AFP – 6: Principles of Food Preservation (2+1) Hours=40

Objectives

1. To acquire the knowledge about different food preservation techniques.

2. To gain the practical knowledge about food preservation.

UNIT-I (13 hours)

Sources, types and perishability of foods; Causes and types of food spoilage; Scope and benefit of food preservation; Methods of food preservation; Preservation by salt and sugar: Principle, method and effect on food quality. Preservation by heat treatment: Principle and equipment for blanching, canning, pasteurization, sterilization; Preservation by use of low temperature: Principle, methods, equipment; Preservation by drying, dehydration, Rehydration and concentration: preservation by chemical and natural preservatives.

UNIT- II (13hours)

Principle, methods, equipment; Preservation by irradiation: Principle, methods, equipment; Preservation by fermentation: Principles, methods, equipment; non-thermal preservation processes: Principles, equipment – Pulsed electric field and pulsed intense light, ultrasound, sonication, dielectric heating, ohmic and infrared heating, high-pressure processing, microwave processing; Quality tests and shelf life of preserved foods. Hurdle Technology

Practicals

- Blanching of selected food items.
- Preservation of food by heat treatment- pasteurization
- Preservation of food by high concentration of sugar
- Preservation of food by using salt.
- Preservation of food by using acidulants i.e. pickling by acid, vinegar or acetic acid;
- Preservation of food by using chemical preservatives;
- Drying of fruit slices pineapple slices, apple slices in drier
- Demonstration of preserving foods under cold temperature & freezing process;
- Processing of foods using fermentation technique, i.e. preparation of sauerkraut;

Course Outcome:

On completion of this course students will able to,

1. Students will learn about different aspects of food preservation.

2. Students will gain the practical knowledge &application, demonstration capacity of food

Preservation.

Reference:

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➢ Sources, types, and perishability of foods

Sources, types, and perishability of foods can vary widely depending on various factors such as their origin, processing, packaging, and storage conditions.

Sources: Foods come from different sources such as

- ✓ plants,
- ✓ animals,
- ✓ fungi, and
- ✓ microorganisms.

Examples of Plant-based foods include fruits, vegetables, grains, legumes, and nuts. Animal-based foods include meat, poultry, fish, eggs, and dairy products. Foods such as bread, beer, and cheese are produced through the fermentation of fungi or bacteria.

Types:

Foods can be categorized based on their **Nutritional content**, such as

- ✓ carbohydrates,
- ✓ proteins,
- ✓ fats,
- ✓ vitamins, and minerals.

They can also be classified based on **their composition**, such as

- ✓ fruits,
- ✓ vegetables,
- ✓ cereals,
- ✓ dairy products, and
- ✓ meat.

Foods can also be classified based on their **level of processing**, such as

- ✓ raw,
- ✓ minimally processed,
- ✓ processed, and
- ✓ ultra-processed foods.

Perishability:

Foods have varying degrees of perishability, which determines how quickly they spoil and become unsafe or unfit for consumption.

Perishability can be influenced by various factors such as the

- ✓ type of food,
- ✓ its water content,
- ✓ storage conditions, and
- ✓ presence of microorganisms.

1. **Perishable foods** such as fresh fruits, vegetables, and meats have a shorter shelf life and require refrigeration or freezing to extend their shelf life.
2. **Semi-perishable foods** such as bread, pasta, and cheese have a longer shelf life but can still spoil if not stored properly.
3. **Non-perishable foods** such as canned and dried foods have a longer shelf life and can be stored at room temperature for an extended period.

In general, it's important to understand the sources, types, and perishability of foods to ensure that they are handled and stored correctly to maintain their quality, safety, and nutritional value.

- **Food preservation** is the practice of extending the shelf life of food while maintaining its safety, nutrition, and quality. Food preservation techniques have been used for centuries to prevent spoilage, reduce food waste, and make food available year-round.

Food preservation methods can be categorized into four main groups:

1. physical methods,
2. chemical methods,
3. biological methods, and
4. hybrid methods that combine multiple techniques.

Physical methods include techniques such as

- ✓ **Heat processing,** Heat processing involves the application of heat to foods to destroy microorganisms, enzymes, and other spoilage agents.
- ✓ Refrigeration freezing, Refrigeration and freezing use low temperatures to inhibit the growth of microorganisms and enzymes, thereby slowing down spoilage.,

- ✓ Dehydration, Dehydration involves the removal of water from foods to prevent the growth of microorganisms and enzymes,
- ✓ Irradiation. while irradiation uses ionizing radiation to kill microorganisms.

Chemical methods include the use of

- ✓ Chemical preservatives such as salt, vinegar, and sugar to prevent microbial growth and spoilage.

Biological methods involve the use of

- ✓ Microorganisms such as yeast and bacteria to produce acid, alcohol, and other compounds that inhibit the growth of spoilage microorganisms. Hybrid methods use a combination of physical, chemical, and biological techniques to achieve preservation.

Factors that affect food preservation

- ✓ pH,
- ✓ water activity,
- ✓ temperature, and
- ✓ packaging.

For example, high-acid foods have a lower risk of spoilage than low-acid foods, While the use of oxygen-free packaging can extend the shelf life of some foods.

Food preservation is an important practice for reducing food waste and ensuring food security. By extending the shelf life of food, we can reduce the amount of food that goes to waste, and ensure that food is available year-round, regardless of seasonal variations.

Three main principles of food preservation

1. **Prevention or delay of microbial decomposition:**

   This principle involves preventing or delaying the growth and activity of microorganisms that can cause spoilage and foodborne illness. This can be achieved through various techniques such as controlling the pH of the food, using chemical preservatives, or reducing the water activity of the food. By preventing or delaying microbial decomposition, the shelf life of the food can be extended and the risk of foodborne illness can be reduced.

2. **Prevention or delay of self-decomposition:**

   This principle involves preventing or delaying the natural deterioration and degradation of food due to enzymatic and chemical reactions. This can be achieved through various methods such as refrigeration or freezing, dehydration, or using enzymes that are specific to the desired product. By preventing or delaying self-decomposition, the quality and nutritional value of the food can be preserved, and the shelf life of the food can be extended.

3. **Prevention of damage caused by insect, animal, or mechanical causes**:

   This principle involves preventing or reducing the physical damage to food caused by insects, animals, and mechanical causes. This can be achieved through various methods such as packaging, storing food in a secure location, or using physical barriers such as nets or fences. By preventing physical damage, the food can be protected from contamination and spoilage, and the shelf life of the food can be extended.

Overall, these principles of food preservation are essential for preventing food spoilage, reducing food waste, and ensuring that food is safe, nutritious, and of high quality.

➢ Causes of food spoilage:

1. Microbial spoilage:

   Microorganisms like bacteria, yeast, and molds are the most common cause of food spoilage. They can contaminate food during processing, storage, or handling. Factors that can contribute to microbial growth include warm temperatures, high humidity, low acidity, and high-water activity. When these conditions are met, microorganisms can multiply rapidly and produce enzymes and other by-products that change the food's characteristics.

2. Enzymatic spoilage:

   Enzymatic spoilage occurs when enzymes naturally present in the food break down its molecules, causing it to ripen, soften, and decay. Enzymatic reactions are usually slow, but they can be accelerated by environmental factors such as temperature, moisture, and pH.

   For example, the enzyme amylase in potatoes can convert starch into sugar, causing them to become sweeter over time.

3. Chemical spoilage:

   Chemical spoilage is caused by chemical reactions that occur in the food. These reactions can be triggered by environmental factors such as oxygen, light, heat, or metals.

   For example, the oxidation of fats and oils in food can cause rancidity and off-flavors.

   Exposure to light can cause color changes and nutrient loss in food. Exposure to heat can cause protein denaturation and texture changes in food.

4. Physical spoilage:

   Physical spoilage is caused by physical damage to the food. This can be due to improper handling, processing, or storage. For example, bruising, crushing, or cutting fruits and vegetables can cause them to spoil faster. Physical damage can also create entry points for microorganisms to enter and spoil the food.

   Similarly, improper storage conditions, such as exposure to air or moisture, can cause physical spoilage of food.

5. Other types of spoilage:

   Other types of spoilage can be caused by factors such as radiation, insects, and rodents.

Radiation can cause chemical changes in the food that lead to spoilage.

Insects and rodents can contaminate food and cause physical damage that leads to spoilage.

For example, insect infestations can cause mold growth and off-flavors in stored grains

- **The scope and benefits of food preservation are wide-ranging and include:**

1. Extended shelf life:

   Food preservation methods can significantly extend the shelf life of perishable foods, allowing them to be stored for longer periods without spoiling.

   This can reduce food waste and ensure a more stable food supply chain.

2. Improved food safety:

   Proper food preservation methods can reduce the growth of harmful microorganisms in food, reducing the risk of foodborne illness and improving food safety.

3. Increased access to nutritious foods:

   Food preservation methods can make fresh foods available year-round, providing greater access to nutritious foods that might not be available locally or seasonally.

4. Enabling year-round availability:

   Food preservation methods can also help to enable year-round availability of certain foods that are seasonal or perishable.

   For example, canning and freezing can allow fruits and vegetables to be preserved for consumption during off-seasons.

5. Cost savings:

   Food preservation methods can help reduce the cost of food by enabling bulk purchasing and reducing spoilage and waste.

6. Preservation of cultural foods:

   Food preservation methods can help preserve traditional or cultural foods that might otherwise be lost due to lack of availability or limited shelf life.

7. Convenience:

   Preserved foods can be more convenient to prepare and use than fresh foods, as they are often pre-prepared and ready to use.

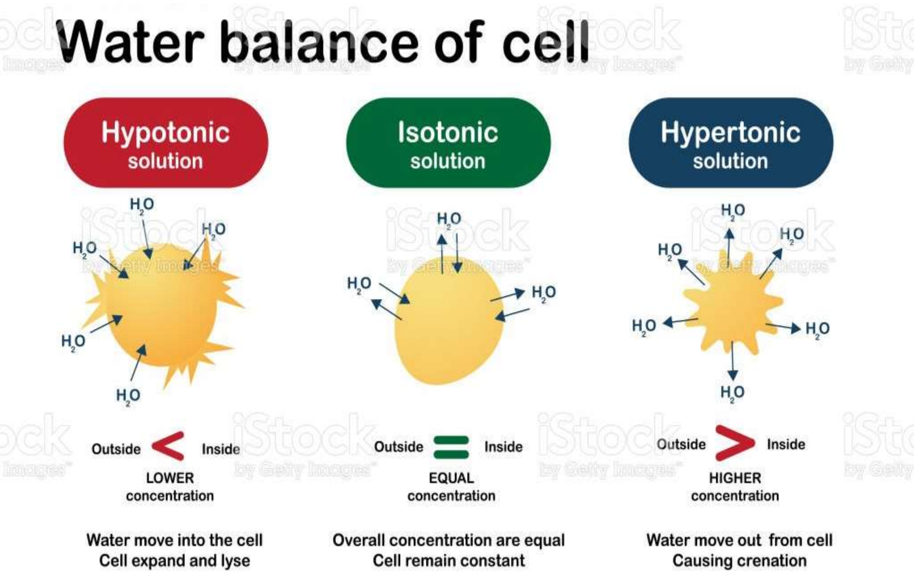
8. Value-added products:

Food preservation methods can be used to create value-added products such as pickles, jams, and dried fruits, which can have a longer shelf life and be sold at a higher price point.

➢ Methods of food preservation

1. Preservation by salt and sugar: Principle, method and effect on food quality

- Preservation by salt and sugar, also known as osmotic preservation, is a traditional method of food preservation that has been used for centuries.
- The principle behind this method is based on the fact that salt and sugar can create a hypertonic solution that causes water to move out of the microbial cells or tissues of the food being preserved, thus inhibiting the growth of bacteria, yeast, and molds that spoil food. In this way, salt and sugar act as natural preservatives that extend the shelf life of food.



The method of preservation by salt and sugar typically involves soaking the food in a solution of salt or sugar, or a combination of both. The concentration of the solution varies depending on the type of food being preserved and the desired level of preservation.

For example, pickling cucumbers in a salt 3solution requires a higher concentration of salt than preserving fruit in a sugar syrup.

The preservation effect of salt and sugar on food quality,

The preservation effect of salt and sugar on food quality can vary depending on several factors, including the

- ✓ concentration of the solution,
- ✓ the type of food being preserved, and
- ✓ the length of preservation.

- When used in the correct concentration, salt and sugar can help to preserve the natural color, flavor, and texture of the food, resulting in a high-quality product.

  However, if the concentration is too high or the preservation time is too long, it can lead to changes in the texture, flavor, and color of the food, which can affect its quality.

  One of the key benefits of using salt and sugar for preservation is that they can help to retain the natural flavor of the food.

  Salt, for example, is often used to preserve meat and fish because it helps to enhance the natural flavor of these foods.

  Sugar is commonly used to preserve fruits and vegetables because it can help to retain their natural sweetness and flavor.

- The preservation effect of salt and sugar on food texture can also vary depending on the concentration of the solution.

  When used in the correct concentration, salt and sugar can help to preserve the natural texture of the food, resulting in a product that is still firm and crisp.

  However, if the concentration is too high, it can lead to changes in the texture of the food.

  For example, high salt concentrations can cause meat to become tough and dry, while high sugar concentrations can cause fruits and vegetables to become mushy and lose their shape.

- The preservation effect of salt and sugar on food color is also important.
  When used in the correct concentration, salt and sugar can help to preserve the natural color of the food, resulting in a product that is visually appealing.
  However, if the concentration is too high, it can cause discoloration of the food, resulting in a product that is unappealing and unappetizing.

Overall, the preservation effect of salt and sugar on food quality is largely dependent on the concentration of the solution used, the type of food being preserved, and the length of preservation. When used in the correct concentration and for the appropriate length of time, salt and sugar can help to preserve the natural color, flavor, and texture of the food, resulting in a high-quality product.

In summary,

- Preservation by salt and sugar is a traditional method of food preservation that has been used for centuries.
- The principle behind this method is based on creating a hypertonic solution that inhibits the growth of bacteria, yeast, and molds that spoil food.
- The method involves soaking the food in a solution of salt or sugar, or a combination of both.
- The concentration of the solution used is important for preserving the natural color, flavor, and texture of the food.
- When used in combination with other preservation techniques, preservation by salt and sugar can help to extend the shelf life of food while maintaining its quality.

Preservation by heat treatment:

1. Blanching is a cooking process that involves briefly immersing food in boiling water or steam to partially cook it before freezing, canning, or further cooking. The primary purpose of blanching is to preserve the
   - ✓ color, texture, and flavor of fruits and vegetables,
   - ✓ inactivate enzymes, and
   - ✓ remove surface dirt and
   - ✓ microorganisms.

The basic principle of blanching is to apply heat to food items for a short period of time to inactivate enzymes and reduce bacterial load without cooking the food completely.

The equipment used for blanching varies depending on the type and volume of the food being processed.

Some commonly used equipment for blanching includes:

1. Blanching Pot: A large pot with a strainer basket is used for blanching vegetables in boiling water.

2. Blanching Basket: A metal basket used to immerse food items in boiling water or steam.
3. Blanching Tray: A tray used for blanching small items like berries or peas, typically used in a commercial setting.
4. Steam Blancher: A machine that uses steam to blanch food items instead of boiling water.
5. Continuous Blancher: A machine that continuously blanches food items at a high volume in a production setting.

The blanching process usually involves the following steps:

1. Preparing the food items: Clean and sort the food items to be blanched.
2. Heating the water: Boil water in a large pot or blanching machine.
3. Immersing the food: Place the food items in a blanching basket or tray and immerse them in the boiling water or steam for a specific time.
4. Cooling: Remove the food items from the hot water and immediately cool them in cold water or an ice bath to stop the cooking process.
5. Drying: Drain and dry the food items thoroughly before further processing or freezing.

Overall, blanching is a simple and effective way to preserve the quality and safety of food items.

➢ EFFECTS ON FOOD QUALITY AND BLANCHING INDICATORS

Flavor, texture, and color are quality parameters that are typically assessed for fresh products, immediately after blanching and after a given storage time.

Flavor

Blanching indirectly and directly affects the flavor of many products by inactivation of enzymes responsible for off-flavor development. The most notable is lipoxygenase (LOX) in several vegetables.

Sometimes Blanching of Foods blanching increases flavor retention, and sometimes it removes undesirable bitter flavors from the product. Headspace volatiles assayed mostly by gas chromatography have been correlated to flavor attributes defined in sensory panels.

Texture

Blanching can result in undesirable softening of vegetable tissues. However, calcium can be added to reduce the softening. A combination of low-temperature blanching and calcium addition has also been shown to be effective in firming canned vegetables.

The latter is due to the activity of pectin methyl esterase that produces pectin with a reduced degree of methylation that readily interacts wih calcium.

Texture assessment of the effects of blanching includes sensory characterization of firmness, crispness, and crunchiness, and instrumental measurements such as cutting energy and maximum shear force.

Color

Blanching can have both direct and indirect effects on color. The former is exemplified by the destruction of pigments, such as chlorophyll, by heat.

A good example of an indirect effect is in potato processing, in which the reducing sugar content can be adjusted via water blanching, affecting color development during later, more intensive heating steps where the Maillard reaction takes place. Color assessment in the food industry is commonly performed visually by comparison to standards. Instrumental methods based on reflectance (e.g., Hunter colorimeter) are also frequently used.

Nutritional Value

Generally, blanching produces a decrease in the nutritional value of foods. Nutrients leach out from the product especially during water blanching. In addition, vitamins are degraded by heat. Vitamin C (ascorbic acid) is, by far, the most commonly assayed nutrient in blanching probably because its high solubility and heat susceptibility make it a conservative indicator of nutrient retention. Vitamins B1 and B2, carotenes, and dietary fibers have also been assayed.

Quality Indicators

Peroxidase and catalase are the most commonly assayed enzymes for blanching before freezing because they are more resistant to heat than most enzymes, and there are simple rapid assays to measure their activity. However, for many vegetables such as corn, peas, and green beans, LOX, a less heat-resistant enzyme, was found to be the enzyme responsible for the development of off-flavors. Although food processors are aware of this, it is only recently that some rapid methods to measure LOX activity have been developed.

2. **Canning** is a method of preserving food by sealing it in airtight containers and heating it to a temperature that destroys bacteria and other microorganisms.

"Appertization" refers to the process of sterilizing food by heating it to a high temperature and sealing it in a container to prevent the re-entry of microorganisms. The term is named after Nicolas Appert, the French inventor who developed the first successful method of preserving food in airtight containers in the early 19th century.

Appertization is essentially the same process as canning, which is widely used today to preserve food. However, the term "appertization" is less commonly used than "canning", and is often used specifically to refer to the historical method developed by Appert using glass jars and cork stoppers.

Today, the term "appertization" is more commonly used in France to refer to the process of sterilizing food in sealed containers at high temperatures, whether in glass jars, tin cans, or other materials. The method is widely used in the food industry to produce long-lasting products such as canned vegetables, fruits, and meat products

This process helps to extend the shelf life of food, making it safe for long-term storage. Here are the principles, steps, and equipment needed for canning:

Principles:

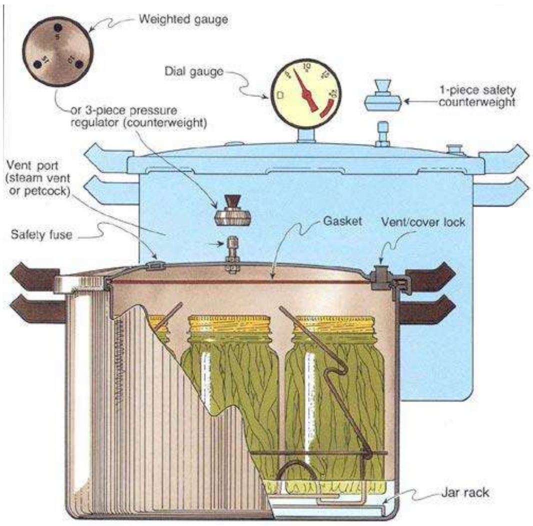
- Canning involves heating the food to a temperature that is high enough to destroy microorganisms that can cause spoilage or disease.
- The food is then packed into jars or cans that are sealed to prevent the entry of air and microorganisms.
- The sealed jars or cans are then processed in a boiling water bath or pressure canner to ensure that all microorganisms are destroyed and the food is properly preserved.

