic acid) and/or alcohol. Fermentation can be carried out by a single microorganism or by a consortium ranging from two species to complex microbial communities. In some cases, fermentation relies on the naturally occurring (resident) microorganisms present in the raw material. For instance, in sauerkraut production, the native bacteria on cabbage ferment the sugars in the leaves to produce organic acids, giving sauerkraut its characteristic sour flavor. This is known as wild or indigenous fermentation.

In other cases, it is necessary to first eliminate the naturally occurring microbes before introducing a specific microorganism or microbial mixture to drive the fermentation. This is achieved through pasteurization, a process that involves heating the material to a temperature high enough to kill the resident microorganisms without damaging the food itself. This approach, known as controlled fermentation, is commonly used in the production of yogurt and most types of cheese.

When a food material undergoes fermentation, its composition is modified in ways that can enhance flavor, improve nutritional quality, and reduce or eliminate undesirable or hard-to-digest components. The organic acids and/or alcohols produced during fermentation act as natural preservatives, helping to extend the shelf life of the final product. In addition, many fermented foods and beverages contain live microorganisms that can enrich the human gut microbiota, offering a variety of health benefits.

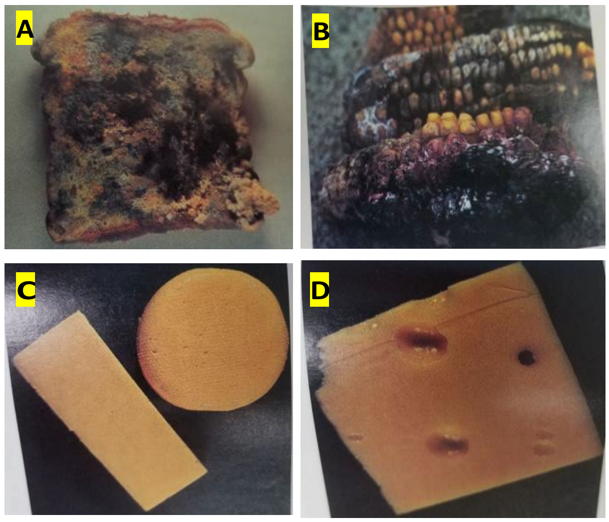

Figure 1. Rotting versus fermentation. Panels A & B – Rotting; Panels C & D – Fermentation.

Fermentation is not rotting: It is important to distinguish between fermentation and rotting (Fig. 1). While both involve biochemical reactions driven by microorganisms, they differ significantly in outcome and process control. In both cases, biological agents (microorganisms) induce chemical changes—for example, converting sugars into acids or alcohols. However, rotting is characterized by *uncontrolled* microbial activity, which leads to the formation of undesirable compounds, off-flavors, unpleasant odors, and spoilage.

In contrast, fermentation is a *controlled* biochemical process. Even when it involves complex microbial communities, conditions such as temperature, pH, and oxygen availability are carefully managed to promote the production of desirable compounds in the right proportions. This results in appealing taste, aroma, and texture. Common control measures include temperature regulation and the exclusion of oxygen (in anaerobic fermentations), both of which help steer the process toward favorable outcomes.

Fermentation modifies food materials: One of the primary goals of fermentation is to transform raw materials into products with extended shelf life, improved digestibility, desirable flavors, or specific health benefits. In achieving this, fermentation alters key properties of food, including its texture, color, aroma, and flavor (Fig. 2). For example, when liquid milk is converted into cheese, its water activity is significantly reduced. This decrease in available moisture limits microbial growth, thereby slowing spoilage and enhancing preservation.

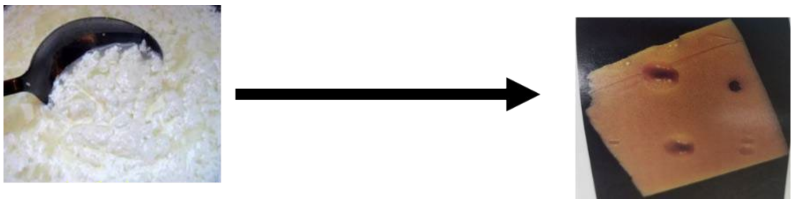

Figure 2. Fermentation modifies the color, texture and flavors of the original food raw material.

