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Principles of Food Preservation

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Content

1. Food Preservation

Overview

Introduction

- Food preservation involves the action taken to maintain foods with the desired properties or nature for as long as possible.
- Food safety is now the first priority of the food production and preservation industry, incorporating innovation and sustainability.
- A number of new preservation techniques are being developed to satisfy current demands of economic preservation and consumer satisfaction in nutritional and sensory aspects, convenience, safety, absence of chemical preservatives, price, and environmental safety.
- Understanding the effects of each preservation method on food has therefore become critical in all aspects.

What Are Foods?

- **Foods**
  - materials of animal or plant origin
  - raw, processed
  - consumed by humans or animals
  - for growth, health, satisfaction, pleasure and satisfying social needs
- **Chemically**
  - water, lipids, protein, carbohydrate, minerals and organic compounds (vitamins, emulsifiers, acids, antioxidants, pigments, polyphenols, and flavour-producing compounds)
- **The different classes of foods**
  - perishable, nonperishable, harvested, fresh, minimally processed, preserved, manufactured, formulated, synthetic, functional, and medical foods

Food Preservation

- Preservation methods start with the complete analysis and understanding of the whole food chain including
  - growing, harvesting, processing, packaging, and distribution; thus an integrated approach needs to be applied.
- First, it is important to identify the properties or characteristics that need to be preserved.
- One property may be important for one product, but detrimental for others.
  - For example, collapse and pore formation occur during the drying of foods. This can be desirable or undesirable depending on the desired quality of the dried product, for example, crust formation is desirable for long bowl life in the case of breakfast cereal ingredients, and quick rehydration is necessary (i.e., no crust and more open pores) for instant soup ingredients.
  - In another instance, the consumer expects apple juice to be clear whereas orange juice could be cloudy.

Why Preservation?

- Food degradation
  - a natural and irreversible process
  - occurs immediately after plant harvesting or animal death
  - continues → during food processing → through storage period → until it is consumed or finally spoiled

The Main Reasons for Food Preservation

- Overcome inappropriate planning in agriculture
- Produce value-added products
    - ensure a safe food or product – safety of the consumer
- Prevent or limit undesired processes – extend shelf-life
- Provide variation in diet
- Ensure appropriate and expected level of quality characters – appearance, aroma, taste, and texture

The Product Quality

- In studying the shelf life of foods, it is important to measure the rate of change of a given quality attribute.
- In all cases,
    - safety is the first attribute, followed by other quality.
- The product quality attributes can be quite varied,
    - such as appearance, sensory, or microbial characteristics.
- Loss of quality is highly dependent on types of food, packaging, and storage conditions.
- Quality loss can be minimized at any stage of food harvesting, processing, distribution, and storage.
- The product quality can be defined using many factors, including appearance, yield, eating characteristics, and microbial characteristics, but ultimately the final use must provide a pleasurable experience for the consumer.

Causes of Deterioration

- Mechanical, physical, chemical, and microbial effects are the leading causes of food deterioration and spoilage.
- Damage can start at the initial point by mishandling of foods during harvesting, processing, and distribution; this may lead to ultimate reduction of shelf life.
- In preservation, each factor needs to be controlled or maintained to a desired level.
- Foods are perishable or deteriorative by nature.
- During storage and distribution, foods are exposed to a wide range of environmental conditions.
- Environmental factors such as pressure, temperature, humidity, oxygen, and light can trigger several reactions that may lead to food degradation.

- Examples of deterioration: bruising of fruits and vegetables during harvesting and postharvest handing, leading to the development of rot; tuberous and leafy vegetables lose water when kept in atmospheres with low humidity and, subsequently, wilt; dried foods kept in high humidity may pick up moisture and become soggy.

Storage Life of Some Fresh Foods at Normal Atmospheric Conditions

Food	**Terminology**	**Storage Life**
Meat, fish, and milk	Perishable	1–2 days
Fruits and vegetables	Semiperishable	1–2 weeks
Root crops	Semiperishable	3–4 weeks
Grains, pulses, seeds, nuts	Nonperishable	12 Months

Changes Occurring in Food During Production And Storage

Major Quality-Loss Mechanisms

Microbiological	Enzymatic	Chemical	Physical	Mechanical
Microorganism growth	Browning	colour loss	Collapse	Bruising due to vibration
Off-flavour	Colour change	Flavour loss	Controlled release	Cracking
Toxin production	Off-flavour	Nonenzymatic browning	Crystallization	Damage due to pressure
		Nutrient loss	Flavour encapsulation	
		Oxidation–reduction	Phase changes	
		Rancidity	Recrystallization	
			Shrinkage	
			Transport of component	

Mechanical and Physical Changes

- Mechanical damage (e.g., bruises and wounds) is conducive to spoilage, and it frequently causes further chemical and microbial deterioration.
- Peels, skins, and shells constitute natural protection against this kind of spoilage.
- Frozen foods – fluctuating temperatures are often destructive.
  - Fluctuating temperatures cause recrystallization of ice cream, leading to an undesirable sandy texture.
  - Freezer burn a major quality defect in frozen foods that is caused by the exposure of frozen foods to fluctuating temperatures.
- Phase changes (melting and solidifying) of fats are detrimental to the quality of candies and other lipid-containing confectionary items.
- Shrivelling occurs due to he loss of water from harvested fruits and vegetables.

Chemical and Enzymatic Changes

- Some compounds and enzymes can cause of chemical reaction in food:
- **Endogenous reactions** – compounds react with each other, creation of new products – Maillard reaction (chemical reaction between amino acids and reducing sugars that gives baked food its desirable flavour)

- **Exogenous reactions** – inner compounds react with ambient compounds, which entered the food during processing or storage (oxygen, ions, additives, components present in packaging materials) – lipid autoxidation – fat rancidity, enzymatic browning of fruits

Microbiological Changes

- The most important changes
- Raw food material, semi-finished products and final products always contain microorganisms (MO).
- The preservative treatment that stops or slows the growth of unwanted MO is an important part of the technological food processing.

The Main Problems Caused by MO

- Source of diseases
  - salmonellosis, shigellosis, campylobacteriosis, listeriosis, viral hepatitis A - danger for consumers' health
- Production of toxic metabolites
  - fungal toxins (mycotoxins), bacterial toxins (botulinum toxin)
- Reduce nutrition value
  - MO consume significant nutrients
- Changes of sensory properties
  - e.g. surface mould growth

Microorganisms

- a. Fungi: mould and yeast
- b. Bacteria
    - can be present in different forms
        - vegetative – living cell form
        - spores (*Clostridium*, *Bacillus*)
            - defensive mechanism of bacteria under unfavourable conditions
            - bacterial spores are very resistant
            - after the improvement of the conditions the spores become a normal cell to multiply in the food
- c. Phages
- d. Protozoa
- Sources of microbial contaminants: oil, water, air, and animals (insects, rodents, and humans).

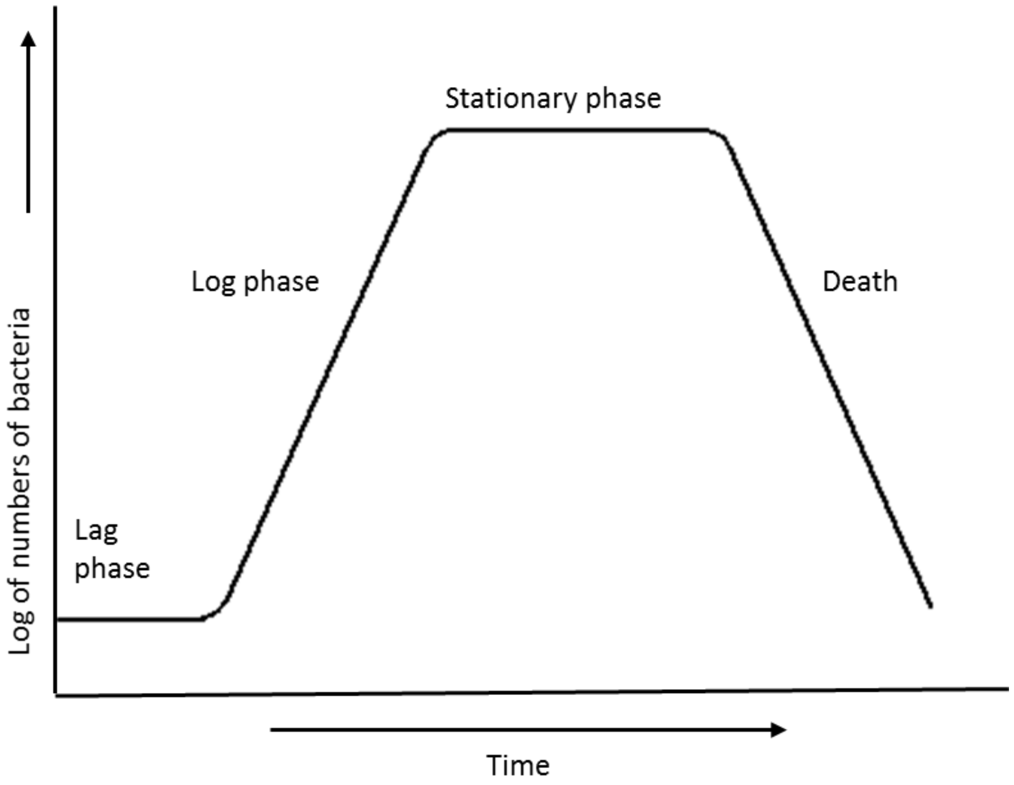
Categories of Microorganisms

- Related to food safety
- **Desired** MO
  - yeast – wine, beer,
  - lactic bacteria
  - moulds – dairy products, meat products
-
- **Undesired** MO
  - responsible for food deterioration, diseases, producing toxins.

- The number of microorganisms in food influences the degree and rate of food spoilage.
- **Infective dose** – amount of pathogenic microorganisms or toxins which produces the disease in humans

Growth Curve of Microorganisms

- 1. Lag phase
    - Adaptation to environmental conditions
    - Goal of preservation methods
- 2. Log phase
    - Growth phase – cell dividing
    - Growth rate is constant
    - Number of cells increases
- 3. Stationary phase
    - Growth stagnation
    - Limited by the amount of nutrients
- 4. Death phase
    - Decrease of live cells



Factors Affecting MO Growth

- Growth speed depends on several factors:
  - 1. Initial concentration of MO
  - 2. Suitable environment
    - Nutrient availability
    - Temperature
    - a_w – water availability
    - pH
    - Redox potential – oxygen availability

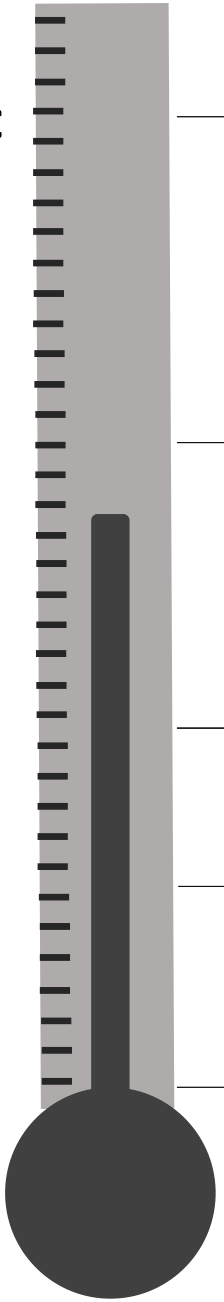
Nutrient Availability

- Intensity of growth increases with the access and availability of nutrients
- Nutrients: proteins, lipids, carbohydrates, minerals and water
- Foodstuff with high nutrient content – high risk of MO growth – meat, milk…

Temperature

- Significant factor for MO growth
  - an optimum temperature at which it grows best

- Thermophilic MO – optimal growth temp. approx. 55°C (45 - 70°C)
- Mesophilic MO – optimal growth temp. approx. 35°C (10 - 45°C)
- Psychrophilic MO – optimal growth temp. approx. 15°C (5 - 20°C)



Sterilisation – killing spores

Pasteurisation – denaturation of cell structures – killing vegetative forms MO

Microbial growth stopped

Themophilic MO

Mesophilic MO

Optimal growth conditions – wide range of MO

Psychrophilic MO

Refrigeration temp.

Microbial growth is slowing

Freezing temp.

Microbial growth stopped

Deep freezing temp.

Moisture Content in Food – Water Activity a_w

- a_w express the amount of free water available for microorganisms
- Macromolecular compounds decrease a_w – (polysaccharides, proteins, sugar, salt etc.).
- In case aw drops below the required limit – MO stop growing.
- MO are usually not killed, however, are able to ‘wait’ for more acceptable conditions to grow again.
- a_w values for MO growth
    - a_w > 0.91 – bacteria
    - a_w > 0.87 – yeasts
    - a_w > 0.70 – moulds

a_w Values Enabling Microbial Growth

Water activity a_w	**Foodstuff**	**MO growth**
0,1 - 0,2	Cereals, sugar, crackers, salt, dried milk	Microorganisms do not grow and multiply, vegetative state, deliberately count decrease.
$<$ 0,60	Honey, chocolate, spaghetti, noodles, biscuits	Microorganisms do not multiply, long term in vegetative state.
0,60 - 0,85	Jams, jelly, aspic, dried fruits and vegetables, parmesan, over-salted fish, nuts, dried egg products	Moulds (at $a_w < 0{,}80$ do not produce mycotoxins), microorganisms vegetate.
0,85 - 0,93	Fermented sausage, sweet condensed milk, dried meat, raw hams, bacon	*Staphylococcus aureus* do grow and multiply, but do not produce toxins. Moulds multiply and produce mycotoxins.
0,93 - 0,98	Condensed milk, tomato puree, bread, fruit juices, salted fish, heat treated sausages, cheese	*Staphylococcus aureus* do grow and multiply and produce toxins. Yeasts and bacteria growth decreases with the decreasing water activity.
0,98 - 0,99	Milk, fresh meat, fish, canned fruits and vegetables, eggs	All microorganisms grow and multiply.

Environment pH

- pH of the foodstuff is a significant preservation factor
- pH ranges from od 0 (very acid) to 14 (very basic), pH 7 – neutral
- MO usually multiply at pH 4.0 – 8.0 (bacteria has a much narrower pH spectrum than moulds and yeasts).

pH Values Enabling Microbial Growth

Microorganisms		**pH_{min}**	**pH_{max}**
Bacteria	*Escherichia coli*	4.4	9.0
	Salmonella paratyphi	4.5	7.8
	Clostridium botulinum	4.7	8.5
Yeasts	*Candida pseudotropicalis*	2.3	8.8
	Hansenula canadensis	2.15	8.6
	Saccharomyces spp.	2.1 – 2.4	8.6 – 9.0
Moulds	*Aspergillus oryzae*	1.6	9.3
	Penicillium italicum	1.9	9.3
	Penicillium variable	1.6	11.1

Oxygen Availability – Redox Potential

- Oxygen concentration has a significant impact on microbial changes in foodstuff.
- Aerobic processes are accelerated in the presence of oxygen and anaerobic decelerated.
- Amount of available oxygen is determined by the redox potential E_H

- MO classification in relation with oxygen
  - Strict aerobic MO – grow only in the presence of oxygene (pseudomonades, moulds)
  - Anaerobic MO – even trace amounts of oxygen is toxic (*Clostridium*)
  - Facultative aerobic – grow both in and without the presence of oxygen (*Lactobacillus*)

- The redox potential (Eh) is a physiochemical parameter that determines the oxidizing or reducing properties of the medium, and it depends on the composition of the food (thiol-containing amino acids, peptides, proteins, and reducing sugars), pH, temperature, and, for a large part, concentration of the dissolved oxygen. This parameter plays an important role in the cellular physiology of microorganisms, such as growth capacity, enzyme expression, and thermal resistance.

Food Preservation Methods

- Based on the mode of action, the major food preservation techniques can be divided into:
- **1. Indirect inactivation (inhibition) of microorganisms**
  - Modification environment that prevents microorganisms from multiplying and performing of enzymatic functions
- **2. Direct inactivation of microorganisms**
  - Directly inactivating bacteria, yeasts, moulds, or enzymes
- **3. Avoid recontamination**
  - Removal of microorganisms from the medium/environment.
  - Preventing/avoiding contamination before and after processing.

Food preservation methods

Inhibition	Inactivation	Avoid recontamination
Low-temperature storage	Sterilization	Packaging
Reduction of water activity	Pasteurization	Hygienic processing
Decrease of oxygen	Irradiation	Hygienic storage
Increase of carbon dioxide	Electrifying	Aseptic processing
Acidification	Pressure treatment	HACCP
Fermentation	Blanching	GMP
Adding preservatives	Cooking	ISO 9000
Adding antioxidants	Frying	TQM
Control of pH	Extrusion	Risk analysis and management
Freezing	Light	
Drying	Sound	
Concentration	Magnetic field	
Surface coating		
Structural modifications		
Chemical modifications		
Gas removal		
Changes in phase transition		
Hurdle technology		

Inhibition

- The methods based on inhibition include those that rely on control of the environment (e.g., temperature control), those that result from particular methods of processing (e.g., microstructural control), and those that depend on the intrinsic properties built into particular foods (e.g., control by the adjustment of water activity or pH value)
- The danger zone for microbial growth is considered to be between 5°C and 60°C; thus chilling and storing at a temperature below 5°C is one of the most popular methods of food preservation

Use of Chemicals

- Wide varieties of chemicals or additives are used in food preservations to control pH, as antimicrobials and antioxidants, and to provide food functionality as well as preservation action.
- Organic acids and esters, sulphites, nitrites, acetic acid, citric acid, lactic acid, sorbic acid, benzoic acid, sodium diacetate, sodium benzoate, methyl paraben, ethyl paraben, propyl paraben, sodium propionate
- Many plants contain compounds that have some antimicrobial activity, collectively referred to as “green chemicals” or “biopreservatives”.

Use of Chemicals

- Antimicrobial agents can occur in foods of both animal and vegetable origin.
- Herbs and spices have been used for centuries by many cultures to improve the flavour and aroma of foods.
  - Essential oils show antimicrobial properties, and are defined by Hargreaves as a group of odorous principles, soluble in alcohol and to a limited extent in water, consisting of a mixture of esters, aldehydes, ketones, and terpenes. They not only provide flavour to the product, but also preservation activity.
- Scientific studies have identified the active antimicrobial agents of many herbs and spices.
  - These include eugenol in cloves, allicin in garlic, cinnamic aldehyde and eugenol in cinnamon, allyl isothiocyanate in mustard, eugenol and thymol in sage, and isothymol and thymol in oregano.
- Interest in naturally occurring antimicrobial systems has expanded in recent years in response to consumers' requirements for fresher, more natural additive-free foods. A range of herbs and spices are known to possess antibacterial activity as a consequence of their chemical composition.

Controls of Water and Structure

- Water is an important constituent of all foods.
- the activity of water as a medium is clearly correlated with the deterioration of food stability due to the growth of microorganisms and for stability this is more important than the total amount of water.
- The minimum water activity is the limit below which a microorganism or group of microorganisms can no longer reproduce.
- For most foods, this is in the water activity range of 0.6–0.7.
- Pathogenic bacteria cannot grow below a water activity of 0.85–0.86, whereas yeast and moulds are more tolerant of a reduced water activity of 0.80, but usually no growth occurs below a water activity of about 0.62.
- Removing water, adding solutes, or change of solute–water interactions can reduce the water activity of a food.

Controls of Water and Structure - *Drying*

- Drying is one of the oldest methods of food preservation, where water activity is reduced by separating out water.
- Drying in earlier times was done under the sunlight, but today many types of sophisticated equipment and methods are being used to dehydrate foods—huge varieties of drying methods are now available.
- Drying is a method of water removal to form final products as solids
- Concentration means the removal of water while retaining the liquid condition.
- The loss of flavour, aroma, or functional compounds is the main problem with drying, in terms of quality.
- The cost of processing, packaging, transportation, and storage is less for dried products than canned and frozen foods.

Controls of Water and Structure - *Freezing*

- Freezing changes the physical state of a substance by changing water into ice when energy is removed in the form of cooling below freezing temperature.
- Usually, the temperature is further reduced to storage level at –18°C. Microbial growth is completely stopped below –18°C, and both enzymatic and nonenzymatic changes continue at much slower rates during frozen storage.
- There is a slow progressive change in organoleptic quality during storage.
- Freezing is more popular than drying due to its ability to retain more fresh-like qualities in the food.

Controls of Water and Structure - *Chilling*

- Favorite preservation method
- Chilling slows down:
  - the rate of MO multiplying
  - the rate of any chemical reactions which could affect the quality of food.
- Chilling temperature is between 1°C and 8°C.
- Little change in flavour, colour, texture or shape
- Fresh foods can be kept at maximum quality for a longer time.
- Nutrients are not destroyed.

- Chilling of foodstuff is possible only for a short time because microbial activity still takes place and the food will still decay.

Hurdle Effect

- The microbial stability and safety of most traditional and novel foods is based on a combination of several preservative factors (called hurdles), which microorganisms present in the food are unable to overcome.
- A combination of several preservatives interventions that alone is not enough to stabilize, but together creating a system of barriers, barriers against the growth of microorganisms
  - Heat treatment
  - Lowering the ph (where possible)
  - Reducing the water activity (where possible)
  - The use of substances with a preservative effect (e.G. Salt, sugar)
  - Cooling, freezing
  - Adjustment of air (vacuum packaging etc.)
  - The use of noble microflora

Direct Inactivation of MO

- A. Sterilisation by physical means
  - Use of Heat Energy (direct heat supply, microwave, infrared heating)
  - Use of High Pressure and Ultrasound
  - Use of Electricity
  - Use of Radiation
  - Use of Magnetic Field

- B. Chemical sterilisation
  - The complete inactivation MO (killing) is achieved by the addition of chemicals (hydrogen peroxide, ozone, silver ions…)

Use of Heat Energy

- Thermal inactivation is still the most widely used process of food preservation.
- The advantages:
  - Heat is safe and chemical-free.
  - It provides cooked flavours and taste.
  - The majority of spoilage microorganisms are heat labile.
  - Thermally processed foods (packed in sterile containers) - very long shelf life.
- The disadvantages
  - Overcooking may lead to textural disintegration and an undesirable cooked flavour.
  - Thermal degradation of some nutritional compounds (vitamins...)
- Heat treatment processes include mainly
  - Pasteurization, sterilization, cooking…

Use of High Pressure and Ultrasound

- **High pressure processing (HPP)** is a promising “non-thermal” technology
  - Microbiologically safe food products without undesirable changes in the sensory and nutritional properties of foods.
  - Product is processed under very high pressure, leading to the inactivation of certain microorganisms and enzymes in the food

  - Also known as pascalization
  - High pressures applied (up to 900 mpa)

- **Ultrasound** is sound wave with frequency higher than the upper audible limit of human hearing, this limit is approx. 20 kHz.
  - Leads to disintegration of the cell wall.

Use of Electricity

- Many different forms of electrical energy are used in food preservation:
- Ohmic heating
- Microwave heating
- Low electric field

Use of Radiation

- **Ultraviolet (UV) radiation**
- Low energy – low penetration – affective only on the surface
  - Promotes oxidative processes
  - Sterilisation of workspaces, surfaces, air or water
- **Irradiation** has wide scope in food disinfection, shelf life extension, decontamination, and product quality improvement.
  - Restricted in come countries, strict safety rules
  - Huge energy – hard radiation – excellent penetrability
  - Possible to sterilise foodstuff in packages
  - Not necessary to combine with other methods
  - Expensive equipment – work safety
- **Irradiated food does not become radioactive.**
- Ionization radiation interacts with an irradiated material by transferring energy to electrons and ionizing molecules by creating positive and negative ions.

Avoid Recontamination

- In addition to the direct approach, other measures such as
  - Hygienic processing
  - Packaging,
  - Quality management tools
    - Need to be implemented in the preservation process to avoid contamination or recontamination.
- Although these measures are not preservation techniques, they play an important role in producing high-quality safe food.

Reduction of contamination during processing	
Rooms, halls, tools, machines, devices	Frequent cleaning and washing of the production place (incl. walls) Floor cleaning – washing with detergents, disinfection Tool cleaning –contact with processed foodstuff
Air	Air filtration Adjusting air humidity -> reducing dust Decreasing microbial resistance to heat treatment
Water	ALWAYS DRINKING WATER – for food processing, tool cleaning and everything which is in direct contact with the foodstuff
Auxiliary raw materials	Spices, herbs, sugar, salt
Personnel/staff	Basic hygiene requirements Medical confirmation – free from infectious diseases

Hygienic Processing

Removal of MO from foods during processing	
Mechanical removal	Washing Cleaning with mechanical abrasives – especially in the combination with water
Liquids	Ultrafiltration – fruit and vegetable juices Microbial centrifuges, bactofugation

Bactofugation refers to a high-speed centrifugation process carried out in a specifically designed separator called a clarifier. The purpose of bactofugation is to separate bacterial cells and spores. The process is particularly important in Europe where it has been used in the cheese industry to remove spores from cheese milk that could cause latent fermentation in some types of cheeses.

Packaging - Purposes of Packaging

- 1. Product containment
  - Liquids, semiliquids, powders, bulk solids, - cannot be marketed without suitable containers
- 2. Preservation and quality
  - Protect the product from surroundings and maintain the quality of the food
  - Throughout the product’s shelf life
  - To avoid contamination or recontamination
- 3. Presentation and convenience
  - Important to display the product in an attractive manner
  - Packaging provides convenience to the consumers
- 4. Protection during distribution
- 5. Information about product
  - Composition, “pack date” and “best-before date”….

Quality Management Concepts

- Hazard Analysis and Critical Control Point (HACCP)
- ISO 9000
- Good Manufacturing Practices (GMP)
- Others…

Hazard Analysis and Critical Control Point (HACCP)

- HACCP is a state-of-the-art prevention approach to safe food production based on prevention and documentation, and is thus cost-effective.
- Most of the food industry around the globe is now targeting the implementation of HACCP programs for their processes to ensure safety.
- HACCP is a scientific, rational, and systematic approach to identification, assessment, and control of hazards during production, processing, manufacturing, preparation, and use of food to ensure that it is safe when consumed.
- This concept is based on the application of prevention and documentation.
- The HACCP system provides a preventive and thus a cost-effective approach to food safety.
- It is important to understand the concept of safety and quality first before planning to implement HACCP in the branch of the food industry or the products being targeted.

The Seven Principles of HACCP

- The seven principles of HACCP were formulated and they are now widely accepted as the standard for developing a food safety program:
- 1. Analyse the hazards and assess the risks
- 2. Identify the critical control points (CCPs)
- 3. Define critical limits for each CCP
- 4. Establish controls to monitor the CCPs
- 5. Establish corrective actions
- 6. Define record-keeping and documentation requirements
- 7. Establish verification procedures

ISO 9000

- ISO 9000 is the generic standard that specifies minimum requirements to be fulfilled by organizations to meet a customer’s needs.
- It does not specifically address the issue of food safety, but it addresses the need to identify and comply with regulatory requirements that are applicable to the product and process.
- ISO 9000 standard and HACCP techniques are complementary.
- HACCP techniques should therefore be used as a tool to support the quality management system ISO 9000.

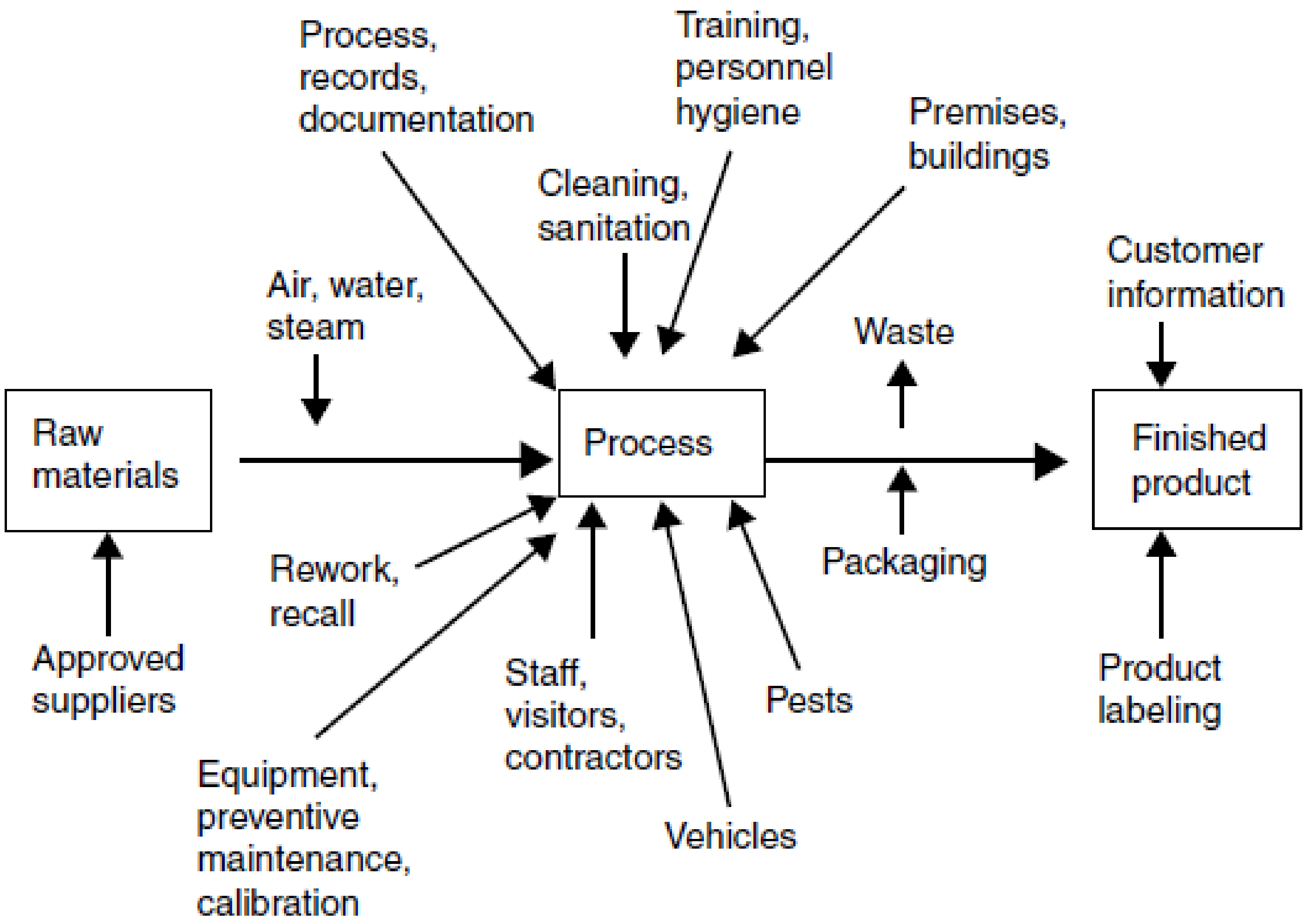
Good Manufacturing Practices (GMP)

- Good manufacturing practices (GMPs) are a series of manufacturing and administrative procedures aimed at ensuring that products are consistently made to meet specifications and customer expectations.
- To meet the requirements of GMP, regulatory bodies provided well-defined guidelines for food processing operations.
- GMP could be considered as the building blocks and cornerstones of the HACCP.
- The regulations governing GMP cover a variety of consumer goods
    - Human pharmaceutical products and veterinary products
    - Biologically derived products
    - Medical devices
    - Manufacturing, packaging, or holding human food
    - Processed food.
- In relation to food, the implementation of GMP results in safe and quality food.

The Philosophy Behind GMP

- GMP is closely aligned with disciplines such as quality, management, food safety, and food quality
- GMP is designed by food manufacturers for food manufacturers
- GMP involves the entire food business operation from the establishment of policy to its implementation
- GMP is a proactive and hands-on document
- GMP has provision to exceed customer's expectations and provides confidence in the product and consistency in the process
- through GMP, value is built into the product and loyalty to the brand

Activites og GMP



Other Preservation Factors - Biotechnology

- Biotechnology is a general term for several techniques that use living organisms to make or modify products for a specific purpose.
- The techniques of biotechnology offer opportunities to address consumer issues of food quality and environmental safety.
- Biotechnology can be used to make fruits more flavoursome; to improve nutritional and functional quality of fruits, vegetables, grains, and muscle foods; to grow foods in a wider climate zone; and to grow foods in a more environmentally benign fashion.
- Application of biotechnology
    - Rapid and sensitive diagnostic kits for the detection of pathogens and unwanted xenobiotic compounds in foods.
    - On-package sensors that could indicate when a food is spoiled, or when a pathogen or its toxic by-product is present at some level of concern

Other Preservation Factors

- Reduce the extent of processing, i.e., the demand for lightly processed or fresh-like, organic, and natural foods
- The desire to maximize automation, control, and efficiency; and the desire to minimize cost
- The need to respond to an ever-increasing strict regulations concerning environmental impact of various processes
- Changing trends and lifestyles demand more specific attributes.
- These include convenience in preparation and consumption, changing taste preferences, attitudes and perceptions about diet and health, more nutritional and functional advances in technology that influence food quality and availability, economic factors, ethnic and geographic regional factors, age, and suitability and convenience for lifestyle.

Other Preservation Factors

- The factors that should be considered before selecting a preservation process are the desired quality of the products, the economics of the process, and the environmental impact of the methods.
- Food industry waste is now also of concern to law-enforcing authorities and consumers.
- Food waste is not only an economic loss, but it also has an impact on the environment.
- It is important to make every suitable systems for value-added products.
- The ultimate success of the food industry lies in the timely adoption and efficient implementation of the emerging new technologies to satisfy the present and the future demands of the consumer.

2. Postharvest Physiology of Fruit and Vegetables

Postharvest Quality

- Postharvest period begins at the separation of plant organ used as food from the medium of its immediate growth or production, and ends when it enters the process of preparation for final consumption or further preservation.
- Fruit and vegetables are live tissues harvested at various stages of growth and development, have tender texture, contain high moisture content (60%–95%) and water activity, lose water to the surrounding atmosphere, and continue respiration, which produces heat and water at the expense of food reserves, carbohydrates, proteins, lipids, etc., which were otherwise replaced by photosynthates and nutrients supplied by the plant before harvest.

Postharvest Quality

- Fruits and vegetables are consumed
    - In fresh
    - Minimally processed
    - Processed forms (canned, frozen, dried, preserves, and fermented products).
- Raw material quality influences the quality of processed fruit and vegetable products as quality can only at best be maintained and not improved by processing.

- Specific quality requirements in terms of raw material vary with the nature of the product and processing applied on it. Quality attributes normally used for raw materials are physical (size, firmness, presence or absence of seeds, etc.), compositional (natural sugars and volatiles), nutritional (vitamins, antioxidants, and functional components), and sensory (colour, texture, taste, flavour, and odour). Quality evaluation consists of measurement of appearance, texture, flavour, nutritive value, and safety of the produce. Safety aspects need to be considered first before all other quality attributes.