Steps:

1. Choose the food you want to can: Choose high-quality, fresh fruits or vegetables that are free of blemishes and defects. You can also can meats, fish, and poultry.
2. Prepare the food: Wash and peel fruits and vegetables, and trim any excess fat from meats. Cut the food into appropriate sizes for canning.
3. Fill the jars/can: Fill the jars with the prepared food, leaving appropriate headspace as recommended in the recipe or instructions.
4. Fill the liquid: Add the appropriate amount of liquid, such as water or syrup, to the jars to cover the food and leave the recommended headspace.
5. Exhausting (Remove air bubbles): Use a non-metallic tool, such as a plastic spatula or bubble remover, to remove any air bubbles from the jars.
6. Wipe rims: Use a clean, damp cloth to wipe the rims of the jars to remove any food residue or liquid.
7. Seal the jars/can: Place the lids and screw bands onto the jars and tighten until finger-tight.
8. Heat Processing: Place the jars in a boiling water bath or pressure canner, following the recommended processing time and pressure for the type of food being canned.
9. Cool and store: After processing, remove the jars from the canner and let them cool to room temperature. Check the seals to ensure they are tight and store the jars in a cool, dry place.

Equipment:

- Canning jars: Choose jars that are designed for canning, such as Ball or Kerr jars, and are the appropriate size for the food being canned.
- Lids and screw bands: Choose new lids and screw bands that are designed for the jars being used.
- Boiling water bath canner or pressure canner: Choose the appropriate canner for the type of food being canned. A boiling water bath canner is suitable for high-acid foods, such as fruits and tomatoes, while a pressure canner is required for low-acid foods, such as vegetables and meats.
- Jar lifter: A tool designed for safely lifting jars in and out of the canner.
- Bubble remover: A non-metallic tool for removing air bubbles from the jars.
- Funnel: A funnel designed for canning to help with filling the jars.
- Clean cloths and towels: Used for wiping rims and drying jars after processing.



- **Pasteurization** and **sterilization** are two common methods of preserving food and beverages by killing or removing harmful microorganisms that can cause spoilage or illness.

Pasteurization:

Definition: Pasteurization is a process of heating food or beverages to a specific temperature for a certain period of time to reduce the number of harmful bacteria, viruses, and other microorganisms.

Principle: The principle of pasteurization is to kill or inactivate harmful microorganisms without significantly altering the taste, texture, or nutritional value of the food or beverage.

The process was first developed by French scientist Louis Pasteur in the 1860s to prevent the spoilage of wine and beer.

The temperature and time required for pasteurization vary depending on the product and the specific microorganisms being targeted.

In general, pasteurization is done at temperatures between 60-100°C (140-212°F) for a few seconds to several minutes.

This process can be done using various methods such as

- ✓ Flash pasteurization,
- ✓ High-temperature short-time (HTST) pasteurization, and
- ✓ Ultra-high temperature (UHT) pasteurization.

Pasteurized products must be kept refrigerated to prevent further microbial growth

Methods: There are several methods of pasteurization, including:

1. High-temperature short-time (HTST) pasteurization: The food or beverage is heated to a temperature of around 72°C (161°F) for 15-30 seconds, then cooled rapidly.
2. Low-temperature long-time (LTLT) pasteurization: The food or beverage is heated to a temperature of around 63°C (145°F) for 30 minutes.
3. Ultra-high-temperature (UHT) pasteurization: The food or beverage is heated to a temperature of around 135°C (275°F) for 1-2 seconds, then rapidly cooled.

➢ Sterilization:

Definition: Sterilization is a process of completely eliminating all forms of microorganisms, including bacteria, viruses, fungi, and spores from a product or surface.

Principle: The principle of sterilization is to kill or eliminate all forms of microorganisms to prevent spoilage and contamination.

This process is more intensive than pasteurization and is typically used for medical equipment, laboratory instruments, and certain food products that require a longer shelf life, such as canned foods.

Sterilization can be achieved using various methods such as

- ✓ High-pressure steam sterilization,
- ✓ Chemical sterilization, and
- ✓ Irradiation.

The specific method used depends on

- ✓ The product,
- ✓ The type of microorganisms present, and
- ✓ The desired level of sterilization.

Sterilized products can be stored at room temperature without the risk of spoilage or contamination.

Methods: There are several methods of sterilization, including:

1. Heat sterilization: The product or surface is heated to a high temperature for a specific period of time, usually using high-pressure steam.

2. Chemical sterilization: Chemical agents such as hydrogen peroxide, ethylene oxide, or chlorine dioxide are used to kill or eliminate microorganisms.

3. Irradiation: The product or surface is exposed to ionizing radiation, such as gamma rays or electron beams, which kill or eliminate microorganisms.

In summary, pasteurization and sterilization are both methods of reducing or eliminating microorganisms to prevent spoilage and contamination of food and beverages. Pasteurization involves heating the product to a specific temperature for a certain period of time, while sterilization involves completely eliminating all forms of microorganisms using various methods.

There are several organisms and enzymes that can be used as indicators to determine whether pasteurization or sterilization processes have been effective. Here are some examples:

1. Alkaline phosphatase: This is an enzyme naturally present in milk, and its activity is destroyed during pasteurization. Therefore, the absence of alkaline phosphatase can indicate that milk has been properly pasteurized.
2. Bacillus stearothermophilus: This is a spore-forming bacteria that is commonly used as a biological indicator for sterilization processes. If this organism is absent after a sterilization process, it can indicate that the process has been effective in eliminating all microorganisms.
3. Clostridium botulinum: This is a bacteria that can produce a potent toxin that can cause botulism in humans. The spores of this bacteria are heat-resistant and can survive in improperly processed canned foods. The absence of this organism can indicate that canned foods have been properly sterilized.
4. Lactobacillus bulgaricus: This is a beneficial bacterium commonly found in yogurt. Its presence in yogurt can indicate that the product has not been pasteurized or has been only partially pasteurized.

In summary, alkaline phosphatase can be used as an indicator of effective pasteurization of milk, Bacillus stearothermophilus and Clostridium botulinum can be used as biological indicators of sterilization processes, and the presence of Lactobacillus bulgaricus in yogurt can indicate that the product has not been fully pasteurized.

➢ Preservation by low temperature

- ➢ Cold temperatures chiefly inhibit the growth of microorganisms and increase the concentration of dissolved substances thereby reducing available water to bacteria
- ➢ Retains nutritional value and their natural color, flavour, and texture
- ➢ Sub-zero levels cause metabolic injury, denaturation, and flocculation of cell proteins
- ➢ In vegetables, enzyme action may still produce undesirable effects on flavour and texture, hence they must be destroyed by heating.

Methods of Preservation by low temperature/ Methods of Freezing

1. **Refrigeration – storage at temperatures (0-5˚C or below)**
   - ➢ Temporary food preservation method that will slow down the growth of microbes
   - ➢ Causes dehydration of stored foods because of moisture condensation and the limitation is overcome by controlling humidity and selecting suitable packaging techniques

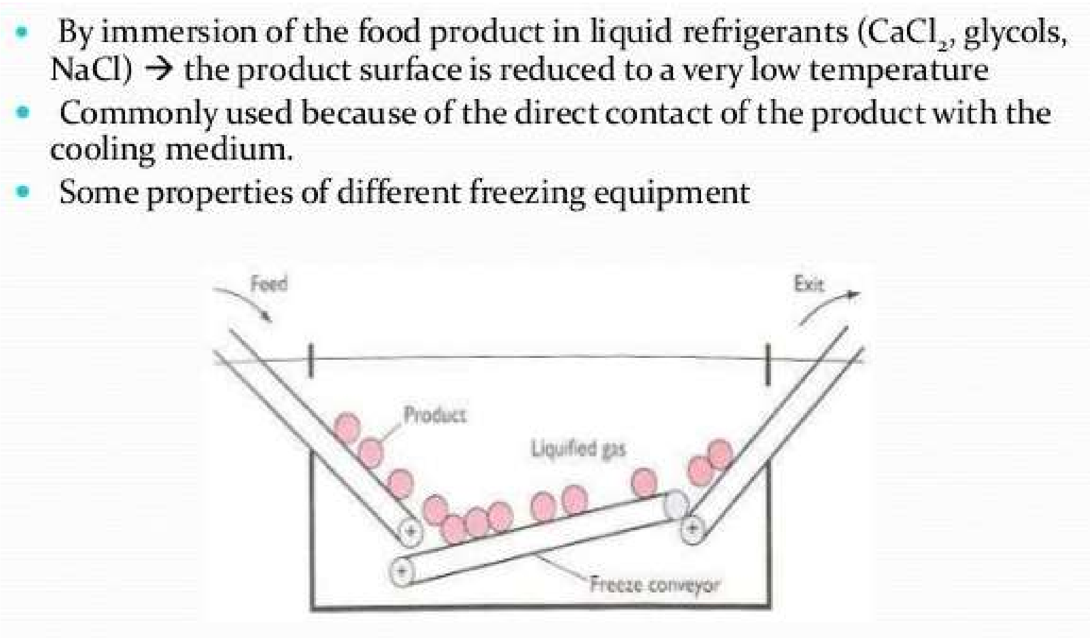

2. **Slow-freezing** process is also known as sharp freezing – Foods are placed in refrigerated temperatures (-4 to -29˚C) for 3 to 72 hrs, for fruits and vegetables (-15 to -21 ˚C)

3. **In Quick-freezing** (-32 to -40 ˚C) foods are rapidly frozen so that fine crystals are formed and fine crystals that are formed have lesser effect on breaking up plant and animal cells.

4. **Dehydro freezing** of fruits and vegetables consists of drying the food to about 50% of its original weight and volume and then freezing the food to preserve it.

- Vegetables are blanched before freezing wherein enzymes are inactivated making them more compact by removing air from the tissues thus preventing rancidity, and loss of chlorophyll and carotene from greens.

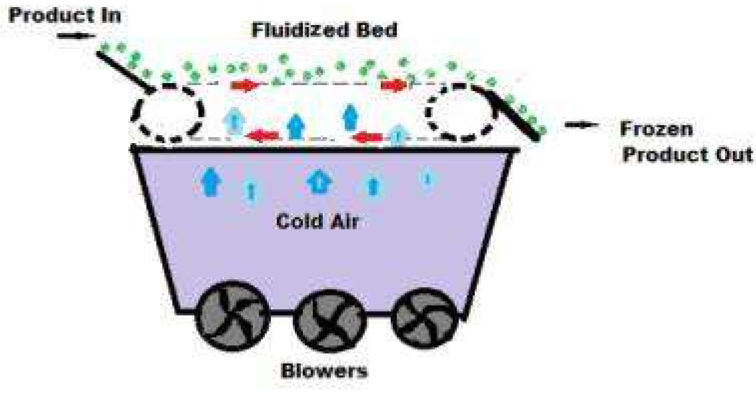
5. **Immersion freezing** – foods are immersed in solutions of salt and ice for several hours like brine, refrigerants are directly sprayed.



6. **Plate freezing** - food (ideal for large blocks of fish) is packed tight to prevent air gaps between flat, hollow refrigerated metal plates, not suitable for irregular shaped items

7. **Blast Freezing** – Food is subjected to steady stream of cold air (-40˚C or lower) in a tunnel, suitable for irregular shaped items.

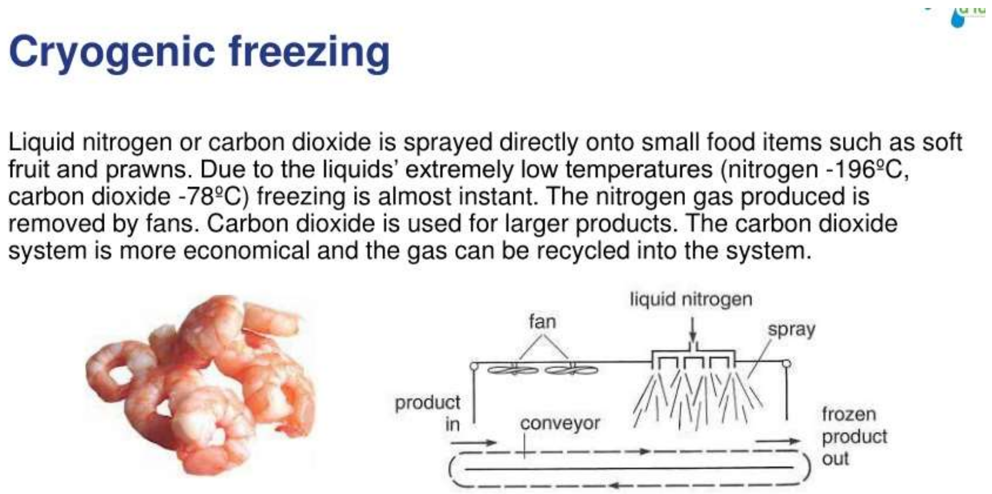
8. **Fluidized bed freezing** – vertical jets of refrigerated air are blown up through the product , used for peas, beans.



Fluidized Bed Freezer

9. **Scrapped heat exchangers – p**roducts such as ice cream are frozen reducing ice crystal formation, producing a smooth product

10. **Cryogenic freezing – liquid nitrogen (- 196˚C) or carbon dioxide(-78 ˚C) is sprayed directly on soft fruit and prawns**



Freezing of Foods

- Fruits are not blanched as it gives cooked flavour and soft texture, bananas suffer chilling injury at less than 12 ˚C
- Meat and poultry are frozen by wrapping resulting in improved tenderness
- Degree of unsaturation of fat in pork, fish, and poultry are responsible for rancidity
- As the fat of meat becomes rancid in freezer storage, the colour of myoglobin fades

Nutritive value of frozen foods

- Some loss of water soluble vitamins because of blanching and subsequent chilling
- Loss of ascorbic acid occurs during storage if the temperature is above -18˚C
- Storage temperature of -18˚C is usually recommended for frozen foods

Equipment used for low-temperature preservation:

1. Refrigerators: Refrigerators are commonly used in households and commercial settings for short-term storage of perishable food items. They operate at temperatures between 0°C and 5°C and are equipped with shelves, drawers, and door compartments for organizing and storing food. Commercial refrigerators are available in different sizes and configurations to meet the needs of various businesses such as restaurants, supermarkets, and hospitals.

2. Freezers: Freezers are used for long-term storage of frozen food items such as meats, vegetables, and fruits. They operate at temperatures below -18°C and are available in different types such as upright freezers, chest freezers, and walk-in freezers. Commercial freezers are designed for large-scale storage and are equipped with temperature controls, alarms, and backup power supplies to ensure that the stored items remain frozen.

3. Walk-in coolers and freezers: Walk-in coolers and freezers are large refrigeration units designed for storing large quantities of perishable food items. They are commonly used in commercial settings such as restaurants, supermarkets, and food processing facilities. Walk-in coolers operate at temperatures between 0°C and 5°C, while walk-in freezers operate at temperatures below -18°C. They are available in different sizes and configurations to meet the needs of various businesses.

4. Blast chillers: Blast chillers are specialized refrigeration units that rapidly lower the temperature of hot food items to below 5°C. This process helps to prevent bacterial growth

and preserve the quality of the food. Blast chillers are commonly used in commercial kitchens and food processing facilities.

5. Cryogenic freezing equipment: Cryogenic freezing equipment uses liquid nitrogen or carbon dioxide to rapidly freeze food items at extremely low temperatures below -150°C. This method of freezing is used for delicate food items such as fruits, vegetables, and seafood. Cryogenic freezing equipment is available in different sizes and configurations to meet the needs of various businesses.

In summary, the equipment used for low-temperature preservation includes refrigerators, freezers, walk-in coolers and freezers, blast chillers, and cryogenic freezing equipment. These devices are designed to maintain a constant low temperature and are equipped with features that ensure the safety and quality of the stored items.

➢ DRYING: PRINCIPLE, METHODS AND APPLICATIONS

Introduction

- ✓ Drying and dehydration of foods is an age-old method to preserve these products.
- ✓ Removal of the water (75-90%) present in fresh commodity results in reduction in the water activity and ultimately resistance against most of the deteriorative agents.
- ✓ The removal of water is carried out by the application of heat and this heat is usually supplied in the form of solar energy or artificially generated hot air.
- ✓ Removal of moisture and exposure of heat often results in poor textural attributes, loss in nutritive value (vitamins), discoloration and loss of flavouring components.
- ✓ Although both drying and dehydration are interchangeably used, drying is referred to removal of water to an equilibrium moisture content while dehydration is removal of water to an almost bone dry condition.

Some of the new technologies have been introduced in recent years to produce a wholesome and nutritive product.

Partial dewatering by osmosis and impregnation soaking process before drying saves energy during drying and improves quality of dried product.

Osmotic dehydration is gaining popularity, as the dehydrated product is more stable during storage due to low water activity by solute gain and water loss.

The low water activity resulted in fewer rates of chemical reactions avoiding deterioration of the food. Osmotic dehydration in many cases is employed to increase sugar to acid ratio of acidic fruits, thereby to improve the taste, texture and appearance of dried product.

Why Drying of Foods? /Advantages.

- ✓ Water activity is defined as the ratio of vapour pressure of food to that of the vapour pressure of pure water at a constant temperature. Reduction in water activity (a_w) so control/check over chemical and microbiological changes (deterioration).
- ✓ Reduction in weight, size and volume of the food material. Hence bulk transportation becomes easier and cheaper.
- ✓ Packaging requirements are simple and cheap.
- ✓ Facilitate further processing. Example: grain drying for flour.

Water content in foods

Water is present in food as free or/and bound water.

Free water is defined as water within a food that behaves as pure water. Unbound water is removed during the constant rate period of drying, when the nature of food does not have a great effect on the drying process.

Bound water can be defined as water that exhibits a lower vapour pressure, lower mobility and greatly reduced freezing point. So, bound water molecules have different kinetic and thermodynamic properties than ordinary water molecules.

The a_w as affected by the extent of bound water is given in Table

Water activity as affected by the extent of bound water

Extent of bound water	Water activity (a_w)
Tightly bound water	< 0.3
Moderately bound water	0.3 to 0.7
Loosely bound water	> 0.7
Free water	~ 1.0

Mechanism of Drying

When hot air is blown over wet food, heat is transferred to the surface and latent heat of vaporization causes water to evaporate.

Water vapours diffuse through a boundary film of air and is carried away by the moving air.

This create a region of lower water vapour pressure gradient is established from the moist interior of the food to the dry air.

The gradient provides the **driving force** for water removal from the food.

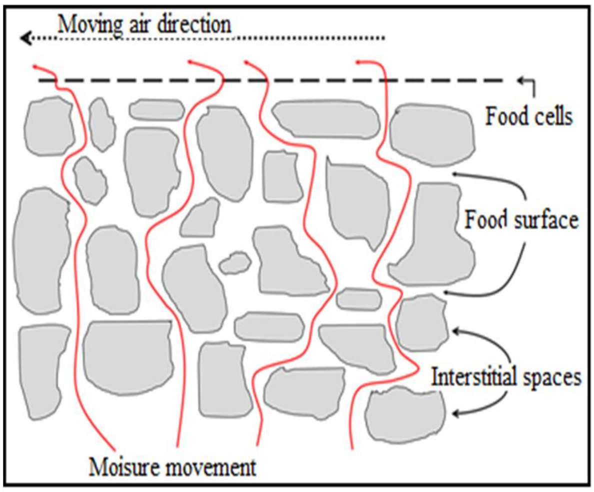


Fig: Schematic diagram of movement of moisture in the interstitial spaces of food cells during drying in fruits and vegetables

1. Liquid movement by capillary force.
2. Diffusion of liquids, caused by concentration gradient.
3. Diffusion of liquids, which are absorbed in layers at the surfaces of solid components of the food.
4. Water vapour diffusion in air spaces within the food caused by vapour pressure gradients.