The benefits of fermentation: One could argue that advances in modern food processing have reduced the necessity of fermentation. However, fermentation has remained popular—largely due to its numerous benefits, including:

- Preservation
- Health and nutritional benefits
- Energy efficiency
- Flavor enhancement

<u>Preservation</u>

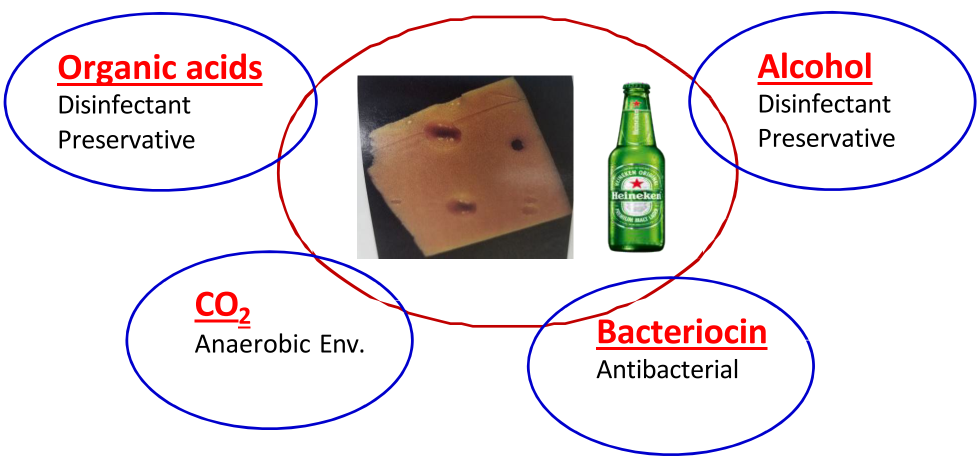

Figure 3: The compounds produced during fermentation and the nature of anaerobic fermentation enhance food preservation.

Organic acids and alcohols are naturally inhibitory to microorganisms, which are the primary agents of food spoilage. By suppressing microbial growth, these compounds help extend the shelf life of fermented foods and beverages (**Fig. 3**). Most fermentation processes occur under anaerobic conditions, where the absence of oxygen inhibits the growth of aerobic spoilage organisms, such as fungi, which are major food spoilage organisms. Additionally, some fermentative bacteria produce antimicrobial peptides—such as bacteriocins—which further enhance the preservative qualities of fermented products (**Fig. 3**).

Health and nutritional benefits

Fermentation enhances nutrient bioavailability by breaking down complex molecules into simpler, more easily absorbed compounds. It also releases bound minerals from complex food matrices, making them more accessible for assimilation. For example, hard-to-digest proteins in soy are degraded into amino acids during fermentation, facilitating uptake. In fermented dairy products, fermentation significantly reduces the risk of lactose intolerance, as lactose is converted into lactate—making these products easier to digest for individuals with lactose sensitivity. In fermented meats, enzymes tenderize the meat, improving digestibility. Additionally, certain phenolic compounds released during wine fermentation have been associated with improved heart health and a reduced risk of cancer.

Energy Efficiency

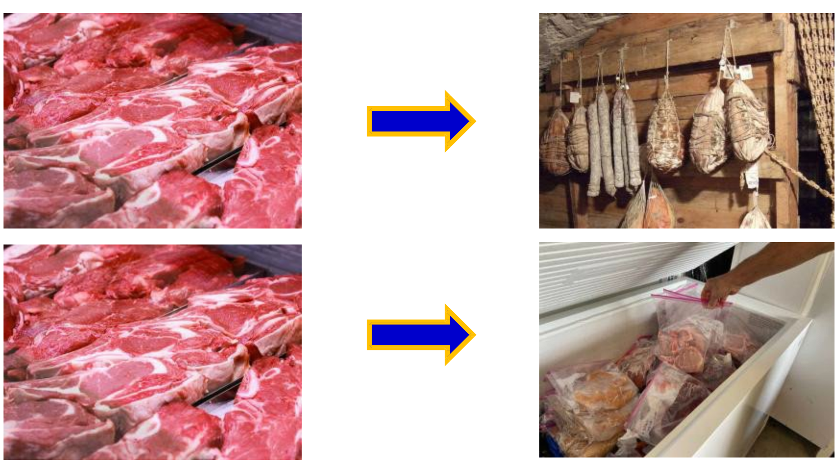

Figure 4. Meat fermentation produces a dryer product with reduced water activity without the need for energy-intensive refrigeration.