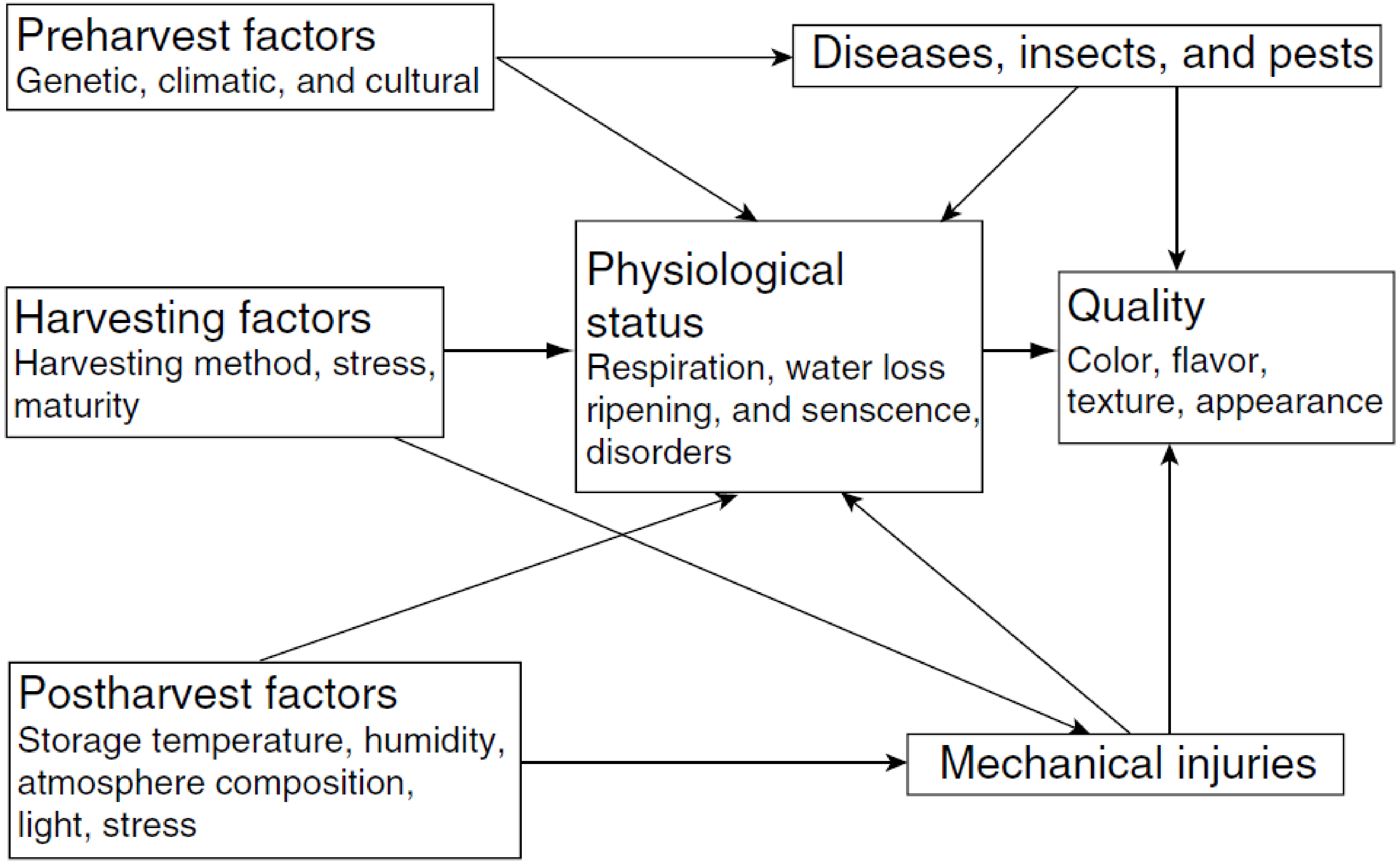
Postharvest Quality

- Specific quality requirements
  - Physical (size, firmness, presence or absence of seeds, etc.)
  - Compositional (natural sugars and volatiles)
  - Nutritional (vitamins, antioxidants, and functional components)
  - Sensory (colour, texture, taste, flavour, and odor)
- Quality evaluation consists of measurement of appearance, texture, flavour, nutritive value, and safety of the produce (safety aspects need to be considered first before all other quality attributes).

Postharvest Quality

- High shelf life of fruits and vegetables before processing is an additional criterion used by processors to assess their suitability as a raw material.
- Minimization of deterioration of postharvest quality of plant produce used for processing is the main aim of suppliers of raw materials.
- Being live, quality of fruits and vegetables is directly related to the physiological status and a host of other factors such as diseases and pests, mechanical injuries, and exposure during postharvest handling.
- Knowledge of postharvest physiology is therefore fundamental to understand the process of deterioration of quality before reaching the processor.

Schematic representation of factors affecting postharvest quality of fruits and vegetables



Factors Affecting Quality

- Preharvest Factors
  - *Genetic*
  - *Climatic*
  - *Cultural Practices*
- Harvesting Factors
  - *Maturity at harvest*
  - *Harvesting Methods*
- Postharvest Factors
  - *Humidity*
  - *Temperature*
  - *Atmospheric Gas Composition*
  - *Light*
  - *Mechanical Injury*
  - *Postharvest Diseases or Infections*

Preharvest Factors - *Genetic*

- Genetic makeup has a profound effect on the selection of a raw material for a given processing application.
- Cultivar and rootstock selection influence the composition, quality, storage potential, and response to processing characteristics that may be inherited.
- In many cases, fruit cultivars grown for fresh market sale are not suited for processing (e.g. grape varieties used for wine-making are different from those used for fresh food market)
- Criteria used in the development of new varieties
  - Higher yield
  - Resistance to disease and disorders
  - Improved compositional and nutritional values
  - Reduction in undesired toxic compounds
  - Improved processing characteristics

Preharvest Factors - *Genetic*

- Transgenic fruits and vegetables have been released that have reduced browning and softening tendencies, and increased shelf life, and uniformity of flavour and colour.

Transgenic Fruits and Vegetables Released with Improved Quality Claims

Produce	**Traits**
Apple	Reduction in the incidence of bitter pit
Banana	Delayed ripening, increased bruise resistance
Melon	Altered ripening
Eggplant	Seedless
Cucumber	Seedless
Pepper	Altered ripening and improved flavour
Potato	Reduced bruise sensitivity, increased amylopectin
Strawberries	Delayed softening and ripening
Tomato	Increased solid content, delayed ripening, increased shelf life

Preharvest Factors - *Climatic*

- The growing region and environmental conditions specific to each region, such as temperature, humidity, light, wind, soil texture, elevation, and rainfall, significantly influence the quality of fruits and vegetables
- The duration, intensity, and quality of light during cultivation - affect the quality at harvest.
- The differences in day length and light quality affect the product physiology

- Examples:
  - When tomatoes grown in full sunlight contain more sugar.
  - Exposure to sun tends to make citrus fruits lighter in weight, with thinner rind, low amounts of juice and acids, and high solid content compared to those that were shaded.
  - Turnips harvested in the morning contain more riboflavin than those harvested at other times of the day.
  - Among leafy vegetables, leaves are larger and thinner under a condition of low light intensity.
  - Onion - varieties developed for short-day climates will not produce large bulbs.
  - Fruits grown in cold climate usually are more acidic than those grown in warmer regions.

Preharvest Factors - *Cultural Practices*

- Soil type, soil nutrient and water supply, pruning, thinning, pest control or chemical spray, and density of planting influence the quality of plant produce
- Fertilizer addition affects the mineral content of fruits.
- Many physiological disorders have been linked to the nutrient status of the soil

- Examples:
  - Potatoes grown in sandy, gravelly or light loamy soils, and low-water or fertility soils have consistently produced higher dry matter than those grown in peat or low-moisture soils.
  - A high N/K ratio and phosphorus deficiency in soil increases the tendency of potato to darken after cooking.
  - Pineapple plants receiving undue amounts of nitrogen produce tart, white, and opaque fruits of poor flavour characteristics.
  - Pesticide residues may give rise to flavour taints in fresh and processed products, and excessive use of pesticides may even produce harmful metabolites and toxicity that may not be necessarily destroyed during processing or heat treatment.

Harvesting Factors - *Maturity at harvest*

- Maturity at harvest is the most important quality criterion for a processor as it directly affects composition, quality, losses, and the storage potential of plant produce.
- The optimum harvest maturity is vital to achieve maximum postharvest life of the fresh produce.
  - Immature fruits are more subject to shriveling and mechanical damage.
  - Overripe fruits are likely to become soft and mealy with insipid flavour soon after harvest.
  - Fruits picked either too early or too late in the season are more susceptible to physiological disorders and have a shorter storage life than those picked at mid-season

Harvesting Factors - *Maturity at harvest*

- The optimum maturity of produce for fresh consumption and processing is determined by the purpose for which it will be used.
- The maturity stage considered best for canning may not be best for dehydration, freezing, or making jams or preserves.
- Harvesting fruits either immature or overripe can cause extensive loss of the produce.

- Maturity indices
- Several indices are used to identify and evaluate the maturity for harvest and for assessing suitability for a processing application.
- Maturity indices vary among types, cultivars of the produce, and intended processing.
- For example, fully ripened fruits should be used for drying and making concentrated products (tomato sauce) to achieve the best flavour, but for fresh marketing these may not be suitable for its susceptibility to damage.

Maturity Indices

- The maturity indices used are based on:
- (I) **Measurable change in visual appearance**
  - Size and shape, overall colour, skin colour, flesh colour, presence of dried outer mature leaves, drying of plant body, development of abscission layer, surface morphology and structure, and fullness of fruit
- (Ii) **Elapsed days from full bloom to harvest**
- (iii) **Physical changes**
  - Ease of separation or abscission, firmness, tenderness, specific density
- (Iv) **Chemical changes**
  - Soluble solids, starch, acidity, sugar/acid ratio, juice content, oil content, tannin content
- (V) **Measurable physiological changes**
  - Respiration and internal ethylene concentration

Index	Examples
Elapsed days from full bloom to harvest	Apples, pears
Mean heat units during development	Peas, apples, sweet corn
Development of abscission layer	Some melons, apples, feijoas
Surface morphology and structure	Cuticle formation on grapes, tomatoes; Netting of some melons; Gloss of some fruits
Size	All fruits and many vegetables
Specific gravity	Cherries, watermelons, potatoes
Shape	Angularity of banana fingers; Full cheeks of mangos; Compactness of broccoli and cauliflower
Solidity	Lettuce, cabbage, Brussels sprouts
Firmness	Apples, pears, stone fruits
Tenderness	Peas
colour, external	All fruits and most vegetables
Internal colour and structure	Formation of jelly-like material in tomato fruits; Flesh colour of some fruits
Starch content	Apples, pears
Sugar content	Apples, pears, stone fruits, grapes
Acid content, sugar/acid ratio	Pomegranates, citrus, papaya, melons, kiwifruit
Juice content	Citrus fruits
Oil content	Avocados
Astringency (tannin content)	Persimmons, dates
Internal ethylene concentration	Apples, pears

Crop	Index
Radish and carrot	Large enough and crispy (overmature if pithy)
Potato, onion, and garlic	Tops beginning to dry out and topple down
Yam bean and ginger	Large enough (overmature if tough and fibrous)
Green onion	Leaves at their broadest and longest
Cowpea, yard-long bean, snap bean, sweet pea, and winged bean	Well-filled pods that snap readily
Lima bean and pigeon pea	Well-filled pods that are beginning to lose their greenness
Okra	Desirable size reached and the tips of which can be snapped readily
Eggplant, bitter gourd, chayote or slicing cucumber	Desirable size reached but still tender
Sweet corn	Exudes milky sap when thumbnail penetrates kernel
Tomato	Seeds slipping when fruit is cut, or green colour turning pink
Sweet pepper	Deep green colour turning dull or red
Muskmelon	Easily separated from vine with a slight twist leaving clean cavity
Honeydew melon	Change in fruit colour from a slight greenish white to cream; aroma noticeable
Cauliflower	Curd compact (overmature if flower cluster elongates and become loose)
Broccoli	Bud cluster compact (overmature if loose)
Lettuce	Big enough before flowering
Cabbage	Head compact (overmature if head cracks)
Celery	Big enough before it becomes pithy

Harvest Maturity Indices for Vegetables and Specifications for Processing

Vegetable	Harvest
Broccoli	Compact bud cluster
Cabbage	Compact head
Carrot	Crispy and long enough
Cauliflower	Compact curd
Cucumber	Size and tenderness
Eggplant	Desirable size and tenderness
Lettuce	Desirable size before flowering
Okra	Desirable size and tips snap off easily
Olives	Straw yellow to cherry red
Onion	Tops beginning to dry
Peas	Well-filled pods that snap easily
Potato	Tops beginning to dry
Sweet corn	Milky sap oozing upon pressing
Tomato	Seeds slip upon cutting the fruit

Maturity Indices for Fruits Harvesting and Specifications for Processing

Fruit	Harvest
Apple	140–150 days from the bloom, starch content
Apricot	¾ of the area of the fruit should have yellowish green or ½ yellow
Banana	Pulp-to-peel ratio of 1.35–1.4, or disappearances of angularity, colour
Grapes	14%–17.5% SS, or SS/A of 20 or higher
Orange	SS/A of 8
Pear	13% SS and yellowish-green colour
Mango	Change of peel colour from green to yellow
Strawberries	2/3 of fruit surface has pink or red colour

SS - Soluble Solids/Acid Ratio
A – acidity

Harvesting Factors - *Harvesting Methods*

- **Manual harvesting**
- The advantages
  - Accurate election and grading according to maturity,
  - Minimum damage to commodity
  - Minimum capital investment
  - Mechanical devices can be used as aids to manual harvesting
- The disadvantages
  - Needs management of labor force
  - Slow

Harvesting Factors - *Harvesting Methods*

- **Mechanical harvesting**
- The advantages
  - Fast
  - low labor and easy management
- The disadvantages
  - It may cause mechanical damage to the produce by skin abrasion and tissue bruising
  - It requires trained personnel and a special field lay out, and cropping patterns
- Thus, for best results, management procedures should include:
  - (i) Selection of optimum time to harvest regarding fruit maturity and climatic conditions,
  - (ii) Training and supervision of workers, and (iii) effective quality control procedure
- Pickers can be trained in methods of identifying the produce that is ready for harvest.

Postharvest Factors - *Humidity*

- Fresh fruits and vegetables contain sizable amounts of water, (e.g. watermelons may contain water more than 95% of its fresh weight)
- The symptoms of loss water
    - Shriveling
    - Wilting
    - loss of crispness.
    - The tissue become tough or mushy (unacceptable to the consumer)
- The reduction of saleable weight and loss of sensory characteristics lower the marketing value.
- Weight loss by even 5% makes certain produces unsaleable.

Postharvest Factors - *Humidity*

- Factors affecting the rate and the extent of water loss
    - The surface area/volume ratio
    - Nature of surface
    - Presence/absence of cuticle,
    - Lenticels (fruits),
    - Injury of the plant tissues affect both the rate and the extent of water loss

- This is the reason why leafy vegetables such as lettuce lose water at higher rates than potatoes and apples.

Postharvest Factors - *Prevent of Loss Water*

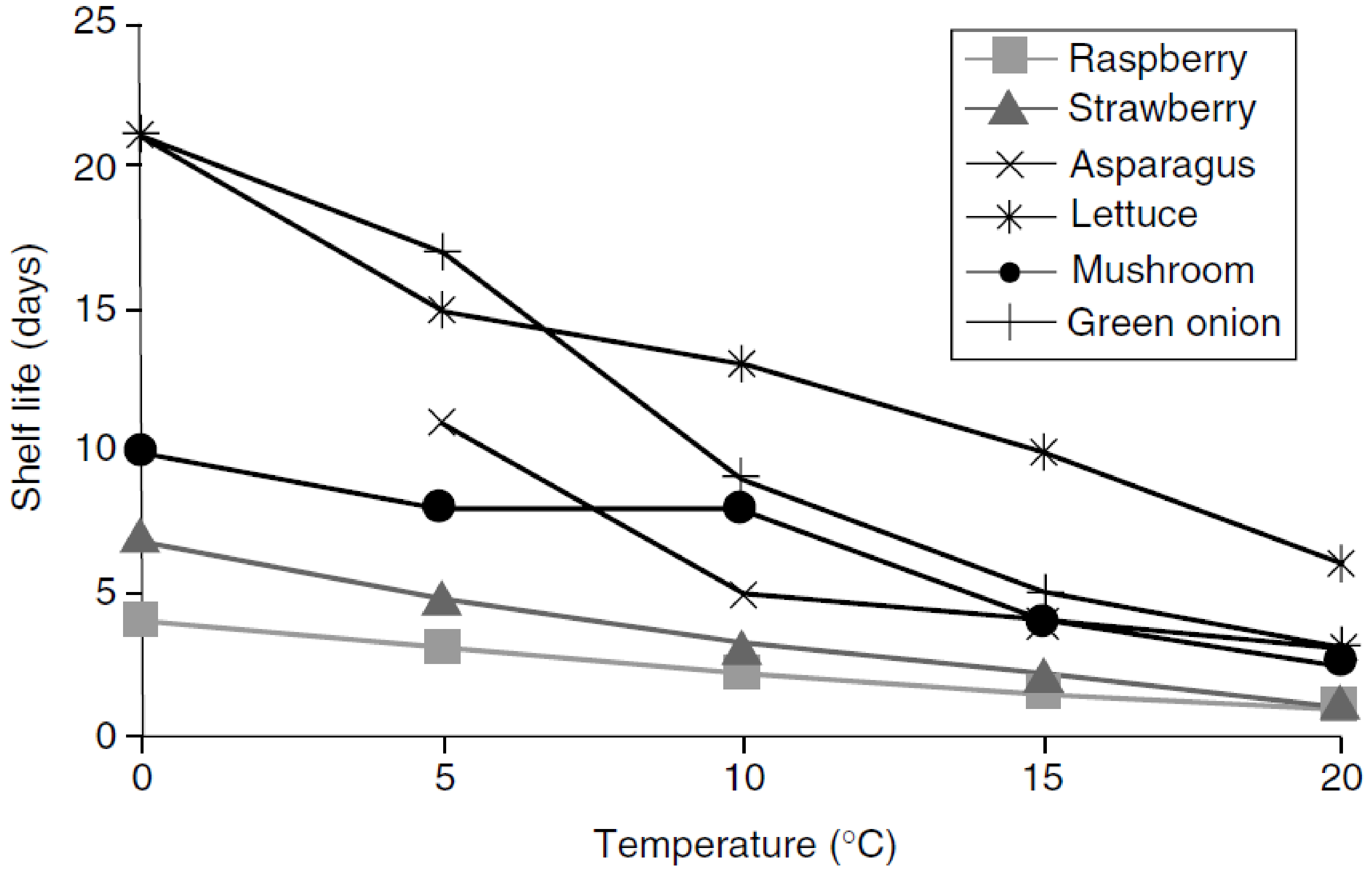
- Water loss can be prevented by
  - Maintaining high atmospheric relative humidity (RH)
  - Low temperature
  - Reduced air movement
  - Increased pressure
  - Avoiding product injury
  - Using suitable packaging during storage and transportation

Postharvest Factors - *Temperature*

- Temperature management is the most important tool in postharvest handling of plant produce to control both physiological and pathological deteriorations.
- The lowering temperature during handling, transportation, and storage is the most effective means of extending the shelf life and reducing the loss of quality by lowering the metabolic processes such as respiration and transpiration.

- The difference in the effect of temperature on the shelf life varies due to differences in physicochemical properties of different types of fruits and vegetables.

Effect of temperature on shelf life of selected fruits and vegetables



Postharvest Factors - *Atmospheric Gas Composition*

- Atmospheric gas composition, such as oxygen, carbon dioxide, and ethylene, influences the microbial decay and physiological processes such as respiration.
- Reduction of oxygen and elevation of carbon dioxide through modified or controlled atmosphere storage complements the effects of maintaining low temperature through the postharvest value chain.

- The beneficial or harmful effects of varying gas composition, however, depend upon commodity, cultivar, physiological age, oxygen and carbon dioxide levels used, temperature, and duration of storage.

- For example, banana transported under 3% O_2 and 5% CO_2 reduces premature ripening and crown rot development by high carbon dioxide/oxygen ratio.

Postharvest Factors - *Light*

- Light may influence the quality of fruits and vegetables by controlling the synthesis/degradation of
  - Pigments responsible for colour (chlorophyll and carotenoids)
  - Flavour by catalyzing oxidation of lipids
  - Sprouting
  - Reducing nutritive value by degrading vitamins such as ascorbic acid and riboflavin
  - Production of toxins
- Light intensity should be minimized.
- Adverse effects of light are prevented by storage in dark and using packaging materials that prevent the transmission of light.

Postharvest Factors - *Mechanical Injury*

- Mechanical injuries expose internal tissue to
  - Contamination
  - Increase respiration rate
  - Promote chemical and enzymatic reactions (i.E., Browning),
  - Allow the spread of decay microorganisms
  - Induce an overall quality decline

- The surface cracks, cuts, punctures, which develop during growth or as a result of mechanical injuries, either remove or weaken the protective outer layers causing water loss.

Postharvest Factors - Postharvest Diseases or Infections

- The postharvest diseases are initiated
  - (i) at the early stage of development when attached to the plant
  - (ii) by direct penetration of certain fungi or bacteria through the intact cuticle or through wounds or natural openings in the surface
  - (iii) through injuries in cut stems or damage to the surface.

- While most of the microorganisms can invade only the damaged produce, a few are able to penetrate the skin of healthy produce.
- Initially, only one or a few pathogens may invade and break down the tissues, followed by a broad-spectrum attack of several weak pathogens, resulting in complete loss of commodity due to the magnified damage.

Postharvest Factors - Postharvest Diseases or Infections

- The postharvest diseases can be controlled based on
  - (i) prevention of infection,
  - (ii) eradication of incipient infections
  - (iii) retardation of the progress of pathogen in the produce by fungicide or bactericides
- The pH of fruits is the major factor that influences the composition and therefore the microflora present.
- Yeasts and moulds are often the predominant microorganisms in fruits and fruit products as they grow well under acidic conditions.

Postharvest Physiological Processes

- Ontogeny
- Respiration
- Transpiration and Water Stress
- Ripening
- Phytohormone Effects
- Physiological Disorders and Breakdowns
  - Disorders due to Mineral Deficiencies
  - Disorders due to Environmental Factors
    - *Low-Temperature Injuries or Disorders*
    - *High-Temperature Injuries or Disorders*
    - *Injuries/Disorders due to Exposure to Adverse Atmosphere*
- Other Biochemical Changes

Ontogeny

- The origin and development (ontogeny) of plants influences various physiological aspects of fruits and vegetables.
- Fruits and vegetables pass through five distinct developmental phases
  - (i) development (morphological and chemical completion of tissue)
  - (ii) young or premature (developmental period before the onset of maturation),
  - (iii) mature (completion or fullness of growth and edible quality, most of the maturation processes must be completed while the produce is still attached to the plant),
  - (iv) ripe (maximum esthetic and edible quality)
  - (v) senescence (leading to death and set the produce worthless and inedible)
- The duration and the rate of these stages vary with type and variety of the product and stage of development.

Respiration

- All living organisms convert matter into energy through a fundamental process of life called respiration, which primarily constitutes enzymatic oxidation of substrates such as carbohydrates, proteins, lipids, organic acids, etc. in the presence of atmospheric oxygen to carbon dioxide and water, and accompanied by a release of energy as follows:

$$C_6H_{12}O_6 + O_2 \rightarrow CO_2 + H_2O + 2872\ kJ$$

- Respiration is an indicator of metabolic activity of all living produce and plays a significant role in the postharvest physiology and deterioration of quality of plant foods.

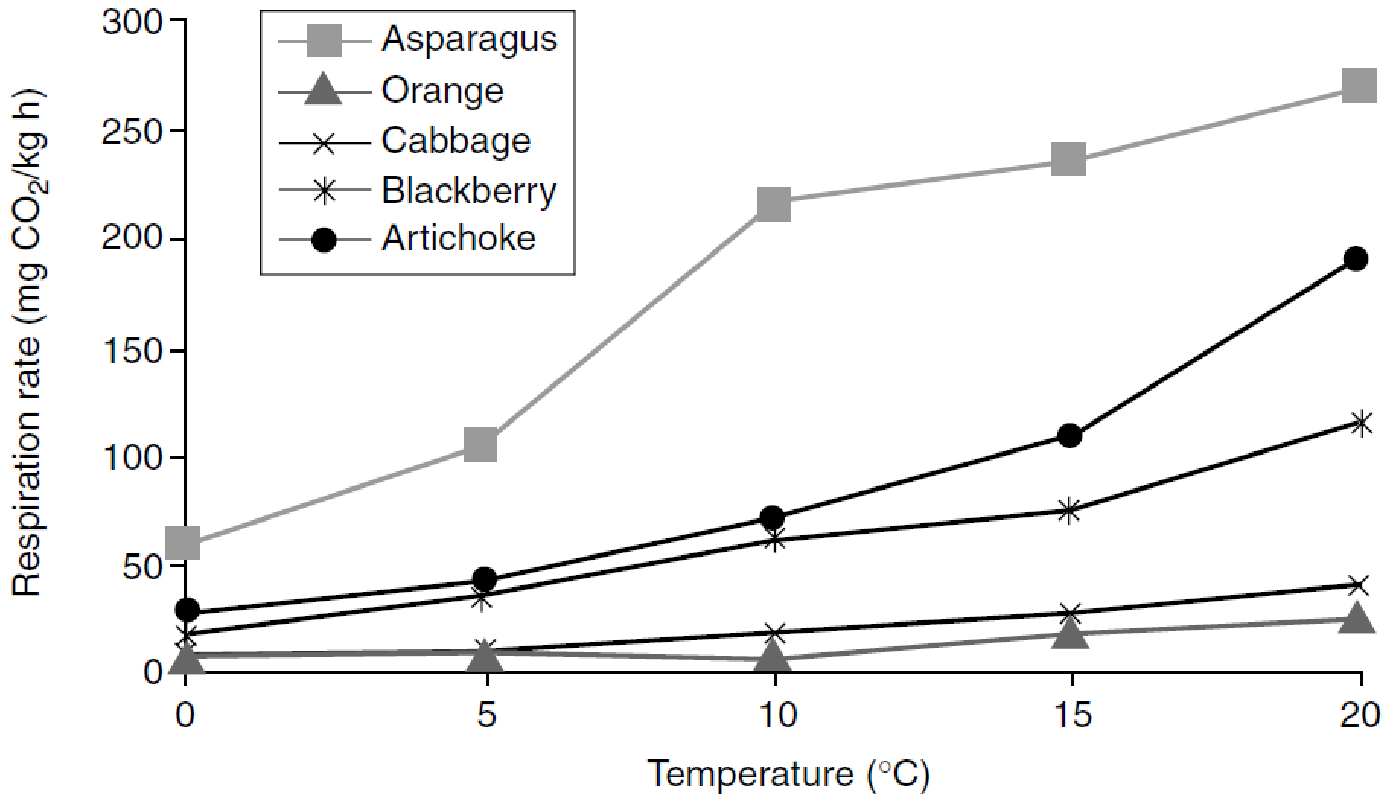
Respiration

- Respiration rate
  - Respiration is an indicator of metabolic activity of all living produce and plays a significant role in the postharvest physiology and deterioration of quality of plant foods.
  - The rate of deterioration is generally proportional to their respiration rate.
  - Higher the respiration rate, shorter the shelf life and vice versa.
  - The respiration increases significantly as the storage temperature increases

Factors Influencing on Respiration Rate

- Internal factors
    - (i) the quantity of substrate (predominantly sugars)
    - (ii) size, shape, cell morphology, and maturity
    - (iii) structure of peel
    - (iv) volume of intercellular spaces
    - (v) chemical composition of tissue that affects solubility of oxygen and carbon dioxide.
- External factors
    - (i) temperature
    - (ii) availability of ethylene, oxygen, and carbon dioxide
    - (iii) light
    - (iv) water stress
    - (v) biological activity
    - (vi) growth regulators

Effect of temperature on the respiration rates of some fruits and vegetables.



Transpiration

- Transpiration is a process of mass transfer in which the water vapors move from the surface of the produce to the surrounding atmosphere.
- Transpiration is mainly responsible for water loss, which leads to a loss of
  - salable weight
  - appearance (wilting and shriveling)
  - textural quality (softening, flaccidity, limpness, crispness, and juiciness)
  - nutritional quality

Transpiration

- The rate of transpiration (M) depends on product and environmental factors.
  - (i) skin structure;
  - (ii) size, shape, and surface area
  - (iii) water vapor pressure difference
  - (iv) air movement
  - (v) heat of respiration
  - (vi) the level of maturity

- Water loss can be minimized by maintaining higher pressure than atmosphere, maintaining low temperature and humidity during storage, choice of suitable packaging material, and loading density and depth, application of waxes and other water-resistant coatings to the surface or by appropriate packaging with plastic films.

Ripening and Senescence

- **Ripening** refers to a stage in tissue development when a fruit reaches an optimal eating quality as evidenced by favorable change in composition, colour, texture, and other sensory attributes.
- Ripening in fruits follows the physiological maturity and precedes senescence, which leads to the death of the tissue.
- **Senescence** is genetically programmed and can be induced by common stressors, such as tissue injury, deficiency of nutrients and water during production, exposure to insects, pests and diseases, and adverse environmental conditions. Senescence may manifest into ripening of fruits, abscission and yellowing of leaves, and softening of tissues.

Ripening and Senescence

- Ripening induces changes that are structural, physical, chemical, nutritional, biochemical, or enzymatic.
  - Degradative changes - chlorophyll breakdown, starch hydrolysis, and cell wall degradation
  - Synthetic changes - formation of carotenoids and anthocyanins, aroma volatiles
- The main changes occurring during ripening
  - Thickening of cell wall and adhesion,
  - Increased intercellular spaces contributing to softening
  - Changes in colour
  - Loss of texture
  - Loss of epidermal hairs

Phytohormone Effects

- Phytohormones play an important role in plant metabolism by controlling the growth and development processes of plant organs used as food or raw material for processing.
- Physiological processes influenced by hormones
  - Ripening
  - Rest
  - Dormancy
  - Rooting
  - Sprouting
  - Abscission
  - Floral induction

Phytohormone Effects

- Most important is ethylene
- Next key hormones responsible for these processes are auxins, gibberellin, cytokinins, and abscisin

Physiological Changes Induced by Phytohormones Other Than Ethylene

Physiological Changes	Phytohormone	Produce Affected
Sprouting	Abscisic acid, gibberellin, cytokinins, auxins	Onion
Senescence	Increased levels of gibberellin and low levels of auxins and cytokinins	Brussels sprouts, lettuce
Elongation of flower peduncle	Gibberellins	Cauliflower
Rooting	High levels of cytokinins and low levels of gibberellins	Carrot
Pithiness of petiole	Abscisic acid	Celery
Ripening	Abscisic acid stimulates, auxins, gibberellins and cytokinins delay ripening	Tomato

Ethylene $CH_2{=}CH_2$

- Natural product of plant metabolism and is produced by all tissues of higher plants and by some microorganisms
- Regulates many aspects of growth and development
- The beneficial and adverse effects - depend on several factors (as type of produce, cultivar, maturity at the time of harvest, temperature, and activity of other hormones)

- Ethylene stimulates mainly
    - Ripening of climacteric and some nonclimacteric fruits,
    - Degradation of chlorophyll (degreening)
    - Abscission and senescence
    - Flower initiation
    - Respiratory metabolism

Ethylene $CH_2{=}CH_2$

- Ethylene is commercially used as a “ripening hormone” for climacteric fruits such as banana and mango and as a “degreening hormone” for citrus fruits.
- Degreening also is called gassing, sweating or curing.
- Its purpose is to improve external skin colour and export market acceptance.

Ethylene $CH_2=CH_2$

- Controlling action of ethylene is of great commercial significance in fruits and vegetables.
- The adverse effects of ethylene can lead to serious economic losses.
- Ethylene production rates by fresh fruits can be regulated
  - by storage at low temperature
  - by reduced oxygen and elevated carbon dioxide (e.g. UV radiation)
  - by avoiding stressors such as fruit injury, diseases incidence, and water stress.

Adverse Effects of Ethylene in Fruits and Vegetables

Produce	Symptoms
Asparagus	Woodiness
Carrots	Bitterness due to isocoumarine formation
Potatoes	Sprouting
Lettuce	Russet spotting
Broccoli	Yellowing, abscission, off flavours
Eggplant	Browning of flesh and seeds, decay induction
Cucumber	Yellowing, softening
Sweet potatoes	Browning of pulp, off flavour, failure to soften upon cooking

Physiological Disorders and Breakdowns

- Disorders inducing serious loss of quality
  - Colour, flavour, texture, and appearance,
  - Deterioration by enzymes and decay microorganisms.
- Preharvest factors
  - Type of the produce, variety, nutritional status of produce and soil, level of maturity, temperature
- Harvest factors
  - Maturity at harvest, cultural practices, climate during growing season, produce size, and harvesting and handling practices

Physiological Disorders and Breakdowns

- Physiological disorders result from metabolic disturbances caused by
  - Internal factors (nutritional imbalance - **Mineral Deficiencies**)
  - External factors (temperature and surrounding atmosphere - **Environmental Factors**)

Disorders due to Mineral Deficiencies

- Plants require a balanced mineral intake from soil and favorable environment for proper development, which leads to desired quality attributes.
- Nutrient transport, water relations, and fruit growth dictate the susceptibility of the tissue to a disorder.

- Example: Bitter pit in apples, characterized by brown lesions in flesh, dark, and corky tissue below the skin and slight bitter taste, develops due to preharvest low fruit Calcium (Ca) and high levels of Potassium and Magnesium. Pre- and postharvest application of Ca controls this disorder.

Disorders due to Environmental Factors

Low-Temperature Injuries or Disorders

- Chilling and freezing injuries result from exposure of plant tissues to low temperature (fruits and vegetables of tropical and subtropical origin, which lack the ability to adapt to low-temperature environments)
- **Chilling injury (CI)** - symptoms such as pitting, browning, scald appearance, darkening of the skin, changes in the flavour and texture, and the loss of ripening ability.
- The lowest safe storage temperature has to be well above the chilling injury (CI) threshold of susceptible product
- CI can be minimized by reducing
    - The exposure time to injury temperatures
    - Precooling produce in stages to build adaptation
    - Selection of resistant varieties
    - Selecting fruits at appropriate level of ripening

Disorders due to Environmental Factors

Low-Temperature Injuries or Disorders

- **Freezing injury (FI)** results from exposure of plant tissues to freezing temperatures (0°C)
  - Formation of ice crystals (damages the cells, mostly irreversibly)
  - Damage to the cell membrane responsible for water loss and death of cells.
- The factors that affect fi
  - Type of produce
  - Variety
  - Nature of solutes
  - Field temperature
- The symptoms of the FI include
  - Discolouration of the tissue
  - Water-soaking appearance
  - Blistering
  - Pitting

Relative Susceptibility of Vegetables to Freezing Injury

Highly Susceptible	Moderately Susceptible	Slightly Susceptible
Artichoke	Cabbage	Beetroots
Asparagus	Carrot	Brussels sprouts
Beet	Cauliflower	Celeriac
Broccoli	Chives	Collard
Celery	Endive	Horseradish
Cucumber	Leek	Kale
Eggplant	Onion (bulb)	Kohlrabi
Sweet corn	Onion (green)	Parsnip
Lettuce	Parsley	Rutabagas
Okra	Shelled peas	Salsify roots
Sweet pepper	Peas (pod)	Turnip roots
Potatoes	Radish	
Summer squash	Spinach	
Sweet potatoes	Winter squash	
Tomatoes		

Relative Susceptibility of Fruits to Freezing Injury

Highly Susceptible	Moderately Susceptible	Slightly Susceptible
Apricot	Apple	Dates
Avocado	Cranberry	
Banana	Grape	
Berries (except Cranberries)	Orange	
Pear		
Lemon		
Limes		
Peaches		
Plums		

Disorders due to Environmental Factors

High-Temperature Injuries or Disorders

- Exposure of tissues to high temperature during production or postharvest results in injuries or disorders, which may cause
    - The loss of ability to ripen normally
    - Burnt or scorched peel
    - Darkening of the pulp

- Examples of such disorders are scald in apples and tomatoes and blossom drop in.

Disorders due to Environmental Factors

Injuries/Disorders due to Exposure to Adverse Atmosphere

- Exposure to low levels of O_2 and high levels of CO_2 may lead to tissue injuries
  - Internal browning in apples and pears

- The factors that influence the susceptibility
  - Exposure to higher concentration of CO_2 at the time of harvest
  - Presence of coatings that restrict the diffusion of gases

Other Biochemical Changes

- Chemical and enzymatic changes cause
  - Tissue softening
  - Off flavours
  - Pigment loss - enzymatic browning
  - Off colours
  - Overall decline in nutritional value and taste

Enzymes Responsible for Key Reactions Associated with Ripening and Senescence in Fruits and Vegetables

Enzymes	Reaction	Result
Polyphenoloxidase, catalase, peroxidase	Oxidation of phenolics	Formation of precursors to coloured and polymers leading to undesirable browning
Polygalacturonase	Hydrolysis of glycosidic bonds between adjacent polygalacturonic acid residues in pectin	Tissue softening
Pectin esterase	Hydrolysis of ester bonds of galacturonans in pectin	Tissue softening
Lipoxygenase	Oxidation of lipids	Production of off flavour and off odors
Ascorbic acid oxidase	Oxidation of ascorbic acid	Loss of nutrition quality
Chlorophyllase	Cleavage of phytol ring from chlorophyll	Loss of green colour
Amylases	Hydrolysis of amylose and amylopectin	Loss of texture and increase in sweetness due to production of sugars
Cellulase and hemicellulases	Hydrolysis of cell wall	Loss of texture
Proteases	Hydrolysis of proteins	Loss of nutritional value and increase or decrease in digestibility
Lipase	Hydrolysis of lipids	Hydrolytic rancidity
Phytase	Hydrolysis of phytic acid	Liberation of phosphates
Glucose oxidase	Oxidation of glucose	Formation of hydrogen peroxide

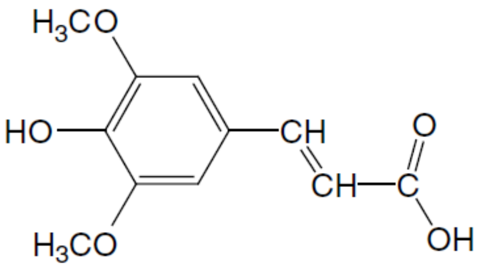
Enzymatic Browning

- Fruits and vegetables contain varieties of phenolic compounds that participate in browning reactions catalyzed by enzymes.
- Cutting or injured plant turns brown on the cut surface as a result of enzymatic oxidation of phenolic compounds.
- In the presence of O_2, phenolases oxidize phenols to benzoquinones, which, although colourless, further get converted into brown pigments in fruits and vegetables (potato, mushroom, apple, and banana).
- The factors influencing enzymatic browning are type and content of phenolic substances, enzymes, temperature, and presence of inhibitors.

