Chapter 03: Introduction to Food Processing and Production Technologies

1. Food Technology

Food technology is a discipline that applies food science and scientific techniques to various aspects of the food life cycle. It covers the selection, preservation, processing, packaging, distribution, and utilization of food products, with the goal of ensuring a healthy, balanced diet of high nutritional and organoleptic quality.

Scientists and technicians in the food sector analyze food composition from different perspectives: physical, microbiological, and chemical. Depending on their specialization, they develop suitable methods for processing, preservation, packaging, and storage of food products. These efforts must comply with the requirements of the food industry, governmental regulations, and current food safety standards.

The history of food technology dates back several centuries. A major breakthrough occurred in 1810 with the invention of the canning process by Nicolas Appert. This method, which preserves food by sealing it in airtight containers, marked a turning point in food preservation techniques. However, Appert did not yet understand the scientific principles underlying his invention.

The research of Louis Pasteur also played a crucial role in the evolution of this discipline. In 1864, he studied wine spoilage and proposed solutions to prevent it. His work later extended to the production of alcohol, vinegar, wine, and beer, as well as milk acidification. He developed the pasteurization process, which involves heating milk and other food products to eliminate pathogenic microorganisms and extend their shelf life. Thanks to his discoveries, Pasteur became a pioneer in bacteriology and preventive medicine.

Finally, agri-food technologies encompass all operations applied to agricultural products after harvest to obtain processed foods. These technologies help improve the quality, safety, and availability of food products.

2. Characteristics of Agricultural Raw Materials

Agricultural raw materials are distinguished by three main characteristics: their complexity, instability, and variability. These properties are linked to their biological origin and influence their processing and preservation.

The raw materials used in the food industry primarily come from agriculture, including plant and animal production. Other sources exist, such as fishing and marine resources (algae, sea salt), the subsoil (mineral water, rock salt), and the chemical industry, which provides certain essential additives in limited but strategically important quantities.

2.1. Complexity of Agricultural Raw Materials

The complexity of agricultural raw materials lies in their multi-scale structure and biochemical diversity. It is important to differentiate complexity from mere complication. A complicated product can be analyzed by breaking it down into simple elements, whereas a complex system is characterized by interactions between its components. These interactions generate emergent properties that cannot be understood solely by studying the individual parts.

In the food sector, this complexity is essential for understanding the behavior of food products and adapting technological processes according to their physicochemical and biological properties.

2.2. Instability of Agricultural Raw Materials

The instability of agricultural raw materials stems from their biochemical composition and the presence of living cells, particularly microorganisms. All agricultural products consist of tissues or organs whose state evolves after harvesting or slaughter.

For example, milk contains some somatic cells from mammary tissue, while meat enters a post-mortem state after slaughter, undergoing enzymatic modifications and progressive degradation of its cellular structure. Similarly, fresh fruits and vegetables remain biologically active after harvest, continuing to respire and ripen. Seeds and grains are in a dormant state but can be reactivated under certain conditions.

This instability represents a major challenge for the food industry, which must develop effective processes to stabilize these raw materials and extend their shelf life without compromising their nutritional and organoleptic qualities.

3. Food Processing Methods

Food processing relies on a set of methods that convert agricultural raw materials into finished products suitable for consumption. These methods can be physical, chemical, or biochemical, each playing a key role in modifying food properties to improve preservation, texture, taste, or nutritional value.

3.1. Production System

The food production system is based on a series of operations that transform raw materials into finished products through specific processes. Each transformation follows a logical sequence of steps, where raw materials undergo controlled modifications to obtain a final product that meets quality and food safety standards.

3.2. Mechanism-Based Approach

Food processing methods can be classified according to the primary mechanism governing them:

- **Physical processes**, which use temperature, mechanical forces, or irradiation to alter the structure or preservation of food. These include thermal treatments, membrane techniques, extrusion cooking, and grinding.
- **Biotechnological processes** (or white biotechnologies), which rely on microorganisms or enzymes to transform food, such as in lactic or alcoholic fermentations.
- **Chemical processes**, which, although less common in the food industry, are used in certain cases to modify or extract specific food components.

These operations are analyzed considering mass, heat, and momentum transfer, which are fundamental elements of chemical engineering. However, the diversity and complexity of raw materials require a complementary approach that combines food science with process technologies.

3.3. Traditional Processing Methods

For centuries, traditional methods have been developed for food preservation and processing. These include sun drying, salting, smoking, brining, and ethanol and lactic fermentations. These techniques not only extend the shelf life of food but also enhance its taste and nutritional qualities. A key principle of these methods is limiting factors that promote the growth of undesirable microorganisms, particularly by reducing available moisture, modifying acidity, or controlling oxygen access.

4. Principles of the Food Industry

The food industry is based on four fundamental principles:

1. **Food transformation** through cooking, fermentation, or other technological processes.
2. **Extraction and purification** of certain components from agricultural products, as seen in sugar production, oil mills, or flour milling.
3. **Ingredient mixing** to achieve specific textures and flavors, as in biscuit-making or charcuterie.
4. **Food stabilization** to extend shelf life using processes such as drying, thermal or refrigeration treatments, and the addition of natural preservatives.