Types of Fermented Products

- **Food**
  - Substantial source of nutrients and calories (kimchi, sauerkraut)
- **Beverage**
  - Some nutrients, but often hedonic
  - Cultural and social standing (wine, beer, whiskey)
- **Condiment/ingredient**
  - Fish sauce, soy sauce, vinegars
- **Flavor**
  - Coffee and chocolate
- **Food ingredients and food production (Food Biotechnology)**
  - Citric acid, enzymes

Four Key Elements of Fermented Products

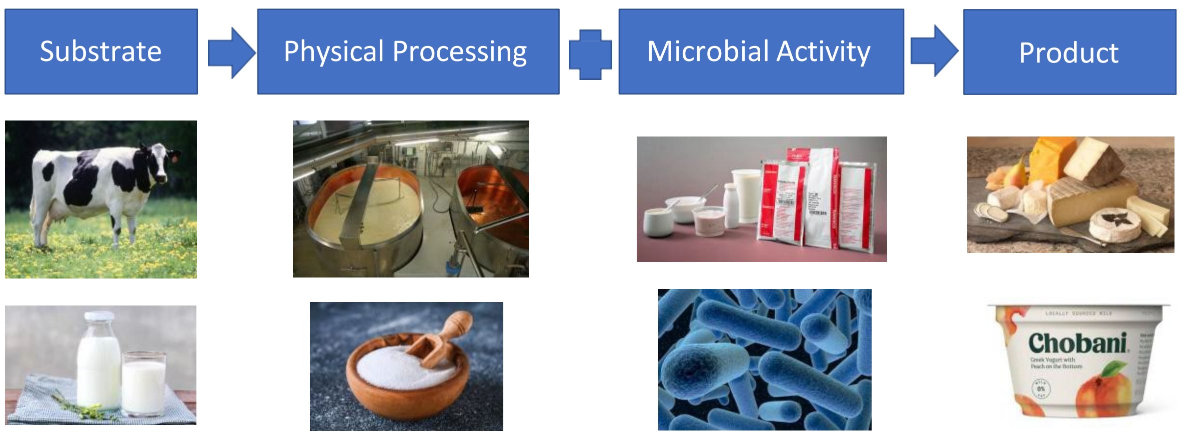

Figure 5. The key elements of fermentation.

Substrate: That which is fermented. The source of carbohydrates during fermentation.

Physical Processing: Some food materials may need to be processed before fermentation. Cabbage is shopped in the case of sauerkraut, while milk is cuddled by the addition of salt in cheese fermentation.

Microbial Activity: The biochemical activities of microorganisms during fermentation bring about the desirable changes.

Product: The resulting product after fermentation.

Tools for managing fermentation:

- Temperature
- Oxygen supply
- Carbon and Nitrogen (Substrate concentrations)
- pH

- Salt concentration
- Sterilization (pasteurization)

Types of Fermentation

- **Wild or Indigenous fermentation**
  - Relies on naturally occurring microbes
  - Manipulates the environment to favor desired microorganisms
    - *Examples*: Vegetable Fermentations, Kombucha, and Sourdough Bread

- **Controlled fermentation**
  - Uses carefully selected microorganisms
  - Indigenous microbes are either limited or eliminated
    - *Examples*: Dairy, Beer and Wine