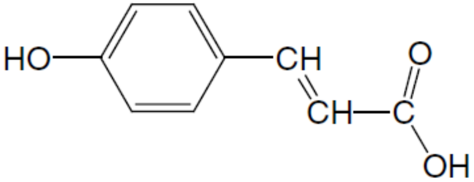
Other enzymes reactions

- Chlorogenic acid, a phenol found in potatoes, is also responsible for aftercooking blackening of potatoes and greening of cooked potatoes. The after-cooking blackening reaction involves formation of ferric dichlorogenate from chlorogenic acid and ferrous ions and favored by conditions leading to higher ratio of chlorogenic acid to citric acid.
- Postharvest sweetening of potatoes is a serious problem in cold-stored potatoes due to conversion of starch into sugars.
- The production of reducing sugars can lead to nonenzymatic browning in potato chips and can be avoided by warming the produce before use.
- Injuries can also lead to formation of stress metabolites through linoleic/linolenic acid cascade producing traumatin and jasmonic acid, which have a role in forming a defence system against insects and microorganisms.
- Degradation of lipids by lipase and lipoxygenase enzymes can lead to the formation of off flavours in fruits and vegetables (e.g., beans and peas), and can be avoided by inactivating these enzymes or by knocking the genes responsible for their expression.

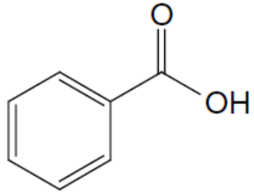
Phenolic compounds found in fruits and vegetables



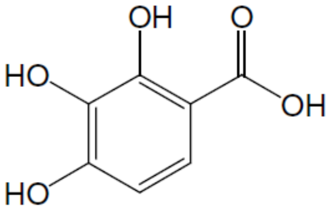
Sinapic acid



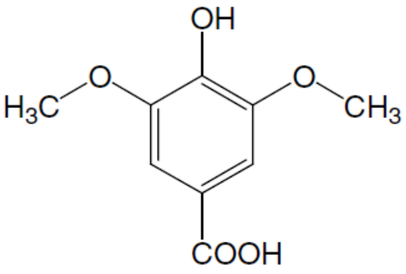
p-Coumaric acid



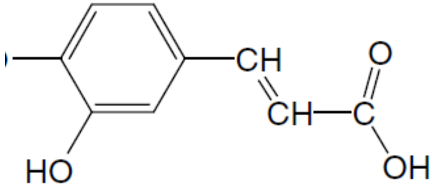
Benzoic acid



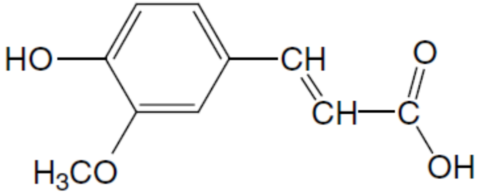
Gallic acid



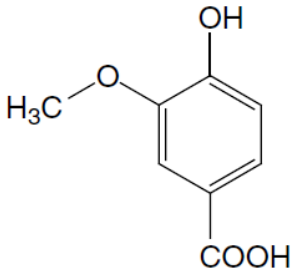
Syringic acid



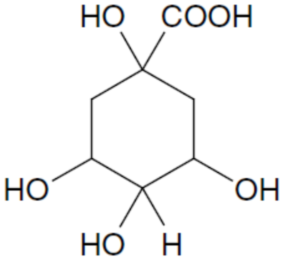
Caffeic acid



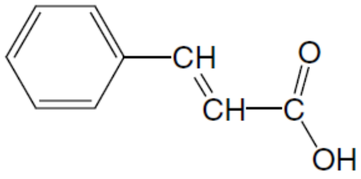
Ferulic acid



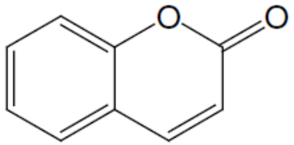
Vannilic acid



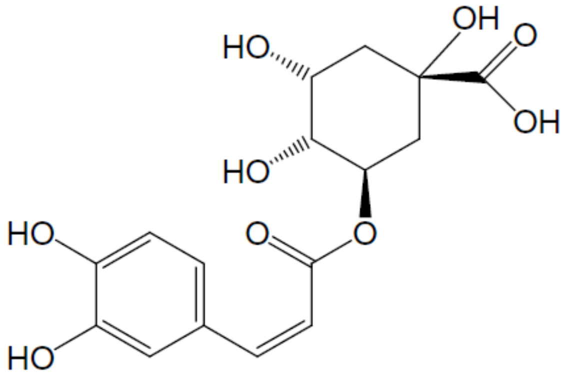
Quinic acid



Cinnamic acid



Coumarin



Chlorogenic acid

3. Postharvest Handling and Treatments of Fruits and Vegetables

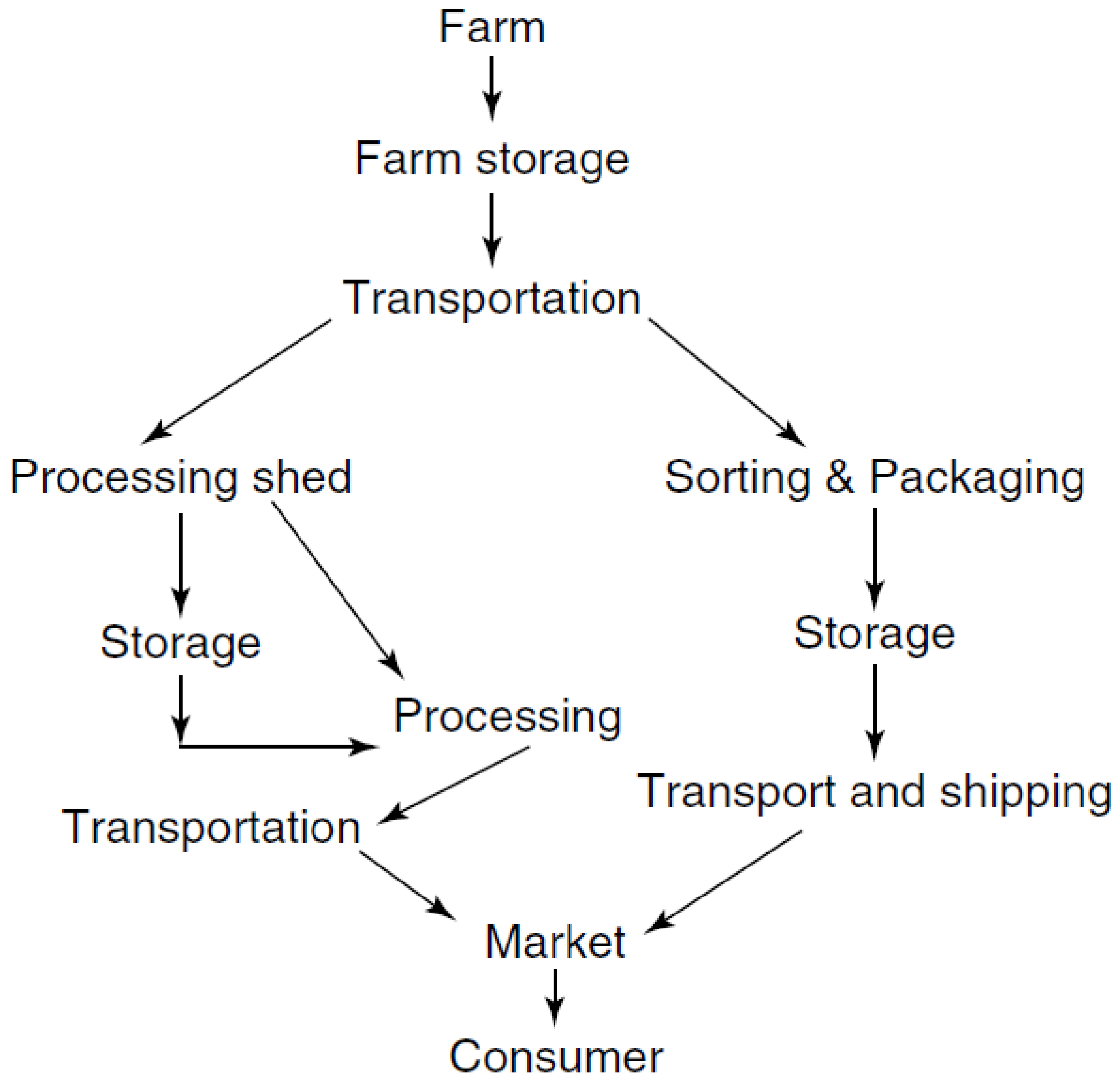
Introduction

- The quality of fruits and vegetables deteriorates progressively after harvest.
- Fruits and vegetables processing is very seasonal in nature, and the harvested produce must be quickly processed to avoid losses
- A good-quality processed product can only be possible when good-quality raw materials are used in their manufacture.

Postharvest Handling Operations

- Sorting and Grading
- Packaging
- Transportation
- Precooling
- Storage and Distribution

Postharvest value chain for fruits and vegetables



Raw Material Quality Specifications for Processed Fruits and Vegetables

Processed Products	Raw Materials	Quality Specifications
Fruit juices	Citrus, apple, tomato	Acidity, sugar content, flavour
Chips and fries	Potato, banana, taro	Texture, starch content, and reducing sugars
Canned products	Apple, peach, pear	colour, texture, flavour
Preserves	Various fruits: apple, peach	Sugar, pectin content, acidity
Pickles	Cucumber, olive, cabbage	Composition, sugar content, texture
Concentrates: sauce, puree	Tomato, apple	Total solids
Alcoholic beverages	Grape, apple	Fermentable sugar, acidity
Dried products	Mango, apricot	Composition, solid content
Frozen products	Pea, carrot, onion	Composition, colour, texture, flavour

Sorting and Grading

- Most fruits and vegetables are sorted and graded for marketing and have a role in protecting and enhancing product quality.
- These are generally an important part of field or packinghouse operations and help in reducing cross contamination of healthy stock destined for storage, transport, distribution, marketing, and processing.
- Immediately after harvest, the produce is sorted according to size, shape, colour, and appearance.
- The damaged and immature fruits must be removed, as these might become sources of ethylene gas, which will increase the rate of respiration, ripening, and senescence of healthy produce.

Packaging

- The main purpose of packaging is to provide protection from mechanical damage.
- Packaging contributes greatly to efficient marketing of fruits and vegetables
  - (i) Serves efficient handling unit
  - (ii) Provides convenient warehouse or home storage unit
  - (iii) Protects quality and reduces waste by avoiding mechanical damage, reducing moisture loss and providing clean or sanitary produce
  - (iv) Provides service and sales motivation
  - (v) Reduces cost of transport and marketing
  - (vi) Facilitates use of new modes of transportation

Packaging

- Two types of packaging are common in fresh produce trade.
- Large-sized containers are used for transport and wholesale
- Small-sized packagers for retail trade
- Proper packaging can protect fresh produce from the environment, such as sunshine, moisture, and light.
- The main purpose of packaging is to provide protection from mechanical damage.
- The container must be strong enough to withstand stacking and impact of loading and unloading, without bruising or scarring the produce.
- The produce can be packed in a box (wooden or paper) with absorbent, lining, or padding materials or in bags.
- The choice of packaging material is based on the requirements of stacking height, duration of storage, pretreatments, cooling, and cost.

Transportation

- The harvested produce is transported via road by trucks in pallet boxes.
- Overseas transportation is normally by sea and rarely by air.
- The main requirement
- proper management of temperature, humidity, and ventilation.
- Bruised, decayed, and overripe products are sorted out before transportation to avoid dissemination of diseases.
- Proper packaging of produce helps in avoiding mechanical injuries.
- Refrigeration during transportation is convenient and the most effective means of reducing losses.
- Proper insulation and ventilation of trucks help in minimizing loss of quality in the absence of truck without refrigeration.
- Overfilling of boxes can cause compression bruises, which makes bruised fruits more prone to decay than those affected by impact bruises. Vibrations lead to friction bruises, which lead to browning of pears. The produce must be protected against mechanical injuries using proper packages and suitable padding materials.

Precooling

- The harvested produce contains substantial amount of heat associated with the product temperature and is known as field heat, a significant part of cooling load.
- **Precooling** is the rapid extraction of heat from the produce before transport, storage, and processing.
- Good temperature management throughout the postharvest chain is the key to avoiding postharvest losses and preservation of quality.
- Precooling reduces
  - The rates of metabolic activities such as respiration, transpiration, and ethylene production
  - Minimizing growth of decay microorganisms
- Precooling can be accomplished by simply blowing cold ambient air over the produce; however, refrigeration is required for ensuring short cooling time that is so critical in preventing the loss of quality.
- The amount of field heat necessary to be removed depends on the produce and the required storage temperatures. At the time of harvest, the produce temperature is same as that of the environment; wherever possible, the produce must be harvested when the ambient temperature is low, during night, morning, or evening, to avoid high cooling loads.

Storage and Distribution

- Most horticultural produce have short harvesting season and short- or long-term storage is necessary
  - to extend the marketing period for fresh produce
  - to regulate the product flow and extend the processing season

- The main goals of storage
  - to extend the availability of fresh produce in the market
  - to ensure continuous supply of quality raw material to the processors
  - to extend the length of the processing season
  - to ripen certain fruits such as mangoes and bananas

Storage Potential of Horticultural Produce in Air at Near-Optimum Storage Temperature and Relative Humidity

Class	Storage Life (Weeks)	Degree of Perishability	Commodity
I	<2	Very high	Apricot, blackberry, blueberry, cherry, fig, raspberry, strawberry, asparagus, bean sprouts, broccoli, cauliflower, green onion, leaf lettuce, mushroom, muskmelon, pea, spinach, sweet corn, tomato (ripe)
II	2-4	High	Avocado, banana, grape, guava, loquat, mandarin, mango, melons, nectarine, papaya, peach, plum, artichoke, green beans, brussels sprouts, cabbage, celery, eggplant, head lettuce, okra, pepper, summer squash, tomato (partially ripe)
III	4-8	Moderate	Apple and pea (some cultivars), grape (Sulfur dioxide treated), orange, grapefruit, lime, kiwifruit, persimmon, pomegranate, table beet, carrot, radish
IV	8-16	Low	Apple and pear (some cultivars), lemon, potato, dry onion, garlic, pumpkin, winter squash, sweet potatoes, taro, yam
V	>16	Very low	Tree nuts and dried fruits

Optimum Storage Temperature and Humidity Conditions for Fresh Fruits and Vegetables

Produce	Optimum Temp (°C)	Freezing Temp (°C)	RH (%)	Storage Life
Apple	-1 to 4.4	-1.7	90-95	1-12 months
Asparagus	2.2	-1.1	95-100	2-3 weeks
Blueberries	0.6-1	-2.2	90-95	2-3 weeks
Broccoli	0	-0.6	95-100	2 weeks
Cabbage	0	-1.1	95	2-3 weeks
Cucumber	7.2-10	-0.6	95	2 weeks
Eggplant	7.8-12.2	-0.6	90-95	1 weeks
Green beans	2.8-7.2	-1.1	95	5-10 weeks
Leafy vegetables	0	-0.6	95	1-2 weeks
Onion	0	-0.6	70	2-3 weeks
Peach	0	-0.6	95-98	2-4 weeks
Peppers	7.2-10	-0.6	90-95	2-3 weeks
Potato	3.3-4.4	-0.6	90-95	5-8 weeks
Strawberry	0	-0.6	90-95	5-7 weeks
Sweet corn	0	-0.6	90-98	5-7 weeks
Sweet potato	12.8	-0.6	90	6-12 weeks
Tomato, pink	8.9-10	-0.6	85-95	7-14 weeks
Turnip	0	-1.1	95	4-5 weeks
Watermelon	10-15.6	-0.6	90	2-3 weeks

Postharvest Treatments

- Postharvest treatments generally aim at preserving and/or enhancing the quality of fruits and vegetables by controlling the physiological, mechanical, and pathological agents responsible for both postharvest losses and degradation of quality.

- Physical Treatments
- Chemicals Treatments

Postharvest Treatments - Physical Treatments

- Cleaning and Washing
- Coating and Waxing
- Heat Treatment
- Irradiation

Physical Treatments - *Cleaning and Washing*

- The main goals of cleaning are
  - (i) to eliminate surface dirt and soil particles and contaminants
  - (ii) to remove residues of pesticides, fertilizers, and chemicals used during production
  - (iii) to reduce the microbial load
  - (iv) to enhance the appearance of the produce
- Air (dry cleaning) - to remove loose scales, soil, dust in products such as onions, garlic….
- Water (washing) - most of fruits and vegetables

Physical Treatments - *Coating and Waxing*

- Presence of surface wax is a natural defense mechanism in fruits and vegetables against water loss and invasion from pests and disease-causing organisms.
- Rough handling, approaching senescence, and washing deplete natural waxes.
- Benefits of waxing:
  - Improve the appeal and acceptability by the consumer
  - The ease of packing and handling
  - To extend the shelf life by reducing weight (water) loss
  - Protection from insects, pests, and fungi
  - Protection from mechanical injuries
  - Curing tiny injuries and scratches on the surface

- Commonly used waxes for coatings are carnauba, shellac, beeswax, paraffin wax, and vegetable oils.
- Examples of fruits and vegetables normally waxed are apples, pears, banana, citrus fruits, cucumber, pepper, and tomato.

Physical Treatments - *Heat Treatment*

- Moderate heating treatment has a positive effect on maintaining fruit quality by
    - Preventing and controlling incipient fungal and insect infestation
    - Reducing the rate of ripening
    - Increasing sweetness and reducing acidity in fruits
    - Reducing the impact of storage disorders such as superficial scald and chilling injury.
    - Increasing the shelf life of plant produce
- As a source of heat can be used - hot air, vapor heat, and hot water.

- Hot water treatment has the advantages of low cost and relatively simple application equipment. The vapor heat treatment is relatively expensive due to costs associated with initial investment for equipment and process operation. In general, both hot water and vapor heat treatment can cause excessive tissue damage and peel injury than forced hot air.

Physical Treatments - *Irradiation*

- Irradiating fruits and vegetables (x-rays, gamma, or electron beam)
  - Inhibit sprouting in tubers (potato) and bulbs (onion)
  - Delay ripening and senescence in tropical fruits such as mango and papaya
  - Control infestation by insects such as fruit fly
- The use of irradiation is limited by
  - Restricted in come countries, strict safety rules
  - Cost of the treatment process

Postharvest Treatments - Chemicals Treatments

- Chemicals have been used in fruits and vegetables to control
  - Microorganisms causing decay and diseases
  - Infestations due to pests
  - Physiological disorders
- It is necessary to consider toxicity, residue in the product, and legal aspects before applying any chemical treatment.

- Disinfestation and decay control
- Ethylene removal
- Controlled ripening and colour development
- Delaying ripening, senescence, and sprouting

Chemicals Treatments - *Disinfestation and Decay Control*

- Fruits and vegetables are exposed to deterioration due to insect pests, fungi, and bacteria at any time from production until consumption or processing.
- **Fungicides -** are chemical compounds used to kill or inhibit fungi or fungal spores.
- Fungal spoilage in fruit is more common due to inherently lower pH found in fruits.
- Incipient growth of both fungi and bacteria in fruits and vegetables used as raw material for processed products causes defects in sensory (colour, texture, and flavour) and microbial quality of end product.
- Increased softening upon canning or pickling, acidic or alcoholic flavour in fruit juices are some examples of spoilage symptoms.
- Fungicides are applied to fruits and vegetables both as pre- and postharvest treatments depending on the nature of produce, the target pathogen, market life, and cost.
- The local and international laws strictly control the use of fungicides.

Chemicals Used in Postharvest Control of Pathogens in Fruits and Vegetables

Chemical	**Pathogen Controlled**	**Host**
Inorganic sulfur as SO_2 gas or salts	*Monillia, Botrytis*	Grapes
Organic sulfur compounds (e.g., thiram)	*Alternaria*	Strawberry, banana
Phenols (sodium o-phenylphenate)	*Penicillium,* bacteria, and fungi	Citrus fruits
Triazoles (imazalil)	*Penicillium, Alternaria*	Citrus fruits
Hydrocarbons (biphenyl)	*Penicillium, Diplodia*	Citrus fruits
Organic acids (dehydroascorbic, acid, sorbic acid, acetic acid, formic acid)	*Botrytis and other fungi*	Strawberry
Benzimidaxoles (benomyl)	*Penicillium, Collectotrichum, Sclerotinia, Botrytis*	Stone fruits, carrots

Chemicals Treatments - *Ethylene Removal*

- Ethylene, a plant hormone, affects physiological processes of ripening and senescence
- Ethylene damage can be reduced by
  - (i) adequate ventilation
  - (Ii) reduction of O_2 and increase of CO_2 levels
  - (Iii) reducing temperature
  - (Iv)reduction of ethylene by forcing air through filters of activated charcoal
- Main ethylene removers
  - **Potassium permanganate** (kmno4)
    - The most accepted ethylene remover used commercially
    - Often is incorporated into different carrier materials such as activated alumina and silica gel
  - **Oxidation by UV light to water and carbon dioxide**
  - Silver thiosulfate
  - 1-methyl cyclopropene - (MCP) or ethyl block

Chemicals Treatments - *Controlled Ripening and Colour Development*

- Climacteric fruits such as banana and mangoes are harvested well before they are fully ripe to avoid mechanical injury and are ripened during storage or transport.
- Controlled ripening facilitates uniform development of colour, texture, and flavour.
- Ethylene is the most active ripening agent.
- Endogenous or exogenous ethylene is used
    - For controlled ripening of fruits (banana and mangoes)
    - Development of uniform colour of the produce (tomatoes and citrus fruits) under controlled conditions.

Chemicals Treatments - *Delaying Ripening, Senescence, and Sprouting*

- Ripening is undesired in most vegetables.
- Various plant growth regulators
  - Used at various stages of production and postharvest handling for delaying ripening, colour degradation, and sprouting.
- The different chemicals can be applied (as dip or spray) for delaying ripening.

Chemicals Used for Delaying Ripening, Senescence, and Sprouting

Chemical	Effect	Produce Used
Cytokinin	Delays chlorophyll degradation and senescence	Leafy vegetables (spinach), pepper, bean, cucumber
Benzyladenine	Delays chlorophyll degradation and senescence	Cherry
Benzylaminopurine	Delays chlorophyll degradation and senescence	Sweet cherry, cauliflower, endive, parsley, lettuce, radish, onion, cabbage, brussels sprouts, broccoli, mustard greens, radish tops, celery, asparagus
Kinetin	Delays chlorophyll degradation and senescence	Leafy vegetables (spinach), pepper, bean, cucumber
Gibberellin	Retards maturation, ripening, and senescence; delays chlorophyll, degradation; increases peel firmness; delays accumulation of carotenoids	Tomato, banana, kiwifruit, citrus fruits (orange, grapefruit)
Maleic hydrazide and its analogs	Sprout inhibition	Onion, sugar beet, turnip, carrot, potato
	Delays ripening	Mango, tomato, sapota fruit
Alar	Delays deterioration and discolouration,	Mushroom
	Preservation of chlorophyll	Leaves of beans
	Inhibition of synthesis of solanine	Potato
Cytocel	Retards senescence and deterioration	Vegetables
Propham	Controls sprouting	Root crops
Chloropropham	Controls sprouting	Root crops
Tecnazene	Controls sprouting and fungi	Root crops
Calcium	Delays chlorophyll degradation and senescence	Vegetables

Chemicals Treatments - *Treatment with Calcium*

- Delaying degradation and senescence
- Reducing
  - Rates of respiration
  - Texture loss
  - Ethylene production
  - Browning
  - Development of bitterness
  - Microbial decay
- Increasing of the concentration of ascorbic acid

4. Postharvest Handling of Grains and Pulses

Cereal Grains

- Cereals have often been considered among the first cultivated crops.
- Belonging to the grass family *graminaceae*
- Grown mainly for their grain
- Cereal grains are used primarily for
  - Human consumption
  - Animal feed
  - The manufacture of beverages
  - Industrial products (adhesives, starch)

Cereal Grains

- Nutritionally, they are important sources of
  - Carbohydrates
  - Protein
  - The B complex of vitamins, vitamin E, iron, other minerals
  - Fiber
- Cereal crops are source of energy, containing 10,000-15,000 kj/kg, about 10-20 times more energy than fruits and vegetables.
- Major cereal grains produced worldwide include
  - Wheat, rice, corn, and barley (corn, wheat, and rice together account for three-quarter of the world's grain production)
  - Other globally important cereal crops include sorghum, oats, millet, and rye

Pulses

- Pulses are annual leguminous crops yielding 1-12 grains or seeds of variable size, shape, and colour
  - Peas, dry beans, vetches, lupins, dry broad beans, lentil, mung bean, chickpea, pigeon pea, cowpea
- They are used for both food and feed, important foodstuff in most of the tropical and subtropical countries.
- Composition of pulses
  - Carbohydrates, mainly starches (55%-65% of the total weight);
  - Proteins, including essential amino acids (18%-25%, and much higher than cereals)
  - Fat (1%-4%).

- The term "pulses" is limited to crops harvested for dry product only. Excluding crops harvested green for forage used for grazing or as green manure harvested green for food (green beans, green peas, etc.). used mainly for extraction of oil (soybeans and groundnuts) whose seeds are used exclusively for sowing purposes

Drying

- The amount of moisture present in cereal grains and pulses greatly affects grain properties such as density, force-deformation characteristics, thermal conductivity, heat capacity, and electrical resistance.
- The market value of grains and seeds is also greatly influenced by their moisture content.
- Moisture is transferred between cereal grains and the surrounding air during drying.
- Drying is carried out as a requisite for safe storage, in order to inhibit microbial growth.
- Drying comprises the reduction of moisture from about 17-30% to values between 8 -15% depending on the grain.
- The final moisture content for drying must be adequate for storage.

Grain-Drying Systems

- **Natural-Air Drying**
  - Moisture is transferred from the kernel to the surrounding air.
  - Air temperature, wind speed, and humidity affect the rate of drying.

- **Heated-Air Drying**
  - When temperatures are below 10°C, the air will not carry much water and the transfer of moisture from the cereal grain to the air is relatively slow.
  - Drying efficiency is greatly increased when heat is added to ambient air.

Grain Storage and Handling

- The primary aim of storage is to prevent deterioration of the quality of the grain.
- This is achieved through control of moisture and air movement, by preventing infestation of microorganisms, and attacks of insects and rodents.
- Food grains can be stored for relatively longer periods of time under proper storage conditions (low temperature, inert atmosphere, etc.), with little or no detectable loss of quality.
- Safe storage must maintain grain quality and quantity.
- This means protecting it from
  - Weather
  - Moulds and other microorganisms
  - Addition of moisture
  - Destructively high temperatures
  - Insects, rodents, birds
  - Contamination
- High temperature and high moisture are the most significant factors affecting grain quality in storage.

Storage and Handling

- Environmental Factors Influencing Grain Quality
- Types of Storage Facilities
- Insects
- Aeration
- Grain Inspection
- Chemical Methods
- Rodents

Environmental Factors Influencing Grain Quality

- The atmosphere, in which grains are stored, must be maintained so as to discourage or prevent the growth of microorganisms that cause spoilage.
- Stored-grain ecosystems are complex of abiotic and biotic factors
- Abiotic factors
  - Temperatures, moisture contents, and gas concentrations
- Biotic factors
  - Population dynamics of insects and mites, and fungal growth

Types of Storage Facilities

- **On the Ground** - only between harvest and the availability of transport equipment
  - Grain is exposed to rodents, birds, insects, and wind (week)

- **Underground** -low cost method of long-term grain storage
  - In good condition after more than 10 years
  - The main disadvantage of underground storage is the difficulty of removing grain.

- **Bagged Storage** can be stored in almost any shelter that protects the bags from weather and predators

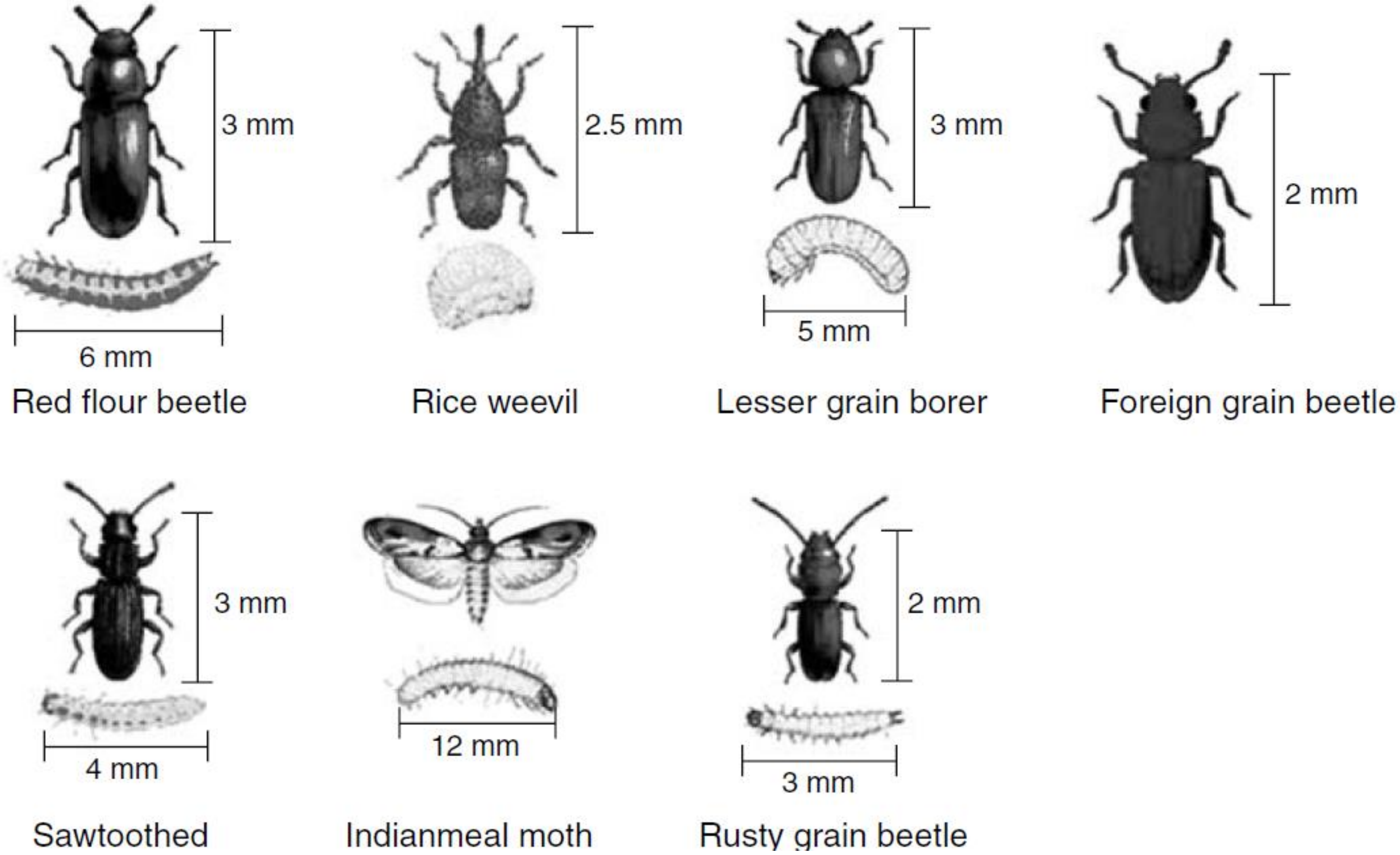
- **Bulk Storage** - in bins is the most widely used type of storage for cereal grains. Bins are constructed of steel, aluminum, concrete, and even wood or plywood

Insects

- Insects are a major problem for the storage grains and seeds
  - Consume part of grain
  - Contaminate the grain
- Factors influencing expansion of insects
  - **Temperature**
    - Grain-damaging insects multiply slowly or not at all below 16°C
    - Not survive in temperatures over 42°C
  - **Moisture**
    - The moisture contents of 9% or lower restrict infestation.

- Even though the grain is stored at relatively safe storage moisture of 11%-14%, in the presence of insects, the grain often "heats." The heat is caused by the metabolic heat of the insects. Because of the increased temperature, moisture migration occurs and results in increased moisture in pockets of grain. This leads to the growth of microorganisms.

Some of the grain insects and their dimensions



Aeration

- Grain stored for long periods of time is generally aerated to maintain the overall quality and reduce the risk of storage losses due to insects and mould growth.

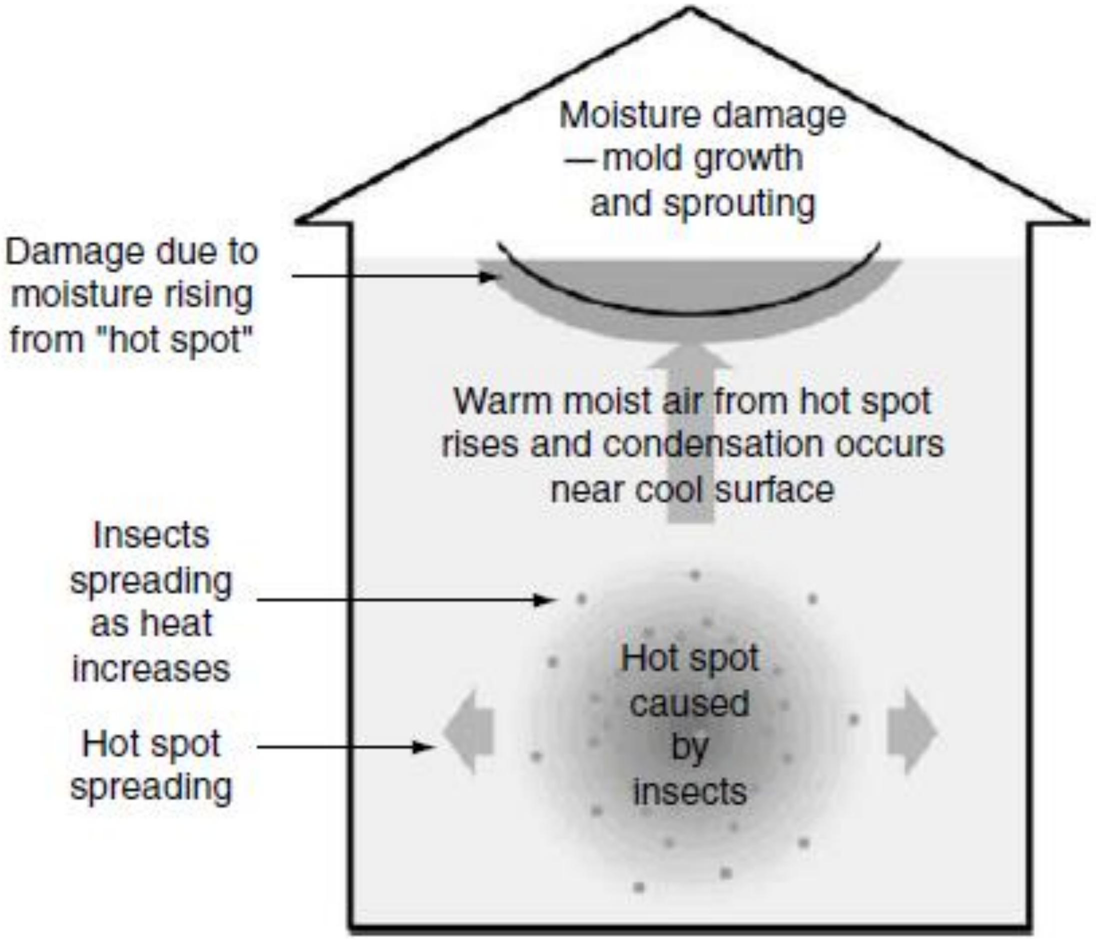
- **Aeration**
  - Is the process of blowing ambient air through grain masses for the purpose of cooling and conditioning grain.
  - Reduces or inhibits biological activity by cooling the grain
  - Preventing moisture migration by maintaining a relatively uniform temperature throughout the grain mass.

Grain Inspection

- The grain surface should be inspected at least every other week throughout the storage period.
- Evidences of hot spots, insect infestations, or other problems that start in the grain mass soon migrate to the surface.
    - Hot spots will be seen as damp, warm, and musty areas.
- Insects and mould growth are more likely to show up where broken grains have accumulated.