Phases of drying

1. Initial warm up period
2. Constant drying rate period
3. Falling drying rate period

In hygroscopic food material more than one falling rate period occurs.

In the first period plane of evaporation moves inside the food and water diffuses through the dry solids to the drying air.

It ends when plane of evaporation reaches to the centre of food and the partial pressure of water falls below the saturated water vapour pressure.

Second falling rate period occurs when the partial pressure of water is below the saturated vapour pressure and the drying is by desorption.

Falling rate period is the longest period during drying of food product.

Equilibrium moisture content (EMC) occurs when dry spots develop at the surface so less area exposed to dry air and evaporation decreases.

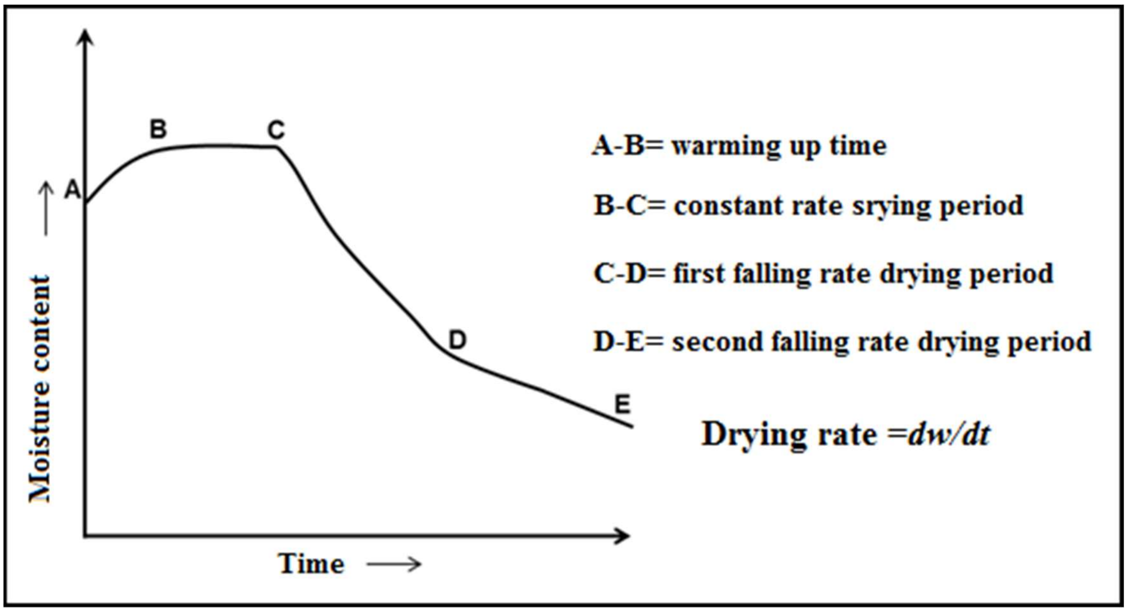


Fig. Schematic diagram of change in moisture content with time (drying rate)

There are 4 resistances to heat transfer in drying:

1. Resistance to external heat transfer
2. Resistance to internal heat transfer
3. Resistance to external mass transfer
4. Resistance to internal mass transfer

Factors Affecting Drying Rate

The factors that affect drying rate are external and internal factors.

The external factors are:

- Dry bulb temperature
- Relative humidity
- Air velocity
- Surface heat transfer coefficient

The Internal factors are:

- Surface to volume ratio
- Surface temperature
- Rate of moisture loss
- Composition i.e. moisture, fat

Effects of Drying on Foods

Shrinkage

During drying as moisture is removed and food material becomes smaller in size. This also affects bulk density (weight per unit volume) of food material.

Slow drying results in development of internal stress. These ruptures compress and permanently distort the relatively rigid cells, to give the food a shrink / shrivelled appearance.

Such food material on rehydration absorbs water more slowly.

Gelatinization of starch, denaturation of proteins, and crystallization of cellulose also affect rehydration characteristics.

Rapid drying improves textural characteristics such as wettability, sinkability, dispersibility and solubility.

Case hardening

Formation of impervious layer over the surface of a dried food product characterized by inner soft and outer hard layer resulting in inadequate drying.

It always occurs in food products rich in solutes and when initial drying temperature is very high.

During the initial high temperature solute particles comes out and deposit at the surface resulting of building up of an impermeable layer which prevents further moisture removal.

It can be prevented by using lower drying temperature.

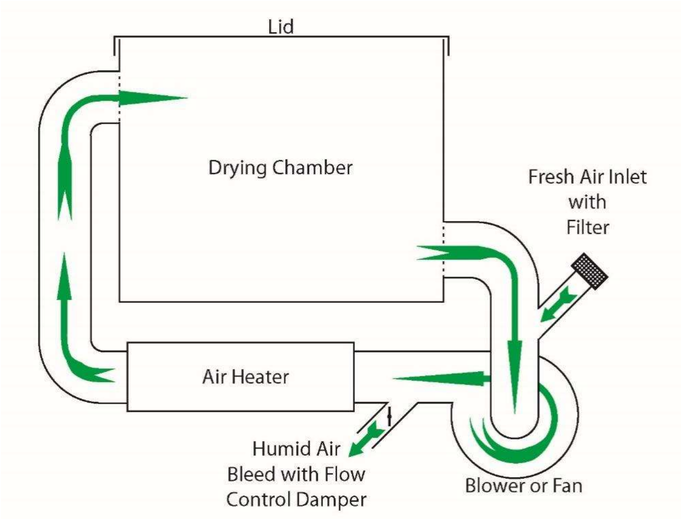
Browning

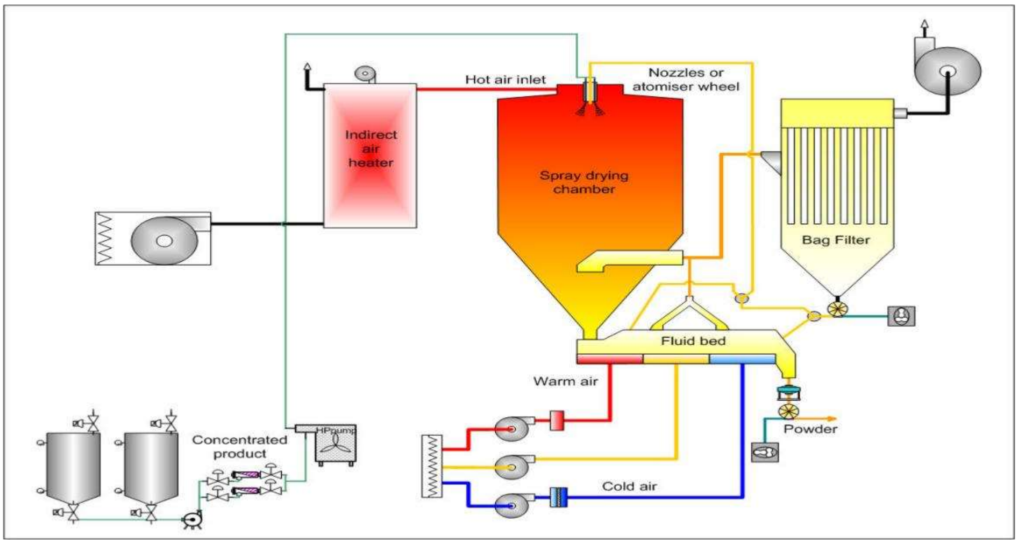
Browning refers to change in the colour of food material to light to dark brown colour. This change in colour may occur by any of the three methods given below.

- ✓ Residual enzymatic browning: the residual enzymes especially in vegetables such as polyphenol oxidases cause oxidation that result in the change of colour.
- ✓ Maillards reaction: it is the reaction between the amino group of proteins and reducing sugars of carbohydrates in presence of heat. This type of browning is most common in dried foods.
- ✓ Caramelization: it is the conversion of sugars only into dark coloured compounds in presence of heat.

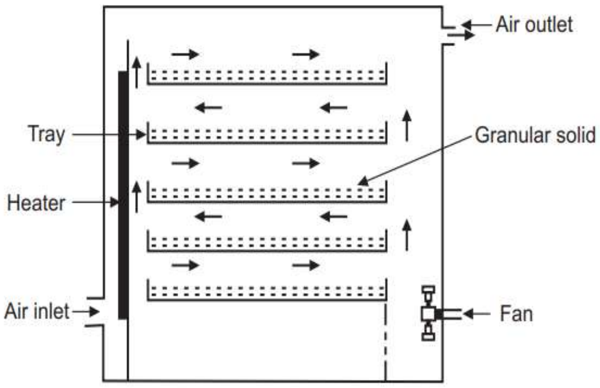
Types of Drying

1. Hot Air drying: It includes spray drying, tray drying, fluidized bed drying, drum dying, etc. In spray drying a fine dispersion of pre-concentrated food (40-60% moisture) is **atomized** to form fine droplets and then sprayed into a co-or counter-current flow of heated air at 150-300 ^{0}C in a large drying chamber. Tray driers consist of an insulated cabinet fitted with shallow mesh or perforated trays, each of which contains a thin (2-6 cm deep) layer of food. Hot air is blown at 0.5-5.0 m/s through a system of ducts and baffles to promote uniform distribution over and/or through each tray.

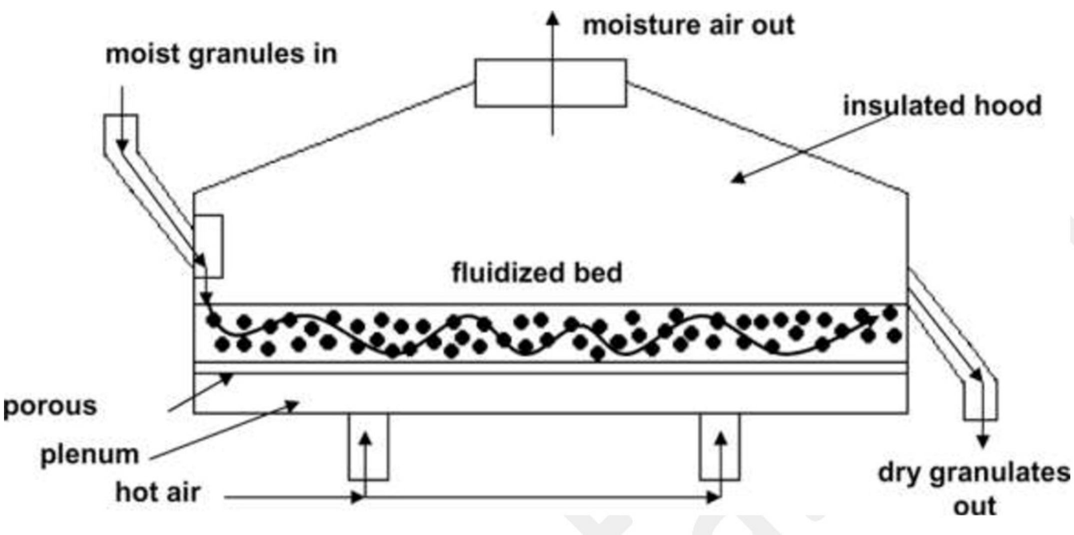




Spray drying

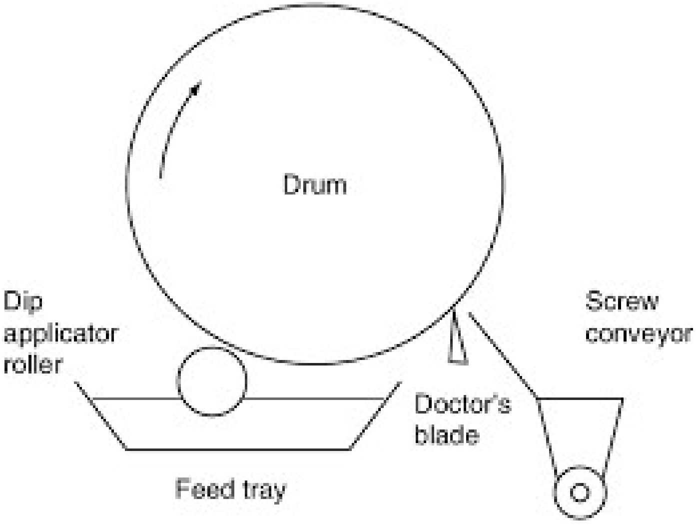


Tray drying

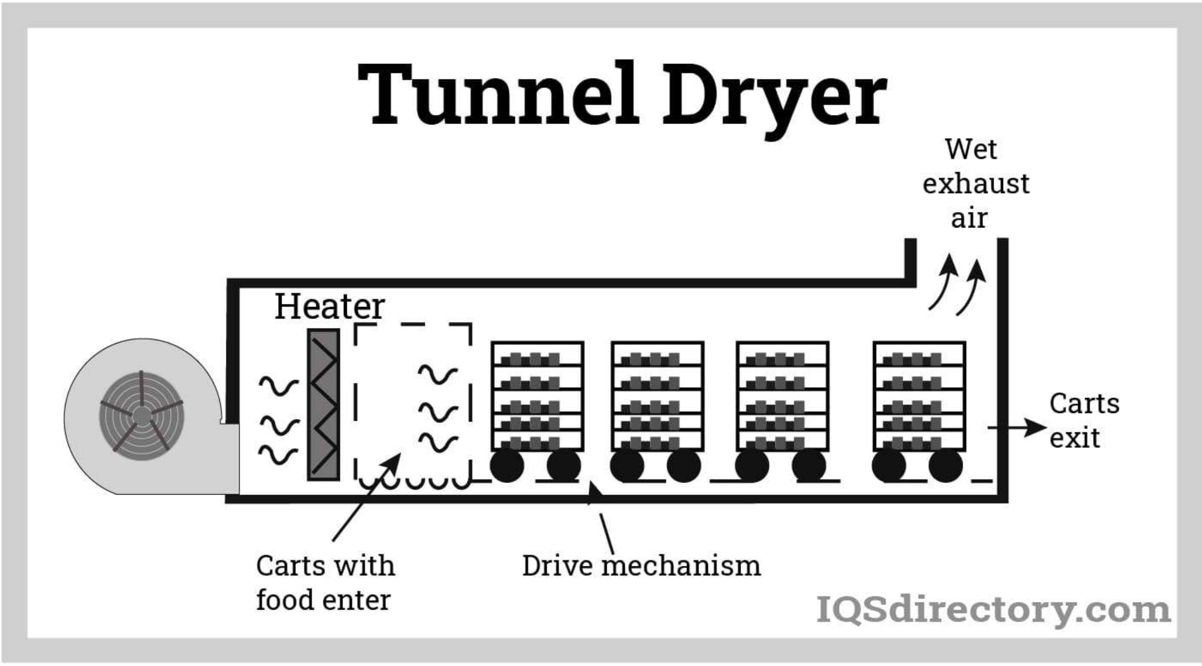


Fluidized bed drying

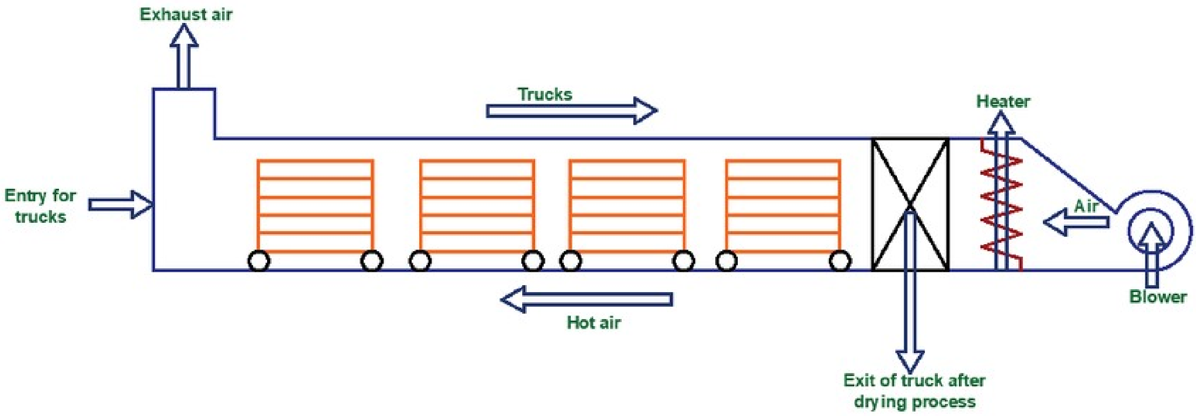

TEMA Process - Fluidized Bed Dryers/Coolers


Drum
Dip
applicator
roller
Screw
conveyor
Doctor's
blade
Feed tray

drum drying

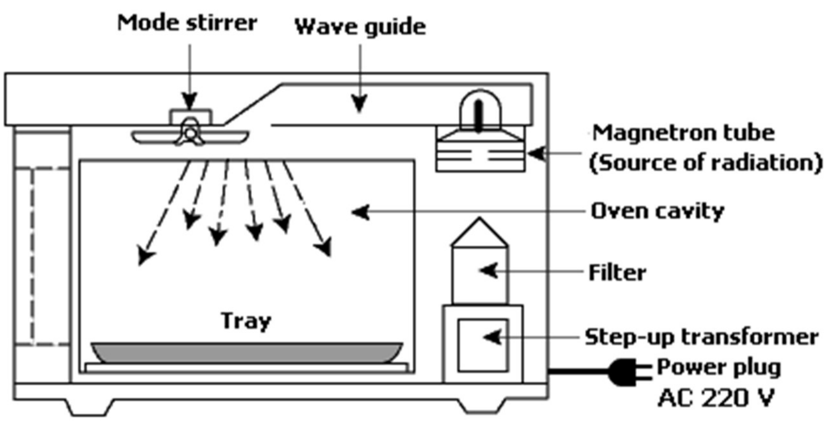


CO-CURRENT FLOW

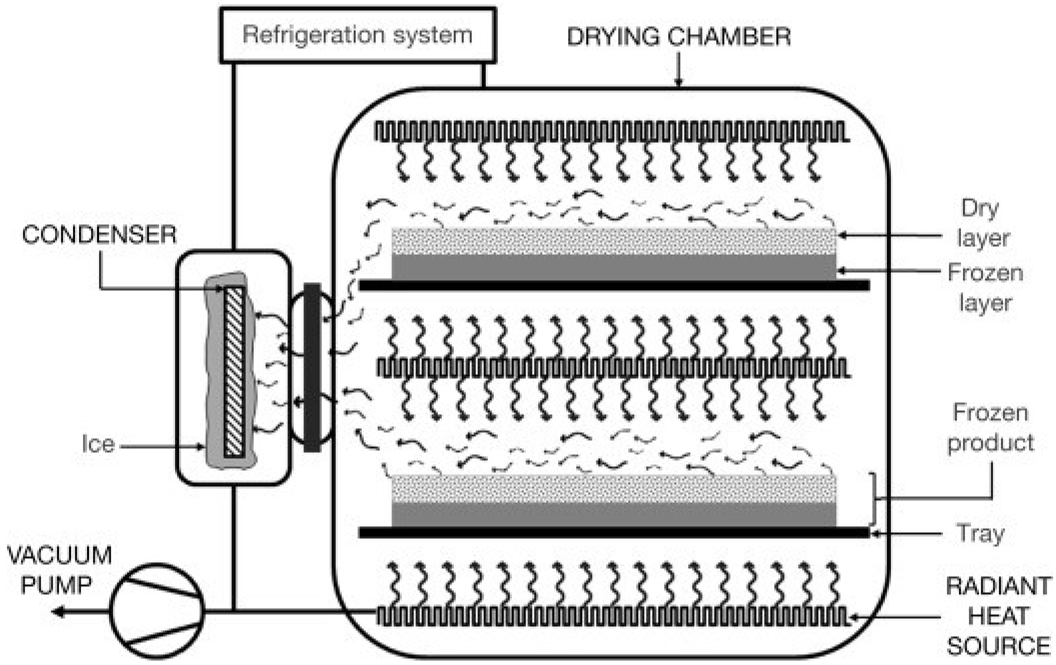


COUNTER-CURRENT FLOW

3. Microwave drying: It involves use of microwaves.



4. Freeze drying: It is also known as **lyophilization** and is usually used for drying heat-sensitive food material by freezing the material and then reducing the surrounding pressure to allow the frozen water to sublimate directly from the solid phase (ice) to gas phase (water vapour).