Examples of fermented foods and beverages and the microorganisms involved

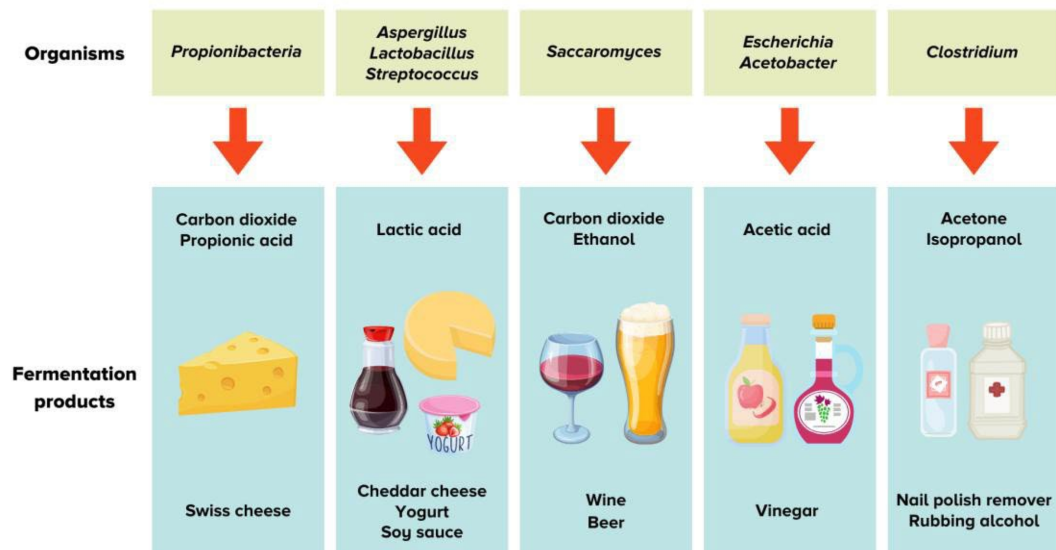

Figure 6. Different fermented foods and beverages and the associated microorganisms.

Microorganisms involved in Fermentation

Bacteria: Different bacteria are involved in fermentation. The most predominant bacteria are lactic acid bacteria (LAB) involved in dairy and vegetable fermentations.

Yeasts: These are single-celled fungi that take part in numerous alcoholic fermentation. The most popular yeast is *Saccharomyces cerevisiae*.

Fungi: These are filamentous multicellular fungi. *Aspergillus* species are examples of fungi that take part in fermentation, mainly in soy sauce and cheese fermentations.

<u>Activity</u>:
These steps can be carried out by the teacher prior to the start of class. Alternatively, the teacher can conduct these demonstrative steps in a dedicated session a week before class. Yogurt is a good source of lactic acid bacteria. The resulting curdled milk will be used in class.

- In clean containers, add 50 ml of milk and then inoculate with a culture of lactic acid bacteria (LAB). A teaspoonful of commercially acquired yoghurt is a rich source of LAB.
- Incubate at 35-37 °C for 3 – 4 hours. Where a dedicated incubator is not available, incubate for a longer period (10 – 12 h) at room temperature.
- As a control, add a teaspoonful of distilled water to 50 ml of fresh milk.
- Incubate both the test and control containers accordingly (under the same conditions).
- After incubation, observe milk curdling due to lactic acid production.
- Use litmus paper to assess the acidity of the fermented milk relative to unfermented milk. Acids turn blue litmus paper red. Lactic acid is produced during milk fermentation. Dip a blue litmus paper into each container for 10 - 20 seconds and observe color change afterwards. Compare the test and control containers and explain the differences in color changes. Include fresh milk during the litmus paper test as naturally occurring LAB in milk may still led to fermentation in some unrefrigerated milk samples even without yoghurt inoculation.

Assessing understanding:
Evaluate students' understanding of the topic and materials

- Which acid is produced during yogurt and cheese fermentation?
- What type of bacteria are involved in yogurt and cheese fermentations
- What other types of microorganisms are involved in fermentation?
- How does the acid produced during yogurt and cheese fermentations interact with milk proteins?
- What sugar is present in milk and how is it converted to acid during dairy fermentation?
- What role does fermentation play in bread making?

<u>Helpful Resources</u>

https://www.youtube.com/watch?v=bWxPpK7t5lE
https://www.youtube.com/watch?v=XREALVgxBEI
https://www.youtube.com/watch?v=YbdkbCU20_M
https://www.pubs.ext.vt.edu/FST/fst-435/fst-435.html
https://ncceh.ca/resources/blog/fermented-foods-safety-guidance-new-resource-public-health-practitioners
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https://eatcultured.com/blogs/our-awesome-blog/fermentation-the-basics