Hot spot

- place with higher temperature within the grain mass
- The heat is caused by the metabolic heat of the insects.
- Because of the increased temperature, moisture migration occurs and results in increased moisture in pockets of grain.
- This leads to the growth of microorganisms.



Development of hotspots due to insect infection

Chemical Methods

- Insect infestation in stored grain and grain products can be controlled effectively by fumigation.
- **Fumigation** is a method of pest control that completely fills an area with gaseous pesticides—or fumigants—to suffocate or poison the pests within.
- Over the past 100 years, fumigation has been the most effective method of pest control in stored rice.

- Up to nine different chemicals have been used as fumigants, but currently, only chlorpyrifos-methyl (Reldan) and phosphine PH_3 are allowed.

Rodents

- Rodents are among the most important global pests.
- Every year, rats in Asia consume food crops that could feed 200 million people for an entire year.
- Two forms of rodent control are normally practiced.
  - Trapping is the most common method of rat killing.
  - Chemical disinfestation - rodenticides

5. Postharvest Handling and Preservation of Fresh Fish and Seafood

Introduction

- Over the last few years, the consumption of fish and fishery products has been strongly influenced by improvements in postharvest handling
  - Packaging, storage, transportation, and marketing
  - Led to significant improvements in postproduction efficiency, lower costs, wider product choice, and safer and improved products.

- The development and application of efficient and cost-effective postharvest technologies for handling and preservation of fresh fish and other seafood is important to ensure product safety and maintenance of quality throughout the supply chain from sea to plate.

Economic Importance

- Fish is an important source of protein.
- The economic activities associated with its harvest, handling, processing, and distribution provide a means of livelihood for millions of people.
- Fish is a highly perishable food product, requiring proper handling, processing, and distribution.
- Global demand for fish is growing, and reductions in postharvest losses and maintenance of product quality and safety can make a major contribution to satisfying this demand as well as increasing financial returns to fishers and marketers.

Contribution of Fish to Human Nutrition

- Fish represents a valuable source of micronutrients, minerals, essential fatty acids, and proteins in the diet of many countries.
- The meat of fish and seafood products contains
  - 80% water
  - 8%–25% proteins
  - 1%–30% fat
  - 0.6%–1.5% mineral compounds
  - Vitamins (B, fish oil - A, D)
- Lipids contained in fish are rich in essential polyenoic fatty acids
  - Valuable nutritionally are the *n*-3 polyenoic acids

- The particularly low incidence of heart disease in fish-eating populations has been attributed to high ingested levels of the so-called omega-3 (called eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA)) polyunsaturated fatty acids (PUFAs) in fish oil.

The Problem of Postharvest Losses in Fish and Seafood

- Fish are highly perishable starting from the point of harvest.
- Factors predispose fresh fish to rapid quality degradation
  - Change of the surrounding environment due to removal from the marine or aquatic environment
  - High moisture content of fish
  - Activities of microorganisms inside the gut and intestine
  - Physical damage resulting from the use of improper harvesting tools and procedures and rough handling practices

Mechanisms and Manifestations of Spoilage in Fish and Seafood

- Fresh fish and other seafood undergo many chemical and biological changes immediately after capture which can ultimately result in spoilage.
- Several factors contribute to such spoilage in fish
  - Interactions between the products and handling equipment
  - Interactions between the product and the surrounding environment and atmosphere
  - The inherent self-destructive biochemical changes that take place inside the fish once it is harvested
- The occurrence of spoilage in fish is manifested and perceived by the end user through changes in several sensory perceptions
  - Odour
  - Colour
  - Shape
  - Texture

Biochemical Aspects of Fresh Fish and Seafood Spoilage

- Prior to harvest, fish are protected by a skin that secretes antimicrobial compounds, such as lysozyme, and by antibodies in the blood.

- Harvesting results in death of fish with the following consequence
    - Stop of energy supply for normal body function.
    - Cell membranes are no longer energized, and molecules and ions can freely diffuse.
    - Antimicrobials are no longer produced or distributed.
    - Microflora penetrates the skin from the outside surface and the flesh from the intestines and gills.

Characterization and Quantification of Fish Spoilage

- A combination of visible signs of degradation and odour production characterize different phases of spoilage after harvest.

Characteristics of Phase Changes during Spoilage of Cod Fish Stored in Ice

Phase	Storage (Days)	Characteristic Changes
I	0-6	No marked sign of spoilage
II	7-10	No odour production
III	11-14	Production of some odour, slightly sweet to fruity odours
IV	>14	Production of hydrogen sulfite and other sulphide compounds, fecal, and strong ammonia odours

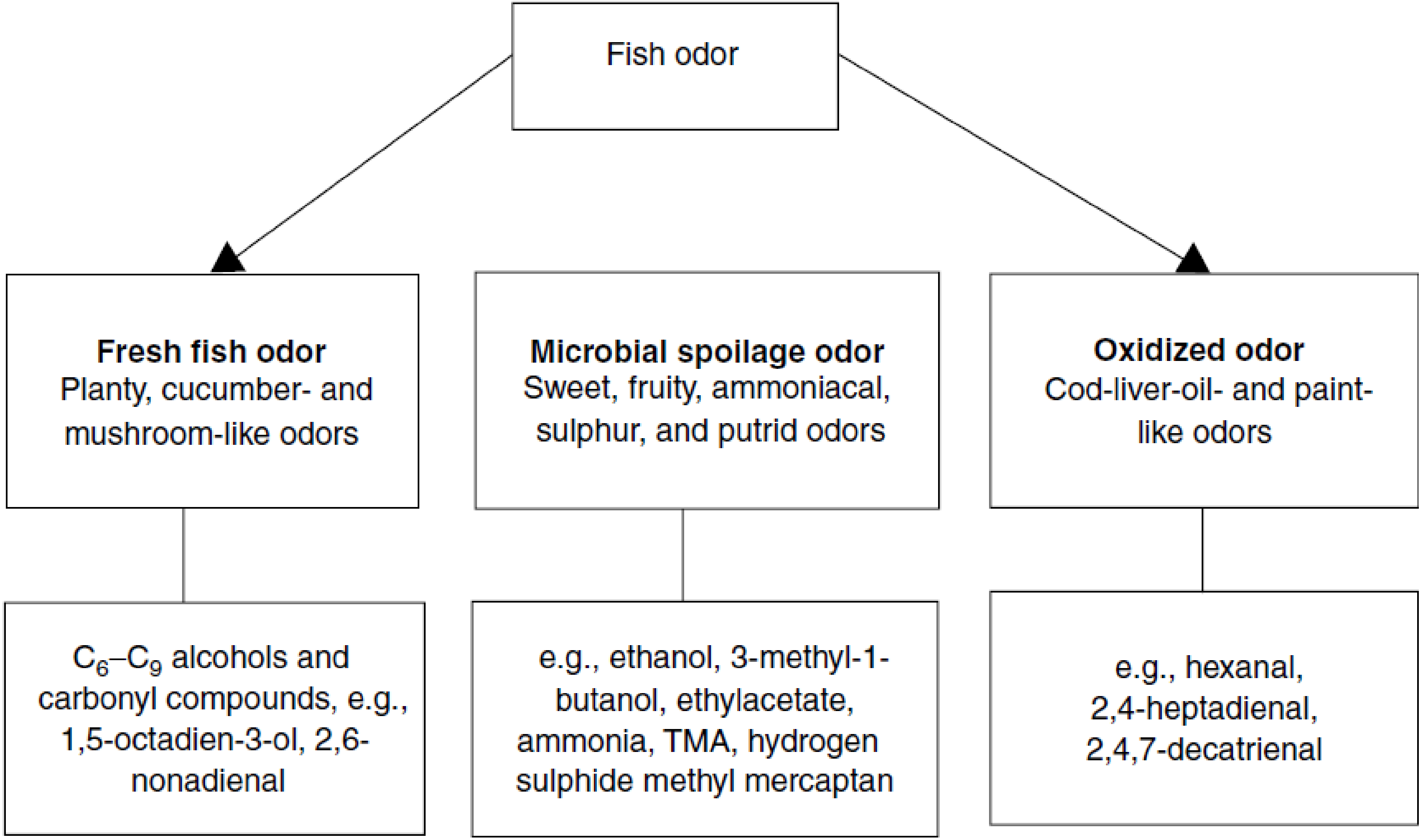
Characterization and Quantification of Fish Spoilage

- Two approaches characterization of fish spoilage:
- **Destructive approach**
  - Cooked flavour without added spices is the most precise objective method of assessing fish spoilage and quality changes - not suitable for rapid assessment during postharvest handling – time consuming
- **Non-destructive measurement** – the quality status of fresh fish
  - Monitorig changes in gill colour, gill odour, eye colour, skin colour, and odour production may be used alone or in combination

Physicochemical Manifestations of Spoilage in Fish and Seafood

- **Colour changes**
  - Fresh fish has a translucent appearance due to even scattering of incident light.
  - With an increase in spoilage - the fish surface then appears opaque
- **Texture changes**
  - Fresh fish has characteristic firmness
  - During postharvest handling and storage, the texture of fresh fish changes from “firm” and “moist” to “mushy” and “runny.”
  - The loss of firmness and development of unpleasant odours and flavours are some of the quality changes that occur in fish and seafood after harvest.
- **Odour changes**
  - The release of volatile compounds is one of the important indicators of freshness and spoilage of fish and seafood

Categorization of fish odours and the volatile compounds that contribute to the characteristic odour of fresh, spoiled, and oxidized fish



Abiotic, Biotic, and Physiological Causes of Fish and Seafood Spoilage

- Spoilage of fish and seafood is caused by a many of factors:
- Mechanical handling damage
  - Harvesting and handling practices and equipment
- Environmental factors
  - Postharvest handling environmental conditions
- Biotic (bacterial) factors
  - The presence of decay-causing microbiological agents
- Physiological (internal) factors: lipid oxidation and hydrolysis
  - Internal physiological changes or biochemical reactions that are associated with normal processes of aging and death

Mechanical Handling Damage

- During harvesting and postharvest handling operations, fish may be subjected to excessive forces, which result in physical injury and blemish.
  - Impact, compression, friction /abrasion, cuts…

- The presence of physical injury such as bruise, cuts, and abrasion provides favorable sites for opportunistic infection and contamination of produce by decay-causing microorganisms

Environmental Factors

- Undesirable environmental conditions contributing to the onset and rate of quality deterioration and spoilage:
- Temperature - the degree of hotness or coldness
  - Most influential factor affecting spoilage of fresh produce such as fish and seafood
- Relative humidity
  - Freshness of high-water-content foods such as fish and seafood is maintained better under high relative humidity conditions.
- Direct exposure to sunlight
- Airflow
  - Airflow around fresh fish and seafoods must be closely monitored to avoid excessive loss of surface moisture and undesirable changes in skin and flesh quality.

Biotic (Bacterial) Factors

- The deterioration of fresh fish is primarily due to bacterial action.
- It is recognized that only some of the bacteria is responsible for producing the off-odours, Off-flavours, appearance, and textural changes.
- Odour is the product of volatile compounds from spoiling fish muscle
    - Ethyl mercaptan, methyl mercaptan, dimethyl sulfide, hydrogen sulfide,
- Consumption of contaminated fish and seafood is a potential source of health and safety hazard to humans.
- The main hazards of fish and seafood
    - Pathogenic bacteria (clostridium botulinum, listeria monocytogenes)
    - Parasites
    - Biotoxins
    - Viruses

Physiological (Internal) Factors: Lipid Oxidation and Hydrolysis

- Lipid oxidation is a major cause of quality deterioration in fish and seafood.
- Catalysts for lipid oxidation
    - Molecular and singlet oxygen
    - Metals (iron and copper)
    - Enzymes (lipoxygenase)
- Technological approaches to minimizing lipid oxidation:
    - Reducing oxygen access to the product
        - Controlled-atmosphere
        - Storage and modified-atmosphere
        - Packaging (e.g., vacuum packaging, edible coating)
    - Maintaining natural antioxidants or adding antioxidants
    - Maintaining low temperatures through cool- and cold-chain management
    - Removing unstable lipids (e.g., subcutaneous fat) and dark muscle, which contains more fat.

Postharvest Treatments and Preservation of Fish and Seafood

- Maximum freshness of harvested fresh produce such as fish and seafood occurs immediately after harvest.
- For the reduction of losses, preservation/maintainig quality, extending storage and shelf life is important
  - Improvement of Harvesting and Postharvest Handling Systems
  - Prestorage Treatments
  - Cold/Cool Chain Technology
  - Chemical Treatments and Use of Biopreservatives
  - The Role of Packaging Technology
  - Warm- and cold-water fish do not always respond in the same way to postharvest handling practices and may often need different treatments to achieve the desired results.

Improvement of Harvesting and Postharvest Handling Systems

- Fish and seafood quality is affected by harvesting and postharvest handling techniques and equipment.
- To reduce the incidence of physical damage
    - Harvesting equipment and containers must be checked regularly
    - Avoiding excessive loading of fish on top of each other or overfilled boxes of fish (particularly the large fish species such as tuna)

- During transportation from catch to landing sites, fish and seafood products need protection against direct sunlight and heat, particularly in tropical and subtropical environments where rapid increases in air temperature can occur in short time.

Prestorage Treatments

- Pretreatment of fish and seafood immediately after harvest and landing is necessary to improve sanitation and remove the inedible parts that would otherwise contribute to accelerated aging and spoilage.
- Washing and cleaning
  - Reduce contamination of physical debris and microbial organisms
- Gutting and bleeding
  - Fish may be bled and gutted (i.e., their intestines removed) prior to subsequent handling storage.
- Depending on the end use and market requirements, fish head may also be removed.
- It is customary to wash fish to remove blood and any remnants of guts.
- However, washing can remove some of the natural antimicrobial secretions and may not be advantageous to the storage life.

Cold/Cool Chain Technology

- Rapid removal of field heat after harvest and maintenance of the cold/cool chain is the effective strategy for fish and seafood preservation and quality maintenance.
- Ice is a very good coolant. It is also cheap, and it must be made from clean, unpolluted, and bacteria-free water. Chilling generally reduces the temperature of fish to 0 °C.
- For longer storage period, fish and seafood may also be frozen.

Approximate Shelf Life of Selected Types of Raw Fish at Different Temperatures

Fish	**Temperature (°C)**	**Shelf Life (Days)**
Cod	0	16
	5	7
	10	4
	16	1
Herring	0	10
	5	4
Salmon	0	2
	10	5
Plaice	0	18
	10	8

Chemical Treatments

- **Chlorine and chlorine dioxide clo$_2$**
  - To killing *escherichia coli*, *listeria monocytogenes*
- **Hydrogen peroxide H_2O_2**
  - Dipping in hydrogen peroxide solution can increase the shelf life of fish.
  - Hydrogen peroxide acts as a preservative as well as a bleaching agent.
- **Lactic acid bacteria**
  - Is used to control pathogen growth in fish. *Listeria monocytogenes*
  - The effect was not due to lactic acid inhibition, but because of the production of the natural preservative nisin (antimicrobial peptide) by the lactic acid bacteria.

The Role of Packaging Technology

- Proper packaging plays a crucial role in preservation of quality and delivery of safe, wholesome fish, and seafood products to the end user.
- Packaging must also be selected to protect against adverse environmental and atmospheric condition as well as penetration of physical and chemical hazards.
- Innovative packaging technologies based on manipulating the gas-exchange characteristics of packaging material to control the oxido-reduction potential have been developed and applied to preserve and extend the storage stability of fish and seafood products.
- The application of vacuum packaging, CA (control atmosphere) or MA (modified atmosphere) packaging around fresh fish is based on the following premise:
  - some spoilage bacteria and lipid oxidation require oxygen—thus, reducing the oxygen around the fish will increase storage and shelf life.
- Depending on the fish species and intended end use, specific combinations of O_2, CO_2, and N_2 determine the level of CA or MA.
- In practice, vacuum packaging, CA storage, and MA packaging are used in combination with refrigerated storage for preservation of fish and seafood products.

Future Prospects for Fresh Fish and Seafood Preservation

- Fish and other marine products are important sources of food for over 1 billion people (as the main source of protein).
- Current estimates project that the demand for fish will continue due to increasing
  - Population growth
  - Increasing purchase as a result of further realization of the health and nutritional benefits of fish diet.
- However, expanding industrialized fishing has a major environmental impact on the rapid worldwide depletion of predatory fish communities.
- Despite the growing demand and importance of fish and seafood in the human food system, the incidence of postharvest losses, quantitatively and qualitatively, remains high, especially among many rural fishing communities.
- Reducing fish losses and preserving its quality over extended storage period will contribute toward improved food security and income without the need for additional catches to meet growing demand.
- Thus, improved harvesting techniques and procedures are needed that reduce the time lag between catch and landing to avoid unacceptable losses in quality (and quantity) prior to handling and processing.

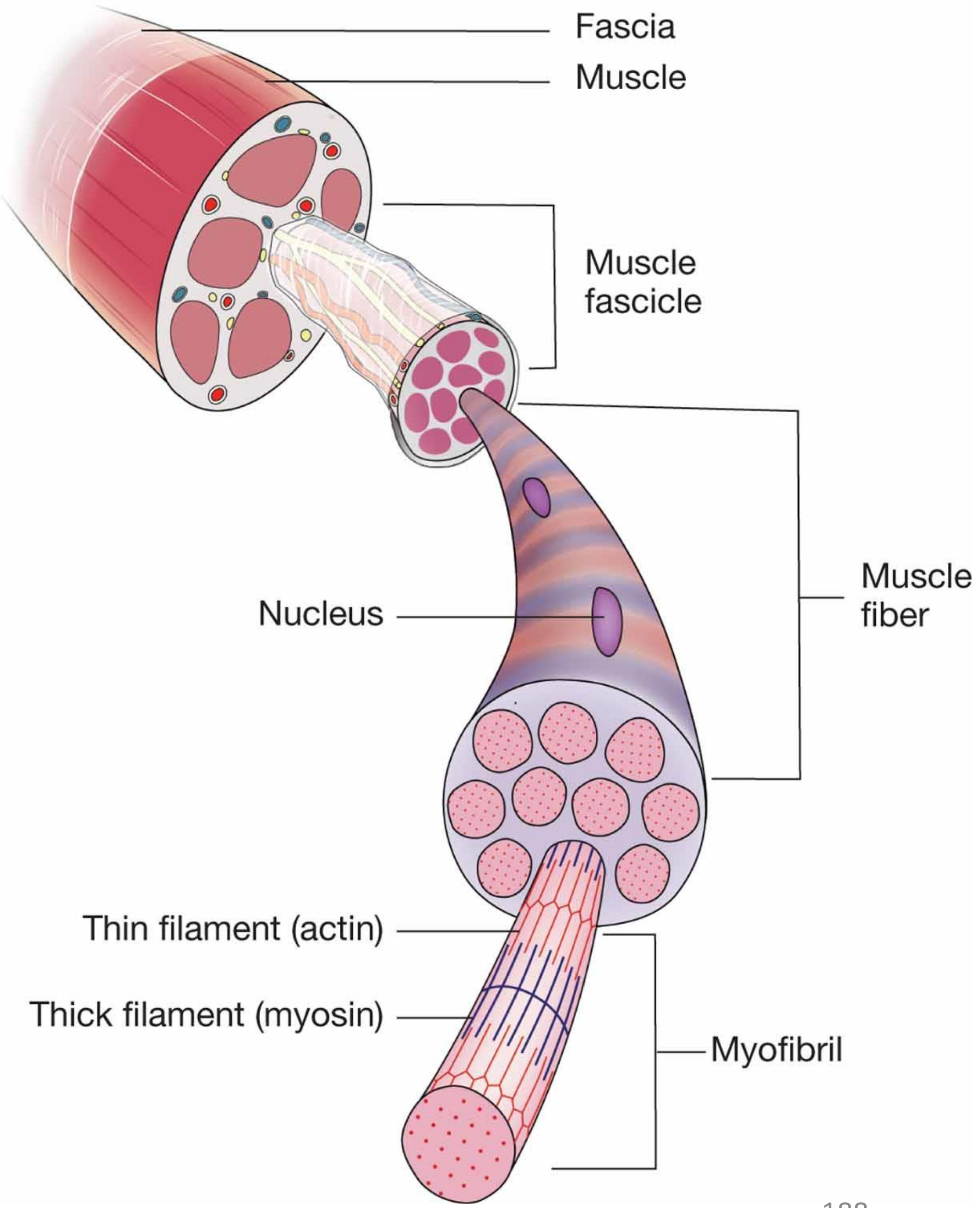
6. Postharvest Handling of Red Meat

Introduction

- Animals' body mass contains a large proportion of skeletal muscle, which is responsible for contraction.
- Meat is the edible flesh of animals' skeletal muscles that is used as food and is an excellent source of many nutrients, especially protein, B vitamins, iron, and zinc.
- Skeletal muscle is made up of thousands of cylindrical muscle fibres.
- The fibres are bound together by connective tissue through which blood vessels and nerves run.

Muscle Structure

- A muscle is composed of muscle fascicles. Around each fascicle are arteries, veins and nerves. Each fascicle contains several muscle fibres (muscle cells). Within each muscle fibre are myofibrils that contain thin strands of actin and thick strands of myosin.
- An ordered arrangement of fibres creates the characteristic texture of meat.



Muscle Physiology

- A period of time normally elapses between
  - The slaughter of an animal and consumption of the meat
  - The carcass cools down
- The meat becomes stiffer the surface dries
- The fat becomes firmer
- The texture and flavour of the lean improve
- These effects are accompanied by significant biochemical changes in the muscles:
  - Acidification
  - The development of rigor mortis

Post-mortem Changes in Muscle

- In a live animal, these protein (actin and myosin) filaments make muscles contract and relax.
- Both actions require enormous amounts of energy, which they get from the energy-carrying molecule ATP (adenosine triphosphate)- **aerobic glycolysis**.
- The most efficient generation of atp requires oxygen, which muscles get from circulating blood.
- In living muscles the fuels for producing this atp are
  - Glucose from the blood
    - Mostly used in fed animals
  - Free fatty acids (FA)
    - Level of free fatty acids is low in fed animals
    - In the fasting state FA -derived from the breakdown of triglyceride stores in the fat depots of the body- are metabolized
  - Glycogen which is stored directly within the muscle fibres
    - Is mobilized only when the rates of breakdown of fatty acids and glucose cannot provide energy at a sufficient rate meet the demands of contracting muscle

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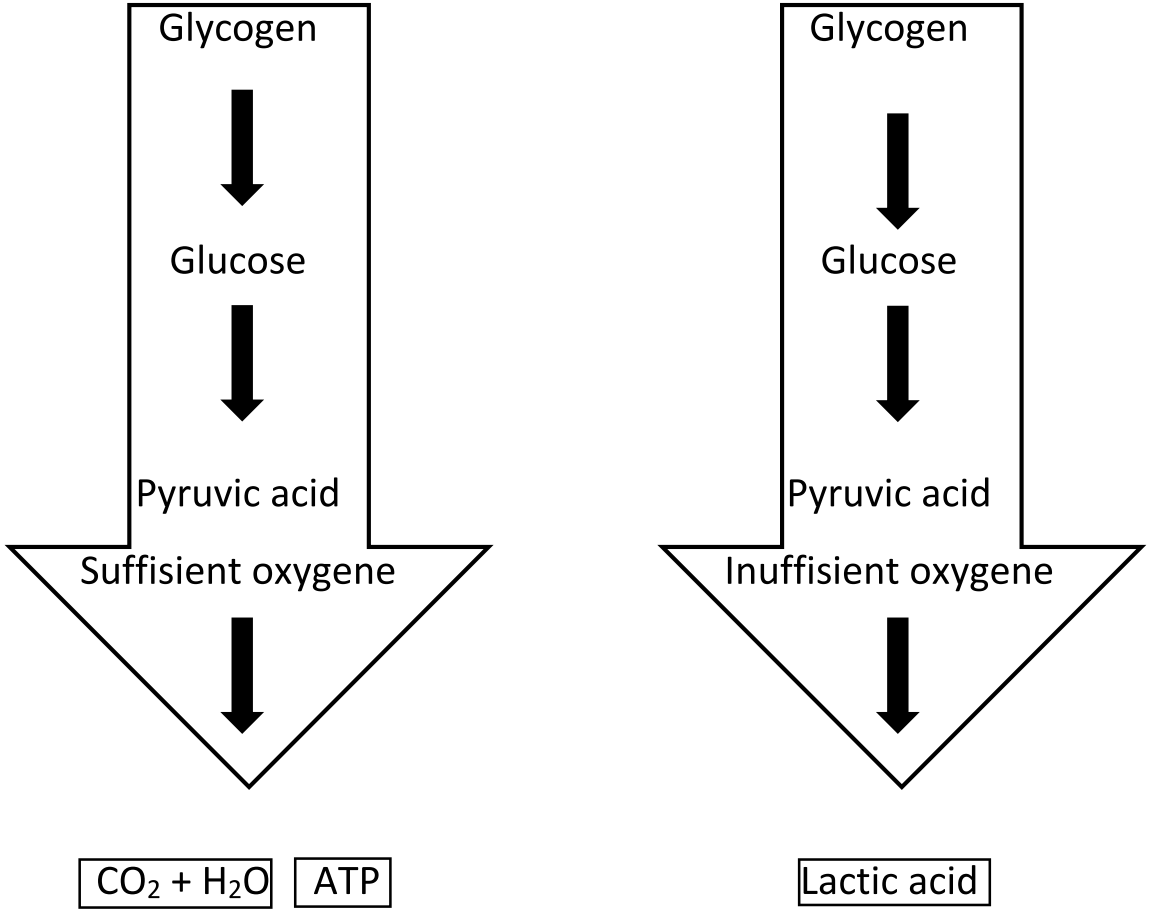
Post-mortem Changes in Muscle

- After an animal is slaughtered, blood circulation stops, and muscles exhaust their oxygen supply.
- Muscle can no longer use oxygen to generate ATP and turn to **anaerobic glycolysis** (a process that breaks down sugar without oxygen, to generate ATP from glycogen, a sugar stored in muscle.)
- The breakdown of glycogen produces enough energy to contract the muscles, and also produces lactic acid.
- With no blood flow to carry the lactic acid away, the acid builds up in the muscle tissue.
- In dying muscle, lactic acid accumulates and lowers pH - acidification.

Aerobic Glycolysis   Anaerobic Glycolysis



Post-mortem Acidification

- The pH of normal muscle at slaughter is about 7.0.
- After slaughter, in a normal animal, the pH falls to pH 5.8-5.4.
- The degree of reduction of muscle pH after slaughter has a significant effect on the quality of the resulting meat.
- If the acid content is too high, becomes pale and watery (pale, soft, exudative - PSE meat)
- If the acid is too low, the meat is tough and dry (dark, firm, dry - DFD meat)

- PSE and DFD meat is not unfit for human consumption, but not well suited for cooking and frying.
- For meat processing purposes, PSE and DFD meat can still be utilized, preferably blended with normal meat.

Rigor Mortis

- As glycogen supplies are depleted, ATP regeneration stops, and the actin and myosin remain locked (actomyosin) in a permanent contraction called *rigor mortis.*
- Rigor mortis is a temporary process occurring during the time course of postmortem glycolysis and is characterized by progressive stiffening of the muscle.
- The rate of postmortem glycolysis and the extent to which it occurs have significant implications on meat quality.
- Ph, temperature
    - Main factors affecting rate of rigor (meat quality)

Contamination of Carcasses

- Meat from healthy animals is sterile.
- Meat is subject to contamination from a variety of sources
  - Internal – from animal - skin, hooves, hair, intestinal contents
  - External - knives, cutting tools, personnel, polluted water, air, faulty slaughtering procedure, postslaughter handling, and storage.

- Slaughter Conditions
- Equipment
- Personnel

Slaughter Conditions

- Slaughter conditions have been implicated as important parameters affecting carcass contamination.
- Mishandling is one of the main causes of stress, which can affect the immune system of the animal and subsequently the meat quality.
- The rate of microbial spoilage of meat varies widely depending on
  - (I) initial microbial contamination
  - (Ii) temperature
  - (Iii) ph
  - (Iv) presence of oxygen
  - (v) presence of nutrients
- The importance of handling animals during slaughter is clear.

Slaughter Conditions

- The most important factors in handling fresh meat
- Speed of handling
- Control of temperature
- Good hygiene conditions

- Slaughter practices are required to minimize both physical and microbiological contamination of carcasses.

Equipment

- The equipment, and slaughter facilities should be properly designed, cleaned, and disinfected.
- The floor and walls of slaughter facilities should be smooth to allow proper cleaning and disinfecting.
- The cleanliness during the slaughtering process can be used to reduce microbial contamination of meat.
- Important source of contamination
  - knives, steels, and aprons of personnel who handle carcasses before skinning
  - protective gloves
  - surfaces of cutting tables

- Hygienic practices correlate with carcass contamination levels, especially the frequency of disinfection.

Personnel

- The most important human sources of bacterial infections are the oral and nasal cavity, digestive tract, and the skin.
- The hazard of these can be reduced by
  - (i) washing, regular cleaning, and disinfection
  - (ii) improving hygienic working conditions
  - (ii) using skilled and careful personnel
  - (v) control of quality and safety
- High frequency of slaughterhouse workers contaminated with bacteria indicated that they play a major role in the cross-contamination of carcasses.
- Good personal hygiene measures are necessary for reducing carcass contamination.
- Hot water (44°C) hand rinse can remove 90% of the microbial contamination from a slaughterhouse worker's hands.

Decontamination of Carcasses

- Decontamination is very important to reduce carcass spoilage and consequently improve meat hygiene.
- The major cause of spoilage is accumulation of microorganisms, specifically bacteria.
- Chilled storage at temperatures less than 10°C is the simplest procedure to store meat products.
- For long storage, the temperature should be as near to the freezing point (1.5°C), and the relative humidity should be controlled within 85%–95% to prevent drying or condensation on the surface.

Decontamination of Carcasses

- Microbial contamination of meat starts during processing on the slaughter line.
- First, the microorganisms reach the carcass surface from where they may penetrate into deeper layers of the meat.
- Reducing this primal surface contamination and avoiding or limiting the microbial growth would improve safety and external shelf life.

- **Water** - Washing with hot water is one of the many potential methods for reducing levels of pathogenic bacteria (80-100 °C) on the surfaces of carcasses
    - The possible heat damage to the appearance of carcass surface
- **Organic Acids -** acetic, propionic, lactic, and formic acids
- **Inorganic Materials** - phosphates, hydrogen peroxide, and ozone
- **Chlorine and Chlorine Dioxide**

Meat Storage and Safety

- Meat is an unstable product largely because microorganisms thrive on its rich supply of nutrients.
- Meat spoilage occurs when undesirable odours and flavours are produced by changes in meat.
- When meat is not properly preserved, it often spoils and then potentially harmful food-poisoning organisms or their products become present in toxic amounts.
- Enzymes, the compounds that catalyze chemical reactions within the meat, are able to produce chemical and physical changes that alter the physical and palatability characteristics of the meat.
- These changes produce meat spoilage.
- Many meat enzymes function better and at a faster rate at or near normal body temperature and neutral pH.
- Low temperature, the presence of high concentrate of ions such as sodium and chloride, low pH, and reduced moisture slow enzyme activity.
- Cooking and other treatments may permanently inactivate enzymes.

Meat Storage and Safety

- Methods of storage and processing are based on the reduction of temperature and pH.

- Refrigeration of Meat
- Aging and Meat Tenderization
- Freezing of Meat

Refrigeration of Meat

- The development of refrigeration had more impact on meat preservation than any other technological advancement.
- Chilling is the most energy-expensive aspect of carcass processing.
- Controlling airflow inside industrial meat chillers is of importance because it determines both the efficiency and the homogeneity of carcass chilling.

Aging and Meat Tenderization

- Aging is necessary as meat is often unacceptably tough immediately following rigor onset.
- The time required for aging varies with the type of meat.
- High-temperature conditioning may accelerate the aging process by keeping carcasses at temperatures of 15°C or greater. This type of conditioning may be applied in the pre- or postrigor state and is very effective in improving meat tenderness.
- The tenderization occurs as a result of protein degradation.

Freezing of Meat

- Freezing is a common practice in preserving meat quality for an extended time and offers several **advantages**.
    - Insignificant alterations in product dimensions
    - Minimum deterioration in meat colour, flavour, and texture
- The **disadvantages** of frozen storage
    - Include freezer burn, dehydration, rancidity, drip loss, and product bleaching.
- Many meat products go directly from the freezer to cooking.
- The main advantages of freezing is the shelf life extension and the purchasing and inventory flexibility offered by frozen meat items.

7. Postharvest Handling of Milk

Composition and Structure

- Milk is a normal secretion of the mammary glands of female mammals.
- Milk consists of
  - (i) an oil-in-water emulsion with the fat in the form of droplets or globules dispersed in the continuous milk serum known as whey
  - (ii) a colloidal suspension of proteins of various sizes in milk serum, consisting mostly of casein micelles, globular proteins, and lipoprotein particles
  - (iii) a solution of lactose, soluble proteins, minerals, vitamins, and other components.

Composition and Structure

- The main component of milk is water.
- The remaining compounds are mainly
  - Fat (3.9%)
  - Protein (3.3%)
  - Lactose (5%),
  - Minerals (0.7%)
  - Vitamins (e.G., Vitamins A and C)
  - Enzymes (e.g., lactoperoxidases (LP) and acid phosphatase)

Microflora of Raw Milk

- Milk is an excellent medium for the growth of a variety of microorganisms owing to its high water content, neutral pH (6.4–6.6), and rich supply of nutrients.
- Microbial contamination generally occurs from three main sources:
  - From within the udder (mastitis - an inflammatory disease of the mammary tissue)
  - From the exterior (water, soil, vegetation, and bedding material)
  - From the surface of milk handling and storage equipment
- Two types of microorganisms:
  - Pathogenic bacteria - the presence of pathogenic microorganisms in milk may result in infection and threat to the consumer's health.
  - Spoilage bacteria - the growth of the spoilage bacteria is more detrimental to the shelf life of milk

Some Types of Spoilage of Milk

Type of Spoilage	Microflora
Souring	Lactic acid bacteria
Casein precipitation	Lactic acid bacteria producing enough acid to drop the pH below 4.6
Gas production	*Clostridium, Bacillus*, yeasts, coliform bacteria, heterofermentative lactics, and propionics
Proteolysis	Psychrotrophic bacteria: *Streptococcus faecalis var liquefaciens, Bacillus cereus, Micrococcus, Pseudomonas, Flavobacterium, Acinetobacter, Aeromonas* Thermophilic organisms: *Streptococcus and Lactobacillus* Sporeforming organisms: *Bacillus*
Lipolysis	Psychrotrophs: *Pseudomonas spp., Achromobacter spp., Alcaligenes spp., Acinetobacter spp.*

Control of Microorganisms in Raw Milk

- Cleaning and Sanitizing
- Cooling of Milk
- Antimicrobial Constituents
- Thermization
- Clarification

Cleaning and Sanitizing

- Hygienic processing of food requires that the equipment are cleaned frequently and thoroughly to restore them to the desired degree of cleanliness (influences the total bulk milk bacterial count).
- Since proper cleaning and sanitizing of dairy equipment are important for production of milk with acceptable microbial quality.
- Many dairy plants use hot water as a common method of sanitation.

Cooling of Milk

- Milk leaves the udder at a temperature of about 37°C, which is favorable for the growth of a large number of microorganisms, mainly mesophiles.
- Milk should therefore be quickly cooled down after leaving the udder.
- Cooling is the main means of slowing down the growth of bacteria in milk.
- The maximum storage time of milk is closely related to the storage temperature.

Antimicrobial Constituents

- The Lactoperoxidase System (LP)
- There are some naturally occurring antimicrobial systems present in raw milk that might improve its shelf life.
- The main representative of these systems is LP.
- The lactoperoxidase system is a significant component of fresh milk.
- The LP system consists of three components:
  - LP, thiocyanate, and hydrogen peroxide.
- All three components are required for antimicrobial activity, act synergistically
- The most effective against gram-negative psychrophilic bacteria.

The enzyme is available in milk in abundance; however, the availability of thiocyanate in milk for the proper LP preservation is not sufficient. Certain bacteria in milk produce small quantities of hydrogen peroxide, but the quantity of oxygen that can be provided is too small for the oxidation process in LP system. Stimulation of LP activity through the addition of exogenous thiocyanate and hydrogen peroxide has been investigated as a means of preserving raw milk in developing countries where ambient temperatures are high and refrigeration is not often available. For proper LP preservation, very small quantities of thiocyanate (0.00015%) and hydrogen peroxide (0.00085%) must be added to milk. These quantities are sufficient to preserve milk at tropical temperatures for about 8h, while the preserved milk can be easily kept overnight at temperatures of 15°C–20°C; at temperatures of 4°C, the milk can be kept for a few days without spoilage.