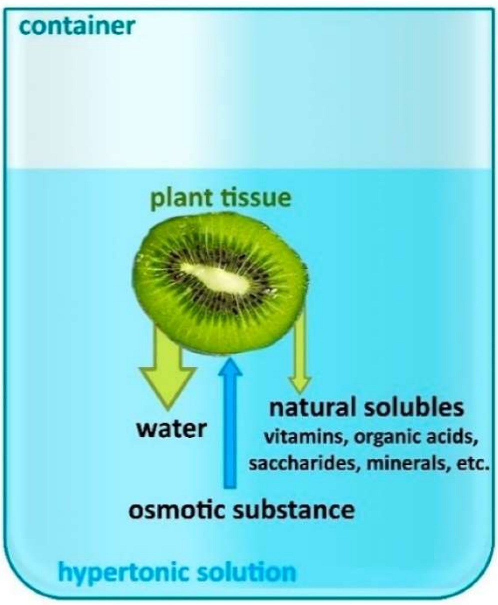


Osmotic drying:

Osmotic Dehydration

Osmotic dehydration, also called as dewatering and impregnation soaking (DIS) process, was pioneered by James D. Ponting in 1966.

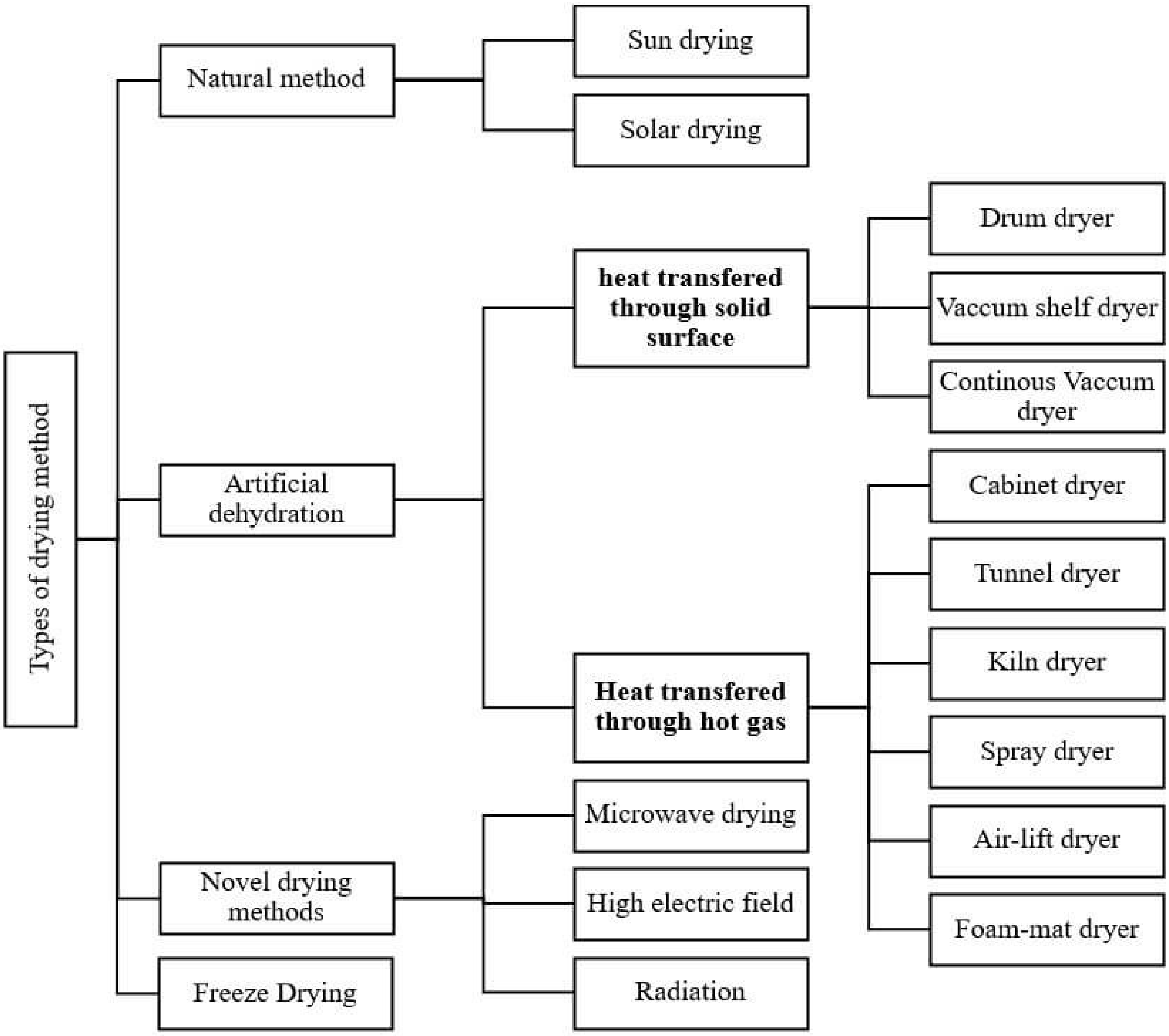
It is a water removal process that involves the soaking of foods mostly fruits and vegetables in hypertonic salt or sugar or in a combined solution, to reduce the water content while increasing the soluble solid content.



Osmotic dehydration is undertaken to reduce the product water activity in minimal processing, which is carried out either at atmospheric pressure or at vacuum conditions.

The raw material is placed in concentrated solutions of soluble solids with higher osmotic pressure and lower water activity.

Water moves through the selective permeable membrane with much greater ease than in the dissolved substances.



Drying of some vegetables.

Drying of onion

Onion is bulbous crop characterized by pungent flavour, attractive colour and high amount of reducing sugar. It an important seasoning item for traditional Indian cuisines. The demand for onion has increased considerably over the years because of its unique flavour profile and well established medicinal and therapeutic properties. To meet the demand of consumers, the onions are processed in various convenient forms as paste, dried slices powder, etc. The flow diagram represents the various unit operations involved in drying of onion.

Medium to large sized onion bulbs

(High solids, higher amount of pungency and pigments)

↓

Peeling

↓

Slicing 5 mm thickness

↓

↓

Dipping into 5% salt solution for 30 min or warm water (70°C) for 1 min. with stirring at regular interval and then dipped in starch solution for 30 min at room temperature

↓

Drying in cabinet dryers at 60°C for 10 h
(final moisture about 4-4.5%)

↓

Blending in grinder

↓

Sieving with 30 mesh size

↓

Packaging in 400 gauge low density polyethylene

↓

Storage at low temperature 7°C at 80% RH

Key differences between drying and dehydration:

Drying	*Dehydration*
✓ Removes moisture from food products	✓ Removes almost all moisture from food products
✓ Can be done through sun drying, air drying, or specialized equipment such as ovens or dehydrators	✓ Requires specialized equipment such as vacuum or freeze-drying
✓ Often used to preserve fruits, vegetables, herbs, and meats	✓ Used to preserve delicate fruits and vegetables and create powders or concentrates
✓ Goal is to remove enough moisture to prevent the growth of bacteria and fungi while preserving flavor and nutrients	✓ Goal is to remove almost all moisture to create long-lasting, shelf-stable products
✓ Can be done at home or on an industrial scale	✓ Typically done on an industrial scale
✓ May have a shorter shelf life than dehydrated foods	✓ Often has a longer shelf life than dried foods
✓ Ideal for use in recipes or snacks	✓ Ideal for long-term storage or emergency situations

Rehydration and concentration are important processes in food processing that involve adding or removing water from food products to achieve certain desired properties, such as texture, taste, and shelf life. Here are the principles, methods, and examples of these processes:

Rehydration:

Principle: Rehydration is the process of restoring the moisture content of dehydrated foods back to their original levels. It involves adding water to the food product to achieve a specific texture and reconstitute the flavors and nutrients that were lost during dehydration.

Methods: There are different methods of rehydration in food processing, including:

- Soaking: This involves submerging the dehydrated food in water for a certain period until it absorbs enough water to become fully hydrated.
- Boiling: This method involves heating the water and adding the dehydrated food to the boiling water until it is fully hydrated.

- Steaming: This involves using steam to rehydrate the food product. The food is placed in a steaming chamber where it is exposed to high temperatures and steam until it is fully hydrated.

Examples: Some examples of foods that undergo rehydration during processing include dehydrated fruits and vegetables, instant noodles, and dried beans.

Concentration:

Principle: Concentration is the process of removing water from a liquid food product to increase its solids content, and thus its flavor and shelf life. It involves boiling the food product to evaporate the water and concentrate the solids.

Methods: There are different methods of concentration in food processing, including:

- Evaporation: This involves heating the food product in an open vessel to evaporate the water and concentrate the solids.
- Freezing: This involves freezing the food product and removing the ice crystals to concentrate the remaining solids.
- Reverse osmosis: This involves passing the food product through a semipermeable membrane under pressure to remove water and concentrate the solids.

Examples: Some examples of foods that undergo concentration during processing include fruit juices, tomato paste, and condensed milk.

Overall, rehydration and concentration are important processes in food processing that allow for the creation of a wide range of products with varying textures, flavors, and shelf lives.

➢ Preservation by Chemical Preservatives

Chemical preservatives are intentional food additives incorporated into food to prevent or retard food spoilage caused by microbiological, enzymological, or chemical reactions.

- These chemical preservatives should be nontoxic to humans or animals.
- Chemical preservatives come under the food additives generally recognized as safe (GRAS).
- Chemical preservatives can also be termed antimicrobials.
- The main purpose of using chemical preservatives is to inhibit the growth and activity of foodborne pathogens and spoilage microorganisms.

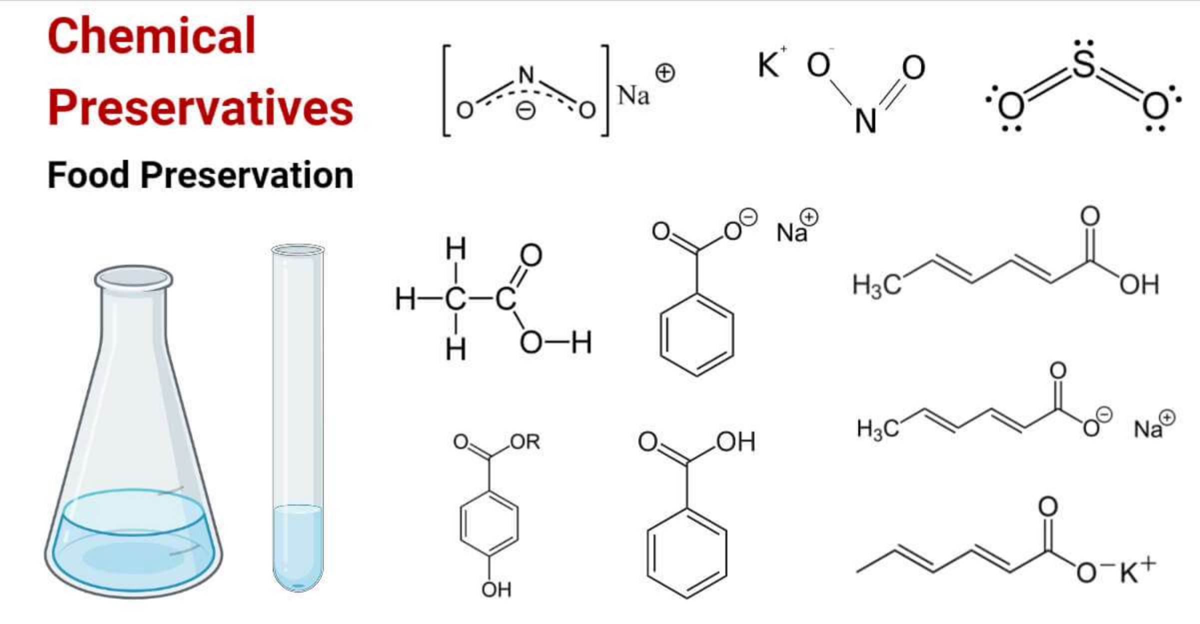
- Chemical preservatives used in food can have both bacteriostatic and bactericidal properties per the concentration used.

How food can get chemical preservatives?

- Intentional addition during food production, processing, or packaging
- Chemical migration from the packaging materials
- Due to a chemical reaction occurring in food
- Residues of pesticides, herbicides, and fungicides on raw food materials
- Migration of disinfectants used on utensils or equipment into foods

Role of chemical preservatives

- Interferes with the cell wall, cell membrane, enzymatic activity, nucleic acids, etc., to prevent microorganisms' growth and activity.
- Retard, prevent or control undesirable changes in flavor, color, texture, or consistency of food and nutritive value of food.
- Control natural spoilage of food



Chemical Preservatives as Food Preservation

Classification of chemical preservatives

- **Class I:** Traditional preservatives (natural)
- **Class II:** Chemical preservatives (Artificial)

Class I: Traditional Preservatives:

These include preservatives like wood, smoke, sugar, honey, salt, spices, alcohol, vinegar, vegetable oil, spices, etc which are commonly used in our kitchen in past.

These chemical preservatives are not restricted to use and there is no imposed limitation on their use.

These naturally occurring preservatives are regarded as safe for human health.

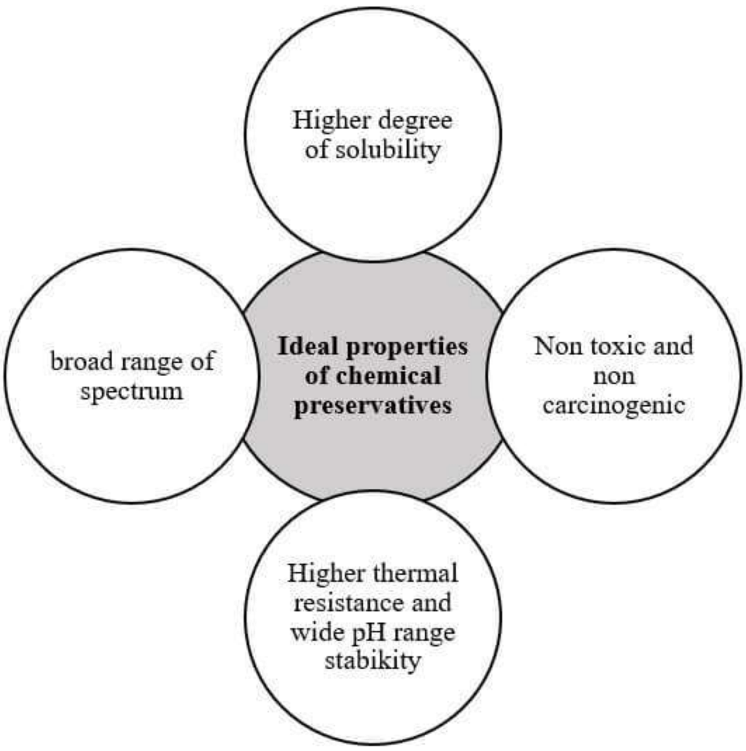
Class II: Chemical preservatives:

These are synthetic chemical preservatives that are made in the laboratory.

For e.g. nitrites, propionates, parabens, benzoates, acetates, sorbates, sulfur dioxide, etc.

Microbial preservatives: These include antimicrobial preservatives like **bacteriocins** (e.g. **nicin)** which are produced by some strains of lactic acid bacteria and inhibit the growth of food spoilage or pathogenic bacteria. E.g nisin, produced by *lactococcus lactis* inhibits the growth of *Clostridium botulinum, and, listeria monocytogenes* in cheese, other dairy products meats, fish, etc.

Using bacteriocins like microbial preservatives help reduce the use of chemical preservatives like nitrates, sorbates, and benzoates which consumers consider bad.



Some food preservatives and their acceptable daily intake

Chemical preservatives with their ADI quantities (mg/kg BW). *E (Europe) number refer to code for substance used as food additives. The E numbers for preservatives range from E200 to E399.*

Table1: According to EU regulation, chemical food additives with their ADI quantities.

Chemical preservative	**E number**	**ADI (mg/kg BW)**
Sorbic acid	**E200**	**25**
Sodium sorbate	**E201**	**25**
Potassium sorbate	**E202**	**25**
Benzoic acid	**E210**	**5**
Sodium benzoate	**E211**	**5**
Parabens	**E214-E219**	**10**
Sulfur dioxide and Sulfites	**E220-E228**	**0.7**
Potassium nitrite	**E249**	**0.07**
Sodium nitrite	**E250**	**0.1**
Sodium nitrate +	**E251 +**	**3.7**
Potassium nitrate	**E252**	**3.7**
Acetic acid	**E260**	
Propionic acid and propionates	**E280- E289**	**5**

Source: Adding Molecules to Food, Pros, and Cons: A Review on Synthetic and Natural Food Additives. Marcio Carocho, Maria Filomena Barreiro, Patricia Morales, and Isabel C.F.R. Ferreira.