These principles ensure safe, efficient, and consumer-adapted food production.

5. Different Food Processing Treatments

5.1. Treatment to Enhance Beneficial Microorganisms

For millennia, beneficial microorganisms have been used in food processing. Lactic acid bacteria, yeasts, and molds play a crucial role in the production of fermented foods such as bread, yogurt, cheese, beer, and wine. In addition to improving preservation and taste, these microorganisms inhibit the growth of pathogenic germs. However, some beneficial strains can be vulnerable to viral infections, leading to production losses. Current research focuses on developing virus-resistant strains and using natural antimicrobial substances, such as bacteriocins, to improve food safety.

5.2. Treatment to Enhance Taste

While food safety is a critical requirement, consumers are increasingly concerned with the sensory qualities of food. The food industry continuously seeks to improve the texture, aroma, and flavor of processed products. Advanced technologies optimize particle size to influence mouthfeel, as seen in fat substitutes and powdered foods. Similarly, plant varieties are selected or modified to increase their sugar content and enhance their taste.

In the meat sector, research is being conducted to preserve the flavor and tenderness of meat while reducing its fat content. The goal is to provide consumers with tasty foods that meet modern nutritional requirements.

5.3. Preservation Treatments

Food preservation relies on a set of techniques aimed at extending shelf life while maintaining nutritional and organoleptic qualities. These techniques slow down or even prevent the proliferation of microorganisms and enzymatic reactions responsible for food spoilage. Among the most commonly used methods are thermal treatments, cooling, drying, and the addition of food additives. Whether traditional or modern, these processes are essential for food safety and ensuring the long-term availability of food products.

a. Traditional Treatments

Heating
Heating is one of the oldest methods of food preservation. It involves raising the temperature to inhibit bacterial growth, deactivate certain enzymes, and, in some cases, completely eliminate pathogenic microorganisms. Different methods exist depending on the degree and duration of heat application. Classic techniques include moist cooking methods, such as blanching, boiling, steaming, and pressure cooking, as well as dry cooking methods like baking, frying, and roasting. These processes modify food structure and improve digestibility, but they may also lead to nutrient losses, particularly for heat-sensitive vitamins.

Technological advances have led to more efficient and faster heating techniques, such as microwave heating, which applies heat through electromagnetic radiation. Similarly, Ultra-High Temperature (UHT) treatments are widely used in the food industry, particularly for sterilizing milk and juices. This process involves heating food to 135°C or more for a few seconds, then rapidly cooling it. This method ensures the total elimination of microorganisms, thereby extending product shelf life while preserving organoleptic properties.

Another commonly used thermal treatment is **pasteurization**, which involves heating food to a temperature below 100°C (typically 72°C for 15 seconds) before quickly cooling it to about 5°C. Unlike UHT sterilization, pasteurization does not destroy all microorganisms but reduces their count sufficiently to ensure food safety and extend product shelf life. It is widely used for milk, fruit juices, liquid eggs, and some meat products.

Cooling
Cooling is an essential food preservation method that slows down deterioration by limiting bacterial growth and enzymatic activity. It primarily includes refrigeration and freezing, which differ in their respective temperatures. Refrigeration, typically around 5°C, extends the shelf life of perishable foods such as fruits, vegetables, meat, and dairy products by delaying microbial growth. However, it does not completely stop enzymatic and bacterial activity, which limits storage duration.

Freezing, on the other hand, allows for much longer preservation by lowering the temperature below -18°C, or even -196°C for certain industrial processes. At these temperatures, the water in food freezes, almost completely inhibiting enzymatic and microbial activity. However, freezing can alter texture, mainly due to the formation of ice crystals that damage food cell structures. Additionally, prolonged temperature fluctuations can reduce the nutritional quality of products, leading to vitamin loss and protein and lipid degradation.

Drying

Drying is one of the oldest food preservation methods. It involves reducing the water content to a level that prevents the growth of microorganisms and enzymatic activity responsible for spoilage. Various techniques are used depending on the type of food and the desired level of dehydration.

Freeze-drying (lyophilization) is an advanced method that freezes food before subjecting it to sublimation under vacuum, thereby preserving its nutritional qualities and texture. It is often used for aromatic herbs, instant coffee, and certain fruits.

Spray drying is another industrial technique used to produce food powders, such as powdered milk. It involves spraying a liquid into a hot air stream, causing rapid water evaporation.

Additionally, more traditional methods, such as **sun drying or tunnel drying**, are still widely used for fruits and vegetables, including tomatoes, apricots, and mushrooms. These techniques are simple and cost-effective but require suitable climatic conditions and strict monitoring to prevent mold growth or other contaminants.