Thermization (Thermalization)

- Thermization
  - Is a method of pasteurizing raw milk with heat
  - Is a mild thermal process applied to milk that may need to be stored over a long period prior to use.
  - Is defined as a heat treatment that uses temperatures between 57°C and 68°C for 15s.
- The purpose of this treatment is to protect against microorganisms that may grow during storage of raw milk, especially gram-negative psychrotrophic bacteria.
- Thermization should be applied soon after milk treatment and it is only effective if thermized milk is kept cool (4°C).
- Thermization may also slightly affect the flavour and texture of cheese, but not the yield.

Clarification

- Clarification is a commonly employed pretreatment of milk prior to its storage/manufacture into other products.
- The shelf life of milk can be extended by clarification.
- Clarification may be as simple as filtration or may include high-speed centrifugation to remove microbial cells and spores.
- Filtration is usually carried out by pumping milk through specially woven cloth. This results in the removal of debris and all extraneous matter.

8. Preservation Using Chemicals

Indirect inactivation (inhibition) of microorganisms

Food Preservation Methods

- Based on the mode of action, the major food preservation techniques can be divided into:
- **1. Indirect inactivation (inhibition) of microorganisms**
    - Modification environment that prevents microorganisms from multiplying and performing of enzymatic functions
- 2. Direct inactivation of microorganisms
    - Directly inactivating bacteria, yeasts, moulds, or enzymes
- 3. Avoid recontamination
    - Removal of microorganisms from the medium/environment.
    - Preventing/avoiding contamination before and after processing.

Introduction

- Preservatives are substances which, under certain conditions,
  - Either delay the growth of microorganisms without necessarily destroying them
  - Or prevent deterioration of quality during manufacture, distribution and storage.

- Natural origin
- Synthetic origin

- These substances are added in very low quantities which do not change (or only very little) the organoleptic and physico-chemical properties of the foods.
- Chemicals that function to preserve the food are generally added after the food has been processed and before it is packaged.

Introduction

- Mechanisms of action:
  - Destroy cell membranes of microorganisms
  - Effect enzyme activity or then genetic mechanisms of MO.

- Guidelines for use of food additives:
  - Maintaining the nutritional quality of food
  - Improving appearance of food
  - Be subjected to adequate toxicological evaluation
  - Be kept under observation for possible undesirable effects

Traditional Chemical Food Preservatives

- Sugar
- Salt

Salt

- Effects of salt
- 1. Increasing the osmotic pressure at a level which prevent microorganism development – osmotic dehydration.
    - Water migrates out from the cells by osmotic pressure. This results in cell shrinkage and some membrane damage.
    - The cell growth of the MO is inhibited.
- 2. Salt has the ability to bind water (hygroscopic) which reduces the proportion of usable water available for growth of MO (decreasing water activity - a_w)
- It is one of the oldest methods of preserving food
    - Fish, fish products, meat (bacon, ham).

- Disadvantage – strong taste of salt. It is not suitable for every food.

Sugar

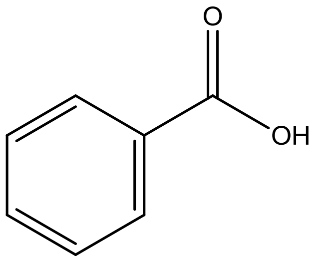
- Similar effect as salt
  - Increasing osmotic pressure and to decreasing water activity (a_w)
- The concentration of 60% of sugar in the liquid phase in the finished product assures food preservation.
- Fruits – jams, syrups, candied fruits
- Vegetables – candied ginger
- Condensed milk

Acids

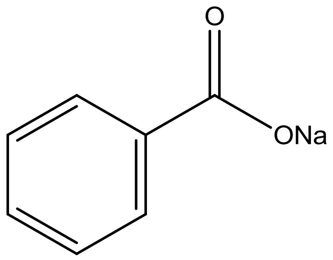
- Benzoic acid
- Sorbic acid (Potassium sorbate)
- Lactic acid

Benzoic Acid

- **Benzoic acid** in the form of its sodium salt, constitutes one of the most common chemical food preservative.
- **Sodium benzoate** is a common preservative in acid or acidified foods such as fruit juices, syrups, jams and jellies, sauerkraut, pickles, fruit cocktails, mustards etc.
- Yeasts are inhibited by benzoate to a greater extent than are moulds and bacteria.



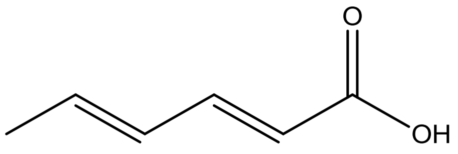
Benzoic acid



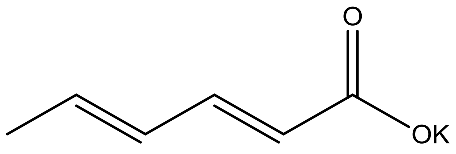
Sodium benzoate

Sorbic Acid and Potassium Sorbate

- **Sorbic acid** and its salts are practically tasteless and odourless in foods.
  - It is considered non toxic and is metabolized (doesn‘t accumulate in the organism).
  - Sorbates are used for mould and yeast inhibition in a variety of foods including fruits and vegetables, fruit juices, pickles, sauerkraut, syrups, jellies, jams, high moisture dehydrated fruits, etc.
- **Potassium sorbate**
  - Potassium sorbate, a white powder, is very soluble in water.
  - Also known as "wine stabilizer"
    - Is used to prevent undesirable refermentation (sweet wines, sparkling wines, ciders)
  - Potassium sorbate is used to inhibit moulds and yeasts in many foods, such as cheese, wine, yogurt, dried meats, apple cider, soft drinks and fruit drinks, and baked goods.



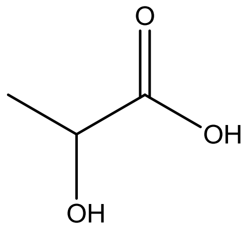
Sorbic acid



Potassium sorbate

Lactic Acid

- This acid is the main product of many food fermentations; it is formed by microbial degradation of sugars in products such as sauerkraut and pickles.
- The acid produced, in such fermentations, decreases the pH to levels unfavourable for growth of spoilage organisms such as putrefactive anaerobes and butyric-acid-producing bacteria.
- Yeasts and moulds that can grow can be controlled by the other preservatives such as sorbate and benzoate.



Lactic acid

Other Chemicals

- Sulphur dioxide and sulphites
- Carbon dioxide
- Nitrates NO^{3-} and Nitrites NO^{2-}

Sulphur Dioxide (SO_2) and Sulphites

- SO_2 and sulphites (sulphites are compounds that contain the sulphite ion SO_3^{2-}) **conserve colour**, **act as antioxidants** and **control microbial growth**.
- Sulphites occur naturally in all wines to some extent.
- Sulphites are commonly used to arrest fermentation at a desired time, and may also be added to wine as preservatives to prevent spoilage and oxidation.
- Without sulphites, grape juice would quickly turn to vinegar.

Carbon dioxide CO_2

- Carbon dioxide is used as a solid (dry ice) in many countries as a means of low-temperature storage and transportation of food products.
- Beside keeping the temperature low, as it sublimes, the gaseous CO_2 inhibits growth of psychrotrophic micro-organisms and prevents spoilage of the food (fruits and vegetables, etc.).

Nitrates NO_3^- and Nitrites NO_2^-

- Nitrates and nitrites are used in many foods as preservatives and functional ingredients.
- Nitrite salts are used for curing of meat, poultry, and fish products.
- Curing with nitrite results in the development of a characteristic pink colour and distinctive flavour.
- **Health Aspect**
  - Prolonged ingestion of sodium nitrite or sodium nitrate has shown to cause methemoglobinemia, especially in infants.
  - Methemoglobinemia causes production of abnormal hemoglobin
  - The major adverse effect of nitrites is the possible induction of cancer.
  - It has been found that **nitrites** react with amino acids (found in proteins of meat) to form nitrosamines - carcinogenic

No mater what kind of preservative (nitrates or nitrites) can be added to meat to keep bacteria from growing on it, but once we consume them, nitrates are converted to nitrites in our digestive system.
The exposure to nitrosamines must be balanced against the risk of not using nitrites and acquiring botulism from cured meat. The comparative risks are more obscure or difficult to quantify.

Nitrites NO_2^-

- Sodium nitrite ($NaNO_2$)
  - Prevent the growth ***clostridium botulinum***, and other microflora (*escherichia, salmonella*...)
- Usually, input concentrations in excess of 100-200 mg/kg are used for protection against microflora.
- Potassium nitrite (KNO_2)

Antioxidants in Food Preservation

- Antioxidants
  - Substances that can protect foods against autoxidation, irrespective of the mechanism of action.
  - Compounds that inhibit oxidation by reaction with free radicals
    - Free radicals are unstable molecules that arise by oxidation of fat – oxidative rancidity

Rancidity of Fats, Oils, and Fatty Foods

- Rancidity is an objectionable defect in food quality.
- Fats, oils, or fatty foods are deemed rancid if a significant deterioration of the sensory quality is perceived (particularly aroma or flavour, but appearance and texture may also be affected, e.g., in fish).
- These lipids degrade to the point of becoming either unpalatable or unhealthy to ingest.
- Rancidity includes several types of changes, but most often the degradation due to changes in lipid constituents is considered the main feature of rancidification.
- **Rancidity**, is the natural process of decomposition of fats or oils by either hydrolysis (Lipolytic rancidity) or oxidation (oxidative rancidity – the most important), or both.

Lipolytic Rancidity

- Lipolytic rancidity is mainly due to lipases (triacylglycerol-acyl hydrolases), which are enzymes catalyzing the cleavage of triacylglycerols (triglycerides) into free fatty acids and partial glycerol esters—monoacylglycerols (monoglycerides), diacylglycerols (diglycerides), and glycerol.
- In most fats and oils, the presence of free fatty acids is not perceptible to human senses, therefore, not considered as flavour deterioration.
- Milk fats are an exception, as they contain esters of butyric acid.
- Free butyric acid, produced by their hydrolysis, imparts a typical disagreeable off-flavour, resembling rancid butter.
- The lipolytic rancidity cannot be inhibited by antioxidants.

In oils obtained from seeds of palms (Palmaceae), such as coconut or palm kernel oils, caproic, caprylic, and capric acids are released by lipolysis, which results in a soapy off-flavour. Such deterioration is frequently observed in stored food products containing coconut.

Oxidative Rancidity

- The most important type of food rancidity.
    - It is due to the auto-oxidation of polyunsaturated fatty acids present in triacylglycerols by the atmospheric O_2 on free radicals.
    - Especially vegetable oils - high content of unsaturated fatty acids
- During autoxidation, all unsaturated fatty acids bound in lipids are slowly oxidized.
- Polyunsaturated fatty acids are the least stable components, being easily attacked by air oxygen.
- At higher temperatures, saturated fatty acids are oxidized as well.

Effects on Sensory Value

- Minor rancidity is not objectionable to most consumers; on the contrary, it makes the flavour richer and more acceptable.
- Larger amounts of secondary oxidation products, however, cause negative consumer response
- Virgin olive oil or fried foods are typical examples of products where minute amounts of oxidation products are desirable but higher amounts are objectionable.

Effects on Nutritional Value

- Essential fatty acids
  - Lose their physiological activity by autoxidation,
  - Turn into antinutritive agents when oxidized.
- Free radicals formed as intermediary products may initiate the development of cardiovascular diseases or cancer in vivo.
- The decomposition of liposoluble vitamins, such as vitamin E, vitamin C, and vitamin A or its provitamins—carotenes.

Sources of Food Oxidants

- **Air oxygen**
  - Fats, oils, and related compounds, which turn rancid on oxidation, are mostly oxidized by air oxygen, which penetrates foods and is dissolved in both aqueous and lipid phases.
- Other oxidants
  - Enzymatically catalysed oxidation, ozone, quinones, metals, hydrogen peroxide…

Reduction and Control of Rancidity in Foods

- Rancidity may be limited by decreasing the storage temperature, the access of oxygen, and the degree of unsaturation of the lipid fraction.
- The problem of rancidity is important because food products are often stored for days or months before their consumption.
- The storage of fat-containing food materials is limited by the period of slow oxidation, where the sensory value is still acceptable.
- The stage of very slow oxidation in the beginning of storage
    - **Induction period**
- The induction period, and thus the shelf life, may be prolonged by appropriate packaging, storage and addition of antioxidants.

Packaging

- Opaque packaging and coloured glass bottles will reduce light induced oxidative rancidity.
- Free space in the container should be kept to minimum to reduce the amount of oxygen present.
- The best way is to use vacuum packaging or fill the package with inert gases.

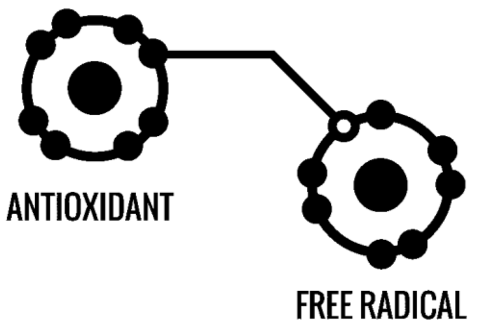
    - Example: Potato crisps which are usually packed in thick foil packets filled with nitrogen.

Storage

- Storing fat and oil rich foods
    - In the cold (refrigeration)
    - In the dark
- Reduce the rate of most reactions that produce rancidity

Antioxidants in Food Preservation

- When application of the appropriate methods is not possible or satisfactory, the best way to control rancidity is the addition of **antioxidants**
- Antioxidants
  - Substances that can protect foods against autoxidation.
  - Inhibit oxidation by reaction with free radicals



The antioxidant donates an electron to the free radical's unpaired electron.

- Free radicals
  - Are unstable molecules seeking electrons for stability.
  - They are known to cause cellular and dna damage

  In our body, which in turn contribute to aging and the

  Onset of various diseases.
- Antioxidants help to slow down this process by donating an electron to an oxygen free radical (the most common type of free radical in our body) so it becomes a stable oxygen molecule.

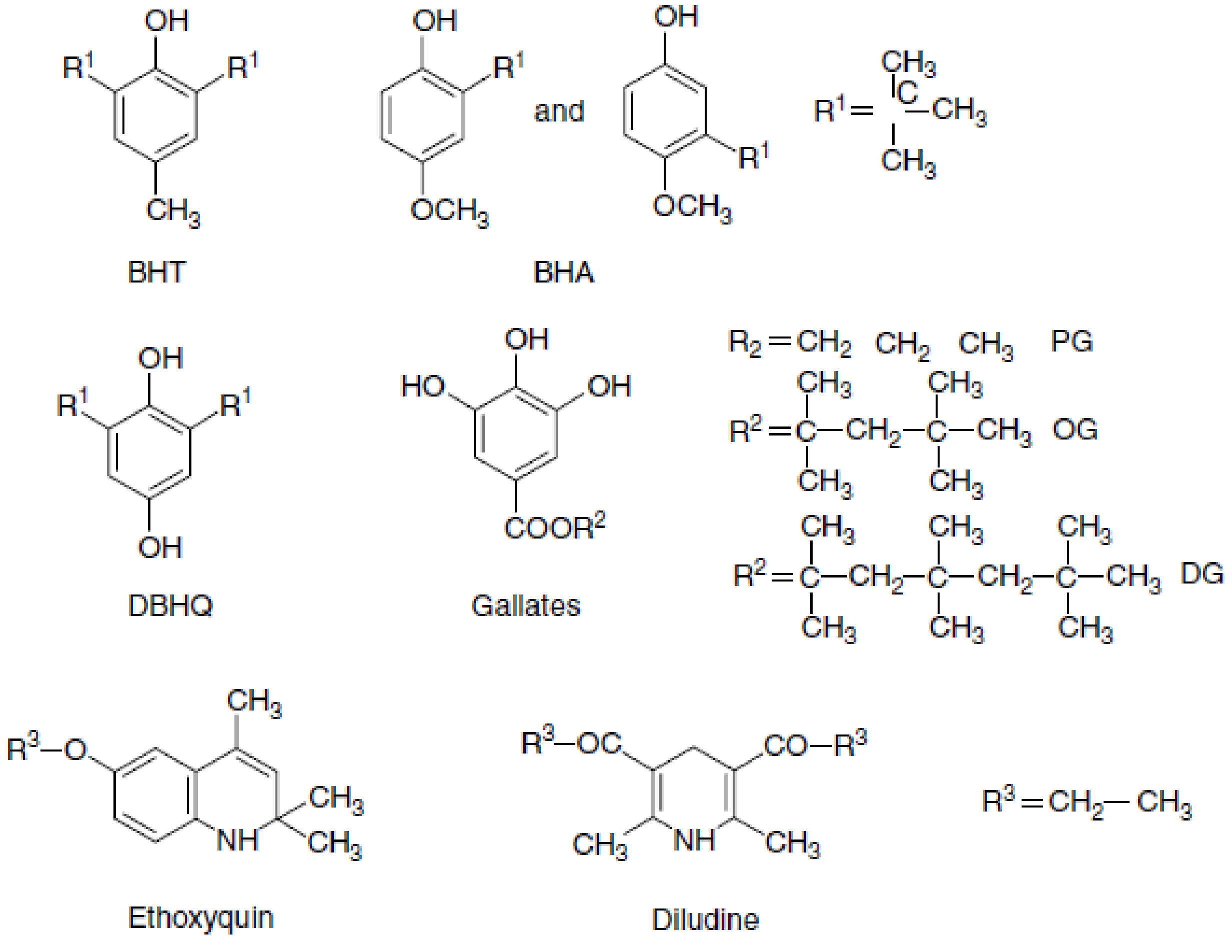
Antioxidants in the Diet and Their Protective Effect against Diseases

- In the last few decades, the consumption of polyunsaturated fats, especially edible oils, has increased several times, mainly as the prevention against some cardiovascular diseases.
- Polyunsaturated fatty acids are easily oxidized *in vivo* resulting in formation of free radicals.
- The application of antioxidants in the human diet for the suppression of free radicals is very important in the prevention of several chronic diseases.
  - Cardiovascular diseases
  - Cancer
  - Aging

Synthetic Antioxidants

- Many phenolic compounds are active as antioxidants, but only a few are used for food stabilization because of very strict safety regulations

BHT, di-*tert*-butylhydroxytoluene
BHA, *tert*-butylhydroxyanisole
DBHQ, di-*tert*-butylhydroquinone
PG, propyl gallate
OG, octyl gallate; DG, *tert*-dodecyl gallate



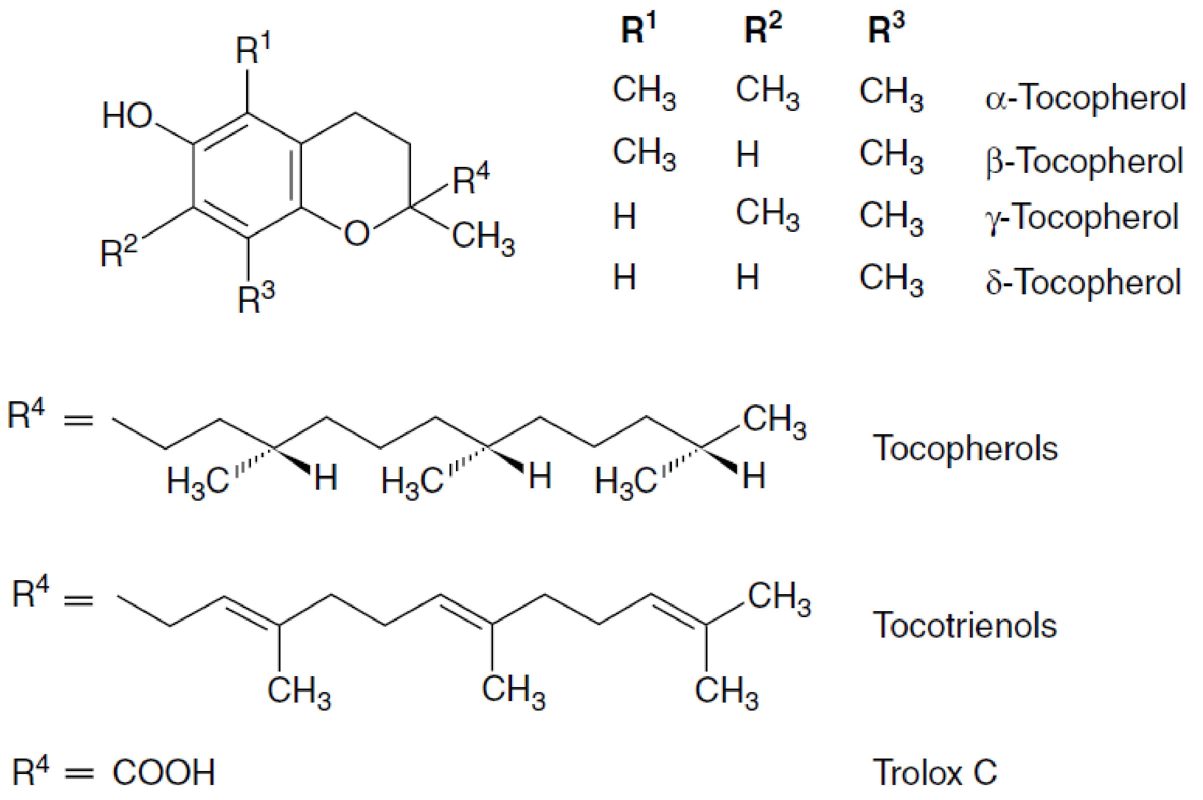
Chemical structures of the most important synthetic antioxidants

Natural Antioxidants

- Consumers prefer food products stabilized with various natural antioxidants
- Almost all plants, microorganisms, fungi, and even animal tissues contain antioxidants of various types, which for various reasons (e.g., availability, food safety, economical reasons) can be used as sources of antioxidants only in certain cases
- The best method of application of natural antioxidants is to use natural food components (e.g., cereals, nuts, fruits, and vegetables) because they are regarded as safe and no special approval for their application is necessary.
- Another possibility is to use natural food ingredients such as spices.

Natural Antioxidants

- Tocopherols
  - Are the most common antioxidants
  - Are present mostly in foods of plant orig
- Antioxidants from Oilseeds
  - Palm fruit - Tocopherols
  - Olive fruit - Oleoeuropein aglycone
  - Sesame seed - Sesamol
  - Cottonseed - Gossypol
  - Rapeseed - Sinapic acid
  - Flaxseed - Lignans
  - Rice bran – Oryzanol
- Antioxidants from Cereals and Grain Legumes
  - contain several types of phenolic compounds



Chemical structures of tocopherols

Natural Antioxidants
Compounds from Fruits and Vegetables

- The most important group of compounds active as antioxidants in fruits and vegetables consists of various flavones and related compounds
- Ascorbic acid present in fruits increases the antioxidant activity of phenolic components
- Grapes
  - Concentration of antioxidants is substantially higher in red wine than in white wine
  - Red wine and deep-coloured fruit juices content anthocyanins, resveratrol (important antioxidants)

- Red wine has been recommended as a source of antioxidants such as resveratrol, to protect humans against the development of cardiovascular diseases, but several other factors may be involved so that the antioxidant activity should be confirmed by further experiments.

Antioxidants in Fruits and Vegetables

Species	Type of Substance
Citrus	Flavonoids, carotenoids
Plums	Phenolics
Persimmon, kaki	Procyanins, catechins
Red wine	Anthocyanins
Pineapple	Flavanols
Onion	Sulfur compounds
Garlic	Sulfides, disulfides
Green pepper	Flavonoids
Carrots	Carotenoids, flavonoids
Betel	Oleoresins, eugenol, hydroxychavicol
Legume	Flavonoids
Green olives	Anthocyanins
Mustard	Phenolics, isothiocyanates
Oak (wood)	Phenolic acids, lignins

Natural Antioxidants
Extracts from Herbs and Spices

- Many species of this group of food materials are active mainly because of their content of phenolic compounds.
- Green tea
    - Contains a high percentage (about 20%) of catechins and related compounds.
    - Extracts from green tea are very active; their activity is comparable to that of synthetic antioxidants.
    - Extracts from leaves of fermented, black tea are less active because a substantial part of the catechins has been converted into less-active tea pigments.
- Rosemary leaves
- Sage
- Other active spices include thyme, juniper, oregano, ginseng, ginger, nutmeg, etc.

Natural Antimicrobials for Food Preservation

- Antimicrobials of plant origin
- Antimicrobials of animal origin
- Antimicrobials of microbial origin

Antimicrobials of Plant Origin

- Spices and herbs are well known to inhibit bacteria, yeasts, and moulds and have traditionally found wide use in food preservation as well as for medicinal purposes.
- Plants produce numerous antimicrobials through enzymatic action on precursors to boost protection against stress, and to fight against microorganism and animals.
- Generally, plants contain preformed mixture of antimicrobial components in active form while some are produced after physical injury.
  - For instance, allicin, an antimicrobial from onion is produced only when physical injury is caused.
- **Phytoalexins**
- **Phenolic Compounds**
- **Essential oils**
- **Organic Acids**

Plants produce numerous antimicrobials through enzymatic action on precursors to boost protection against stress, and to fight against microorganism and animals.
Generally, plants contain preformed mixture of antimicrobial components in active form while some are produced after physical injury. For instance, allicin, an antimicrobial from onion is produced only when physical injury is caused.

Phytoalexins

- Phytoalexins are defined as host-synthesized, low-molecular-weight, broad-spectrum antimicrobial compounds whose synthesis from distant precursors is induced in plants in response to microbial infection or treatment of plant tissues with a range of naturally occurring or synthetic, artificial compounds (biotic or abiotic elicitors)
- Broad-spectrum antibiotics, generally active against phytopathogenic fungi

Phenolic Compounds

- Phenolic compounds represent a common constituent of the human diet, they can be found in fruits, vegetables, coffee, tea, beer, wine, and chocolate
- Contribute to the defense mechanisms of plant tissues as well as to the sensory (taste, odour, and appearance) and nutritional qualities of fresh or processed plants
- Beneficial effects on human health such as antioxidant, anticarcinogenic, antimutagenic, anti-inflammatory, antiallergic activities

Essential Oils

- Essential oils are aromatic and volatile liquids extracted from plant material, such as flowers, roots, bark, leaves, seeds, peel, fruits, wood, and whole plant.
- Chemically, essential oil contains monoterpenes, sesquiterpenes, alcohols, ethers, aldehydes, esters, and ketones as the main constituents.
- Essential oils from oregano, thyme, sage, rosemary, clove, coriander, garlic, and onion are known to exhibit potent antimicrobial activities against foodborne pathogenic bacteria.

Organic Acids

- Citric, succinic, malic, and tartaric acids are commonly found in fruits (e.g., citrus, rhubarb, grapes, and pineapples) and vegetables (e.g., broccoli and carrots).
- Through their use as acidulants or antioxidants in foods, their antimicrobial properties provide additional benefit.
- They are active against a wide range of microorganisms.

Antimicrobials of Animal Origin

- Animals produce several antimicrobial compounds, as first line of defense, which are also found in products of animal origin such as, milk and eggs.
- **Chitosan -** crustacean shells, used in coatings and edible antimicrobial films
- **Lactoferrin -** is commonly present in milk
- **Lactoperoxidase -** is a native enzyme in animal secretions such as saliva, milk
- **Lysozyme -** hen's egg

Antimicrobials of microbial origin
Protective cultures

- Microorganisms in a habitat generally operate by suppressing the growth of certain microorganisms of the surrounding environment.
- Antagonistic cultures are added to food to inhibit growth and/or extend shelf life of food product, termed as protective cultures.
- The most common protective cultures in food preservation:
  - Lactic Acid Bacteria (LAB)
- LAB generally exerts antimicrobial effect through competition for nutrients, space and creating unfavorable environment through production of antagonistic/antimicrobial compounds (peptide nisin).

9. Fermentation as a Method for Food Preservation

Indirect inactivation (inhibition) of microorganisms

Introduction

- Preservation method based on eliminating microorganisms or controlling their growth.
- Fermentation could be described as a process in which microorganisms change the sensory (flavour, odour, etc.) and functional properties of a food to produce an end product that is desirable to the consumer.
- Fermentation, along with salting, cooking, smoking, and sun drying, is one of the earliest ancient tradition, developed by cultures all around the world, to extend the possible storage time of foods.
- For thousands of years, raw animal and plant ingredients have been fermented.

Examples of the More Common Fermented Foods

Food	Principal Ingredient	Key Microorganisms
Wine	Grapes	Yeasts
Beer	Barley	Yeasts
Cider	Apples	Yeasts
Sake	Rice	moulds
Bread	Wheat	Yeasts
Yogurt	Milk	LAB
Chesse	Milk	LAB
Buttermilk	Milk	LAB
Kefir	Milk	LAB + yeasts
Vinegar	Grapes	Yeasts followed by *Acetobacter* or *Gluconobacter*
Tempeh	Soybeans	moulds
Soy sauce	Soybeans	moulds + LAB + yeasts

Fermentation as a Preservation Method

- Fermentation can be effective at extending the shelf life of foods and can often be carried out with relatively inexpensive, basic equipment.
- Therefore, it remains a very appropriate method for use in developing countries and rural communities with limited facilities.
- Fermentations use a combination of the first three principles
  - 1. Minimize the level of microbial contamination in the food
  - 2. Inhibit the growth of the contaminating microflora
  - 3. Kill the contaminating microorganisms

- Microorganisms can improve their own competitiveness by changing the environment so that it becomes inhibitory or lethal to other organisms while stimulating their own growth, and this selection is the basis for preservation by fermentation.

Microbial Contamination of Foods

- Foods are continuously exposed to microbial contamination.
- Many raw foods make ideal environments for microbial replication.
- The rate of microorganisms grow depends on the enviromntal conditions (temperature, pH, redox potential, water activity)

- The basis of fermentation is manipulating the environmental conditions, such that is possible to select for specific kinds of microorganisms that impart a particular taste, odour, texture, or appearance to the food.

Benefits of Fermented Foods

- The acceptability of a food to the consumer is based mainly on its sensory properties.
- Fermented foods were developed by many cultures for two main reasons:
  - (i) to preserve harvested or slaughtered products
  - (ii) to improve the sensory properties
- The simple techniques mean that the procedures can often be carried out in the home.

Microorganisms Used in Food Fermentations

- Lactic Acid Bacteria
- Acetic Acid Bacteria
- Yeasts
- Moulds

Lactic Acid Bacteria (LAB)

- LAB perform an essential role in the preservation and production of healty foods.
- Examples of lactic acid fermentations include
  - (a) fermented vegetables such as sauerkraut, pickled cucumbers, radishes, carrots, and olives
  - (b) fermented milk such as yogurt, kefir, and cheeses
  - (c) sourdough breads
  - (d) fermented sausages
- Their most effective mechanism is to grow readily in most foods, producing acid, which lowers the pH rapidly to a point where other competing organisms can no longer grow.

Acetic Acid Bacteria

- Acetic acid is one of the oldest chemicals known; it is named after the Latin word for vinegar "acetum."
- The acetic acid bacteria are aerobes, acid tolerant, grow well at pH levels below pH 5.
- They derive energy from the oxidation of ethanol to acetic acid.

$$\underset{\text{Ethanol}}{CH_3CH_2OH} + O_2 \rightarrow \underset{\text{Acetic Acid}}{CH_3COOH} + H_2O$$

- The most desirable action of acetic acid bacteria is in the production of vinegar.
- The same reaction can also occur in wines, when oxygen is available, and here the oxidation of alcohol to acetic acid is an undesirable change, giving the wine a vinegary off-taste.

Yeasts

- Yeasts are widely distributed in natural habitats that are nutritionally rich and high in carbohydrates, such as fruits and plant nectars.
    - Rarely toxic or pathogenic
    - Generally acceptable to consumers
- Yeasts have been classified into about 500 species
- The most frequently used strain is saccharomyces cerevisiae
- Yeasts are used to produce ethanol, CO2, flavour, and aroma

$$C_6H_{12}O_6 \rightarrow 2CH_3CH_2OH + CO_2$$

Yeasts + Glucose Ethanol

Moulds

- Moulds are important to the food industry, both as spoilers and preservers of foods and in particular in fermentations for flavour development.
- Moulds from the genus *Penicillium* are associated with the ripening and distinctive flavour of cheeses (Roquefort and blue cheeses, Camembert) or some sausage.
- Other moulds *(Aspergillus oryzae, Rhizopus oligosporus)* are used in fermentations of soybeans to make miso, soy sauce and tempeh from soybeans.
- Tempeh is a traditional soy product originally from Indonesia. It is made by a natural culturing (*Aspergillus* or *Rhizopus*) and controlled fermentation process that binds soybeans into a cake form.

Fermented Products

- Alcoholic Beverages
  - Beer
  - Wine
- Distilled Spirits
- Lactic Acid Products
  - Dairy Products (Yogurt, Cheese)
  - Fermented Vegetables
  - Fermented Animal Products (Fermented Sausages, Fermented Fish)
- Other fermented products
  - Bread
  - Sourdough
  - Vinegar
- Oriental Fermented Products (Soy Sauce, Tempeh)

Beer

- Beer is produced by the fermentation of partially germinated cereal grains, referred to as malt, by yeasts.
- Beers have usually a final ethanol content of about 3%–8%.
- Used yeasts - *Saccharomyces cerevisiae* (Ale), *Saccharomyces carlsbergensis* (Lagers)
- Ales are produced using warm fermentation temperatures, 12°C–18°C
- lager fermentation temperature is generally cold, 8°C–12°C .
- Most beer produced is of the lager variety.

Wine

- Wine can be produced from any fruit juice with sufficient levels of fermentable sugars.
- In most cases wine is a beverage obtained by full or partial alcoholic fermentation of fresh, crushed grapes or grape juice.
- The fresh sweet must is treated with sulfur dioxide to suppress the growth of undesirable microorganisms, and prevent enzymatic browning and oxidation thus stabilizing wine colour.
- Ferment for 3–5 days at temperatures between 21°C and 32°C.
- During this period, ethanol level may reach 14%–17%.

Distilled Spirits

- The fermentations can only produce a maximum alcohol content of about 17%.
    - Concentrations in excess of this inhibit the metabolism of the yeasts.
- To obtain higher alcohol concentrations, the fermented product must be subsequently distilled.

Yogurt

- Yogurt is a milk product obtained by lactic acid fermentation through the action of ***Streptococcus*** *thermophilus* and ***Lactobacillus*** *delbrueckii* subsp. *Bulgaricus* (the symbiotic growth of the two microorganisms).
- Streptococci produce lactic acid, formic acid, and carbon dioxide. Formic acid stimulates the growth of lactobacilli.
- The lactobacillus liberate some amino acids needed for the growth of the streptococci and produce acetaldehyde and more lactic acid.
- Acetaldehyde is the compound that contributes mostly to the typical flavour of yogurt.

Cheese

- Cheese is a concentrated milk product obtained after coagulation and whey separation of milk, cream or partially skimmed milk, buttermilk, or a mixture of these products.
- Cheese is commonly made from cow, sheep, goat, or buffalo milk.
- Milk is inoculated with an appropriate lactic starter. The starter culture produces lactic acid, gives rise to curd formation.
- In addition, lactic acid is also responsible for the fresh acidic flavour of unripened cheeses and plays a major role in the suppression of pathogenic and some spoilage microorganisms and in the production of volatile flavour compounds and the synthesi of lipolytic and proteolytic enzymes involved in the ripening process of cheese.
- The starter organisms most used for cheese production are mesophilic starters, strains of *Lactococcus lactis* and its subspecies.
- Cheeses could be grouped or classified according to texture, moisture content (soft, hard), brined (feta), fresh or ripened, and ripened by bacteria or moulds

Cheese Varieties and Their Classification

Designation	Principal Curing Characteristics	Examples
Uncured or unripened	No curing—must be made from pasteurized milk	Cottage, Quark, Cream, Mozzarella
Cured or ripened	Salt-cured or pickled	Feta, Domiati
	Ripened by bacteria and surface microorganisms	Limburger, Brick, Port du Salut
	Ripened primarily by bacteria, without eyes	Provolone, Edam, Gouda, Cheddar, Parmesan, Romano
	Ripened primarily by bacteria, with eyes	Emmental, Gruyère
mould cured or ripened	Ripened by surface moulds	Camembert, Brie
	Ripened principally by internal mould growth	Roquefort, Stilton, Gorgonzola, Cheshire, Danish Blue

Fermented Vegetables

- A large number of vegetables are preserved by lactic acid fermentation around the world.
  - The most important commercially fermented vegetables are cabbage (sauerkraut), cucumbers, olives, carrots, cauliflower, celery, okra, onions, and peppers.
- The salt extracts liquid from the vegetable, which serves as a substrate for the growth of LAB.
- Growth of undesirable spoilage microorganisms is restricted by the salt.
- Aerobic conditions should be maintained during fermentation
  - to allow naturally occurring microorganisms to grow and produce enough lactic acid,
  - to prevent growth of spoilage anaerobic microorganisms.