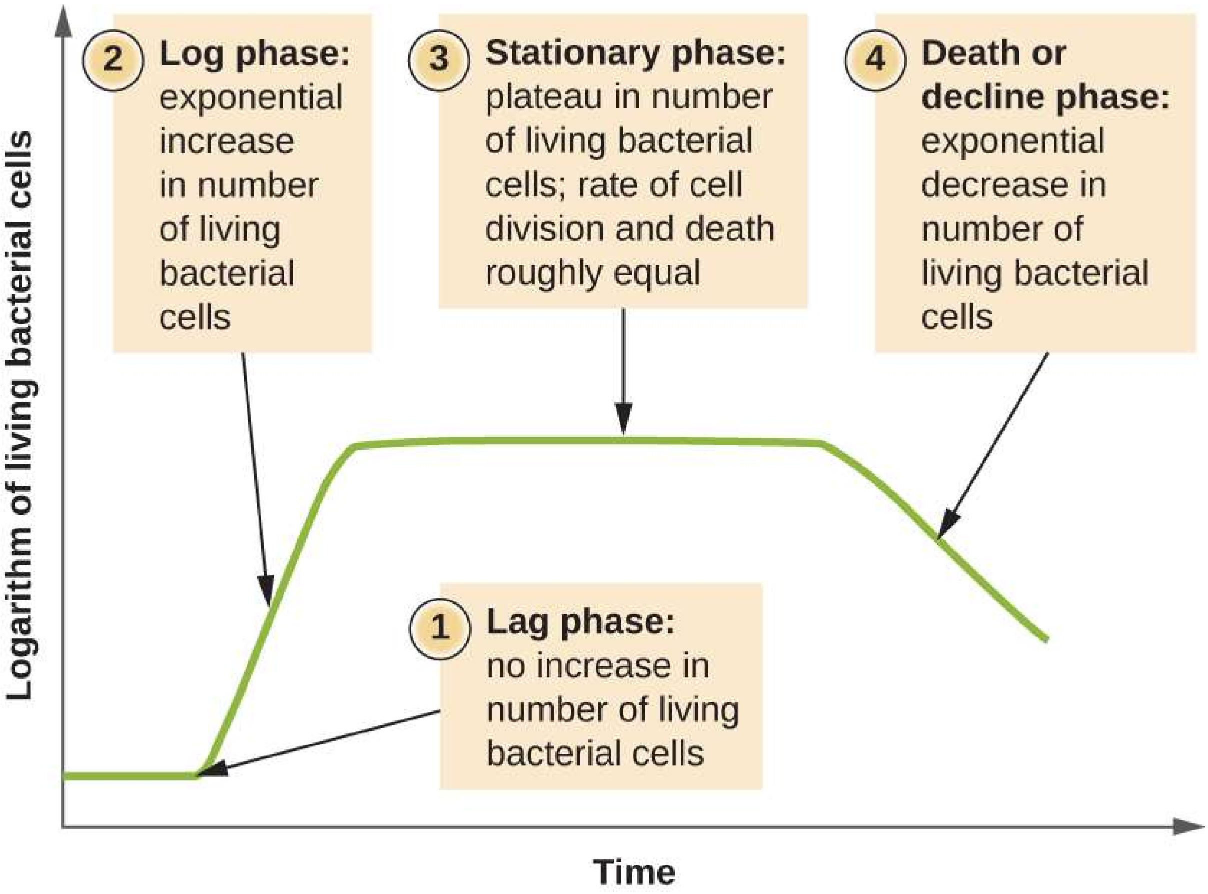
Factors affecting the effectiveness of chemical preservatives

1. **Chemical preservative properties**

    1. Solubility
    2. Toxicity

2. Microbial factors

2. Microbial inherent resistance to chemical preservatives
3. Initial microbial load
4. Growth rate and phase of microorganisms



5. Stress reaction of microorganisms
6. Homeostasis ability of microorganisms
7. Use of additional preservative methods

3. Intrinsic factors of food

9. pH of the food

10. Water activity of food

4. Extrinsic factors

11. Storage time and temperature

12. Gas composition

13. Atmosphere and relative humidity

Different chemical preservatives and their application in the food industry

Chemical preservatives	**Targeted microorganisms**	**Mode of action**	**Advantages**	**Disadvantages**	**Applications**
Sulfur dioxide (SO_2)	Yeast, mold	Increase pH and imbalance cellular metabolic process, alter the enzymatic system,	Antioxidant properties, prevent browning, preserve color, cheaper and easily available	The intense pungent odor and corrosive property makes it unuseful in canning	Beverages, fruits products, heat-sensitive foods, effective for low pH foods
Sorbates(Sodium sorbate and Potassium sorbate)	Yeast, Mold, Bacteria	Disturb enzyme system, inhibit many enzymes involved in TCA cycle			Beverages; juices, wines, cheese, fish meat bakery items,

Benzoic acid and benzoates	Yeast, molds	Disturb enzymatic system	Most active against yeasts and molds. Used to preserve colored fruit juices	Risk of respiratory disease	High acid foods, fruit drinks, cider, carbonated beverages, pickles, jams, salad dressings, soy sauce
Parabens (p-hydroxybenzoic acid)	Yeast, Mold, bacteria	Destroy complex structure of the cell and denature protein inside the cell			Soft drinks, fish products, salad dressing
Propionic acid	Mold, yeast, and a few bacteria	Disturb enzyme system			Low acid foods, processed cheese preservation
Nitrate and nitrite	Anaerobic bacteria (*Clostridium botulinum*), other pathogenic microbes	Inhibit metabolic enzyme	Preserve the color of red meat by forming nitrosomyoglobin	The formation of carcinogenic nitrosamines is triggering extensive research	Used in cured meats, better at low pH foods
Phosphates	More against gram-positive bacteria (*Bacillus,*	Chelating metal ions			

	clostridium)				
Sulfites	More Bacteria, less effective to yeast and mold	Target to the cytoplasmic membrane, DNA replication, protein synthesis, and enzymatic actions	Acts as antioxidants and inhibit enzymatic browning		Fruits and vegetable products, wine
Sodium chloride (NaCl)	Bacteria	Osmotic shock to Plasmolysis	Better preservation if used as a pretreatment before canning, pasteurization, or drying	Weak against *Staphylococcus* and *listeria monocytogens*	Salting of meats and fish
Wood smoke (Traditional method)	Bacteria, fungi	The release of different phenolic compounds, ketones, aldehyde, and alcohol, which serves as an antimicrobial preservative	Easy to use		Meat, sausage, ham, bacon, fish
Nisin	Clostridium botulinum and other bacteria				Cheese, cooked meat, poultry

The working mechanism of organic acids on the bacterial cell

Organic acids like Acetic acid, benzoic acid, lactic acid, propionic acid, sorbic acid, etc., are effective as preservatives for foods with a pH of less than 5. So, they are the best for preserving acidic foods.

1. At acidic pH, protonated or uncharged organic acid crosses the cell membrane and enters the cytoplasm.
2. In neutral cytoplasmic pH, organic acids dissociate and release the proton that acidifies the cytoplasm.
3. This cell uses ATP to pump protons out of the cell to deacidify the cytoplasm, which makes energy unavailable for their growth.

Table: Guidelines for using chemical preservatives in food by DFTQC, Nepal 2075 B.S. (2018 A.D.)

Food	**Preservatives**	**PPM**
Sausage meat containing raw meat, Cereals, spices	Sulfur dioxide	450
Undried fruits: Cherries, Strawberries, and raspberries. Other fruits	Sulfur dioxide	2000 1000
Concentrated fruit juice	Sulfur dioxide	1500
Dried fruits	Sulfur dioxide	1500
Apricots, peaches, apples, pears	Sulfur dioxide	2000
Sugar, dextrose, jaggery, refined sugar	Sulfur dioxide	70
Beer	Sulfur dioxide	70
Cider	Sulfur dioxide	200
Alcoholic wine	Sulfur dioxide	450
Dried ginger	Sulfur dioxide	2000

Squash, fruit syrups, barley water	Sulfur dioxide, or benzoic acid	350 600
Pickles	Sulfur dioxide, or benzoic acid	250 100
Jam, marmalade, fruit jelly	Sulfur dioxide, or benzoic acid	40 200
Coffee extract	Benzoic acid	120
Tomato or other juices	Benzoic acid	750
Pickled meat, bacon, canned meat	Sodium nitrite or potassium nitrite	200
Cheese or processed cheese	Sorbic acid or Sodium sorbate or potassium sorbate	3000
Paneer	Sorbic acid or Sodium sorbate or potassium sorbate	2000
Flour confectionery	Sorbic acid or Sodium sorbate or potassium sorbate	1500
Baking flour	Sodium diacetate, Propionates, Methyl propyl hydroxybenzoate	2500 3200 500

Do you know?

- Nitrite and nitrate preservatives should not be used in infant foods.
- The use of titanium dioxide (E171) is fully banned as a food additive in the EU.

"Preservatives can be used to extend the expiration dates of food but unfortunately not of people."

HURDLE TECHNOLOGY

History of Hurdle technology

- The combined use of several preservation methods, possibly physical and chemical, or a combination of different preservatives is an age-old practice.
- It has been commonly applied by the food industry to ensure food safety and stability.
- In recent years, the concept of combining several factors has been developed by Leistner (1995) and others into the 'hurdle effect'.
- From an understanding of the hurdle effect, hurdle technology has been derived, which has the goal not just to understand why a certain food is safe and stable, but to improve the quality of the food by an optimization and intelligent modification of the hurdles present.
- It employs the intelligent combination of different hurdles or preservation techniques to achieve multi target, mild but reliable preservation effects.

Hurdle technology has arisen in response to a number of developments:

– Consumer demands for healthier foods that retain their original nutritional properties

– The shift to ready-to-eat and convenience foods which require little further processing by consumers

– Consumer preference for more 'natural' food which require less processing and fewer chemical preservatives.

- Hurdle technology provides a framework for combining a number of milder preservation techniques to achieve an enhanced level of product safety and stability.

Hurdle technology is a technique to control and eliminate pathogens by combining two or more factors. These factors are called hurdles. The pathogens have to overcome these hurdles to survive. The right combination of the hurdles can inactive the pathogens and thereby make the food products safe for consumption along with a extended shelf-life. Hurdle technology is a technology where appropriate types of hurdles are selected and combined to provide microbial safety, stability, sensory, nutritional value and the economic viability to food products.

Hurdle technology is a concept that was developed to address the consumer demand for more natural and fresh foods. It is an intelligent combination of hurdles which secures the microbial safety and stability as well as retains the organoleptic, nutritional quality and economic viability of food products.

Hurdle technology (also called combined methods, combined processes, combination reservation, combination techniques or barrier technology) was developed several years ago as a new concept for the production of safe, stable, nutritious, tasty and economical foods.

The Hurdle Concept

In the hurdle concept, multiple factors or techniques are employed to affect the control of microorganisms in foods. Barrier technology, combination preservation, and combined methods are among some of the other descriptions of this concept.

Referred to as "hurdle technology" since the mid-1980s by L. Leistner in Germany, the practice has been applied to some foods for over a century.

A simple example of the hurdle concept or barrier technology is demonstrated by preventing the germination of spores of proteolytic or group I strains of *Clostridium botulinum.*
Among the intrinsic and extrinsic parameters that are known to prevent their germination and growth are: pH <14.6; *a*w <0.914; NaCl of 10% or more; NaNO2 ca. 120 ppm; incubation temperature<10◦C; and a large aerobic bacterial biota.

Foods that employ the hurdle concept in their formulation would embody a series of the above, thus making for a multitargeted approach to preventing germination and growth of these spores. In order for *C. botulinum* to grow, it must "hurdle" a series of the barriers noted. Note that the hurdles listed above include "aerobic bacterial biota", which is microbial interference.

The important parameters of pH and a_w may be controlled by the growing food biota, especially the lactic acid bacteria. The concept of growth/no growth (G/NG) has been advanced to better quantify the hurdle concept by employing the synergy that exists between two or more parameters. Implicit in this concept is the interaction between two or more parameters to a point where growth ceases, the G/NG interface. Precise definitions and determinations of those factors/parameters that permit and prevent growth of a given organism should make it possible to devise models for the hurdle concept.

Need for hurdle technology

- The demand for fresh and natural food products
- The need for minimally processed products
- Trend of eat out and to consume ready-to- eat foods
- Emergence of new routes for the growth of microorganisms

Common Hurdle Technology

The most important hurdles generally used in food preservation are temperature (high or low), water activity (a_w), acidity (pH), redox potential (Eh), preservatives (e.g., nitrite , sorbate, sulfite), and competitive microorganisms (e.g., lactic acid bacteria). However, more than 60 potential hurdles for foods, which improve the stability and/or quality of the products, have been already described, and the list of possible hurdles for food preservation is by no means complete. Some hurdles (e.g., Millard reaction products) will influence the safety and the quality of foods, because they have antimicrobial properties and at the same time improve the flavour of the products. The same hurdles could have a positive or a negative effect on foods, depending on its intensity. For instance, chilling to an unsuitable low temperature is detrimental to some foods of plant origin ('chilling injury'), whereas moderate chilling will be beneficial for their shelf life. Another example is the pH of fermented sausage which should be low enough to inhibit pathogenic bacteria , but not so low as to impair taste. If the intensity of a particular hurdles in a food is too small it should be strengthened, if it is detrimental to the food quality it should be lowered. By this adjustment, hurdles in foods can be kept in the optimal range, considering safety as well as quality, and thus the total quality of a food. For each stable and safe food a certain set of hurdles is inherent, which differs in quality and intensity depending on the particular product, but in any case the hurdles must keep the ‘normal’ population of microorganisms in this food under control. The microorganisms present (‘at the start’) in a food should not be able to overcome (‘leap over’) the hurdles present during the storage of a product; otherwise the food will spoil or even cause food poisoning .

Severe heat treatments can impair the organoleptic properties and nutritional value of foods. Excessive Low temperature treatment may reduce food quality by destroying food surface (chilling injury) or due to release of enzymes by dead microbes. Too low pH of a food may impair taste of a food. MAP in excess may change color, flavor, and texture of food. Irradiation at high doses can be harmful to food like production of free radicals. Hurdle effect was first introduced in 1978. Leistner and co-workers acknowledged that the complex interactions of temperature, water activity, acidity, redox potential, preservatives etc; are significant for the microbial stability and safety of most foods. In modern food preservation techniques using bacteriolytic enzymes, irradiation, high pressure or pulsed technologies, secondary hurdles are employed to achieve the desired preservation. Pulsed electric fields can be combined with other hurdles such as pH, aw, temperature or preservatives. Effect of high pressure can be improved if combined with heat, antimicrobials or ionizing radiations.

Various factors like the microbial load determines the type and amount of hurdles required.

· If only few microorganisms are present at the start, than a few or low hurdles are sufficient for the stability of the product

· If microbes present are sub lethally injured, they lack vitality & are easier to inhibit by few hurdles

· Food rich in nutrients and vitamins will enhance the growth of microorganisms (booster or trampoline effect), thus the number & intensity of hurdles should be increased

· Water content is an essential component of food, if an increased water activity is compensated by other hurdles (pH, Eh etc.), the food becomes more economical

· If energy preservation is the goal, than energy consuming hurdles such as refrigeration are replaced by other hurdles that do not demand energy but still ensures a stable and safe food

Most important hurdles for food preservation and their symbols

S.No.	Symbol	Parameter	Application
1	F	High temperature	Heating
2	T	Low temperature	Chilling / freezing
3	aw	Reduce water activity	Drying/curing

4	pH	Increased acidity	Acid addition or formation
5	Eh	Reduced redox potential	Removal of oxygen /addition of ascorbate
6	Pres.,	Preservatives	Sorbate, sulfite, nitrite
7	cfu/mL	Competitive flora	Microbial fermentations

Hurdles and Their Roles:

Hurdles refer to individual factors or conditions that can hinder microbial growth. These hurdles can be classified into four main categories: physical, chemical, biological, and physiological.

✓ Physical hurdles include temperature, water activity, and packaging.

✓ Chemical hurdles encompass pH, preservatives, and antioxidants.

✓ Biological hurdles involve the use of beneficial microorganisms, while

✓ Pysiological hurdles consider factors like competitive exclusion and enzymatic inhibition.

Each hurdle contributes to preventing microbial proliferation and ensuring the safety of food products.

Basic aspects of hurdle technology or Principles of hurdle technology

The hurdle technology affects the physiology and growth of microorganisms in food. There are mainly 4 major mechanisms by which hurdle technology affects the growth of microorganisms in foods:

- Homeostasis
- Metabolic exhaustion
- Stress reaction
- Multi target preservation of food

Homeostasis

Strong tendency of organisms to maintain their internal environment stable and balanced so that homeostasis is in balanced condition. If homeostasis is disturbed by preservative factors (hurdles) in foods, they will remain in lag phase or even die before their homeostasis is re-established. Repair of disturbed homeostasis demands much energy, thus restriction of energy supply inhibits repair mechanism and leads to synergistic effect of preservative factors. Energy restrictions are caused by anaerobic conditions, low $_{aw}$, low pH and low redox potential.

Metabolic exhaustion

It leads to auto sterilization of foods. Counts of variety of bacteria, yeasts and molds that survive the mild heat treatment decrease quite fast in the products during unrefrigerated storage because the hurdles applied do not allow growth. Microorganisms in hurdle technology foods try every possible repair mechanism for their homeostasis. By doing this, they completely use up their energy and die, that leads to auto sterilization of foods.

Stress reactions

Bacteria become more resistant or even more virulent under stress – heat shock proteins. Protective stress shock proteins are induced by heat, pH, Aw, ethanol, starvation etc. Activation of shock protein genes would be more difficult if different stresses are received at the same time.

Multi target preservation

A Synergistic effect could be achieved if hurdles in a food hit, at the same time, different targets (e.g., cell membrane, DNA, enzyme system, RNA) within the microbial cell and thus disturb the homeostasis of the microorganisms. Repair of homeostasis as well as the activation of stress shock proteins would become more difficult. Nisin, damages the cell membrane, in combination with Lysozyme and citrate, which then easily penetrate the cell and disturb the homeostasis with different targets.

Mechanism

Microorganisms react homeostatically to stress factors. When their environment is disturbed by a stress factor, they usually react in ways that maintain some key element of their physiology constant. Microorganisms undergo many important homeostatic reactions.

Stress factor	**Homeostatic response**
Low levels of nutrients	Nutrient scavenging; oligotrophy; ‘stationary-phase response’; generation of ‘viable non-culturable’ forms
Lowered pH	Extrusion of protons across the cell membrane; maintenance of cytoplasmic pH; maintenance of transmembrane pH gradient
Lowered water activity	Osmoregulation; accumulation of ‘compatible solutes’; avoidance of water loss; maintenance of membrane turgor
Lowered temperature for growth	‘Cold shock’ response; changes in membrane lipids to maintain satisfactory fluidity
Raised temperature for growth	‘Heat shock’ response; membrane lipid changes
Raised levels of oxygen	Enzyme protection (catalase, peroxidase, superoxide dismutase) from H2O2 and oxygen-derived free radicals

Presence of biocides	Phenotypic adaptation; reduction in cell wall/membrane permeability
High hydrostatic pressure	Uncertain; possibly low spore water content
Ionizing radiation	Repair of single-strand breaks in DNA
High voltage electric discharge	Low electrical conductivity of the spore protoplast
Competition from other microorganisms	Formation of interacting communities; aggregates of cells showing some degree of symbiosis; biofilms

- The success of hurdle technology depends on ensuring metabolic exhaustion.
- Most stress reactions of microorganisms are active processes, and this often involves the expenditure of energy, e.g. to transport protons across the cell membrane, to maintain high cytoplasmic concentrations of ‘osmoregulatory’ or ‘compatible’ solutes.
- Restriction of the availability of energy is then a sensible target to pursue.
- This probably forms the basis of many the successful, empirically derived, mild combination preservation procedures exemplified by hurdle technology.
- However, environmental stresses can provide varying results because some bacteria may become more resistant or even more virulent under stresses through stress reactions such as synthesis of protective stress shock proteins.
- It has been reported that synthesis of protective stress shock proteins is induced by several stresses including heat, pH, aw, ethanol, oxidative compounds, and starvation.
- Although each stress has a different spectrum of antimicrobial action, those stress reactions might have a non-specific effect, since due to a particular stress, microorganisms become also more tolerant to other stresses i.e. ‘cross-tolerance’.
- Conversely, the heat shock response that follows mild heating can result in cells becoming more acid tolerant.
- Therefore, the various stress responses of microorganisms might hamper food preservation and could turn out to be problematic for the application of hurdle technology when hurdles are used consecutively.
- However, the use of different stresses at the same time (combination treatment) prevents the synthesis of those protective proteins because simultaneous exposure to different stresses will require energy- consuming synthesis of several or at least much more protective stress shock proteins which in turn may cause the microorganisms to become metabolically exhausted.
- This antimicrobial action of combining hurdles is known as ‘multi target preservation’.

Types of hurdles with examples

Type of hurdle	Examples
Physical	• High temperatures (sterilization, evaporation, pasteurization, extrusion, baking, frying, blanching) • Low temperature (freezing), modified atmospheres, controlled atmospheres • Ultra-High Pressure • Ultrasonication • Ultraviolet radiation • Ionizing Radiation • Aseptic packaging • Packaging films • Electromagnetic energy (microwave, radio frequency, pulsed electric field)
Physicochemical	• Carbon dioxide • Ethanol • Lactic Acid • Lactoperoxidase • Low pH • Low redox potential • Low water activity • Organic acids • Oxygen • Ozone • Phenols • Phosphates • Spices and herbs
Microbial	• Antibiotics • Biopreservative –Bacteriocin • Competitive flora

Applications of Hurdle Technology in different products

Hurdle Technology is a novel concept which has several applications in the preservation of various food products such as:

Dairy products

- Hurdle technology has been applied in many dairy products to enhance their shelf life.