Food Additives

The addition of preservative substances is an ancient preservation method that relies on reducing water activity and modifying the pH of food. The use of salt and sugar, for example, has been practiced for centuries to extend the shelf life of meats, fish, and fruits. Salting and sugaring inhibit the growth of microorganisms by reducing the availability of free water necessary for their development. Similarly, acidifying food by adding vinegar or other food acids is an effective technique to prevent bacterial proliferation.

With the development of the food industry, the use of additives has significantly increased. Today, these substances can be natural, nature-identical, or artificial. Their use is strictly regulated by regulatory bodies to ensure consumer safety. Each additive must be authorized and listed on food packaging. In Europe, these substances are designated by a code preceded by the letter “E,” such as **E330** for citric acid, a natural preservative found in citrus fruits. This compound was first isolated in 1784 by Swedish chemist **Carl Wilhelm Scheele**, who succeeded in crystallizing it from lemon juice.

Food additives are not limited to preservatives. There are also antioxidants, emulsifiers, stabilizers, and colorants, which help improve the stability, appearance, and texture of processed foods. However, their use remains a topic of debate, as some consumers prefer to avoid artificial additives in favor of more natural and less processed foods.

b) New Technologies

Some traditional preservation methods, while effective, can lead to nutritional losses and alter the texture or flavor of foods. To address these challenges, new technologies known as

“minimal processing” treatments have been developed. These aim to **maximize** the nutritional and sensory quality of foods while ensuring their microbiological safety.

Microwave Processing

Microwave heating is based on the emission of **electromagnetic radiation**, which acts on the water molecules in food, causing them to oscillate and generate heat. Unlike conventional heating methods that rely on conduction or convection, microwaves allow for **rapid and uniform heating**, although some areas of the food may be less exposed if not stirred regularly. One of the main advantages of this method is the **limited nutrient loss**, particularly of **water-soluble vitamins**, which often degrade during prolonged boiling or water-based cooking.

Modified Atmosphere Packaging (MAP)

Modified atmosphere packaging consists of **packing food in a controlled gaseous environment** to slow its deterioration. Typically, the gases used include **oxygen, carbon dioxide, and nitrogen**. Depending on the nature of the product, the gas mixture can be adjusted to inhibit microbial growth.

Non-respiring products, such as **meat and cheese**, require **hermetically sealed packaging** with low gas-permeability films, whereas **fruits and vegetables**, which release carbon dioxide over time, need **packaging with adjustable permeability** to maintain the internal gas balance. A recent advancement in this technology is **active packaging**, where the gaseous environment evolves based on the product’s needs, further enhancing preservation efficiency.

Irradiation

Food irradiation is a technology that increases the shelf life of food by **destroying pathogenic microorganisms**, **inhibiting tuber sprouting**, and **delaying fruit ripening**. Unlike thermal processes, irradiation does not significantly affect the **nutritional quality** of food, as it does not heat it.

However, this method is **strictly regulated**. In Europe, its use is permitted only if it meets specific criteria: **a proven technological need, no health risks, a benefit to consumers, and no substitution for proper hygiene practices**. Additionally, **labeling irradiated products is mandatory** to inform consumers.

Ohmic Heating

This thermal treatment generates heat **internally** by alternating electric currents passing through the food, which acts as an **electrical resistor**. This process is also known as **"resistance heating"** or **"direct resistance heating"**.

Unlike conventional heating methods that rely on energy transfer through water molecules, **ohmic heating** is particularly effective for **low-water-content foods**. It is a **high-temperature, short-time (HTST) method**, which reduces the risk of **overprocessing** and associated **nutrient loss**. Another advantage is that **it preserves the delicate structure of certain foods**, such as strawberries.

Ultra-High Pressure Processing (HPP)

High-pressure technology exposes food to pressures ranging from **100 to 1,000 MPa**, typically for **5 to 20 minutes**. This process **inactivates microorganisms**, **modifies biopolymers**, and **preserves attributes such as color, flavor, and nutrients**.

This method **acts directly on non-covalent bonds** without the need for heat, allowing for the **preservation of vitamins, pigments, and flavor compounds** while simultaneously inactivating **microorganisms** or **enzymes responsible for food spoilage**.

Pulsed Light Technology

This method uses **intermittent bursts of white light** (**20% UV, 50% visible, and 30% infrared**) with an intensity equivalent to **20,000 times the sunlight on Earth's surface**. Applied to **meat, fish, and bakery products**, pulsed light significantly reduces the **microbial load on surfaces**.

This technique is also **effective for decontaminating packaging materials**, particularly on **smooth and dust-free surfaces**.

Pulsed Electric Fields (PEF)

This process applies **short, repeated pulses of high-voltage electric fields** (**10 to 50 kV/cm**) to a **pumped fluid** circulating between two electrodes. Unlike thermal treatments, **PEF does not heat the product**, but instead inactivates **microorganisms by disrupting their cell membranes**.

This technology is primarily used for **refrigerated or ambient-temperature products** and offers **nutritional benefits** by preserving **heat-sensitive nutrients**.

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