Fermented Animal Products

- The primary reason for developing methods to ferment meats and fish was to extend the shelf life of these highly prized, perishable foods.
- Several products became popular, including fermented sausages, fish sauces, and fish pastes.
- Fermentation of fish is most common in southeast Asia where fish is a major component of the human diet (fish sauces and pastes - they are used to flavour soups, curries, salads, rice, etc.).

Bread

- Breads have relatively short shelf lives; therefore, the primary reason for using yeasts, is not preservation, but to improve the digestibility and eating appeal of grains.
- The metabolic activity of the yeasts helps to chemically ripen the gluten (protein in grains), enabling the dough to expand evenly and retain the gases during baking.
- The gas is a combination of air incorporated during mixing and kneading and CO_2 produced from the fermentation of sugars by yeasts.
- The yeasts contribute to the flavour and provide an appealing aroma.

- The release of carbon dioxide by microorganisms has two major roles in food fermentations:
- (i) it can act as a leavening agent
- (ii) it can be used for carbonation of beverages.
- One of the most common uses of carbon dioxide is to leaven dough during bread making

Sourdough

- The fermentation combines the metabolic activity of LAB for souring and yeasts for leavening.
- The complexity of the bread flavour is based on the lactic and acetic acids produced by LAB and flavour compounds formed by the activity of endogenous cereal enzymes, microbial metabolism, and the baking process.

- Traditionally, a natural starter culture (Saccharomyces-Candida)) that iscontinuously propagated from one fermentation to the next, is used in sourdough fermentations.

Vinegar

- Vinegar is one of the oldest known culinary products.
- Vinegar contains a minimum of 4% w/v (40 g/l) acetic acid and ph value between 2.0 and 3.5
- Vinegars are produced from a variety of fermentable substrates
  - The most common - fruits, honey, coconut, malt, and cereal grains
- Vinegars are produced from a two-stage fermentation:
  - Initially an anaerobic, alcoholic fermentation of sugars by yeasts,
  - Followed by oxidation of the ethanol to acetic acid by bacteria (acetification)

Oriental Fermented Products

- Soy Sauce
  - Dark brown liquid produced by the fermentation of soybeans and wheat in a salt brine.
  - Culture of *aspergillus oryzae*

- Tempeh
  - Is a protein-rich food (may be considered one of meat analogs)
  - It is made by growing the mould *rhizopus oligosporus* or related species on soaked, dehulled, partially cooked soybeans, knitting them into a firm cake, which can be sliced and deep-fried or cut into cubes and used in place of meat in soups.

10. Drying and Food Preservation

Indirect inactivation (inhibition) of microorganisms

Introduction

- The preservation of foods by drying is the and most common method used by humans and the food processing industry.
- Dehydration of food is one of the most important achievements in human history, making humans less dependent upon a daily food supply even under adverse environmental conditions.
- In earlier times drying was dependent on the sun, nowadays many types of sophisticated equipment and methods are used to dehydrate foods.

- The terms dried and dehydrated are not synonymous. The U.S. Department of Agriculture lists dehydrated foods as those with no more than 2.5% water (dry basis), while the term dried foods applies to any food product with more than 2.5% water (dry basis).

Drying - Mode of Preservation

- 1. **Drying reduce the water activity** - preserving foods by avoiding microbial growth and deteriorative chemical reactions
- 2. **Higher temperature** – The degrading effects of heat on microorganisms and the activity of enzymes

- In the case of foods to be preserved by drying, it is important to maximize microorganism and enzyme inactivation for preventing spoilage.
- Termal drying
- One of the most widely used methods of drying foods
- Heat is mainly used to remove water from the foods
- Industry drying of food is one of the most energy-intensive processes

The Considered Factors before Selecting a Drying Process

- (a) the type of product to be dried
- (b) desired properties of the finished product
- (c) allowable temperature tolerance,
- (d) the product's susceptibility to heat
- (e) pretreatments required
- (f) capital and processing costs (rentability)
- (g) environmental factors (temperature, pH…)

Classification of Food Materials in Relations to Thermal Drying

- Food materials can be classified as
  - (a) homogeneous gels
  - (b) porous materials with interconnecting pores or capillaries
  - (c) materials having an outer skin that is the main barrier to moisture flow

- The type or structure of foods always plays an important role in the drying process.

Thermal Drying methods

- Sun Drying
- Solar Drying
- In-Store Drying
- Convection Air Drying
- Explosive Puff Drying
- Vacuum Drying
- Freeze Drying
- Heat Pump Drying
- Smoking

Sun Drying

- Earlier, only sun drying was used for drying.
- In this process, foods are directly exposed to the sun by placing them on the land or left hanging in the air.
- The main disadvantages of this type of drying are
  - Contaminations from the environment
  - Product losses and contaminations by insects and birds
  - Floor space requirements
  - Difficulty in controlling the process
  - Large areas of space and for high labor inputs
- Sun drying is the cheapest method of drying foods

Solar Drying

- Solar drying is an extension of sun drying that uses radiation energy from the sun.
- The solar dryer has a absorbing surface which collects the sun light and converts it to heat.
- Solar drying is a non-polluting process and uses renewable energy.
- Drying means the use of solar dryers for dehydration of various agricultural products
- The product is dried in a closed space and is thus better protected against
    - Weather (rain)
    - Mechanical impurities (dust)
    - Insects and pets

- Disadvantages
    - Limit its use in large-scale production (compared to sun drying)
    - Higher cost

In-Store Drying

- In-store drying can also be called
    - **Low-temperature in-bin drying**
- It may be used when grains are stored until milled or sold.
- The drying process is slow and can take several days to weeks depending on the depth of the grain bulk.
- Weather conditions in tropical climates are less favourable for in-store drying, due to high ambient temperatures and relative humidity values.

Convection Air Drying

- This is the simple drying technique, which takes place in an enclosed and heated chamber.
- The drying medium, hot air, is allowed to pass over the product, which has been placed in open trays.
- Air drying is usually accomplished by passing air at regulated temperature and humidity over or through the food in a dryer.
- **Important factors**
- Temperature
  - The hotter is the air temperature, the faster is the drying rate
- Humidity
  - The lower is the air humidity, the higher is the drying rate
- Air velocity
  - The higher is the velocity, the higher is the drying rate
- Product geometry structure and composition

Explosive Puff Drying

- Explosive puff drying uses a combination of high temperature and high pressure, and a sudden release of the pressure (explosion) to flush superheated water out of a product.
- Products of this method easy rehydrate.
- Breakfast cereals

Spray Drying

- Spray drying is used to remove water from a liquid mixture, liquid is very rapidly evaporated, and is transformed it into powder form (dry soup, milk powder, coffee, cocoa…).

- Disadvantages
  - The size of the equipment required to achieve drying is very large.
  - Very oily materials might require special preparation to remove excessive levels of fat before atomization.

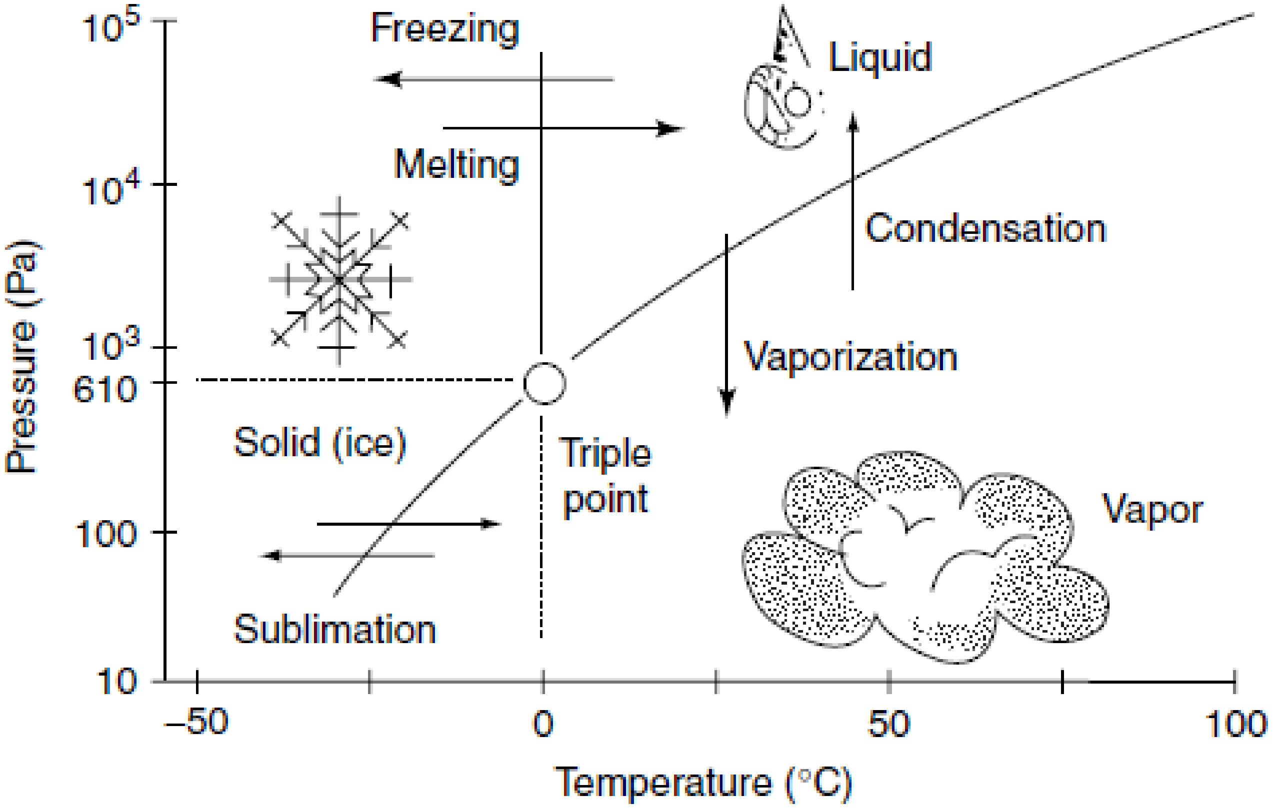
- The fluid to be dried is first atomized by pumping it through either a nozzle or a rotary atomizer, thus forming small droplets with large surface areas. The droplets immediately come into contact with a hot drying gas, usually air. The liquid is very rapidly evaporated, thus minimizing contact time and heat damage.

Vacuum Drying

- Vacuum drying can be a useful tool for solid products that are heat-sensitive – fruit powders.
- The vacuum allows the water to vaporize at a lower temperature than at atmospheric conditions, thus foods can be dried without exposure to high temperature.
- In general, colour, texture, and flavour of vacuum-dried products are improved compared with air-dried products.

Freeze Drying

- Freeze drying, works by freezing the material and then reducing the surrounding pressure to allow the frozen water in the material to sublimate directly from the solid phase to the gas phase.
- This method is usually used for high quality dried products, which contai heat-sensitive components such a vitamins, antibiotics, and microbia culture.
- Frozen material is subjected to a pressure below the triple point (at 0°C, pressure: 610 Pa) and heated to cause ice sublimation to vapor.



A schematic diagram of the different states of water with triple point

Heat Pump Drying

- The heat pump dryer is a further extension of the conventional convection air dryer with an inbuilt refrigeration system
- Dry heated air is supplied continuously to the product to pick up moisture.
- Advantages
  - Higher energy efficiency,
  - Better product quality,
  - The ability to operate independent of outside ambient weather conditions,
  - Zero environmental impact.
  - Condensate can be recovered and disposed of in an appropriate manner,
  - There is also the potential to recover valuable volatile components from the condensate
  - Ability of the heat pump dried to operate at low temperatures.
    - Reducing volatile aromatics losses, heat-labile vitaminsn losses, and colours degradation of dried food

Schematic diagram of the operation of a typical heat pump dryer

(1) vapor-sealed and insulated structure

(2) Humidifier

(3) overheat vent

(4) external condenser

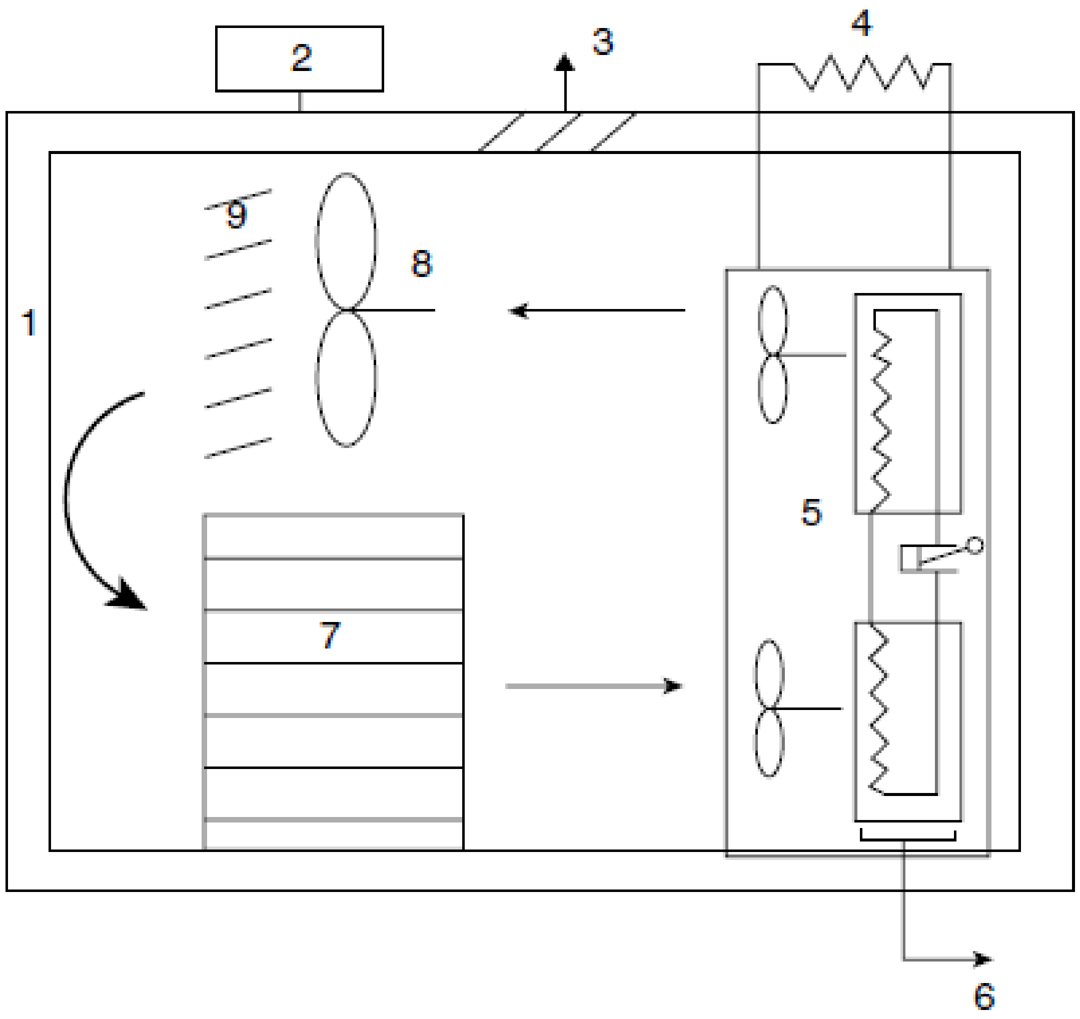
(5) heat pump dehumidifier

(6) condensate

(7) product tray

(8) primary air circulation fan

(9) air distributor



Smoking

- Smoking foods is one of the most ancient food preservation processes and in some communities one of the most important.
- Although not primarily used to reduce the moisture content of food, the heat associated with the generation of smoke also causes a drying effect.
- In many cases, smoking is considered as a pretreatment rather than a drying process.
- Smoking has been mainly used with meat and fish.
- The main purposes of smoking are
  - Desirable flavours and colours to the foods
  - Preservation - some of the compounds formed during smoking have a preservative effect (bactericidal and antioxidant)
  - Preventing lipid oxidation in meat and fish products

Smoke - Chemical Composition

- Smoking is a slow process and it is not easy to control.
- Wood smoke is extremely complex more than 400 volatiles.
  - **Nitrogen oxides** are responsible for the characteristic colour of smoked foods,
  - **Polycyclic aromatic hydrocarbon** components and **phenolic compounds** contribute to its unique taste
- These three chemicals are also most controversial from a health perspective.

- The odour, composition of flavour compounds, and antimicrobial activity of the smoke are recognized to be highly dependent on the nature of wood. Some studies have recognized beech and oak woods as those which produce wood smoke with the best sensory properties. Further, herbs, spices (bay leaves, black peppers, cloves, coriander seed, and spice), or pinecones may also be added to produce unique aromatic smoke flavours.

Smoking - Health Risk

- The concentration of these chemicals (nitrogen oxides, polycyclic aromatic hydrocarbons and phenolic compounds) in smoked food can reach levels hazardous for human health, especially when the smoking procedure is carried out under uncontrolled conditions.
- Processing conditions must be standardized, controlled, monitored, and documented so that the potential for producing toxic food products is eliminated.

Smoking Methods

- The traditional method of smoking fish involves passing hot smoke, from a range of woods, over the fish to partially dry it and impart the flavour and aroma of the smoke.
- Hot smoking
  - Apply heat and smoke to the products
  - Cooking temp. 62.8°C for at least 30 minutes
- Cold smoking
  - Only to apply smoke to the product
  - Cooking temp. Below 35°C
- Both hot- and cold-smoked fish are preserved primarily by controlling the salt and moisture content (water-phase salt).
- Smoke deposition is effective only in controlling surface spoilage
- More modern methods of smoking fish use formulations of liquid smoke to provide flavour. Synthetic smokes are nearer to actual smoke curing and harmful components can be eliminated from synthetic smokes. The fish is dipped in smoke solutions prior to drying.

Pretreatments

- Pretreatments are common in most of the drying processes in order to improve product quality, storage stability, and process efficiency.

- Blanching
- Sulfur Dioxide Treatment
- Salting or Curing
- Other Dipping Pretreatments
- Freezing Pretreatment
- Cooking

Blanching

- Blanching is a process of preheating the product by immersion in water or steam.
- The main purpose of blanching is
  - To inactivate the naturally occurring enzymes present in foods (enzymes are responsible for off-flavour development, discolouration or browning, deterioration of nutritional quality, and textural changes in food materials)

- Change of the texture, colour, and flavour
- The loss of water-soluble vitamins (C, B)

Sulfur Dioxide Treatment

- Sulfur dioxide preserves the texture, flavour, vitamin content, and colour that make food attractive to the consumer.
- Sulfur dioxide treatment is used widely in the food industry to reduce the fruit-darkening rate during drying and storage, and preserves ascorbic acid and carotene.
- Sulfur dioxide improves food by
    - Displaces air from the tissue in plant materials
    - Softens cell walls so that drying occurs more easily
    - Destroys enzymes that cause darkening of cut surfaces
    - Enhances the bright attractive colour of dried fruits

- In sensitive individuals, sulfites can cause allergic reactions.

Curing (salting)

- Curing was originally developed to preserve certain foods by the addition of sodium chloride.
- Now also ssodium and potassium nitrite (or nitrate) are considered as curing salts.
- Salting is one of the most common pretreatments used for fish products.
- In combination with drying, these processes contribute to the development of characteristic sensory qualities in the products, which influence their utilization as food.

Other Dipping Pretreatments

- Dipping treatment with chemicals is also used in addition to blanching or sulfite treatment.
- The dipping treatment is a process of immersion of foods in a solution containing additives.
- The main purpose of the dipping treatment is to improve the drying characteristics and quality.

Chemicals Used for Dipping Treatment

Type	Compounds
Chemicals	
Esters	Methyl oleate, ethyl oleate, butyl oleate
Salts	Potassium carbonate, sodium carbonate, sodium chloride, potassium sorbate, sodium polymetaphosphate
Organic acids	Oleic acid, steric acid, caprillic acid, tartaric acid, oleanolic acid
Oils	Olive oil
Alkali	Sodium hydroxide
Wetting agents	Pectin, tween, nacconol
Others	Sugar, liquid pectin
Surfactants	
Nonionic	Monoglycerides, diglycerides, alkylated aryl polyester alcohol, polyoxyethylene, sorbitan monostearate, sorbitan monostearate, D-sorbitol, polyoxyethylene
Anionic	Sodium oleate, steric acid, sorbitan heptadecanyl sulfate, dimethyl-benzyl-octyl ammoniumchloride

Freezing Pretreatment

- Freezing treatment affects the drying process.
- The rehydration rate of air- and vacuum-dried fruits and vegetables subjected to freezing treatment increased to a level comparable with that of freeze-dried products.

Cooking

- Cooking at different pressure levels before drying can destroy microorganisms and affect the physicochemical properties of dried products.
- The bacterial load on the final product can thus be reduced considerably, and the cooked product can be minced and spread evenly on drying trays with much less trouble than the raw material.
- Precooking is usually used for rice, beef, fish, and beans.

Quality Changes During Drying

- Optimum freshness plays an important role in determining the quality and stability of dried foods;
- The fresher the raw material, the more stable and better is the quality of the product.
- Suitable varieties of produce with the desired maturity should be used to achieve a product that is best in quality.

Quality Changes During Drying

- The quality characteristics of dried foods can be grouped as microbial, chemical, physical, and nutritional.

Quality Characteristics of Dried Foods

Microbial	Chemical	Physical	Nutritional
Pathogens	Browning	Rehydration	Vitamin loss
Spoiling	Oxidation	Solubility	Protein loss
Toxin	colour loss	Texture	Functionality loss
	Aroma development	Aroma loss	Fatty acid loss
	Removal of undesired	Porosity	

Microflora in Dried Foods

- Reducing the water activity of a product inhibits microbial growth but does not result in a sterile product.
- The highest possible drying temperatures should be used to maximize thermal death of mo, even though low drying temperatures are best for maintaining organoleptic characteristics.
- The microbial deactivation depends on several factors
    - Such as variety, water content (i.E., Water activity), temperature, and compositions of the medium (acidity, types of solids, ph, etc.)
    - On the heating (drying) method

Browning Reactions

- Browning reactions change colour, decrease nutritional value and solubility, create off-flavours, and induce textural changes.
- Browning reactions can be classified as enzymatic (browning apples) and **non-enzymatic**- more important for drying food.
  - Maillard browning - carbonyl compounds (carbohydrates with amino groups – meat protein)
  - Contribute to the product's external surface colour
- The rate of browning affecting:
- **Moisture level**
  - The rate of browning is most rapid in the intermediate moisture range and decreases at very low and very high moistures.
  - Systems or heating schedules generally are designed to dehydrate rapidly through the 15%–20% moisture range so as to minimize the time for maillard browning.
- **Temperature**
  - Browning occurs at temperatures of 80°C - 90°C and increases with time and temperature.

Lipid Oxidation

- Dehydrated foods containing fats are prone to develop rancidity after a period, particularly if the water content is reduced too much.
- Oxidation is a serious problem for commercial drying of fatty fish and seafood.
- Lipid oxidation is responsible for rancidity, development of off-flavours, and the loss of fat-soluble vitamins and pigments in dehydrated foods.
- Minimizing oxygen level during dry processing and storage, and the addition of antioxidants is recommended to prevent lipid oxidation.

Changes in Proteins

- The non-fatty part of fish is very susceptible to changes caused by the high temperature of initial cooking, as well as drying and storage.
- Every process involved in the conversion of muscle to meat alters the characteristics of the structural elements .
- Heating at 60°C is cause of the denaturation of the muscle proteins.
- At 70°C - 75°C, there is hardening of the dried meat products due to increased crosslinking and loss of water by the myofibrillar proteins.

Rehydration

- Rehydration is a process of moistening dry material.
- It is mostly done by applying an abundant amount of water.
- In most cases, dried foods are soaked in water before cooking or consumption, thus rehydration is one of the important quality criteria.
- The factors affecting rehydration:
  - Porosity, capillaries and cavities near the surface - enhance the rehydration process
  - Temperature strongly increases the early stages of water rehydration

Texture

- Texture is one of the most important properties connected to product quality.
- High air temperatures (particularly with fruits, fish and meats) changes to the surface, and the formation of hard impermeable skin “case hardening”.
- It is minimised by controlling the drying conditions to prevent excessively high moisture gradients between the interior and the surface of the food.
- Texture is dependent on the moisture content, composition, variety or species, pH, product history (maturation or age), sample dimensions and method of dehydration and pretreatments.

Vitamins Retention

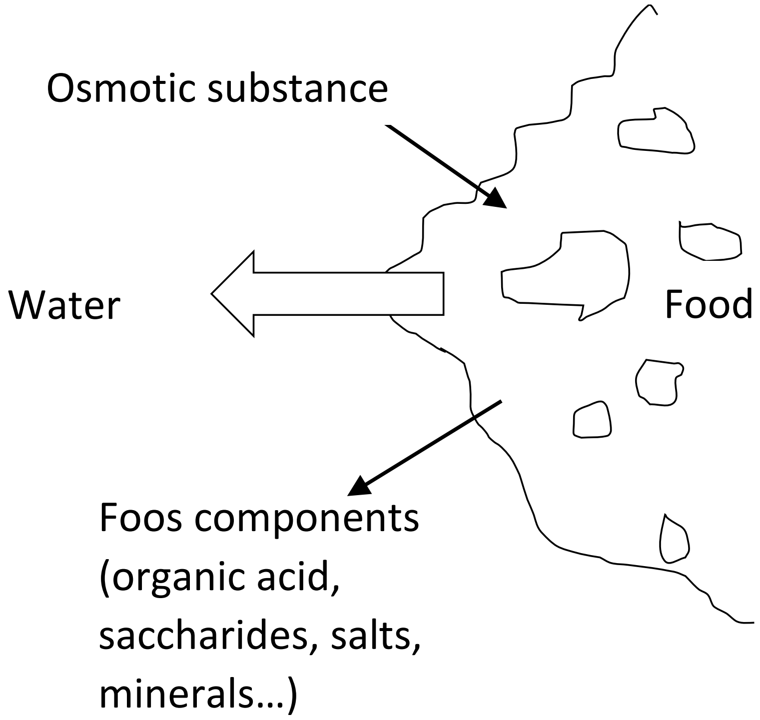
- The losses of B vitamins are usually less than 10% in dried foods.
- The vitamin C is largely destroyed during drying due to heating.

11. Osmotic Dehydration of Foods

Indirect inactivation (inhibition) of microorganisms

Introduction

- Osmotic dehydration is the process of water removal by immersion of water-containing cellular solid in a concentrated aqueous solution.
- The driving force for water removal is the concentration gradient between the solution and the intracellular fluid.
- If the membrane is perfectly semipermeable, the solute is unable to diffuse through the membrane into the cells.



Osmotic Processes and Their Effects

- Osmotic dehydration of foods has potential advantages in fruit and vegetable processing industries.
- This dehydration process generally does not produce a product of low moisture content that can be considered shelf stable.
- Consequently, the osmotically treated product should be further processed
  - by air, freeze-, or vacuum-drying methods to obtain a shelf-stable product,
  - or the dehydration process could be used as a pretreatment for canning, freezing, and minimal processing.

Advantages of Osmotic Dehydration

- **Improves the product quality**
  - Colour, flavour, vitamins, and texture
- **Energy efficiency**
  - Less energy-intensive process than air- or vacuum-drying because it can be conducted at low temperatures
- **Reduction in packaging and distribution costs**
  - Partially concentrating fruits and vegetables prior to freezing saves packaging and distribution costs, the product quality is comparable with that of conventional products.
- **Elimination of the need for chemical treatment**
  - Using osmotically treated apple pieces in the canning process resulted in a firmer texture and improved quality of the product
- **Product stability and retention of nutrients during storage**
  - The product obtained by osmotic process is more stable than untreated fruits and vegetables during storage due to low water activity by solute gain and water loss.

Factors Affecting Osmotic Dehydration Process

- Types of Osmotic Agents
- Concentration of Osmotic Solution
- Temperature of Osmotic Solution
- Material Geometry
- Physicochemical Properties of Food Materials

Types of Osmotic Agents

- The most commonly used osmotic agents are **sucrose** for fruits and **sodium chloride** for vegetables, fish, and meat.
- Other osmotic agents - glucose, fructose, lactose, dextrose, maltose, corn starch syrup, whey, sorbitol, ascorbic acid, citric acid, calcium chloride, and combinations of these osmotic agents.
- The ultimate choice of blend depends on many factors such as solute cost, organoleptic compatibility with the end product, and additional preservative action by the solute.

Concentration of Osmotic Solution

- The water loss and osmotic-drying rate increase with the increasing osmotic syrup concentration.
- The higher the concentration of the osmotic syrup the higher the rate of osmotic - drying of foodstuffs

- Both water loss to equilibrium level and osmotic-drying rate increase with the increase in osmotic syrup concentration, since water activity (i.e., mass transfer driving force) of syrup decreases with the increase in solute concentration in the syrup. A dense solute-barrier layer at the surface of the product is formed with the increase in syrup concentration, thus enhancing the dewatering effect and reducing the loss of nutrients during the process . A similar solute barrier is also formed in the case of syrups with higher molecular weight solutes at even low concentration.

Temperature of Osmotic Solution

- The rate of osmosis is markedly affected by temperature.
- Temperature is the most important parameter influencing the kinetics of water loss and solute gain.
- Water loss increases with increase in temperature.

Material Geometry

- Osmotic concentration behavior depends on the geometry of sample pieces, due to the variation of surface area per unit volume (or mass), and diffusion length of water and solutes involved in mass transport.

Physicochemical Properties of Food Materials

- Rate of osmosis in food is affected by:
    - The chemical composition (protein, carbohydrate, fat, and salt)
    - Physical structure (porosity, arrangement of the cells, fiber orientation and skin)
    - Pretreatments

- Examples:
    - Soft-textured fish tend to absorb salt faster than tough or firm-textured fish.
    - Frozen flesh absorbs negligible salt, thus needs thawing.
    - High-fat-content fish absorb salt slower than low-fat fish.
    - Different species of fish have different flesh characteristics and may absorb salt at different rates.
    - Salting times should be specific for each species.

Conclusion

- Osmotic dehydration process being a simple process, it facilitates processing of tropical fruits and vegetables such as banana, pineapple, mango, guava, carrot, pumpkin, papaya etc. with retention of initial fruit characteristics - colour, aroma and nutritional compounds.
- In preservation of fruits and vegetables osmotic dehydration process add value to the finished product, which is wholesome, nutritious and available round the year.

12. Food Preservation by Freezing

Indirect inactivation (inhibition) of microorganisms

Freezing in Biological Materials

- Freezing provides a significant extended shelf life and has been successfully employed for long-term preservation of many foods.
- Freezing is still one of the most widely used methods of food preservation
- Freezing changes the physical state of a substance by changing water into ice when energy is removed in the form of cooling below freezing temperature
- Usually, the temperature is further reduced to storage level (e.g., -18°C).

Mode of Preserving Action

- The freezing of foods slows down, but does not stop, the physicochemical and biochemical reactions that govern the deterioration of foods.
- During storage, there is a slow progressive change in organoleptic quality, which does not become objectionable for some time.
- The loss of quality of frozen foods depends primarily on storage temperature, length of storage time, and thawing procedure.
- Microbial growth is completely stopped below –18°C, and both enzymatic and nonenzymatic changes continue at much slower rates during frozen storage.

Freezing Rate

- Important factor in the quality of frozen foods
- Fast freezing produces better quality frozen food than slow freezing
- Is important because it determines the size of the ice crystals, cell dehydration, and damage to the cell walls

Physical Changes and Quality

- Free and Bound Water
- Weight Loss
- Recrystallization
- Freezer Burn
- Functional Properties - textural, mechanical, consistency, appearance and sensory attributes have been correlated with freezing and thawing processes (vegetables, fruits, cheese)

Free and Bound Water

- Different types of water are present in frozen foods.
- Free water
- Unfreezable water
  - Which does not freeze even at very low temperatures.
- A major cause of product degradation is the amount of unfrozen water present in the frozen matrix.
- Unfrozen water is known to be reactive, particularly during frozen storage, rendering the product susceptible to deteriorative and enzymatic reactions and limiting its frozen shelf life.

Weight Loss

- Dehydration or weight loss should be regarded as an important quality parameter for frozen unpacked foods, mainly in animal tissue.
- Foods lose moisture during the freezing process because their surface is exposed to heat and a moisture gradient exists within the environment
- Surface dehydration strongly influencing the meat quality

Recrystallization

- Recrystallization of solutes and ice in frozen foods is also important to quality and shelf life
- Frequent large fluctuations during retail display and during the carry-home period cause ice crystals to ripen or grow, coalesce, and move to the product surface.
- This leads ultimately to a freeze-dried product if packaging is permeable to moisture, allowing the sublimed or evaporated water vapor to escape.
- The loss of moisture results in toughening of animal tissue and greater exposure to any oxygen present.

Freezer Burn

- Moisture loss by evaporation from the surface of a product leads to freezer burn, an unsightly white colour that can be mistaken for mould but is resolved on rehydration during cooking unless it is severe.
- It is usually in the form of patches of light-coloured tissues, produced by evaporation of water, which leave air pockets between meat fibers.
- Dehydration of the product or freezer burn may occur while freezing
- An unpackaged food item in blast freezers.
- This dehydration can be controlled by humidification, lowering of storage temperatures, or better packaging.

Chemical Changes and Quality

- Rancidity
  - Oxygen leading to oxidative rancidity (if any unsaturated lipids are present), loss of colour, and development of off-flavours in frozen foods
- Release of enzymes
  - The disruption of plant or animal tissues by freezing leads to the release of enzymes bound to the structures.
- Hydrolysis
  - Starch in vegetables does not change significantly during frozen storage
  - The reducing sugars of these frozen vegetables were increased during storage owing to the hydrolysis of both oligo- and polysaccharides of these products

Colour, Flavour, and Vitamin Loss

- Colour
  - The most important colour changes in fruits and vegetables are related to three biochemical or physicochemical mechanisms:
  - (a) changes in the natural pigments of vegetable tissues (chlorophylls, anthocyanins, carotenoids),
  - (b) development of enzymatic browning,
  - (c) breakdown of cellular chloroplasts and chromoplasts
- Flavour
  - Freezing affects the flavour and aroma of frozen foods (strawberries, - reduction in aroma and the development of off-flavour)
- Vitamin loss
  - Destruction of vitamin C (ascorbic acid) - mainly due to the oxidation or to the action of ascorbic acid oxidase
  - Vitamin B losses sometimes occur in frozen meat products

Thawing

- Thawing as a final and obligatory step of the freezing process is quite important.
- Thawing properly is essential to maximize quality retention and safety of frozen foods.
- Microbiologically safe thawing process includes:
  - (a) inside a refrigerator at temperatures below 5°C,
  - (b) microwave oven
  - (c) as part of the cooking treatment

- Although thermal processing in microwave and cooking assures a better microbial destruction when compared with thawing inside a refrigerator, sensory retention is compromised.

Freezing Methods

- Freezing by contact with a cooled solid: plate freezing
  - The product is sandwiched between metal plates and pressure is usually applied for good contact
  - Suitable only for regular shaped materials or blocks
- Freezing by contact with a cooled liquid: immersion freezing
  - Food is immersed in a low-temperature brine (sodium chloride, sugar solutions, glycol and glycerol solutions, and alcohol solutions) to achieve fast temperature reduction through direct heat exchange.
- Freezing by contact with a cooled gas
  - The temperature of food is reduced with cold air flowing at a relatively high speed (2.5 and 5 m/s)
  - Tunnel freezing, belt freezing, and fluidized bed freezing, depending on how air interacts with the product

Storage and Display

- Packaging, storage, and display also affect the frozen food quality
- Loss of quality in frozen foods is a gradual process; the changes being slow or very slow, cumulative, and irreversible
- Optimum quality requires care in every stage of processing, packaging, storage, and marketing sequence.
- Storage temperature is important for frozen food
- A package for frozen product should
  - (a) be attractive and appeal to the consumer,
  - (b) protect the product from external contamination during transport and handling, and from permeable gases and moisture vapor transfer,
  - (c) allow rapid, efficient freezing and ease of handling, and
  - (d) be cost effective

13. Preservation Using Heat

Direct inactivation of microorganisms

Food Preservation Methods

Based on the mode of action, the major food preservation techniques can be divided into:

1. Indirect inactivation (inhibition) of microorganisms
   - Modification environment that prevents microorganisms from multiplying and performing of enzymatic functions

2. Direct inactivation of microorganisms
   - Directly inactivating bacteria, yeasts, moulds, or enzymes

3. Avoid recontamination
   - Removal of microorganisms from the medium/environment.
   - Preventing/avoiding contamination before and after processing.