- Shelf stable paneer can be prepared by applying various hurdles such as pH, aw, preservatives and Modified Atmosphere Packaging.
- Another product brown peda, a traditional Indian heat desiccated milk khoa based product have also been prepared and preserved through hurdle technology.

Fruits & Vegetables

- Several hurdles are considered to be important in the preservation of various vegetables and fruits like carrot, pineapple, coconut & papaya to enhance their stability and shelf life.
- Hurdle technology can also be applied to develop shelf stable RTE (ReadyTo-Eat) intermediate moisture pineapple with increased shelf life. Osmotic dehydration, infrared drying and gamma radiation can successfully reduce the microbial load in pineapple slices increasing its shelf life up to 40 days.
- Hurdle technology in the preservation of fresh scrapped coconut. Additives such as humectants, acidulants and preservatives were used.
- Minimally processed shelf stable high moisture grated papaya is also prepared by hurdle technology using different hurdles like mild heat treatment, aw, pH reduction, and the addition of preservatives.

Fruit derived products

- Several conventional hurdle strategies are effectively used along with the novel ones for the preservation of various fruit products.
- Some of the hurdles applied in fruit processing includes UV light, pulsed light (PL), ultrasound (US), and high hydrostatic pressure (HHP).
- Hurdle or combined technology is also applied in the preservation of high moisture fruit products such as peach, pineapple, papaya, mango and banana. The technology is based on the combination of heat treatment, aw and addition of antimicrobials.

In Meat & Meat products

- Hurdle technology has been applied to a number of meat products. The effect of different hurdles such as (pH, aw, vacuum packaging and post package treatment) in pork sausages at refrigerated temperature.
- Shelf stable ready to eat pickle type spiced buffalo meat products was also prepared and preserved by controlling different hurdles like pH, water activity, proximate composition, FFA, Soluble hydroxyl proline, TBA values, nitrite content, protein solubility

Ready-to-Eat Foods

- Hurdle technology finds extensive application in ready-to-eat foods. These include deli meats, salads, sandwiches, and other convenience foods. Multiple hurdles, such as low temperature, modified atmosphere packaging, and preservatives, are employed to ensure product safety and quality throughout the shelf life of these perishable items.

Fermented Foods

- Fermentation is a natural hurdle process that has been used for centuries to preserve foods. Hurdle technology is crucial in the production of fermented foods like yogurt, cheese, sauerkraut, and kimchi. Factors like pH control, salt, and starter cultures act as hurdles, inhibiting the growth of harmful microorganisms while promoting the growth of beneficial ones. This contributes to the safety, flavor development, and extended shelf life of fermented products.

Novel Technologies

- Hurdle technology continues to evolve with the advent of novel technologies. High-pressure processing, pulsed electric fields, and ultraviolet radiation are emerging technologies that act as additional hurdles in food preservation. These innovative techniques offer advantages such as improved preservation effectiveness, reduced nutrient loss, and minimal impact on sensory attributes. However, challenges related to cost, scalability, and equipment availability need to be addressed for wider adoption.

Limitations of hurdle technology

Synthesis of protective proteins due to the stress of bacteria caused in them, in hurdle technology, different results can be given for preserving foods. The stress reactions or crosstolerance may not evn be present if we combine the different types of hurdles. There might be three possible results if the hurdles are given in different types of combinations :

- Additive effect- It explains the effects of individual components added to foods.
- Synergistic effect – It is inhibitory action where one component depends on the other one for giving a beneficial or better effect rather than working separately.
- Antagonistic effect- It is the effect, opposite of the other one, i.e. where the mixture concentration required is higher than that of the individual constituents

FOOD IRRADIATION

Food irradiation is a physical process like drying, freezing, canning and pasteurization. Food can be irradiated wet, dry, thawed or frozen. It is a cold process and does not cause change in texture and freshness of food unlike heat. In fact you will not be able to differentiate between irradiated and nonirradiated food on the basis of colour, flavour, taste, aroma or appearance.

This radiation technique is very effective and due to its highly penetrating nature, it can be used on packed food commodities. It means a food commodity, which is packed, can be radiated for sterilization, disinfestation or disinfection purposes and shipped directly.

As you may be aware that many chemical fumigants / preservatives are used to preserve food commodities. Which sometimes leave toxic residues in foods that may be carcinogenic in nature. Contrary to these chemical fumigants, irradiation does not leave any toxic residue in treated foods. So, it is considered very safe. Besides, radiation-processing facilities are environment friendly and safe to workers and public around.

In spite of all its benefits, the radiation processing technique is not a magic wand. It cannot be used to make spoiled or bad food look good. It cannot eliminate already present toxins and pesticides in food. It is a need based technique and can't be applied to all foods. Amenability of a particular food commodity to irradiation needs to be scientifically established and the food commodities that are duly permitted under PFA Act should only be radiation processed.

IONIZING RADIATIONS

Kinds of Ionizing Radiations

Gamma rays, X-rays and electron beam are the part of invisible light waves of electromagnetic spectrum (U.V. rays are also part of this invisible range but wavelength is not as short as that of X-rays or gamma rays). These high energy radiations can change atoms into electrically charged ions by knocking out an electron from the outer orbit and thus, are called ionizing radiations. But, at dose levels approved for food irradiation, these radiations cannot penetrate nuclei and thus, food can never become radioactive.

Other types of radiation energy with longer wavelengths are infrared and microwaves. Infrared radiation is used in conventional cooking. Microwaves, due to their relatively longer wavelength, have lower energy levels but are strong enough to move molecules and generate heat through friction.

Three types of ionizing radiations are approved to be used for food irradiation.

i) Electron beams generated from machine sources operate at a maximum energy of 10 MeV.

ii) X-rays generated from machine sources operate at a maximum energy of 5 MeV.

iii) Gamma rays are emitted from Co-60 or Ce-137 with respective energies of 1.33 and 0.67 million electron volts (MeV).

1. **Electron beams**

Electron beams are streams of very fast moving electrons produced in electron accelerators. For your better understanding, an electron beam generator is comparable to the device at the back of TV tube that propels electrons into the TV screen at the front of the tube. For irradiation using electron beams, only approved electron accelerators can be used. Electron beams have a selective application in food irradiation due to their poor penetration. They can penetrate only one and one half inches deep into the food commodity. As a result, shipping cartons (pre-packed bulk food commodities) are generally too thick to be processed with electron beams. Since electron beams are generated through machine sources, so they can be switched on or off at will and require shielding.

2. **X-rays**

X-rays are also generated through machine sources. X-rays are photons and have much better penetration and are able to penetrate through whole cartons of food products. To produce useful quantities of X-rays, a tungsten or tantalum metal plate is attached to the end of accelerator scan horn. The electrons strike the plate and X-rays are generated which pass through the metal plate and penetrate the food product conveyed underneath. But, remember that this X-ray machine is a much powerful version to the machine used in many hospitals and dental clinics. Since X-rays are generated through machine sources, so they can be switched on or off at will and require shielding.

3. **Gamma rays**

The third type of ionizing radiations approved for food processing are gamma rays that are produced from radioisotopes either Co-60 or Ce-137. Contrary to electron beams and X-rays, radioisotopes cannot be switched off or on at will and they keep on emitting gamma rays. Radioisotopes require shielding. Co-60 source is kept immersed under water when it is not in use and Ce-137 is shielded in lead. Due to their continuous operation, radioisotopes need to be replenished from time to time. Gamma rays are photons and have deep penetration ability.

Units of Irradiation

The units used to measure the effects of radiation are gray and sievert in accordance with recommendations of International Organisation for Standardisation (ISO). Formerly, units used for measuring radiation were the rad and the rem.

The gray (Gy) is the unit used to measure absorbed dose of radiation and is equal to one joule of energy absorbed per kg of matter being irradiated. 1 Gy corresponds to 100 rad.

The unit used to measure the dose equivalent to one given exposure, taking into account the different biological effectiveness of different type of radiation, is the sievert (Sv). 1 Sv corresponds to 100 rem.

The unit used to measure the activity of a given source of radiation is Becquerel (Bq). The former unit was Curie (Ci). 1 Bq is equivalent to 2.7 x 10-11 Ci.

EFFECT OF IONIZING RADIATION ON NUTRIENTS

All processes cause changes in nutritional value of foods, even storage causes fresh foods to loose nutrients. It is well demonstrated that irradiation up to 10 kGy does not cause any significant change in the nutritional value of macronutrients, i.e., lipids, proteins and carbohydrates.

Vitamins are the most essential micronutrients present in foods. Certain vitamins like A, E, C, K and B1 are radiation sensitive. They can be reduced by irradiation but they are similarly reduced when treated by other food processing methods. Irradiation may convert Vitamin C (ascorbic acid) to dehydro ascorbic acid, which is another equally usable form of Vitamin C. Fat soluble vitamins like Vitamin D are radiation resistant and survive irradiation of food products.

Minerals are virtually unchanged. Iron is oxidized but the nutrient value of oxidized iron is same as that of unoxidized iron. Other processes like freezing, thawing, storage have similar effects on iron.

So, the bottom line is that irradiation does not have any adverse impact on the nutritional content of a person’s diet.

The FAO / IAEA / WHO Joint Expert Committee has concluded that any food commodity irradiated up to an overall dose of 10 kGy is safe and wholesome for human consumption.

RADIATION SENSITIVITY OF MICROORGANISMS

In case of living organisms, exposure to radiation causes structural and functional changes in macromolecules thereby leading to cell death / injury. DNA or RNA is the most important target for radiation inactivation of living cells. Please note that a low dose that may cause little chemical changes in food can cause sufficient changes in DNA to cause cell death. As you must be aware that DNA carries genetic information and its intactness is important for it’s functioning. So, any damage to DNA will result into severe cell injury / death.

Now, radiation acts on DNA in two ways, i.e., i) direct and ii) indirect. In direct action, DNA absorbs radiation and is damaged. The damage to DNA is of various types – single strand breaks, double strand breaks (dsb), alteration of purine or pyrimidine bases or interchain bond formation. In the indirect action, other molecules like water and the free radicals thus produced react with DNA absorb radiation.

Both prokaryotic as well as eukaryotic cells possess various DNA repair mechanism, such as direct rejoining of broken ends, excision repair, past replication repair, etc. The double strand breaks are important because most of the microorganisms cannot repair these damages and cells cannot replicate.

When a population of microorganisms is irradiated with a low dose, only a few of the cells are damaged or killed. With increasing dose, the number of survivors decreases exponentially. Different species and different strains of same species require different doses to reach the same degree of inactivation. In order to characterize organisms by their radiation sensitivity, the decimal reduction dose (D10) is used. D10 is the dose required to kill 90 per cent of a population.

1. **Bacteria**

Bacteria are prokaryotic organisms. The cytoplasm is highly hydrated (70- 80% water) and is surrounded by cytoplasmic membrane and a cell wall. Chromosomal DNA is not surrounded by a nuclear membrane. Because of high water content and large amount of DNA, bacteria are very sensitive to radiation.

In general, gram –ve bacteria are more sensitive while some gram +ve cocci are extremely resistant due to their highly efficient DNA repair system. Spores are 10-20 times more resistant than vegetative cells because they have little or no free water and are surrounded by thick impermeable wall. Each bacterium is characterized by a particular D10 value reflecting its inherent sensitivity to radiation. Certain extrinsic factors like temperature, O2 content, water activity, nature of medium and presence or absence of sensitizers or protectors also determine the D10 value of a particular microorganism.

2. **Virus**

Viruses are simplest biological entities. They are metabolically dormant and do not contain cytoplasm or metabolic enzymes needed for growth. They are the obligate intracellular parasites. The simplest virus particle consists, basically, of a nucleic acid genome (DNA or RNA) and a protein coat. The genome size is 100 to 1000 times smaller than that of bacteria. Therefore, viruses are considerably more resistant to radiation than bacteria or fungi. Further, estimation of dose requirements, to ensure safety from viral infections solely through irradiation, ranged from 20 to 100 kGy, which makes irradiation an unlikely choice for virus treatment in foods.

3. **Yeasts and Moulds**

Yeats and moulds are eukaryotic cells, i.e., they have a true nucleus. Generally, they are as sensitive to radiation as vegetative cells of bacteria. However, filamentous fungi contain more than one nucleus (may be 100 nucleus per cell) and are highly resistant to radiation.

4. **Prion**

The prion particles associated with BSE (Bovine spongiform encephalopathy), commonly known as mad cow disease, do not have nuclei at all. They are not inactivated by irradiation except at extremely high doses. This means irradiation will work very well to eliminate parasites and bacteria from food but will not work to eliminate viruses and prions.

PRACTICAL APPLICATIONS OF FOOD IRRADIATION

The recommended doses of ionizing radiation for different purposes in food preservation are different as explained below

a). Low dose, up to 1 kGy

- Sprout inhibition in bulbs and tubers (0.03 – 0.15 kGy).
- Delay in fruit ripening (0.25 – 0.75 kGy).
- Insect dis-infestation and elimination of food-borne parasites (0.25 – 1 kGy).

b) Medium dose, 1 – 10 kGy

- Reduction of spoilage microbes to improve shelf-life of meat, poultry and sea foods under refrigeration (1.5 – 3 kGy).
- Elimination of pathogenic microbes in fresh and frozen meat, poultry & sea foods (3 – 7 kGy).
- Reduction of microbes in spices to improve hygiene (10 kGy).

c) High dose, 25 – 70 kGy

- Elimination of viruses.
- Sterilization of packaged meat, poultry and their products which are shelf stable without refrigeration (25 – 70 kGy).
- Sterilization of hospital diets for immuno compromised patients.
- Food for astronauts in space.

BENEFICIAL ASPECTS OF FOOD IRRADIATION

Decontamination of Spices

Spices, herbs and vegetable seasonings are valued for their distinctive flavours, colours and aromas. Unfortunately, they are often contaminated with high levels of bacteria, moulds and yeasts. If untreated, the spices will result in rapid spoilage of foods they are supposed to enhance. Since spices are often contaminated with pathogenic bacteria, they can result in serious food-borne illnesses.

Spices are generally decontaminated by irradiation or fumigation with ethylene oxide gas (ETO). To understand the advantages of irradiation over ETO, the various points are given below:

1. **Effectiveness**

Irradiation is considered the most effective way to sanitize spices and the most countries have allowed it worldwide. Irradiation at a dose between 7.5 – 15 kGy (average dose 10 kGy) has been established to effectively control the microbiological contamination. Storage further enhances the sanitation effect because injured cells are unable to repair and die out over the time.

In comparison, ETO is far less effective. Although, it is a known fact that ETO is highly toxic to microbial contaminants but, it cannot be used alone. To stabilize ETO, it is mixed with 80% CO2 and steam is used to deliver the gases, which in turn, reduces its microbiological efficacy. Infact, steam increases the moisture level of treated spices and may result in increased mould growth. Moreover, ETO has low penetration than radiation and hence, bulk ground spices cannot be treated effectively using ETO.

Further, to meet the requirements of international standards, spices are generally treated twice or more with ETO and thus, can easily result into unacceptable high levels of toxic chemical residues in treated spices. On the contrary, irradiation is an effective one time process.

2. **Toxic residues**

ETO reacts with organic spice components to leave harmful residues, like ethylene chlorohydrin and ethylene bromohydrin, in spices. Ethylene chlorohydrin is a known carcinogen that persists in the spices for many months, even after food processing. For this reason, ETO is banned in many countries. On the contrary, irradiation does not leave any harmful toxic residue and is completely safe.

3. **Loss of sensory attributes**

The use of steam with ETO is a strong argument against its use as a spice treatment. Steam results in the loss of volatile oils and hence, loss of aroma and flavour. Treatment with ETO can also result in unacceptable colour change. It results into darkening of onion and garlic powder. Chilies, paprika and turmeric may loose their bright colour. It may cause development of off-flavours in mustard and mustard flour.

On the other hand, radiation treatment preserves all sensory attributes in spices. Chili, paprika and turmeric colours are stable to radiation treatment.

4. **Environment safety issues**

Since ETO is a known carcinogen, worker safety issues are the biggest concern in ETO operations. Irradiation has been established as an environment friendly food processing technique.

5. **Packaging problems**

Most spice packaging materials are compatible with irradiation. Spices packed in bulk packages, retail packages, heat-sealed bags, and gas impervious packs, can be easily and effectively irradiated. Irradiation allows the spice package to remain closed and sealed at all times. On the other hand, in ETO treatment gas impervious packs cannot be used. Further, after treating with ETO, spice packages need to be stored open (for a week or so) gas escape. This causes increased warehousing cost as well as recontamination of spices. In irradiation, there is no waiting period after processing and the material can be shipped directly and thus, no additional storage costs are incurred.

So on the basis of above-mentioned facts, it is concluded that irradiation is the most effective method to sanitize spices, particularly because.

- it results in cleaner, better quality spices,
- it does not significantly change the sensory or functional properties of spices,
- it results in much lower levels of microbial contamination and thus, it is an effective treatment to meet international standards of food safety.

A prototype commercial demonstration irradiator with a throughput of 20 tonnes per day for treatment of spices is operational in Vashi, Navi Mumbai. This is under the management of Board of Radiation and Isotope Technology (BRIT), a constituent unit of Deptt. of Atomic Energy (DAE), BARC, Mumbai. A commercial irradiator, Shriram Applied Radiation Centre (SARC), a constituent unit of Shriram Institute for Industrial Research, Delhi is also licensed by AERB to irradiate spices for sanitization.

6. **Delayed Ripening in Fruits**

Irradiation at low dose levels (0.25 to 0.75 kGy) can delay ripening and overripening in mature but unripe tropical fruits like banana, mango and papaya. Climacteric fruits exhibit delay in ripening only if irradiated in the preclimacteric stage. Once the ripening has been initiated, irradiation does not change or alter the course of ripening.

The self-life of irradiated fruits can further be extended by combing other post harvest procedures like waxing, packaging in perforated bags, refrigeration and modified atmosphere.

7. **Sprout Inhibition in Tubers and Bulbs**

Traditionally, onions are bulk stored under ambient conditions in chawls, medas or sheds, the size and design of which varies from region to region. During prolonged storage, losses occur due to sprouting, desiccation and microbial rottage. The estimated losses are 30–50 per cent. Low ambient temperature and high humidity during rainy season promote sprouting. The losses through microbial spoilage can be reduced but sprouting can’t be checked by improving ventilation. Sprouting alone causes 25–30 per cent of total losses. Sprouted onions shrivel faster due to increased water loss by transpiration. The reserve food substances present in the fleshy scales are also used up for the sprout growth, which ultimately renders the onion bulb unfit for consumption

Some chemical sprout inhibitors such as maleic hydrazide and isopropyl carbamate are used in temperate countries but these are not very effective in sub-tropical and tropical climates. Cold storage at 0-1°C with low relative humidity (65-70%) is also practiced in many temperate countries but strict temperature and humidity control is must. Moreover, cold storage is energy intensive and expensive technique.

On the other hand, irradiation at very low dose levels (0.06-0.09kGy) inhibits sprouting when properly cured bulbs are irradiated within 2-3 weeks of harvesting.

Potatoes cannot be stored more than 4-6 weeks at ambient temperature. They are stored in cold storage at 2-4°C having relative humidity 85-95 per cent. Since the refrigeration facilities in India are not meeting the requirements of increased crop production, so it is feared that 25-30 per cent of the commodity is lost within 2-3 months of harvesting due to dehydration and microbial spoilage.

Irradiation of potatoes combined with refrigeration at 15°C can extend the storage period up to six months with minimum losses. Irradiation has extra benefit over prevailing refrigeration technique.

In general, irradiation at the dose levels required for sprout inhibition of bulbs and tubers does not change their texture, and external appearance, sensory qualities and processing potential.