Pasteurization of Food

- Pasteurization is one of the most important steps in preservation and is essential for food safety.
- It greatly improves the product's quality by effectively destroying almost all microorganisms (not bacterial spores).
- Pasteurization is a process of heat treatment to inactivate enzymes and kill heat-sensitive microorganisms that cause spoilage, with minimal changes in food properties (sensory and nutritional).
- It is also defined as "mild heat treatment" for avoiding microbial and enzymatic spoilage.
- It is used to extend the shelf life of food at low temperatures, usually 4°C for several days (e.g., milk) or for several months (e.g., bottled fruit).
- Heating liquid foods to 100°C destroy spoilage organisms such as **non-spore-forming bacteria**, yeast, and moulds.

Purpose of Pasteurization

- The primary object of pasteurization is to free the food of any microorganism that might cause deterioration or endanger the health of the consumer.
- The severity of the heat treatment and the resulting extension of shelf life are determined mostly by the pH of the food.
  - In low-acid foods (pH 4.5), the main purpose is destruction of pathogenic bacteria
  - Below pH 4.5 destruction of spoilage microorganism or enzyme inactivation is usually more important.

Purpose of Pasteurization for Different Foods

Food	Main Purpose	Minimum Processing Conditions
pH < 4.5		
Fruit juice	Enzyme inactivation (pectinesterase and polygalacturonase) (yeasts, fungi); Destruction of spoilage	65°C for 30 min; 77°C for 1 min; 88°C for 15 s
Beer	Destruction of spoilage microorganisms (wild yeasts, Lactobacillus species) and (residual yeasts, *Saccharomyces species*)	65°C–68°C for 20 min (in bottle); 72°C–75°C for 1–4 min at 900–1000 kPa
pH > 4.5		
Milk	Destruction of pathogens: Brucellaabortis, *Mycobacterium tuberculosis*, *Coxiella burnetti* Destruction of spoilage microorganisms and enzymes	63°C for 30 min; 71.5°C for 15 s
Liquid egg	Destruction of pathogens *Salmonella seftenburg*; Destruction of spoilage microorganisms	64.4°C for 2.5 min; 60°C for 3.5 min
Ice cream	Destruction of spoilage microorganisms and patoghens	65°C for 30 min; 71°C for 10 min; 80°C for 15 s

Types of Pasteurization

- Pasteurization can be achieved by a **combination of time and temperature** such as
    - Heating foods to a relatively lower temperature and maintaining it for a longer time
    - Heating foods to a high temperature and holding it for a short time.
- Pasteurization can be performed in two ways:
    - By first filling sterile containers with the product and then pasteurizing
    - By pasteurizing the product first and then filling in sterile containers.

Types of Pasteurization

- **In-package pasteurization**
  - Inside packages
- **Pasteurization prior to packaging**
  - Preheating is good for foods that are sensitive to high temperature gradients
- **Batch pasteurization**
  - Also called **low temperature short time** process.
  - Fluid foods such as milk are held in a tank where they are heated to 62.8°C for 30 min.
- **Continuous pasteurization**
  - Also called **high-temperature-short-time** (HTST) process.
  - Foods such as milk are subjected to 71.7°C for about 15 s or more by flowing through different heat exchangers. The heating medium is usually steam or water.

Pasteurization Equipment

- **Pasteurization of Packaged Foods**
  - Water Bath Pasteurization
  - Continuous Steam or Water Spray Pasteurizer
  - Tunnel Pasteurization
- **Pasteurization of Unpacked Foods**
  - Long Hold or Vat Pasteurizing
  - Plate Heat Exchanger Pasteurizer
  - Flash Pasteurization
  - High-Temperature-Short-Time Pasteurizers
  - Ultra-High-Temperature Pasteurizers

Pasteurization of Packaged Foods - *Water Bath Pasteurization*

- A water bath is one of the simplest methods of heating for pasteurization.
- 100 °C or below for acidic food products
- The product is packed in and immersed in the bath.
- Pickles, applesauce, fruits…

Pasteurization of Packaged Foods - *Continuous Water or Steam Spray Pasteurizer*

- The continuous water spray pasteurizer is extensively used for pasteurizing beer and acidic food products.
- The bottles or cans are conveyed through the pasteurizer by a continuous belt conveyor.
- Six different temperature zones or sections for maximum efficiency of pasteurization:
  - First preheat
  - Second preheat
  - Pasteurizing zone
  - Precooling
  - Cooling
  - Final cooling zone

Pasteurization of Packaged Foods - *Tunnel Pasteurization*

- **Hot-water sprays** are used to heat containers as they pass through the different heating zones of the tunnel and provide an incremental rise in temperature until pasteurization is achieved.
- Cold water sprayed later on cools the containers as they continue through the tunnel.

- **Steam tunnels** have the advantages of faster heating, shorter residence time, and smaller equipment.
  - Savings in energy and water are achieved from heat recovery from the hot products and recirculating water.
  - Temperatures in the heating zone are gradually increased by reducing the amount of air in the steam–air mixtures
  - cooling takes place using water sprays or by immersion in a water bath.

Pasteurization of Unpacked Foods - *Vat Pasteurization*

- Vat or tank-type heat exchangers are used for the long-hold method of pasteurization
- The raw product is pumped into the vat, heated to the pasteurizing temperature, held for the required time, and pumped from the vat through the cooling equipment.
- Slow, expensive
- Well suited for small plants and for low-volume products,
    - Where they handle a variety of products with a wide range of physical characteristics.

- They are especially well adapted to the processing of cultured products such as buttermilk and sour cream, which, in addition to being pasteurized and cooled, require mixing for the incorporation of starter culture, several hours of quiescent holding for incubation, agitation for breaking the curd, and final cooling in the tank.

Pasteurization of Unpacked Foods - *Heat Exchanger Pasteurizer*

- A **heat exchanger** is a device used to transfer heat between two fluids.
- The fluids are separated by a solid wall to prevent mixing consists of a series of thin vertical stainless-steel plates.
- Fruit juice, wine milk
- The advantages of heat exchangers over in-bottle processing
  - More uniform heat treatment,
  - Simpler equipment and lower maintenance costs
  - Reduced space requirements and labor costs
  - Greater flexibility for different products
  - Greater control over pasteurization conditions

Pasteurization of Unpacked Foods - *Flash pasteurization*

- The process of heating liquid food for only a short time at a high temperature.
- The liquid moves in a controlled, continuous flow while subjected to temperatures of 71.5°C to 74°C, for about 15 to 30 seconds.
- Fruit, vegetables juice, wine, milk

- High-Temperature-Short-Time Pasteurizers (HTST) - for milk
- This is the most common form of pasteurization in the dairy industry.
- This method is faster and more energy efficient than batch pasteurization.
- 71.7°C for 15 seconds

Pasteurization of Unpacked Liquids - *Flash Pasteurization* (HSTS)

- The advantages
  - Minimizes flavour loss
  - The retention of vitamins
  - It helps to keep the juice uniformly cloudy
  - Enzyme inactivation, destruction of vital microorganisms

Pasteurization of Unpacked Liquids - *Ultra-High-Temperature Pasteurizers*

- The equipment for ultra-high-temperature (UHT) pasteurizers is much the same as for HTST units
- The controls are similar but the operating temperature is higher and time shorter (135°C – for 1 to 2 seconds)
- UHT milk, if not opened, has a typical unrefrigerated shelf life of six to nine months. (HTST pasteurized milk has a shelf life of about two weeks from processing.)
- Used for liquid foods – milk, wine, juice, ice cream…

Quality of Pasteurized Foods

- Pasteurization is a relatively mild heat treatment,
    - There are only minor changes in the nutritional and sensory characteristics of most foods.
- The shelf life of pasteurized foods is usually only extended by a few days or weeks compared with several months using by heat-sterilization methods.
    - In milk are 5% loss of serum proteins and small changes to the vitamin content

Quality of Pasteurized Foods

- **Changes in colour**
  - Enzymatic browning (fruit juices)
    - This is promoted by the presence of oxygen, and fruit juices are deaerated prior to pasteurization.
  - Whiteness of milk and other pigments in plant and animal - unaffected by pasteurization
- **Changes in aroma**
  - A small loss of volatile aroma compounds during the pasteurization of juices.
  - Loss of volatiles from raw milk removes the hay-like aroma and produces a blander product
- **Vitamins and nutrients**
  - Minor losses of vitamins and nutrient
    - In fruit juices, losses of vitamin C and carotene
    - In milk are 5% loss of serum proteins and small changes to the vitamin content

Packaging of Pasteurized Foods

- Glass Bottles
  - + Not susceptible to mould growth and is impermeable to odorous vapours and liquids, easily cleaned, transparent, and rigid.
  - - High weight and fragility
  - Hot filling and in-bottle pasteurization are generally employed for pure fruit juices or products that do not contain preservatives.

- PET Bottles
  - + Less breakable, lighter (in compare to glas)
  - - Unlike glass the PET bottle will lose carbon dioxide with time

Packaging of Pasteurized Foods

- Cans
  - The most common are standard tin-plate containers, but for high-acid products can be used specially coated cans.
  - + The products (fruit juice) tend to deteriorate in the cans due to corrosion and an increasing amount of tin and iron in the product.
  - - Cans are usually hot filled.

- Cartons (trademark - Purepak, TetraPak…)
  - Pasteurized fruit juice and soft drinks can be packaged very successfully in cartons with a polyethylene coating or in plastic containers.
  - Materials selected must not absorb flavour components from the product.
  - Packaging materials must also provide the best possible barrier to light, which affects the colour and nutritive value of product (juice, milk).

Canning and Sterilization of Foods

- Sterilization is the complete destruction or elimination of all vital organisms in a food product.
- Sterilization destroys yeasts, moulds, vegetative and spore formers bacteria, and allows the food processor to store and distribute the products with extended shelf life.
- Sterilization procedures involve the use of heat, radiation, or chemicals, or physical removal of cells.
- The sterilization process consists of distinct stages.
    - The product must be heated to a temperature of 110°C–125°C to ensure sterilization.
    - The product must be held at this temperature for a certain period.
    - The product has to be cooled mainly to arrest further heat treatment and avoid over cooking.
- Commercial sterility is defined as a product that has been optimally processed so, that under normal conditions, the product will neither spoil nor endanger the health of the consumer and also retain the organoleptic properties and nutrients.

Methods of Sterilization

- The food sterilization methods are divided into two categories:
- Sterilization by heating (thermal processing)
  - Bulk canning - in-container sterilization
  - Aseptic processing - a sterile (aseptic) product is packaged in a sterile container

- Sterilization without heating (non-thermal processing)*

*See in Chapter 14.

Bulk Canning

- The thermal processing operation requires the heating of food products.
    - Usually in the range of 115°C–130°C
- The time–temperature procedure required to render a product commercially sterile must be carefully determined using established procedures.

Processing Equipment

- The food processing industry produces a wide range of products in a variety of containers.
- This requires the need of an equally wide range of processing techniques, retort designs, and operating procedures.
- **Batch systems**
  - The retort is filled with product, closed, and then put through a processing cycle.
  - Batch retorts are available in a number of configurations for various applications, including static, rotary, steam heated, and water heated with or without air.
- **Continuous retorting systems**
  - Containers are continuously fed into and out of the retort

- The heating medium used in retort are: steam, steam/air, water, direct flame or fluidized bed

Aseptic Processing

- Products are sterilized **prior to packaging** by continuous processes.
- Products, sterilized in bulk, to be filled and sealed into sterile containers, under aseptic conditions
- Products such as puddings, sauces, dips, and pastes are currently aseptically processed.
- Aseptic processing of foods is a process that enables products, sterilized in bulk, to be filled and sealed into sterile containers, under aseptic conditions.

Aseptic Sterilization

- Application of the aseptic process involves
  - Sterilization of the product
  - Sterilization of the packaging material
  - Maintaining sterility during the filling and sealing operations.

- The advantages
  - A higher quality product
  - A wide variety of packaging materials of different sizes and shapes can be used (can be used containers that are unsuitable for in-package sterilization)
  - There is minimum handling of the containers during the sterilization process.

Sterilization Systems

- The production of a sterile product by continuous-flow sterilization involves
  - (a) heating the product by passing it through a suitable heat exchanger to raise it to operating temperature
  - (b) passing the product through a holding section for a predetermined time to effect sterilization
  - (c) cooling it to a temperature of 35°C or less prior to aseptic filling.
- The most common methods of sterilization
  - Superheated steam
  - Hot, dry air
  - Hydrogen peroxide
  - Combination of hydrogen peroxide and ultraviolet light
  - Combination of hydrogen peroxide and heat
  - Irradiation by gamma rays

Methods for Sterilizing Aseptic Packages

Method	Application	Advantages	Disadvantages
Superheated steam	Metal containers	High temperature at atmospheric pressure	Microorganisms are more resistant than in saturated steam
Dry hot air	Metal or composite juice and beverages containers	High temperature at atmospheric pressure	Microorganisms are more resistant than in saturated steam
Hot hydrogen peroxide	Plastic containers, laminated foil	Fast and efficient method	
Hydrogen peroxide/UV	Plastic containers (preformed cartons)	UV increases effectiveness of hydrogen peroxide	
Ethylene oxide	Glass and plastic containers		Cannot be used where chlorides are present or where residual would remain
Heat from CO extrusion	Plastic containers	No chemicals used	
Radiation	Heat-sensitive plastic containers	Can be used to sterilize heat-sensitive packaging materials	Expensive; problems with locations radiation source

Quality of Canned Foods

- The purpose of heat sterilization is
    - To extend the shelf life of foods while minimizing the changes in nutritive value and eating quality.

- Generally, the heat process itself has a major effect upon the quality of a food product and is responsible for a range of changes.
- Differences between the heating characteristics of microorganisms, enzymes, and sensory or nutritional components of foods are exploited to optimize processes for the retention of nutritional and sensory qualities.
- The degree of heat processing varies according to the product.

Effect of Heat Processing on Major Nutritional Components

Nutrient	**Effect**
Dry matter	Loss of total solids into canning liquor Dilution Dehydration
Protein	Enzymic inactivation Loss of certain essential amino acids Loss of digestibility Improved digestibility
Carbohydrate	Starch gelatinization and increased digestibility No apparent change in content of carbohydrate
Dietary fiber lipids	Generally no loss of physiological value Conversion of cis-fatty acids to trans by oxidation Loss of essential fatty acid activity
Water-soluble vitamins	Large losses of vitamins C and B, due to leaching and heat degradation Increased bioavailability of biotin and niacin due to enzyme inactivation
Fat-soluble vitamins	Mainly heat stable Losses due to oxidation of lipids Losses due to leaching
Minerals	Possible increase in sodium and calcium levels by uptake from canning liquor

Quality of Canned Foods - Plant Origin Foods

- **Texture**
  - To loss of crispness and softening of the heat-processed product
  - The losses in solubility, elasticity, and flexibility due to denaturation of protein
- **Colour**
  - Natural pigments are generally unstable compounds that are broken down on heating (chlorophyll , carotenoids , anthocyanins)
- **Flavour**
  - Heat preservation does not significantly alter the basic flavours of sweetness, bitterness, acid, or salt
- **Nutrients** – *proteins, Vitamins, Minerals, Carbohydrates, Lipids - tab*

Quality of Canned Foods - Animal Origin Foods

- **Colour**
  - The time–temperature combinations used in canning have a substantial effect on most naturally occurring pigments in meat foods (acceptable change in cooked meats)
  - Sodium nitrite and sodium nitrate are added to some meat products to reduce the risk of growth of *C. Botulinum* - red-pink colouration
  - Loss of colour is often corrected using permitted synthetic or natural colours.
- **Flavour and aroma**
  - In canned meats, there are complex changes having a significant effect on the flavour of foods (pyrolysis, deamination and decarboxylation of amino acids, maillard reactions and caramelization of carbohydrates, and oxidation of lipids)
  - Desirable changes cooked meat

Quality of Canned Foods - Animal Origin Foods

- **Texture**
  - Shrinkage and stiffening of muscle tissues are caused by coagulation of proteins,
  - Softening is caused by hydrolysis of collagen

- **Nutrients**
  - Canning causes the hydrolysis of carbohydrates and lipids, but these nutrients remain available and the nutritive value of the food is not affected.
  - Proteins are coagulated in canned meats, losses of amino acids are 10%–20%.

Packaging of Canned Foods

- The container is an essential factor in the preservation of foods by canning.
- **Hermetically sealed container** - means a container that is designed and intended to be secure against the entry of microorganisms.
- The container protects the canned food from spoilage by recontamination with microorganisms.
- It is then most important for the success of the canning operation to use good-quality, reliable containers and properly adjusted closing machines.

- Metal packaging
  - most of the thermally preserved products are in metal containers
- Glass jars
- Plastic
- Aluminum/plastic laminated pouches

Cooking and Frying of Foods

- Some foods are consumed raw while others are cooked
- Cooking is a very important part of food preparation and is also used for preserving food.
- Temperatures used in cooking leads to the inhibition of most microorganisms.

Reasons for Cooking

- **Improves the flavour**
  - The flavour of uncooked flour is not very pleasant, but when the flour has been converted into bread its flavour is much improved.
- **Improve the attractiveness**
  - A raw chop is not much good, but after cooking, it has an appetizing appearance and a good smell.
- **Food more digestible**
  - It would be difficult to eat the flesh of a raw chop (or uncooked flour), but after cooking, it is much tender and therefore easier to chew and digest.
- **Improve the keeping quality of a food and make it safe**
  - Milk may be boiled to delay the souring process and kill bacteria.

Cooking Methods

- Cooked food is food that has been changed in various ways by heat treatment.
- **Dry-heat methods –** baking, roasting (100-300°C)
- **Moist-heat methods – water, steam**
  - It is a relatively quick method of cooking (water has a great capacity for holding heat and for transferring this heat rapidly to food)
- **Frying -** food is cooked in hot fat, quick method of cooking because of the high temperature used.
- **Microwave cooking -** the heat is generated within the food, microwaves penetrate the food and are converted into heat within the food
  - Microwaves can only penetrate food to a depth of 3–5 cm; thus, small pieces of food are cooked very quickly.
- **Slow cooking** - electrically heated pot, made from a material with good insulating properties.
  - Slow cookers work on low power (1 kW) so that the cooking temperature remains below 100°C.
  - The result is that food is cooked at a low temperature over a long period, usually 4–6 h.

Summary of Cooking Methods

Method of Heating	Method of Cooking	Description
Dry heat	Baking Roasting Grilling	Cooking carried out in an oven Baking with the addition of fat Baking with the addition of fat
Moist heat	Boiling Stewing and poaching Steaming Pressure cooking	Using boiling water Using hot water below its boiling point Using steam from boiling water Using water boiling above its normal boiling point
Fat	Frying	Using hot fat
Infrared	Similar to rapid grilling	Using infrared radiation
Microwave	Similar to rapid grilling	Using microwaves

Effects of Cooking on Nutrients

- Fats
- Carbohydrates
- Proteins
- Mineral Elements
- Vitamins

Fats

- When fats are heated they melt, and if they contain water it is driven off as water vapor.
- Fats are stable to heat and can be heated almost to their boiling point before they start to break down.
- When fats are heated too much, they break down, producing an unpleasant-smelling smoke – “smoke point“

- **The smoke point** of an oil or fat is the temperature when a bluish smoke becomes clearly visible from the oil.
- At this temperature, volatile compounds, such as free fatty acids, and short-chain degradation products of oxidation come up from the oil.
- The smoke point indicates the temperature limit up to which that cooking oil can be used.

Smoke Point of Fats and Oil

Oil	Smoke Point °F	Smoke Point °C
Avocado Oil	570°F	271°C
Butter	250-200°F	120-150°C
Canola Oil (refined)	400°F	204°C
Coconut Oil (extra virgin)	350°F	177°C
Coconut Oil (refined)	450°F	232°C
Corn Oil	440°F	227°C
Flax seed Oil	225°F	107°C
Ghee (clarified Butter)	485°F	252°C
Lard	370°F	188°C
Olive Oil (extra virgin)	375°F	191°C
Olive Oil (virgin)	391°F	199°C
Peanut Oil	450°F	232°C
Sesame Oil (unrefined)	350°F	177°C
Soybean Oil (refined)	460°F	238°C

Carbohydrates

- When exposed to dry heat, carbohydrates are broken down and darken in colour (sucrose browns on caramelization and finally becomes black)
- The Maillard Reaction
  - Is a reaction between amino acids and sugars that gives browned food its desirable flavour.
- **Polysaccharides - starch**
  - When a mixture of starch and water is heated, the starch granules absorb water and swell and gelatinize, forming a thick white paste (using flour to thicken sauces….)
  - Uncooked starchy foods are difficult to digest because the digestive juices cannot penetrate into the starch grains
- The polysaccharides cellulose, and pectin are important constituents of fruits and vegetables.
  - Cellulose - insoluble, on cooking changes little
  - Pectin becomes more soluble and make the fruit and vegetable easier to eat (fruits with a high pectin content, such as apples, become soft and pulpy on cooking).

Proteins

- Proteins undergo great changes when they are heated.
- Many proteins coagulate when heated, (egg white) above 60°C.
- As proteins coagulate they become solid.
- Cheese is important protein food, and when it is heated it softens and on further heating some of the proteins coagulate and the cheese becomes stringy and tough.
- **Collagen and elastin**
  - Are two important insoluble proteins in meat, and because they are not soluble they are not easily digested.
  - Tough meat (meat containing a lot of collagen and elastin) must be cooked in a way that will make it tender.
  - If such meat is cooked at high temperatures it remains tough or may even become tougher.
  - Tough meat needs to be cooked slowly using low temperatures; converts the tough collagen into easily digested gelatin (a soluble protein).

Mineral Elements

- Heat does not affect mineral salts found in food because they are stable substances that do not break down at the temperatures used in cooking
- Moist-heat methods of cooking (stewing and boiling), cause loss of salts, which are soluble in water.
- Boiled fish, meats, vegetables are rather tasteless because of the considerable loss of mineral salts that occurs during cooking.
- The salts are present in the water in which the food has been boiled, and this liquid can be used for making a tasty sauce or soup.

Vitamins

- Dry-heat cooking methods destroy those vitamins, which are unstable to heat.
- Vitamin C is destroyed at quite low temperatures, and so all methods of cooking cause some loss of this vitamin - some loss during cooking cannot be avoided.
- Two of the B vitamins, thiamine and riboflavin, are unstable at high temperatures.
- Vitamins A and D are insoluble in water and stable except at high temperatures.

Lycopene and Health
One of the most beneficial components in the tomato isn't a vitamin or mineral, but the phytochemical lycopene. This compound, which gives tomatoes their distinctive red colour, acts as an antioxidant in the body. Consuming high levels of lycopene can lower the risk of heart disease and certain types of cancer. Cooking tomatoes for two minutes, a quarter-hour and a half-hour boosts the lycopene levels in tomatoes by 6, 17 and 35 percent, respectively.

14. Preservation Using Energy

Innovative techniques

Direct inactivation of microorganisms

Introduction

- The technological revolution, nutritional awareness, and continuous demands of the new generation have necessitated search for **new or improved food processing technologies**.
  - Microwave and radio frequency heating, pulse-electric field treatment, high-pressure processing, ultrasonic applications, irradiation, and oscillating magnetic fields.

Novel Food Processing Technologies

- 1. Microwave heating
- 2. Ohmic Heating
- 3. Infrared heating
- 4. Pulsed Electric Field
- 5. High Pressure Processing
- 6. Ultrasonic
- 7. UV Light Energy
- 8. Irradiation
- 9. Magnetic Field

Thermal and Non-thermal

- Thermal processing has been a major processing technology in the food industry.
- Apart from inactivation of pathogens, thermal treatment can also result in some other desirable changes, such as
  - Protein coagulation, texture softening, and formation of aromatic components
- Limitations
  - Destruction of quality attributes of food products, especially heat-labile nutrients
  - Reducing sensory attributes

Why Non thermal?

- The main problem with the thermal processing of food is loss of volatile compounds, nutrients, and flavour.
- To overcome these problems non thermal methods came into food industries to increase the production rate and profit.
- The non thermal processing is used for all foods for its better quality, acceptance, and for its shelf life.
- The new processing techniques are mostly employed to the liquid packed foods when compared to solid foods.
- Since the non thermal methods are used for bulk quantities of foods, these methods of food preservation are mainly used in the large scale production.
- The cost of equipment used in the non thermal processing is high when compared to equipment used in thermal processing.
- After minimising the investment costs of non thermal processing methods, it can also be employed in small scale industries.

Preservation Processes

- **Thermal**
  - Microwave heating
  - Ohmic heating
  - Infrared heating
  - Radio frequency heating
  - Chilling
  - Freezing
  - Drying
  - Cooking
  - Blanching
- **Non-thermal**
  - Pulsed Electric Field
  - High Pressure
  - Pulsed Light
  - Ultrasound
  - Irradiation
  - Oscillating Magnetic Field

Microwave Heating

- It is currently being used for a variety of domestic and industrial food preparations and processing applications
- used successfully for finish drying of potato chips, precooking of chicken and bacon, proofing and frying doughnuts, tempering of frozen foods, and drying pasta products.
- Microwaves are electromagnetic waves in frequencies between 300 MHz and 300 GHz.
- Microwave heating refers to the use of electromagnetic waves of certain frequencies (2450MHz and 915MHz) to generate heat in material
- Microwave heating applications is limited to narrow bands to avoid interference with the radio frequencies used for telecommunication purposes.

Mechanism

- Microwave heating in foods occurs due to coupling of electrical energy from an electromagnetic field in a microwave cavity with the food and its subsequent dissipation within food product.
- This results in a sharp increase in temperature within the product.
- Microwave energy is delivered at a molecular level through the molecular interaction with the electromagnetic field, in particular, through molecular friction resulting from dipole rotation of polar solvents and from the conductive migration of dissolved ions.
- The principal mechanisms involved in microwave heating are **dipole rotation**.
- The rotation of water molecules would generate heat for cooking
- Food containing water is a good absorber of microwave energy.

- Dipolar rotation:
  - Any molecules (such water) are electric dipoles - meaning that they have a partial positive charge at one end and a partial negative charge at the other- and therefore rotate, as they try to align themselves with the alternating electric field of the microwaves.

Basic Components

- Power supply and control: It controls the power.
- **Magnetron:** It is a vacuum tube in which electrical energy is converted to an oscillating electromagnetic field.
- **Waveguide:** It is a metal tube which directs the microwaves generated from the magnetron to the cooking cavity.
- **Stirrer:** Distribute microwaves from the waveguide and allow more uniform heating of food.
- **Turntable:** The rotation of food ensures uniform heating.
- **Cooking cavity:** It is a space inside which the food is heated when exposed to microwaves.
- **Door and choke:** The door and choke are specially engineered that they prevent microwaves from leaking through the gap between the door and the cooking cavity.

Advantages

- Compared with conventional methods
- Microwave penetrates inside the food materials and, therefore, cooking takes place throughout the whole volume of food internally, and rapidly (reduces the processing time and energy)
- Since the heat transfer is fast, nutrients and vitamins contents, as well as flavour, sensory characteristics, and colour of food are well preserved
- High heating efficiency (80% or higher efficiency can be achieved)
- Easy cleaning
- Suitable for heat-sensitive, high-viscous, and multiphase fluids
- Low cost in system maintenance
- Heating is silent and does not generate exhaust gas

Limitations

- Nonavailability of actual temperature profiles. Measurement of temperatures at few locations does not guarantee the real temperature distribution of the product during microwave heating, as the heating pattern can be uneven and difficult to predict, and change during heating.
- Low penetration depth
- Non uniform heating in the large pieces of food

Materials and Applications

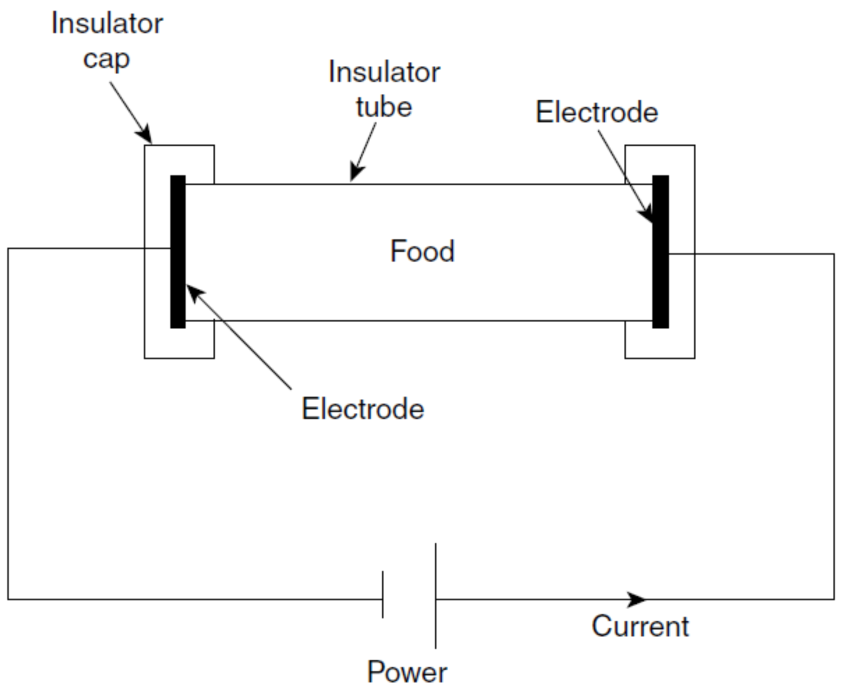
- Materials
  - Plastic containers, high density polyethylene, papers.
  - (metal is not suitable - metal objects reflect microwaves)
- Application
  - Baking, cooking, curing, drying, freeze drying, pasteurizing, sterilizing, tempering and thawing

Ohmic Heating

- Ohmic heating is an advanced thermal processing method, wherein the food material, which serves as an electrical resistor, is heated by passing electricity through it.
- Electrical energy is dissipated into heat, which results in rapid and uniform heating.
- Ohmic heating is also called electrical resistance heating, Joule heating, or electro-heating

Working Principle of Ohmic Heating

- The working principle is based on the Joule effect:
- Ohmic heating occurs when an electric current is passed through food, resulting in a temperature rise in the product due to the conversion of the electric energy into heat.



Schematic diagram of an ohmic heating precess

Advantages of Ohmic Heating

- Liquid–particle mixtures can heat uniformly.
- There are no hot surfaces for heat transfer, resulting in a low risk of product damage from burning.
- Energy conversion efficiencies are very high.
- Relatively low capital cost

Products Suitable for Ohmic Heating

- Ohmic heating can be used for heating **liquid foods** containing large particulates, such as soups, fruit slices in syrups and sauces, and heat sensitive liquids.
- The technology is useful for the treatment of proteinaceous foods, which tend to denature and coagulate when thermally processed (liquid egg).
- Juices can be treated to inactivate enzymes without affecting the flavour.

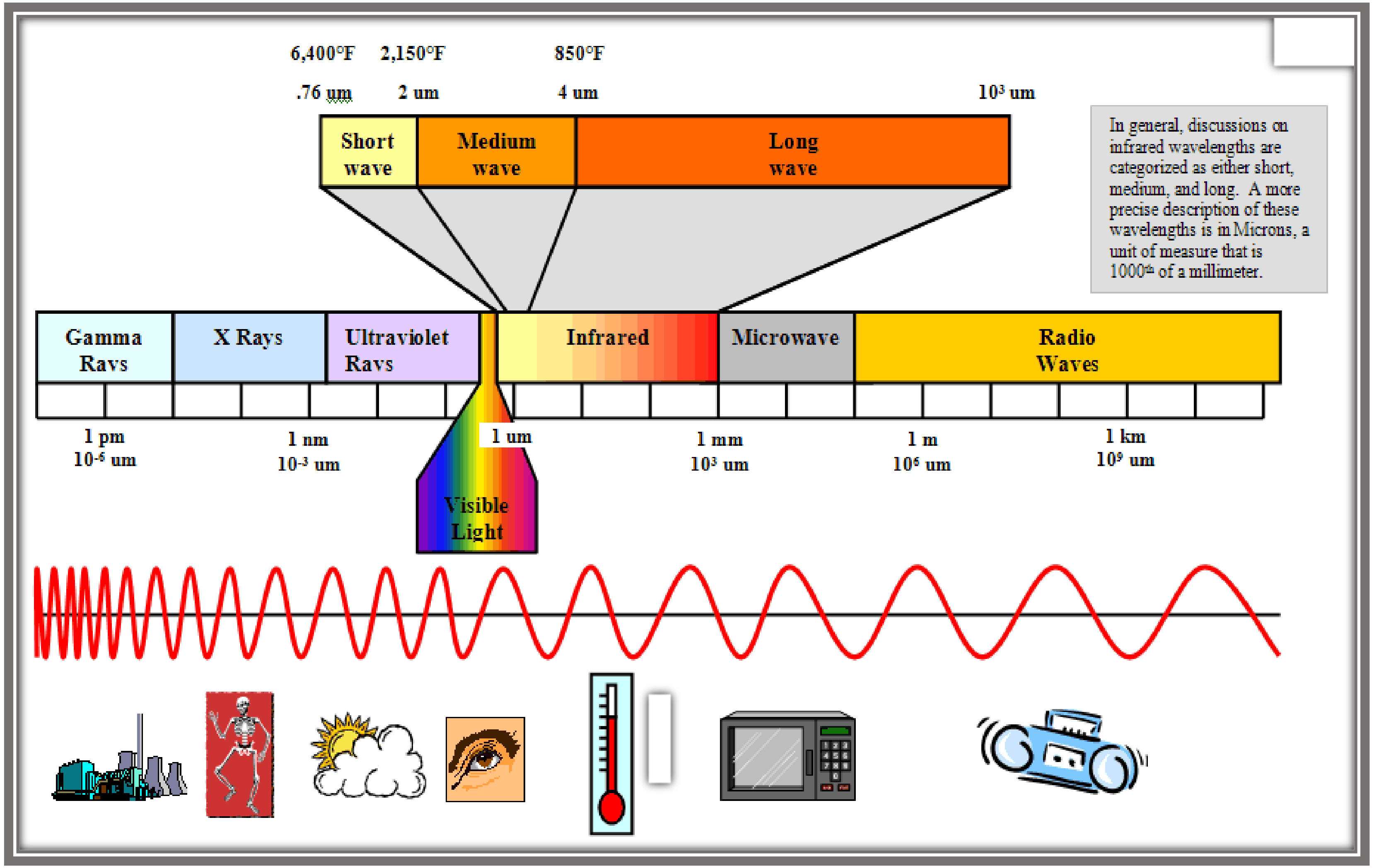
Novel Uses of Ohmic Heating

- Other potential applications of ohmic heating include blanching, thawing, fermentation, peeling, dehydration, and the extraction of components from foods (sugar from sugar beets, soymilk from soybeans).
- The shelf life of ohmically processed foods is comparable to that of canned and sterile, aseptically processed products.

Infrared Heating

- IR light penetrates food and causes changes in the vibration and rotation of molecules.
- When the molecule returns into the normal state, the absorbed energy is transferred into heat.
- In food products, water is the molecule most affected by IR radiation.
- Other molecules affected by IR are proteins, lipids and carbohydrates, compounds containing polar groups (-NH, -CO, -OH, C=C)

Infrared (IR) radiation is a part of the electromagnetic spectrum



Applications of Infrared Heating

- Infrared (IR) heating of foods involves applications such as
  - Thermal processing
  - Microbial decontamination
  - Roasting
  - Drying
  - Baking
- The use of IR heating in food applications
  - Reduces the processing time and energy loss
  - Extend shelf life of the food product.

Applications of Infrared Heating

- Products
  - Fruits, vegetables, fish, pasta, rice (drying)
  - Pizza, bread, biscuit (baking or surface pasteurisation of bread)
  - Coffee, cacao, cereals, nuts (roasting, pasteurisation, sterilisation)
- Operations
  - Baking, roasting, drying, surface pasteurisation, sterilisation, frying, thawing, blanching.