The first prototype commercial demonstration irradiator for potatoes and onions (POTON) with a throughput of 10 tonnes/hour is being set up in Lasalgaon, Nashik, Maharashtra. This unit is under the management of Board of Radiation & Isotope Technology (BRIT), a constituent unit of Department of Atomic Energy (DAE), BARC, Mumbai. Besides, two pilot plant irradiation facilities, namely the Food Package Irradiator in Food Technology Division, BARC, Mumbai and another at the Defense Laboratory, Jodhpur have been licensed for irradiating food items that have been cleared for domestic trade and consumption.

Irradiation has the same objectives as other food processing methods - the reduction of losses due to spoilage and deterioration and control of the microbes and other organisms that cause food borne diseases. But the techniques and equipment employed to irradiate food, the health and safety requirements that have to be taken into account, and a variety of problems that are unique to this way of processing food, put food irradiation into a category by itself. An understanding of how irradiation compares with the more conventional ways of processing food should begin with a brief, non-technical account of what the process is and how it works.

Ionizing radiation

Many of the traditional methods of food processing make use of energy in one form or another - the heat used in canning and sun-drying, for example. Food irradiation employs a particular form of electromagnetic energy, the energy of ionizing radiation. X-rays, which are a form of ionizing radiation, were discovered in 1895. Radioactivity and its associated ionizing radiations, alpha, beta, and gamma rays, were discovered the following year. (The term "ionizing radiation" has been used to describe these various rays because they cause whatever material they strike to produce electrically charged particles, called ions.)

Early experiments showed that ionizing radiation kills bacteria. There followed a number of isolated efforts to use this newly discovered energy to destroy the bacteria responsible for food spoilage. Promising and scientifically interesting as they were, these early efforts did not lead to the use of ionizing radiation by the food industry. At the turn of the century and for many years thereafter, there was no cost-effective way of obtaining radiation sources in the quantity required for industrial application. The X-ray generators of the day were very inefficient in converting electric power to X-rays, and the naturally occurring radioactive materials, such as radium, were too scarce to provide gamma rays, or other forms of radiation, in sufficient quantities for food processing.

In the early 1940s, advances in two areas paved the way for the economic production of sources of ionizing radiation in the amounts needed for industrial food processing. Machines, principally electron accelerators, were designed and developed that could generate ionizing radiation in unprecedented amounts and at acceptable cost. The other avenue of discovery was the study of atomic fission, which produced not only nuclear energy, but also fission products, such as caesium-137, that were themselves sources of ionizing radiation. The related discovery that certain elements could be made radioactive led to the production of other gamma-ray sources, such as cobalt-60. These advances stimulated renewed interest in food irradiation. Investigations using these new energy sources made it increasingly evident that ionizing radiation had the potential, at least, to become a powerful weapon in the battle against preventable food loss and foodborne illness.

Uses of food irradiation

Many of the practical applications of food irradiation have to do with preservation. Radiation inactivates food spoilage organisms, including bacteria, moulds, and yeasts. It is effective in lengthening the shelf-life of fresh fruits and vegetables by controlling the normal biological changes associated with ripening, maturation, sprouting, and finally aging. For example, radiation delays the ripening of green bananas, inhibits the sprouting of potatoes and onions, and prevents the greening of endive and white potatoes. Radiation also destroys disease-causing organisms, including parasitic worms and insect pests, that damage food in storage. As with other forms of food processing, radiation produces some useful chemical changes in food. For example, it softens legumes (beans), and thus shortens the cooking time. It also increases the yield of juice from grapes, and speeds the drying rate of plums.

Sources of ionizing radiation

As has been mentioned, an essential requirement for the industrial use of food irradiation is an economic source of radiation energy. Two types of radiation source can satisfy this requirement today: machines and man-made materials. Although they differ in the method of operation, both types of source produce identical effects on foods, microorganisms, and insects.

Machines called electron accelerators produce electron radiation, a form of ionizing radiation. Electrons are sub-atomic particles having very small mass and a negative electric charge. Beams of accelerated electrons can be used to irradiate foods at relatively low cost. 'Fhis cost advantage is offset, however, by the fact that accelerated electron beams can penetrate food only to a maximum depth of about 8 em, which is not deep enough to meet all the goals of food irradiation. Accelerated electrons are, therefore, particularly useful for treating grain or animal feed that can be processed in thin layers; electron beam irradiation is particularly suitable for these applications because of the very high throughputs involved in grain handling and the convenience of being able to switch the machine on and off at will.

Another machine source of ionizing radiation is the X-ray generator. An X-ray is a wave-form of energy similar to light. Unlike accelerated electrons, X-rays have great power to penetrate some materials. But as the early experimenters found, converting electricity into X-rays is a very inefficient, hence expensive, operation. The X-ray machines available for food processing have generally been adapted from those used in medical and industrial radiography and are not well suited to supply the power needed for food processing. Recent developments suggest that these problems of cost and power output may be solved by a new type of X-ray generator.

Man-made radionuclides constitute the other main source of ionizing radiation; radionuclides are radioactive materials that, as they decay, give off ionizing gamma-rays that can be used for food processing. One radionuclide that is readily available in large quantities is cobalt-60, which is produced by exposing naturally occurring cobalt-59 to neutrons in a nuclear reactor. The availability of another radionuclide, caesium-137, a by-product of nuclear reactor operations, is limited and it is not used widely at present. Gammarays from either of these radionuclides will penetrate deeply enough to meet virtually all food irradiation needs. The cost of man-made radionuclide sources is considered acceptable for industrial food irradiation in view of the great versatility and penetrating capacity of the gamma-rays.

Changes in sensory characteristics

The chemical changes that radiation produces in food may lead to noticeable effects on flavour. The extent of these effects depends principally on the type of food being irradiated, on the radiation dose, and on various other factors, such as temperature, during radiation processing.

Some foods react unfavourably even to low doses of radiation. Milk and certain other dairy products are among the most radiationsensitive foods. Doses as low as 0.1 kGy will impart an off-flavour to milk that most consumers find unacceptable.

The high radiation dose required for sterilization has been associated with unwanted flavour changes in meat, and it appears that the change occurs in the lean rather than the fat portion of meat. Irradiation of lean cuts of meat produces more off-flavour than irradiation of cuts with a higher fat content. Furthermore, pork is less adversely affected than beef or veal, presumably because of its higher fat content. The off-flavour is most pronounced immediately after irradiation; it decreases or disappears during storage and cooking. Investigators have also observed that meat irradiated at low temperature is less liable to flavour change. Enzyme-inactivated, vacuum-packed beef, chicken, pork, and various meat products that received about 50 kGy of radiation at a temperature of - 30°C for long-term shelf-stability were judged to have an acceptable flavour by panels of food experts and consumers in one study.

Colour is another property of meat that can be changed by irradiation. Doses higher than 1.5 kGy may cause a brown discoloration of meat exposed to air.

The practical upper dosage limit for the irradiation of fruits and vegetables is determined by effects on the firmness of the plant tissue. Depending on the product being processed, radiation doses of 1-3 kGy will cause softening of some fruits. This effect is not really a direct result of the radiation; it is, instead, a physiological response - the breakdown of cell membranes by the action of enzymes. This softening is not immediately noticeable; it begins to appear hours or even days after the exposure to radiation.

Other sensory or physical changes caused by irradiation include a thinning (reduced viscosity) of soups and gravies whose starch components, such as potatoes and grains, have been irradiated. The effect is not seen at the relatively low doses required to inhibit sprouting or control insects, but it can occur at higher doses - above 1 kGy. In certain situations, this effect of irradiation is desirable. It appears to account for the reduced cooking time required for dry soups and also to improve the rehydration properties of dried fruits.

Changes in nutritional quality

Food processing and preparation methods in general tend to result in some loss of nutrients. As in other chemical reactions produced by irradiation, nutritional changes are primarily related to dose. The composition of the food and other factors, such as temperature and the presence or absence of air, also influence nutrient loss. At low doses, up to 1 kGy, the loss of nutrients from food is insignificant. In the medium-dose range, 1-10 kGy, some vitamin loss may occur in food exposed to air during irradiation or storage. At high dosages, 10-50 kGy, vitamin loss can be mitigated by protective measures - irradiation at low temperatures and exclusion of air during processing and storage. The use of these measures can hold the vitamin loss associated with high dosage to the levels seen with medium-range doses when protective measures are not employed.

Some vitamins - riboflavin, niacin, and vitamin D - are fairly insensitive to irradiation. Others, such as vitamins A, B , E, and K are more easily destroyed. Little is known about the dffect of irradiation on folic acid, and conflicting results have been reported concerning the effects of irradiation on vitamin C in fruits and vegetables.

The significance of radiation-induced vitamin loss in a particular food depends, of course, on how important that food is as a source of vitamins for the people who consume it. For example, if a specific food product is the sole dietary source of vitamin A for a given population, then radiation processing of that particular food may be inadvisable because it could greatly reduce the availability of this essential nutrient. Furthermore, since many irradiated foods are cooked before use, the cumulative loss of vitamins through processing and cooking should be taken into account. Chemical analyses and animal feeding studies have shown that the nutritional value of proteins is little affected by irradiation, even at high doses. Animal studies in various species have also demonstrated that the effects of radiation on other nutrients are minimal.

ULTRASONIC PROCESSING: PROPERTIES AND APPLICATIONS

Introduction

Ultrasound is defined as sound waves having frequency that exceeds the hearing limit of the human ear (~20 kHz). Some animals utilize ultrasound for navigation (dolphins) or hunting (bats) using the information carried by back-scattering sound waves. Ultrasound is one of the emerging technologies that were developed to minimize processing, maximize quality and ensure the safety of food products. Ultrasound is applied to impart positive effects in food processing such as improvement in mass transfer, food preservation, assistance of thermal treatments and manipulation of texture and food analysis (Knorr et al., 2011). Ultrasound (i.e., mechanical waves at a frequency above the threshold of human hearing) can be divided into three frequency ranges; power ultrasound (16–100 kHz), high frequency ultrasound (100 kHz–1 MHz) and diagnostic ultrasound (1–10 MHz) (Patist and Bates,2008).

In recent years, ultrasound technology has been used as an alternative processing option to conventional thermal approaches. Ultrasonication can pasteurize and preserve foods by inactivating many enzymes and microorganisms at mild temperature conditions, which can improve food quality in addition to guaranteeing stability and safety of foods. In addition, the changes to the physical properties of ultrasound, such as scattering and attenuation caused by food materials have been used in food quality assurance applications (Chandrapala et al.2012). Ultrasound is composed of sound waves with frequency beyond the limit of human hearing. By tuning frequency, ultrasound can be utilized in many industrial applications including food. Ultrasound techniques are relatively cheap, simple and energy saving, and thus became an emerging technology for probing and modifying food products (Awad et al. 2012). Based on frequency range, the applications of ultrasound in food processing, analysis and quality control can be divided into low and high energy. Low energy (low power, low intensity) ultrasound has frequencies higher than 100 kHz at intensities below 1 W·cm2, which can be utilized for non-invasive analysis and monitoring of various food materials during processing and storage to ensure high quality and safety. Low power ultrasound has been used to nondestructively support genetic improvement programs for livestock and for evaluating the composition of raw and fermented meat products, fish and poultry. It is also used for the quality control of fresh vegetables and fruits in both pre- and postharvest, cheese during processing, commercial cooking oils, bread and cereal products, bulk and emulsified fat based food products, food gels, aerated and frozen foods. Other applications include the detection of honey adulteration and assessment of the aggregation state, size and type of protein.

High energy (high power, high-intensity) ultrasound uses intensities higher than $1 W \cdot cm^{-2}$ at frequencies between 20 and 500 kHz, which are disruptive and induce effects on the physical, mechanical or chemical/biochemical properties of foods. These effects are promising in food processing, preservation and safety. This emerging technology has been used as alternative to conventional food processing operations for controlling microstructure and modifying textural characteristics of fat products (sono crystallization), emulsification, defoaming, modifying the functional properties of different food proteins, inactivation or acceleration of enzymatic activity to enhance shelf life and quality of food products, microbial inactivation, freezing, thawing, freeze drying and concentration, drying and facilitating the extraction of various food and bioactive components.(Gallego-Juarez et al.2010). Utilization of ultrasound in food technology for processing, preservation and extraction is such a system that has evolved to keep the wheel of development rolling. Ultrasound makes use of physical and chemical phenomena that are fundamentally different compared with those applied in conventional extraction, processing or preservation techniques. Ultrasound offers a net advantage in term of productivity, yield and selectivity, with better processing time, enhanced quality, reduced chemical and physical hazards, and is environmentally friendly (Chemat et al.2011).

Microbial quality control is an important stage of the production chain for many food products in which biological contamination would have adverse effects on food quality. Acoustic streaming induced by ultrasound in a liquid is affected by the microbial activity, and thus, bacteria that alter the physicochemical parameters of a liquid (e.g. viscosity, elasticity) can be detected through the use of ultrasonic waves (Elvira et al., 2006). Ultrasound refers to sound waves beyond the audible frequency range (in general, >20 kHz). When ultrasound passes through a liquid medium, the interaction between the ultrasonic waves, liquid and dissolved gas leads to an exciting phenomenon known as acoustic cavitation (AC). The main mechanism responsible for the ultrasonic deactivation effect is the physical forces generated by acoustic cavitation. The asymmetric collapse of a cavitation bubble leads to a liquid jet rushing through the centre of the collapsing bubble. The speed of this microjet is a few hundred metres per second. Due to this high speed jet, pitting on solid surfaces has been observed.

Microorganisms may have hydrophobic surfaces, which will promote the collapse of the cavitation bubbles on the surface leading to severe damage to the cell wall. Similarly, the microstreaming can lead to the erosion of cell walls, resulting in the inactivation of the microorganisms (Chandrapala et al. 2012). High power ultrasound has only recently (<5 years) become an efficient tool for large scale commercial applications, such as emulsification, homogenization, extraction, crystallization, dewatering, low temperature pasteurization, degassing, defoaming, activation and inactivation of enzymes, particle size reduction and viscosity alteration. This can be attributed to improved equipment design and higher efficiencies of large scale continuous flow-through systems. Like most innovative food processing technologies, high power ultrasonics is not an off-the-shelf technology and therefore needs to be developed and scaled up for each application (Patist and Bates,2008).

Properties of ultrasonic waves:

Ultrasonic waves are high frequency waves that have a heating effect. They also have smaller wavelength than all the other waves and they form stationary wave pattern when passing through liquids. The ultrasonic waves have constant velocity in homogeneous medium. Many modes of vibration. High resolution, used for flaw detection. Sonic beam and highly energetic.

1. The ultrasonic waves cannot travel through vacuum.
2. These waves travel with speed of sound in a given medium.
3. Their velocity remains constant in homogeneous media.

4. These waves can weld certain plastics, metals etc.
5. These can produce vibrations in low viscosity liquids.
6. The ultrasonic waves are reflected and refracted just like light waves.
7. As ultrasonic waves cannot travel through vacuum, therefore if these waves travel through a non- homogeneous medium, then at each discontinuity like crack or change in density or presence of impurity etc., the amplitude and thus intensity of ultrasonic waves decreases by some amount. This decrease in intensity of ultrasonic waves as these travel through a medium is called Attenuation. The vacuum in the material causes strong reflection of ultrasonic waves while impurities or discontinuity cause the scattering of ultrasonic waves leading to net decrease in intensity. The attenuation is increased with increase in frequency of ultrasonic waves for a given medium. The intensity of ultrasonic waves decreases exponentially according to the relation.
8. The speed of ultrasonic waves/acoustic waves is more in more dense media.
9. Ultrasound travels through various media including gases, liquids and solids, but cannot travel through a vacuum. The speed of sound varies by the medium it travels through. Sound is likely to travel faster through solids, followed by liquids and gases. For example, the speed of sound in the air is about 340 meters per second (m/s). That in water is about 1530 m/s and that in iron as high as about 5,850 m/s. Another typical property of sound is that its energy is more likely to be lost in gases while it travels through liquids or solids more efficiently.

Table 1
Applications of ultrasound in food processing.

Applications	Conventional methods	Ultrasound principle	Advantages	Products
Cooking	Stove Fryer Water bath, …	Uniform heat transfer	Less time Improving heat transfer and organoleptic quality	Meat Vegetables
Freezing/crystallization	Freezer Freezing by immersion, by contact, …	Uniform heat transfer	Less time Small crystals Improving diffusion Rapid temperature decreasing	Meat Vegetables Fruits Milk products
Drying	Atomisation Hot gas stream Freezing Pulverisation	Uniform heat transfer	Less time Improving organoleptic quality Improving heat transfer	Dehydrated products (fruits, vegetables, …)
Pickling/marinating	Brine	Increasing mass transfer	Less time Improving organoleptic quality Product stability	Vegetables Meat Fish Cheese
Degassing	Mechanical treatment	Compression-rarefaction phenomenon	Less time Improving hygiene	Chocolate Fermented products (Beer, …)
Filtration	Filters (membranes semi-permeable, …)	Vibrations	Less time Improving filtration	Liquids (juices, …)
Demoulding	Greasing moulds Teflon moulds Silicon moulds	Vibrations	Less time Reducing products losses	Cooked products (cake, …)
Defoaming	Thermal treatment Chemical treatment Electrical treatment Mechanical treatment	Cavitation phenomenon	Less time Improving hygiene	Carbonated drinks Fermented products (Beer, …)
Emulsification	Mechanical treatment	Cavitation phenomenon	Less time Emulsion stability	Emulsions (ketchup, mayonnaise, …)
Oxidation	Contact with air	Cavitation phenomenon	Less time	Alcohols (wine, whisky, …)
Cutting	Knives	Cavitation phenomenon	Less time Reducing products losses Accurate and repetitive cutting	Fragile products (cake, cheese, …)

Ultrasound in food processing:

Nowadays, the processed foods that are flourishing in supermarkets are modern processed foods and traditional foods, but their manufacturing, processing and packaging technologies have been advanced and rationalized to an incomparable extent. The principle aims of these technologies are to reduce the processing time, save energy and improve the shelf life and quality of food products. Thermal technologies (radio frequency and microwave heating), vacuum cooling technology, high pressure processing and pulsed electric field technology are those novel technologies who have potential for producing high-quality and safe food products but current limitations related with high investment costs, full control of variables associated with the process operation, lack of regulatory approval and importantly consumer acceptance have been delaying a wider implementation of these technologies at the industrial scale. In recent years, ultrasound (US) in the food industry has been the subject of research and development. There is a great interest in ultrasound due to the fact that industries can be provided with practical and reliable ultrasound equipment. Nowadays, its emergence as green novel technology has also attracted the attention to its role in the environment sustainability. Ultrasound applications are based on three different methods:

- Direct application to the product.
- Coupling with the device.
- Submergence in an ultrasonic bath.

Several processes such as freezing, cutting, drying, tempering, bleaching, sterilization, and extraction have been applied efficiently in the food industry. The advantages of using ultrasound for food processing, includes: more effective mixing and micro-mixing, faster energy and mass transfer, reduced thermal and concentration gradients, reduced temperature, selective extraction, reduced equipment size, faster response to process extraction control, faster start-up, increased production, and elimination of process steps. Food processes performed under the action of ultrasound are believed to be affected in part by cavitation phenomena and mass transfer enhancement.

Ultrasound has not only attracted considerable interest in the food industry due to its positive effects in processing, but more recently due to its promising effects in food preservation. Knorr (2004) shows successful reduction of E. coli in liquid whole egg using ultrasound. Generally, most micro-organisms showed greater sensitivity to ultrasound at increased temperatures over 50°C (Villamiel & de Jong, 2000). Elevated temperature weakens the bacterial membrane, which enhances the effect of cavitation due to the ultrasound. 'Ultrasonic pasteurization' at 50°C has the potential of preserving the quality of many food products in terms of physicochemical properties, color, and flavor compared to conventional pasteurization techniques at much higher temperatures (Patist and Bates, 2008).

Filtration:

In the food industry, the separation of solids from liquids is an important procedure either for the production of solid-free liquid or to produce a solid isolated from its mother liquor. But the deposition of solid materials on the surface of filtration membrane is one of the main problems. The application of ultrasonic energy can increase the flux by breaking the concentration polarization and cake layer at the membrane surface without affecting the intrinsic permeability of membrane (Fig. 1). The liquid jet serves as the basis for cleaning, and some other cavitational mechanisms lead to particle release from the blocked membrane. Ultrasonically assisted filtration (generally referred to as acoustic filtration) has been successfully employed to enhance the filtration of industrial wastewater that is generally considered difficult to process. Moreover, the optimized ultrasound intensity is very important to prevent the damage of filters. Ultrasound can also be applied to the production of fruit extracts and drinks. In the case of juice extraction from apple pulp, conventional belt vacuum filtration achieves a reduction in moisture content from an initial value of 85% to 50%, whereas electroacoustic technology achieved 38%. The use of ultrasound in combination with membrane filtration has also been investigated, with positive results. Here ultrasonic irradiation at low power levels was employed to aid the filtration of whey solutions.

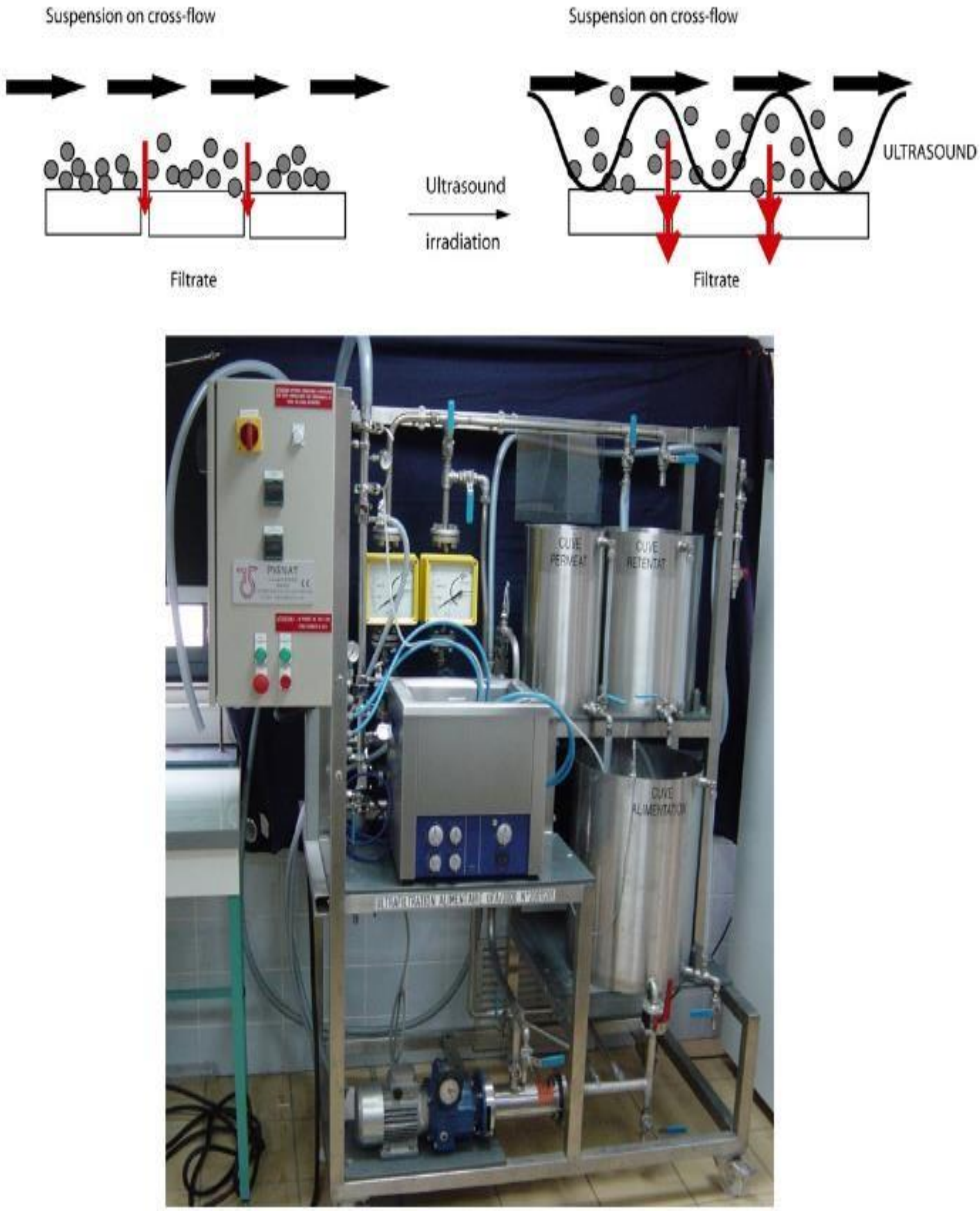


Fig. 1. Enhancement of permeability using ultrasound.

Applications of ultrasound:

Meat products:

In the beef industry, **ultrasound** has been a fast, reproducible and reliable technology to enhance genetic improvement programs for livestock (Crews & Kemp, 2002). Real time ultrasound has become widely used for estimation of the body and carcass chemical composition of growing lambs (Ribeiro et al., 2008), sheep carcass (Silva et al., 2006) and degree of muscle development in lamb (Theriault, Pomar, &Castonguay, 2009) and it has also been used for studying the composition of fish and poultry. Ultrasound used to determine the composition of chicken analogs and the solid fat content of chicken fat (Chanamai & McClements, 1999) suggesting the advantages of LPU as a rapid and non destructive method in food analysis. Ultrasonic velocity and temperature profiles were also used to study the composition of Atlantic mackerel (Scomber scombrus) tissues including fat content, solids and non-fat content (Sigfusson, Decker, & McClements, 2001). Ultrasound velocity measurements (UVM) have been used to determine the composition of raw meat mixtures (Benedito, Carcel, Rossello, & Mulet, 2001).

The quality of meat depends on the aroma, flavour, appearance, tenderness and juiciness. Consumer behavioural has shown that tenderness is most important palatability factor in determining meat quality. The traditional method used for meat tenderization is mechanical pounding, which makes poorer quality meat more palatable. Power ultrasound has also been found to be useful for this process. Ultrasound can act in two ways: by breaking the integrity of muscular cells or by enhancing enzymatic reactions, i.e. via a biochemical effect. Sonicating beef muscle at $2Wcm^2$ for 2 h at 40 kHz produced damage to the perimysal connective tissue, resulting in improved eating texture. Ultrasonic tenderization can be achieved with poultry meat, veal and beef. In the course of investigations into meat sterilization using heat and ultrasound, it was found that a side-effect was tenderization. It proved possible to reduce traditional heat treatment by 50% by using high-energy ultrasound. From these tests, it was concluded that an increased kill effect on micro-organisms could be achieved in various food test systems by using a combination of ultrasound and mild heating, a process known as thermosonication, or with pressure mano-sonication. Ultrasound has been used in the production of processed meats. In recombined meat products such as beef rolls, the pieces of muscle are held together by a protein gel, formed by the myofibrillar proteins released during processing. Tumbling the meat pieces and adding salt achieve this release. A sticky exudate is formed on the pieces, which binds them together when they are compressed. The binding strength, water holding capacity, product colour and yields were examined after treatment with either salt tumbling or sonication or both. Samples that received both salt treatment and sonication were superior in all qualities. Hence ultrasound can lead to improved physical properties of meat products, such as water-binding capacity, tenderness and cohesiveness.

Application of ultrasound for Brining, pickling and marinating:

Pickling and marinating are used for a wide variety of vegetables and meat products. Most current salt-brining or pickling-fermentation processes are subject to three main drawbacks: (1) in brining, a very high sodium chloride content is required, which may require a 'desalting' process prior to shipping to reduce the sodium chloride content of the product; (2) there is a potential lack of control in fermentation due to the occurrence of natural outside intrusion of ‘wild’ fermentation; and (3) any soaking process can lead to enzymatic softening, structural damage and bloating. All three of these side-effects are detrimental to rapid and efficient food preservation and so alternative technologies are of interest to food producers. Ultrasound allows the pickling time of products to be reduced considerably, particularly those foods with a crunchy texture. It also provides a method for manufacturing a pickle having a low level of sodium chloride compared with the pickles currently on the market. Hence there is no need to ‘desalt’, repack to reach the desired finished product salt level. Brining is a two way mass transfer process as the water migrates from the meat to the brine and solute from the brine to the meat. Pork loin slices were immersed in a saturated solution of NaCl at 21ºC for 45 min and different types of agitation of the solution and different levels of ultrasound intensity were applied during brining. It was found that the water and NaCl contents of samples after treatment were higher in sonicated than non-sonicated samples. Moreover, ultrasound reduces the salting time, the formation of a crust and unwanted colouring of raw meat. The process also provides a product which is uniformly salted. In the cheese industry, the effect of ultrasound on mass transfer during cheese brining has been investigated. Many cheese varieties are salted by immersion in brine. Moreover, the influence of different process conditions, such as the use of agitation, brine concentration, sample: brine ratio and temperature, can be affected by acoustic energy. The rate of water removal and sodium chloride gain increased when ultrasound was applied in comparison with brining performed under static or dynamic conditions, suggesting that ultrasound improves both external and internal mass transfer.

Fig. 2. Ultrasound extraction devices for liquid and solid products. (www.etsreus.com)

In the food industry, this Ultrasound technique can be used to degas carbonated beverages such as beer (defobbing) before bottling. In the processing of carbonated drinks, the purpose is to displace the air from the liquid surface in order to avoid organoleptic damage of the product by bacteria and oxygen. This process involves coupling a transducer to the outside of the bottle, leading to degassing. Compared with mechanical agitation, the ultrasonic method decreases the number of broken bottles and overflow of the beverage. The application of relatively low-intensity ultrasound during the fermentation of saké, beer and wine resulted is a reduction in the time required by 36–50%. Ultrasonically assisted degassing is particularly rapid in aqueous systems, but the removal of gas is much more difficult in very viscous liquids such as melted chocolate. Ultrasound technology has a wide range of current and future applications in the food industry. These industrial applications include texture, viscosity and concentrations measurements of many solid or fluid foods; composition determination of eggs, meats, fruits and vegetables, dairy and others products; thickness, flow level and temperature measurements for monitoring and control of several processes; and non-destructive inspection of whole fruits and vegetables, egg shells and food packages and also listed direct process improvements such as cleaning surfaces, enhancement of dewatering, drying and filtration, inactivation of micro-organisms and enzymes, disruption of cells, degassing of liquids, acceleration of heat transfer and extraction processes, and enhancement of any process dependent upon diffusion of the ultrasonic extraction processes, biological cell

Fruits and vegetables:

Plant foods including fruits and vegetables are highly attenuating materials due to the scattering of sound from voids and pores, which complicates the interpretation of ultrasound data and thereby unsuitable for evaluating their tissues. Mizrach, (2008) studied the application of ultrasound for the quality control of fresh vegetables and fruits in both pre- and postharvest applications and Mizrach explained the various physiological and physiochemical changes taking place during growth and maturation, and in the course of the harvest period, storage and shelf-life, and how linking the results of ultrasound measurements and other physiochemical measurements, such as firmness, mealiness, dry weight percentage (DW), oil contents, total soluble solids (TSS), and acidity enables the indirect assessment of the proper harvesting time, storage period or shelf-life (Mizrach, 2008). An early study has shown that the amplitude of the ultrasound wave transmitted through fruit peels increased when the color changed from green to yellow indicating a good correlation between the ripeness and the acoustic attenuation (Mizrach et al., 1991). In other work, the maturity and sugar content of plum fruits determined by measuring ultrasound attenuation in the fruit tissue correlated well with the firmness of plums (Mizrach, 2004) and that of tomato in other study (Mizrach, 2007). This proved the importance of using the attenuation parameter, which has also been used earlier for detecting defective potatoes (Cheng & Haugh, 1994). Ultrasound velocity measurements have also been used to determine the content of different sugar species in fruit juices and drinks (Contreras, Fairley, McClements & Povey, 1992). A non-contact ultrasonic system operating in either pulse–echo or through-transmission mode was used to measure the sugar content and viscosity of reconstituted orange juice (Kuo, Sheng, & Ting, 2008). This system gave a good linear correlation with sugar contents in solution denoted by Brix, and an exponential correlation with viscosity. Another application of ultrasound velocity measurements is for the evaluation of oil composition, purity and quality. Sankarappa and coauthors measured the density and ultrasonic velocity at a frequency of 3 MHz in some refined and unrefined edible oils of coconut, castor, sunflower, safflower and groundnut (Sankarappa, Kumar, & Ahmad, 2005), which allowed to estimate various physical parameters (e.g., specific volume, molar sound velocity, adiabatic compressibility, molar compressibility and intermolecular free length).

Low intensity ultrasound (50 or 100 kHz) has been used to assess the quality of various fruits and vegetables, including apples, tomatoes, carrots, avocadoes, mangoes and melons according to ripeness/texture/firmness. This was achieved by evaluating ultrasound parameters (velocity, attenuation) in relation to the physical characteristics (texture/firmness, total soluble solids, dry weight, and acidity) of the produce. Ultrasound has also been used as a pretreatment prior to the drying of a range of vegetables. The treatment produced a reduction in subsequent conventional and freeze-drying times and also in rehydration properties. The peroxidase and polyphenol oxidase are the principal enzymes involved in the browning process of fresh-cut fruits and vegetables. Browning is important limiting factor in the consumers' acceptance. The study revealed that combined treatment of ultrasound and ascorbic acid had synergistic inhibitory effects on several enzymes related to enzymatic browning. Ultra sound extraction method has also been developed for essential oil from aromatic plants such as peppermint leaves, or from other vegetal matrix such as garlic and citrus flowers. Increased yields of essential oil were found for peppermint leaves (up to 12%) and for artemisia when using Ultra sound, and increase by 2 to 3-fold of the main compounds of lavandula essential oil when comparing Ultra sound to conventional distillation. Moreover, Ultra sound extraction not only improved yields but as the method is fast and run at low temperature, the final product usually showed less thermal degradation than traditional method. Several studies have been run out on extraction of the main aroma compounds from spices. For example the vanillin was extracted from vanilla pods, carvone from caraway seeds, and safranal from Greek saffron. Yields of vanillin were comparables after one hour by UAE vs. 8 h in conventional extraction. Another publication showed that 80% of the pure vanillin was obtained after only 120 s of ultrasounds (ultrasonic probe) whilst it took 24 h with the conventional method to obtain 100%. For carvone extraction, the UAE method was compared to the Soxhlet. Unwanted fatty materials were extracted by Soxhlet extraction while the extract with Ultra sound extraction was of better quality and richer in carvone than in limonene. Wide varieties of fruits and vegetables have been studied by Ultra sound extraction because antioxidants are present in different amounts in different varieties of plants and these antioxidants come from different families.

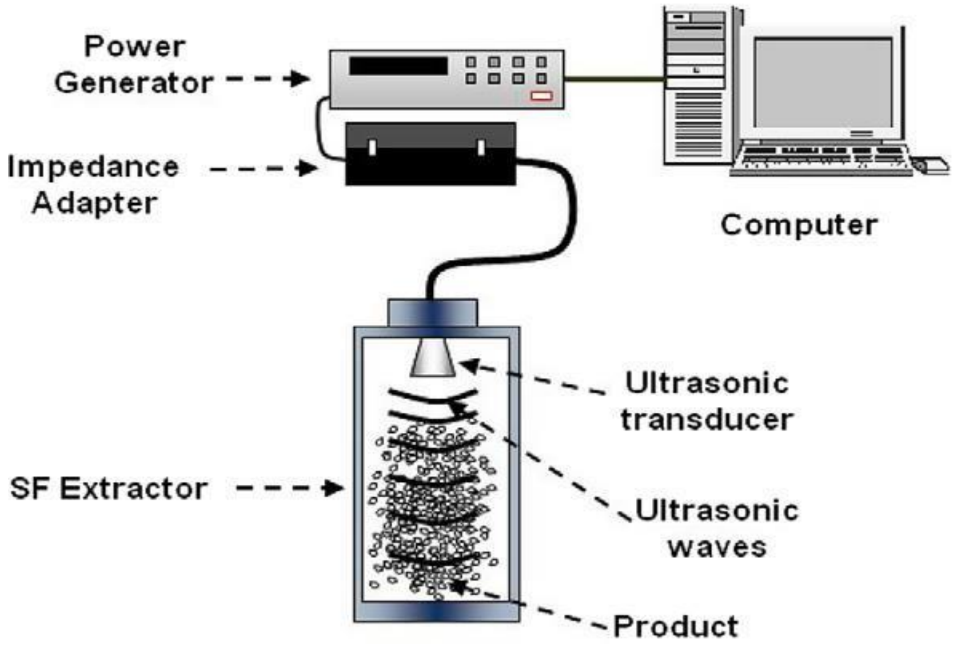


Fig.3. Scheme of the supercritical fluid extractor provided with an ultrasonic system to assist the extraction (Riera et al., 2004).

The effects of ultrasound could be related to the compressions and decompressions, the radiation pressure or the streaming (Riera et al., 2004). No clear evidence of cavitation was found under the conditions used for supercritical fluids (Balachandran et al., 2006). The high pressure needed to achieve supercritical conditions, above 72bar, makes the appearance of cavitation bubbles difficult. The application of ultrasound affects the heat and mass transport processes. The effects linked to ultrasound include cavitation, compressions and expansions, microstirring, etc. and affect both the external and the internal heat and mass transfer resistance. The importance of each effect in the global influence of ultrasound on transport is different for the system considered: solid–liquid, solid–gas or solid-supercritical, since, for example, cavitation does not take place in a gas or supercritical medium. The process variables influence the magnitude of the ultrasound effects and it is necessary to establish the optimum value for each specific application. This offers new possibilities for food process innovation, ranging from energy savings to process yield or product quality. The use of ultrasound is opening up a field of activity in food processing (Carcel et al., 2012). The main applications of ultrasound in food processes are linked to the effects it has on heat or mass transfer operations. Most of the ultrasonic applications reported in literature are found in liquid–liquid and liquid–solid systems (Mulet et al., 2003) due to the relative ease with which ultrasonic waves are transmitted in liquids. There is a wide offer of commercial equipment available on the market, including ultrasonic baths and different probe systems, which may be adapted for different operations. Thus, ultrasound has been applied in osmotic dehydration.

Fermentation: Several processes that take place in the presence of cells or enzymes are activated by ultrasonic waves. High intensity ultrasound can break cells or denature enzymes, however low intensity ultrasound can improve mass transfer of reagents and products through the boundary layer or through the cellular wall and membrane (Pitt & Rodd, 2003). Matsuura, Hirotsune, Nunokawa, Satoh, and Honda (1994) showed an increase in the fermentation rate of sake, beer and wine, when a relatively low intensity ultrasound was applied during the fermentation. The proposed mechanism is that the ultrasound (a great degassing tool) drives off CO_2 (produced during the fermentation) which normally inhibits the fermentation.

Future trends:

Research shows ultrasound can play an important role in food technology: processing, preservation and extraction. Although conventional cutting, emulsification and cleaning are often bottlenecks, lack of knowledge keeps industry from implementing ultrasound in their processes. A recent survey and market study of the possible future applications of new process technologies (like microwave, ultrasound) in the food industry has revealed that many companies are reluctant to apply these new technologies. The main reason is poor understanding of these new techniques by food professionals and the reason or weight of tradition. Commercial standard ultrasonic equipment is developing at great pace and no novel process for the application of ultrasound in industry is possible without ultrasonic equipment manufacturers willing to build new designs according to the requirements of customers.