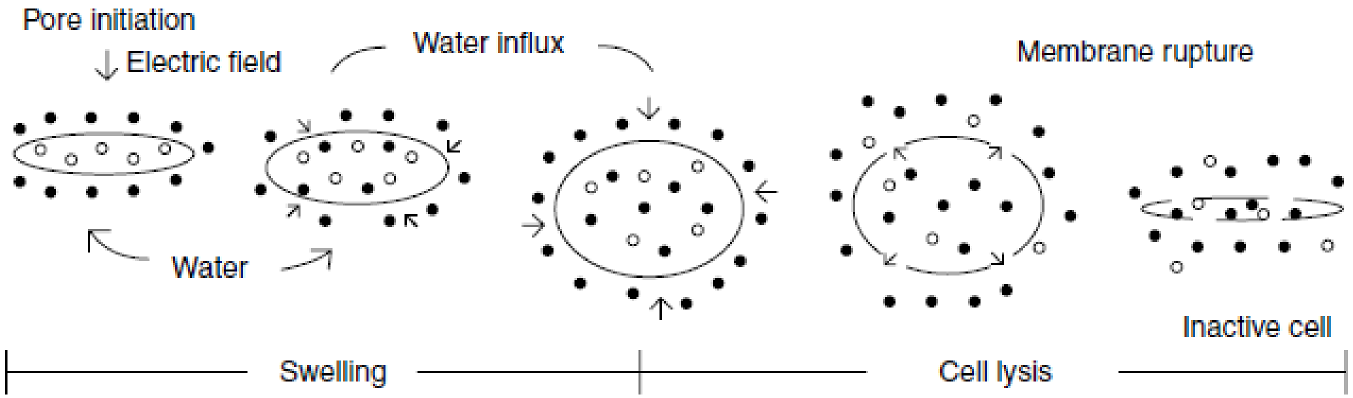
- Low penetration
  - Attractive technique for surface heating applications

Pulsed Electric Field (PEF) Technology

- PEF is a method for processing cells by means of brief pulses of a strong electric field.
- The concept of pulsed power is simple: electric energy at low power levels is collected over an extended period and stored in a capacitor.
- That same energy can then be discharged almost instantaneously at very high levels of power.
- PEF is a non-thermal food preservation technology that involves the discharge of high voltage electric pulses (up to 70 kV/cm) into the food product, which is placed between two electrodes for a few microseconds.

Effect of PEF

- The plasma membranes of cells become permeable to small molecules after being exposed to an electric field
- Permeation then causes swelling and the eventual rupture of the cell membrane, which leads to the release of intracellular liquid, and cell death.



PEF Technology

- **Advantage**
  - No significant effect on heat-labile components present in foods such as vitamins
  - Reduction of processing time
  - Sterilisation

- **Limitations**
  - The major disadvantage of PEF operation is the initial investment.

Application of PEF in Different Food Products

- PEF holds potentials as type of low temperature alternative pasteurization process for sterilization of food products.
- Processing of
  - Apple juice
  - Orange juice
  - Milk, milk products
  - Eggs, liquid egg
  - Green pea soup
  - Other soups

High Pressure Processing (HPP)

- High pressure processing (HPP) is a promising "non-thermal" technology that has been developed with the aim of obtaining microbiologically safe food products while avoiding undesirable changes in the sensory, physicochemical, and nutritional properties of foods.
- Thus HPP has become one of the innovative food processing technologies most accepted by consumers.

High Pressure Processing of Food

- High pressure processing (HPP), is a method of preserving and sterilizing food, in which a product is processed under very high pressure processing of food
- High pressure processing (HPP) is based on le chatelier's principle which states that actions that have a net volume increase will be retarded and actions that have a net volume decrease will be enhanced at high pressures
- HPP utilizes isostatic or hydrostatic pressure which is equal from every direction.
- High pressure, leading to the inactivation of certain microorganisms and enzymes in the food
- Also known as pascalization.
- High pressures applied (up to 900 MPa) at short periods of time (10-20 min.).

How Much Pressure?

- Pressure of the deepest part of the oceans is 10-100 MPa
- At the centre of the earth it is 360 GPa
- In commercial applications, the highest pressure used is around 5–6 Gpa (applied for diamond grit production)
- For food processing, 200-900 MPa pressure is required.
- Usually, 600 MPa is the optimum pressure for processing commercial food products.

- Effect of pressure on microorganisms
    - High pressure can kill microorganisms by interrupting their cellular function without the use of heat that can damage the taste, texture, and nutrition of the food.

Processing

- In-container processing:
    - Applied to all solid and liquid foods
    - Minimal risk of post processing contamination and easier cleaning.

- A typical HPP uses food products packaged in a high-barrier, flexible plastic container.
- Sterile container filled with food is sealed and placed in the pressure chamber for pressurizing.
- Ethylene-vinyl alcohol copolymer (EVOH) and polyvinyl alcohol (PVOH) films are recommended for packaging food for high-pressure treatment.
- The shape of the package needs to be designed to fill the vessel volume as far as possible, to increase the economical feasibility of the process.

Processing Operation

- The basis for applying high pressure to foods is to compress the water surrounding the food.
- The packages are loaded into the high-pressure chamber.
- The vessel is sealed and filled with a pressure fluid (water).
- The packages of food, surrounded by the pressure fluid, are subjected to the pressure.
- After holding the product for the desired time at the target pressure, the vessel is decompressed by releasing the water.
- Approximately 5–6 cycles/hr are possible, allowing time for compression, holding, decompression, loading, and unloading.
- After pressure treatment, the processed product is removed from the vessel and stored/distributed in a conventional manner.

Foods Suitable for HPP

- Low-medium moisture, semi-solid/solid foods, vacuum packaged
  - Dry-cured or cooked meat products
  - Cheese
  - Fish, seafood, marinated products
  - Ready to eat meals, sauces
- High moisture, solid foods, vacuum packaged
  - Fruits, marmalades/jams
  - Vegetables
- High moisture, liquid foods in plastic bottle/flexible packaging
  - Dairy products
  - Fruit juices
  - Bioactive beverages

Applications

- Sterilization of heat sensitive ingredients like shellfish, flavourings, and vitamins.
- Sterilization of fruits and fruit products, sauces, pickles, yoghurt, pasteurization of meat and vegetables, decontamination of high risk products, high value products
- Shelf life extension
- Inactivate microorganisms and quality-deteriorating enzymes
- Higher sensorial, functional and nutritional values while improving food safety.

Conclusion

- Consumers: HPP is a consumer acceptable, environmental friendly, scientifically recognized method to achieve higher quality in certain foods.
- Processing: Pressure transmission is instantaneous, uniform, short processing times, assured safety in whole pack, suitable for solids and liquids
- Quality: Retains flavour and nutrition
- Environmentally: Safe and no process by-products, no emissions
- Packaging: Package design, geometry and format should be tailored for HPP.

Ultrasound in Food Processing and Preservation

- Ultrasonic waves are similar to sound waves, but their frequencies are far too high for perception by the human ear.
- The range of frequencies perceived by humans is 20 Hz to 20 kHz, ultrasound is more than 20 kHz.
- Ultrasound is one of the emerging technologies that were developed to minimize processing, maximize quality and ensure the safety of food products.

Ultrasound in Food Processing

- Low-power, high-frequency ultrasound (100 khz)
  - Is normally used to monitor food products or processes.
  - The use of ultrasound monitoring has been evaluated in a wide range of food systems, including meat, fats and oils, milk, bread, fruit, and sauces.
- High-power, low-frequency ultrasound (20–100 khz)
  - Is normally used to alter the properties of a material or affect the progress of a process.
  - It does this through physical, chemical, and mechanical effects.

Antimicrobial Treatment of Ultrasound

- The antimicrobial effect of ultrasound is caused localized, but extreme, the effect of pressure and temperature (50 MPa, 5500 °C), produced during cavitation leading to damage to cell walls.

- Ultrasound treatment is an effective antimicrobial treatment, destroying a variety of microorganisms, including bacteria, bacterial spores, yeasts.

- When sonicating liquids at high intensities, the sound waves that propagate into the liquid media result in alternating high-pressure (compression) and low-pressure (rarefaction) cycles, with rates depending on the frequency. During the low-pressure cycle, high-intensity ultrasonic waves create small vacuum bubbles or voids in the liquid. When the bubbles attain a volume at which they can no longer absorb energy, they collapse violently during a high-pressure cycle. This phenomenon is termed cavitation.

Some Applications Ultrasound in the Food Industry

- Anti-microbial Effects - Microbial destruction, microbial removal from surfaces
- Heat transfer - Increase the rate of freezing, thawing and cooking
- Mass transfer - Increase the rate of mass transfer in drying (solid, liquid, and osmotic drying), brining, membrane separation, dewatering,
- Meat processing - Meat tenderisation, Homogenization, Homogenise and emulsify milk, emulsification
- Fermentation - Increase rate of fermentation (e.g., wine)
- Enzyme inactivation; protein denaturation

Light Energy in Food Preservation – UV Radiation

- Ultraviolet (UV) radiation has been known for a long time as the major factor in the bactericidal value of sunlight.
- The low penetration depth, it is mainly used to sterilize air and thin films of liquid.
- When used at high dosages, there is a marked tendency toward flavour and odour deterioration (oxidation – rancidity) before satisfactory sterilization is achieved.
- But low levels of radiation at carefully applied doses usually extend the shelf life of foods without serious quality effects.
- The technique of UV radiation to kill off bacteria in water is well known.
- UV radiation has been used in dairy plants for many years.
- It is also being used in the ice cream industry, and in meat- and vegetable-processing plants.

UV in Food Preservation and Deterioration

- UV irradiation is being applied commercially in the food processing industry through the use of bactericidal UV lamps
    - For tenderizing or aging of meat,
    - Curing and wrapping of cheeses,
    - Prevention of surface mould growth on bakery products,
    - Air purification in food industry

UV in Sanitation

- UV rays (nonionizing radiation) is used extensively in the disinfection of equipment, glassware, and air by industries.
- The bactericidal effect of UV light is widely used for sanitation purposes.
- It is particularly effective in destroying airborne organisms and, consequently, is an important sanitary aid to in-plant installations.
  - It may eliminate detrimental contamination and keep away objectionable invaders.

Irradiation

- Food irradiation is the process of exposing foodstuffs to ionizing radiation.
- Ionizing radiation is energy that can be transmitted without direct contact (radiation) and is capable of freeing electrons from their atomic bonds (ionization) in the target food.
- This treatment is used to preserve food, reduce the risk of food borne illness, prevent the spread of invasive pests, and delay or eliminate sprouting or ripening.
- **Irradiated food does not become radioactive.**
- The radiation can be emitted by a radioactive substance or generated electrically.

Characteristics of Irradiation Sources

Radiation Source	Characteristics
Cobalt-60	1. High penetrating power 2. Permanent radioactive source 3. High efficiency 4. Source replenishment needed 5. Low throughput
Electron beams	1. Low penetrating power 2. Switch on–switch off capability 3. High efficiency 4. High throughput 5. Power and cooling needed 6. Technically complex
X-rays	1. High penetrating power 2. Switch on–switch off capability 3. Low efficiency 4. High throughput 5. Power and cooling needed 6. Technically complex

Dose

- The radiation dose (level of treatment) is defined as
    - The quantity of energy absorbed during exposure (***gray*** (Gy)).
- Food irradiation doses are generally characterized as low (less than 1kGy), medium (1–10 kGy), and high (greater than 10 kGy).
- Different levels of dose are required to achieve desired results for the products.
- The energy level used for food irradiation, to achieve any technological purpose, is normally low, e.g., 0.1 to 10 kGy.

Extent of Dose and Purpose of Food Irradiation

Dose Limit	Purpose	Dose Limit (kGy)	Examples
Low dose (<1 kGy)	Sprouting inhibition	0.05–0.15	Potatoes, onions, garlic
	Insect and parasite disinfection	0.15–0.50	Cereals, pulses, dried fruit, pork
	Delay of ripening	0.50–1.00	Fresh fruits and vegetables
Medium dose (1–10 kGy)	Reduction of spoilage microorganisms	1.0–3.0	Fish, strawberries
	Reduction of non-spore pathogens	2.0–7.0	Poultry, shellfish
	Microbial reduction in dry products	7.0–10.0	Herbs, spices
High dose (10–50 kGy)	Sterilization	25–50	Herbs, spices
Very high dose (10–100 kGy)	Reduces or eliminates virus contamination	10–100	Sterile diet meals

Mechanisms of Microbial Inactivation

- Ionization irradiation affects microorganisms, such as bacteria, yeasts, and moulds, by causing lesions in the genetic material of the cell, effectively preventing it from carrying out the biological processes necessary for its continued existence.
- The principal targets of irradiation are nucleic acids and membrane lipids.

The Effects of Irradiation on Nutritional Qualities of Foods

- **Effect on Proteins**
  - Low doses of irradiation may cause molecular coagulation, molecular cleavage and splitting of amino acids.
- **Effects on Carbohydrates**
  - Irradiation can break high-molecular-weight carbohydrates into smaller units leading to depolymerization.
  - This process is responsible for the softening of fruits and vegetables through breakdown of cell wall materials, such as pectin (softening may have advantages or disadvantages depending on the requirement).

The Effects of Irradiation on Nutritional Qualities of Foods

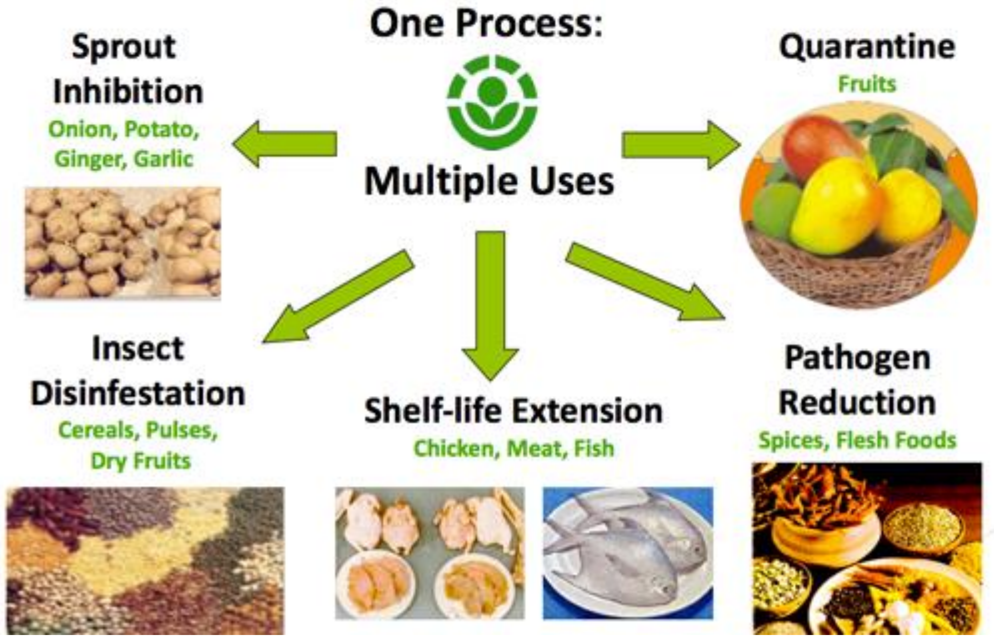
- **Effect on Lipids**
  - Irradiation initiates the normal process of autoxidation of fats which gives rise to rancid off-flavours.
  - Highly unsaturated fats are more readily oxidized than less unsaturated fats.
  - This process can be slowed by the elimination of oxygen by vacuum or modified atmosphere.
- **Effect on Vitamins**
  - The extent of vitamin C, E, and K destruction depends on the dosage used, and thiamine is very labile to irradiation.
  - The losses are low with low dose.
  - Ascorbic acid in solution is quite labile to irradiation but in fruits and vegetables seems quite stable at low doses of treatment.

The Effects of Irradiation on Nutritional Qualities of Foods

- **Effects on Enzymes**
  - Enzymes in foods must be inactivated prior to irradiation because it is much more resistant to radiation than microorganisms.
  - Usually, enzyme inactivation is accomplished thermally.
  - The complete inactivation of enzymes requires about 5–10 times the dose required for the destruction of microorganisms

Applications of Irradiation in Foods

- Disinfestation
- Shelf life extension - to inhibit sprouting of potatoes, yams, onions, and garlic
- Decontamination - reduce microbial load and destruction of pathogens
- Product quality improvement - higher juice yield could be obtained if fruits are first irradiated at a dose level of several kGy



Applications of Irradiation in Foods

- **Plant Foods**
- Spices (the most common irradiated food products for commercial use are spices and dry vegetable seasonings)
  - Spices imported into Europe are often heavily contaminated by pathogenic microorganisms as a consequence of open air drying procedures
- A dose of 2.5 kGy reduced the fungal and bacterial load
- Fruits and Vegetables - prolonged the shelf life
- Cereals and Grains - low doses of irradiation to eliminate fungi (mycotoxins)
- **Animal Foods**
- The irradiation is effective in preventing or delaying the microbial spoilage of fresh meats and poultry
  - Processed meats - The amount of nitrite required in cured meats possibly can be reduced by irradiation.
  - Fish and fish products – low dose control of pathogenic organisms and the extension of shelf life

Legal Aspects and Safety Issues

- FDA (*Food and Drug Administration)* has evaluated the safety of irradiated food for more than thirty years and has found the process to be safe.
- The World Health Organization (WHO), the Centers for Disease Control and Prevention (CDC) and the U.S. Department of Agriculture (USDA) have also endorsed the safety of irradiated food.
- The application and cost effectiveness of irradiation as a method to control foodborne pathogens will depend on consumer attitude, regulatory actions, economics, and logistics associated with different situations.

Magnetic Field

- **Magnetism** is a phenomenon by which materials exert an attractive or repulsive force on other materials.
- The origin of magnetism lies in the orbital and spin motions of electrons, and how the electrons interact with each other.

Magnetic Fields in Food Preservation

- The microbial growth can either be stimulated or retarded during exposure to magnetic fields.
- Retardation of growth and reproduction of microorganisms might be
  - Due to change in deoxyribose nucleic acid (DNA) synthesis,
  - A change in the orientation of biomolecules and biomembranes to a direction parallel or perpendicular to the applied magnetic field
  - Changes in ionic permeability of the cell membrane

- A strong field has significantly affect microorganisms, or even kill them.

Application of Magnetic Fields in Food Preservation

- Pasteurization
- Sterilization
  - Milk, yoghurt, juice
- The use of magnetic fields as an alternative food processing technology has not gained full commercial acceptance possibly due to inconsistent results on microbial growth and death kinetics.
- In addition, there is a significant lack of information on the field and the development of machineries.
- Application of magnetic fields could be effective and beneficial for biomass production at controlled growth rate using superconducting technology.
- This would help the growth of fermentation and pharmaceutical industries.

15. Combined Methods for Food Preservation

Hurdle technology

Introduction

- The microbial stability and safety of most foods is based on a combination of several preservative factors (called hurdles), which the microorganisms present in the food are unable to overcome.
- There are many preservation methods used for making foods stable and safe, e.g., heating, chilling, freezing, freeze drying, drying, curing, salting, sugar addition, acidification, fermentation, smoking, and oxygen removal.

Principles of Combined Preservation Methods

- The processes are based on relatively few parameters or hurdles
  - High temperature (F value)
  - Low temperature (t value)
  - Water activity (a_w)
  - Acidification (pH)
  - Redox potential (Eh)
  - Preservatives
  - Competitive flora
- In some of the preservation methods mentioned, these parameters are of major importance, while in others they are only secondary hurdles

Hurdle Effect

- For each stable and safe food, a certain set of hurdles is inherent, which differs in quality and intensity depending on the particular product;
- However, in any case, the hurdles must keep the “normal” population of microorganisms in the food under control.
- The microorganisms present (“at the start”) in a food should not be able to overcome (“leap over”) the hurdles present.

Hurdle Effect

- Food, which contains six hurdles: high temperature during processing (F value), low temperature during storage (t value), water activity (a_w), acidity (pH), redox potential (Eh), and preservatives (pres.).
- The microorganisms present cannot overcome these hurdles, and thus the food is microbiologically stable and safe.

Example of the hurdle effect.

Partial List of Potential Hurdles for Foods of Animal or Plant Origin, Which Improve the Stability and the Quality of These Products

Temperature (low or high)

pH (low or high)

aw (low or high)

Eh (low or high)

Modified atmosphere (nitrogen, carbon dioxide, and oxygen)

Packaging (aseptic packaging, vacuum or modified atmosphere or active packaging, and edible coatings)

Pressure (high)

Radiation (microwaves, UV, and irradiation)

Other physical processes (mano-thermo-sonication, high electric field pulses, oscillating magnetic field pulses, radio frequency energy, and photodynamic inactivation)

Microstructure (emulsions, fermented sausage, and ripened cheese)

Competitive flora (lactic acid bacteria)

Preservatives (organic acids, lactate, acetate, sorbate, ascorbate, glucono-delta-lactone, phosphates, propylene glycol, diphenyl, parabens, free fatty acids and their esters, phenols, monolaurin, chelators, Maillard reaction products, ethanol, spices and their extracts, nitrite, nitrate, sulfite, carbon dioxide, oxygen, ozone, chlorine, smoke, antioxidants, pimaricin and other antibiotics, lysozyme, chitosan, lactoperoxidase, nisin and other bacteriocins, pectine hydrolysate, protamine, and hop extracts)

High Temperature

- **Pasteurization**
  - Mild heat treatment (e.g., 63^oC for 30 min; 100^oC for 12 sec)
  - Destroys vegetative pathogens (disease-causing microbes)
  - Reduces total microbial load, increases shelf-life
  - Does not destroy spores (dormant stage of some bacteria)
- **Sterilization**
  - Complete destruction of microorganisms
  - Severe heat treatment (equivalent to several min at 121.1^oC)
  - Destroys spores
  - Gives "shelf-stable" product
  - Some nutrient, quality destruction (colour, flavour, texture)
  - Combined with other hurdles (e.g., refrigeration)

Low Temperature

- **Refrigeration**
  - Ideally 0^{o}C to 4^{o}C for most foods
  - Short-term preservation (days to weeks)
  - High product quality (fresh, minimally processed)
  - Slows down microbial growth, respiration, enzyme/chemical reactions
  - Some pathogens can grow (e.g.*, C. botulinum* (type E), *Listeria*)
- **Freezing**
  - generally -18^{o}C to -30^{o}C
  - Quality depends on product, time, temperature
  - Long-term preservation (months to years)
  - Stops microbial growth, respiration
  - Slows down chemical reactions

Reduced Water Activity (a_w)

- a_w is water "availability"
- Water is required for microbial growth, enzyme/chemical reactions
- Pathogenic microorganisms cannot grow at a_w <0.86
- Yeast & moulds cannot grow at a_w <0.62
- Free water can be removed by concentration,
- Dehydration and freeze drying
- In general, the lower the a_w, the longer the storage life

- Reduce a_w: Glucose, Fructose, Sucrose, Sodium chloride, Potassium chloride

Increased Acidity (lowered pH)

- Acidity slows down growth of spoilage organisms and pathogens
- Pathogens won't grow, spores won't germinate at pH<4.5 (e.g., fruit juices, sauerkraut)
- Above pH 4.5, must sterilize for shelf stability
- Below pH 4.5, can pasteurize

- To reduce pH
- Organic acids
    - citric acid, malic acid, tartaric acid, benzoic acid, lactic acid, propionic acid, Inorganic acids,
- Fermentation

Controlling Oxygen

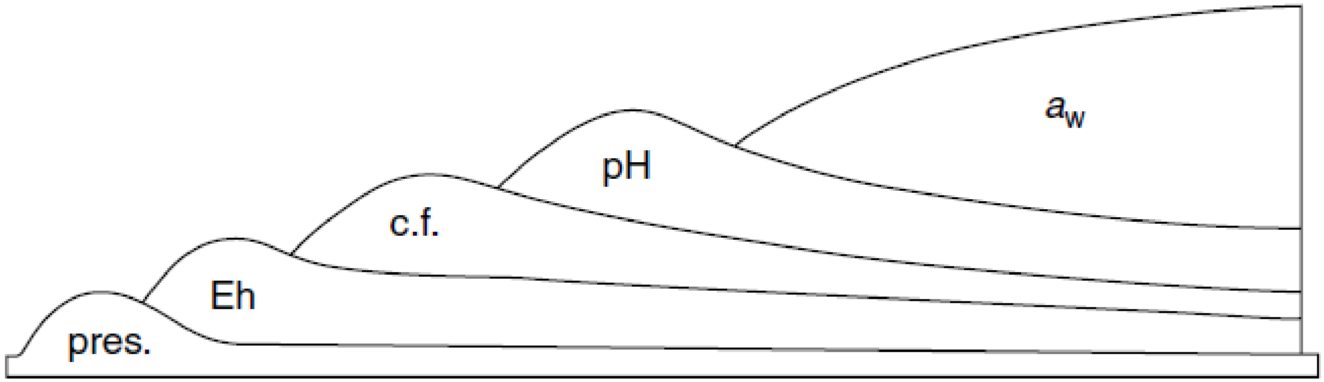
- Low oxygen inhibits growth of many spoilage organisms
- But: anaerobic conditions required by some pathogens (e.g., *C. Botulinum*)

Preservatives

- Inhibit bacteria, yeasts, moulds
- Used at low levels (mg/kg) for specific applications
- e.g., Benzoate (soft drinks), propionate (baked goods), nitrites (meats), sulfites (wine), ascorbate (juices)

Fermented Sausages (salami)

- Sequence of hurdles occurring during the ripening and drying of fermented sausages (salami).
- Preservatives., addition of nitrite-curing-salt
- Redoxpotential - decrease of redox potential
- Fermentation - growth of competitive flora
- pH – acidification
- a_w- decrease of water activity during the drying process.



Conclusion

- The concept of hurdle technology for mild and effective preservation of a variety of foods has attracted much attention in industrialized as well as developing countries, and probably it will be employed increasingly in future food preservation.
- Combined methods used for tissue preservation are by no means a new process (study on the mummification in ancient Egypt).
- The mummies contained, more than 3000 years ago (at least), three hurdles namely reduced a_w (0.72), increased pH (10.6), and preservatives (spices, aromatic plants).

16. Packaging as a Preservation Technique

Avoid recontamination

Preservation Methods

- Based on the mode of action, the major food preservation techniques can be divided into:
- 1. Indirect inactivation (inhibition) of microorganisms
  - Modification environment that prevents microorganisms from multiplying and performing of enzymatic functions
- 2. Direct inactivation of microorganisms
  - Directly inactivating bacteria, yeasts, moulds, or enzymes
- **3. Avoid recontamination**
  - Removal of microorganisms from the medium/environment.
  - Preventing/avoiding contamination before and after processing.

Introduction

- Packaging dates back to when people first started moving from place to place.
- Originally, skins, leaves, and bark were used for food transport.
- Neolithic humans used metal containers and discovered pottery.
- In ancient Egypt - glass making was an important industry.
- The Greek and the Roman times saw the rise of pottery and the use of glass.
- Napoleon Bonaparte was involved in the invention of canning.
- More recently, plastics were developer (United States around 1935–1942).
- One hundred years ago there was little use for packaging in the food industries.
- Now, extreme progress in the development of diversified packaging materials and in the packaging equipment.
- Over the last three decades, packaging has grown in volume and importance into one of the most significant areas of food production

Packaging and quality management tools need to be implemented in the process to avoid contamination or recontamination.
Play an important role in producing high-quality safe food.

Purposes of Packaging

- Product containment
- Preservation by maintaining quality
- Presentation and convenience
- Protection
- Information about product and Provide storage history

Product Containment

- The primary purposes of packaging are **containment** and **protection**.
- Liquids, semiliquids, and powders, bulk solids, cannot be marketed without suitable containers.
- According to the size of the package, different amounts of the product can be delivered to consumers (suiting their choice and convenience).
- **Containment** refers to holding goods in a form suitable for transport
- **Protection** refers to safe keeping goods in a way that prevents significant quality deterioration.

Preservation by Maintaining Quality

- The second function of packaging is
  - To control the local environmental conditions to enhance storage life and safety.
  - Protect the product against surroundings contaminations
- Packaging protects before enzymatic, chemical, physical, and microbiological changes, insects, pests, and rodents.

Presentation and Convenience

- In many cases, these are most important factors to the consumers.
- **Presentation**
  - It is important to display the product in an attractive manner to the potential buyer.
  - A cleverly designed and beautifully produced packaging can help sell a product, which is an essential ingredient of an effective marketing campaign
  - It depends on the type of final consumer.
- **Convenience**
  - Packaging provides convenience to the consumers
  - Eating styles, such as ready-to-eat meals, snacks, and microwaveable ready meals, have been changed over the years, which need innovation in packaging.
  - For children, the packaging might represent innovation or fun

Changes in society, such as diminishing population pattern, increasing average age, smaller families, more leisure time, as well as improvements in the quality of life, standard of living, and general level of education, may also demand specific function of packaging. Today's consumer wants to buy food that is ready to eat, or needs a minimum of preparation, and is good value for money.

Protection during Distribution and Processing

- Protection of the product during transit to the consumer.
- Packaging is part of the distribution process necessary to deliver goods to the consumer and facilitate handling and transportation.
- Proper packaging is necessary for the delivery of goods to the markets and consumers.
- Packaging can handle better when there are challenges in food distribution chain, such as heat, humidity, or dew.
- Protective packaging is a term applied to packaging primarily designed to protect the goods, rather than for appearance or presentation.
- The most widely used protective package is the outer carton.
- A pallet is the frame base for carrying the transport packs.
- Another aspect of protective packaging involves primary packaging designed to prevent anyone from opening the package before purchase.

Information about Product and Provide Storage History

- **Food labels** are intended by law to provide the information that consumers need to be able to make the necessary decisions about those purchases of food.
- Weight, volume, nutritional composition, ingredients, allergens…
- **Provide Storage History**
- Time-temperature indicator (TTI) is effective for predicting microbial concentrations and other parameters of food quality during shipping and storage.
- It helps in ensuring proper handling and provides a gauge of product quality for sensitive products in which temperature control is imperative to efficacy and safety.
- TTIs are tags that can be applied to individual packages or shipping cartons to visually indicate whether a product has been exposed to time and temperature conditions that adversely affect the product quality.
- TTI could be used in chilled foods to identify the temperature abuse during storage and distribution.

Ideal Packaging

- There is no such thing as the ideal packaging.
- Packaging should be such that we could come close to the ideal and the criteria of ideal packaging:

- Zero toxicity
- High product visibility
- Strong marketing appeal
- Ability of moisture and gas control
- Stable performance over a large temperature range
- Low cost and availability
- Suitable mechanical strength
- Easy machine handling
- Closure characteristics, such as opening, sealing and resealing, pouring
- Ability to include proper labeling
- Resistance of migration or leaching from package
- Protection from loss of flavour and odour
- Controlled transmission of required or unwanted gases

Types of Packaging Materials

- Originating from natural materials such as skins, leaves, and bark, tremendous progress has been made in the development of diversified packaging materials and packaging equipment.
- Packaging materials are grouped into
  - Flexible materials (plastic film, foil, paper, and textiles)
  - Rigid (wood, glass, metals, and hard plastics)

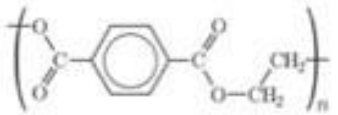
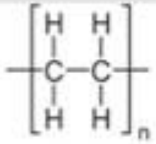
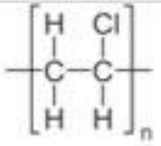
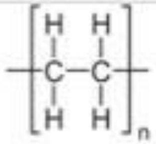
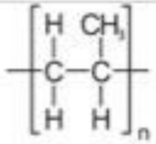
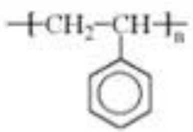
Plastics Material

- Polymers (plastics) are the fastest-growing group of materials in food packaging.
- The first plastic materials used for flexible packaging entered commercial production in 1939.
- The main development took place in the mid-1950s

- Using plastics package in food
    - Plastic bags
    - Bottles
    - Boxes
    - Closures

Plastic Material

- Polyethylene terephthalate (PET)
- High density polyethylene (HDPE)
- Polyvinyl chloride (PVC)
- Low density polyethylene (LDPE)
- Polypropylene (PP)
- Polystyrene (PS)
- Cellulose (cellophane- trademark)

Resin Code	Polymer Resin	Structure	General Applications
1 PET	Polyethylene Terephthalate		• Plastic drinking bottles • Food jars
2 HDPE	High Density Polyethylene		• Shampoo, dish, laundry and house cleaning bottles • Shipping containers
3 PVC	Polyvinyl Chloride		• Packaging materials • Pipes, fencing • Blood bags, medical tubing
4 LDPE	Low Density Polyethylene		• Bags for dry cleaning & newspapers • Shrink wrap, film
5 PP	Polypropylene		• Medicine bottles • Bottle caps • Automotive parts • Carpeting
6 PS	Polystyrene		• Disposable cups, utensils, food containers • Foam packaging
7 OTHER	Other	Resin is other or a mixture of mentioned resins	• 3 and 5 gallon reusable water bottles • Packaging

Plastic Material

- Advantage
  - Wide diversity and extremely broad spectrum of properties
  - Cheap
  - Light
  - Easily processed and shaped
  - Easy to seal
- Disadvantages
  - Permeability to gases and vapours
  - The possibility of their interacting with the product
  - Negative impact on the environment

Metal Packaging

- Steel, tin, and aluminum are used mainly for canned foods and beverages.
- The most common use of metals for packaging is in tin-coated steel and aluminum cans.

Advantages

- Their strength providing mechanical protection,
- Effective barrier properties
- Resistance to high temperatures
- Providing stability during processing
- Opacity (advantage for light-sensitive products), but disadvantage in that contents are invisible)

Disadvantages

- Heavy mass
- High cost
- Tendency to interact with contents
- Opacity (contents are invisible)
- Internal and external corrosion

Tin Coated or Lacquered Steel

- Product in the can must be stable and perfectly sealed.
- Tin coating or lacquering is an important part of can manufacture.
- The lacquer – acrylic, epoxy, phenolic or vinyl resin.
- The interior coating
    - Withstand sterilization temperatures and action of acids, as well as sulfide staining

Aluminium

- Lightness (three times lighter than steel)
- Strength (alloys are as strong as steel)
- Corrosion resistance, electrical conductivity
- Easy of recycling
- It has the barrier properties of steel, but without the corrosion problem.
- It can be bonded with paper (e.g., chewing gum) to allow easier printing.
- It has excellent strength so that thin films can be made.
- It can be extruded into complex shapes.

Aluminium - Applications

- Foil packaging, e.g., chocolate, household, or industrial foil
- Bottle closures and overwraps, e.g., caps and wine bottles
- Convenience food containers and lids, e.g., frozen-stored/oven-heated, single portion sizes, yogurt tub lids
- Kitchenware, e.g., saucepans and cutlery
- Special applications, e.g., shrimp freeze blocks

Glass

- Glass containers used to be and still are considered a prestigious means of packaging.

Advantages

- Highly inert
- Impermeable to gases and vapors (excellent oxygen barrier)
- Diverse shaping
- Transparency, but where required it can be given different desired colours (selective light protection properties)
- Completely neutral in contact with foods
- Can be recycled

Disadvantages

- Fragility
- Heavy mass
- High energy requirement during manufacturing
- Difficulty of vacuum packaging (ground or roasted coffee)
- Not suitable for frozen products (expansion of frozen food may cause break glass)

Glass Containers

- The cylindrical shape is chosen for maximizing strength for a given volume.
- The main uses of glass for packaging
    - Milk bottles, diary products
    - Drinks (wine, distillate, beer, juice…), oils, vinegars…
    - Canned fruits and vegetables
    - Sauces (mustard, ketchup, mayonnaise…)
    - Baby foods

Wood

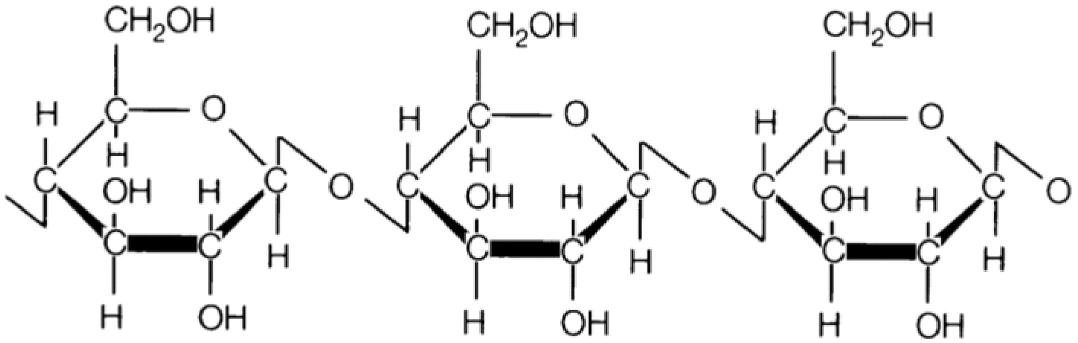
- Use of wood in packaging today is rather limited (replaced by plastic)
- Primarily to different boxes, cases, casks and pallets.

Cardboard

- Mainly protective package
- **Corrugated cardboard** consists of two linerboards, covering a central corrugated sheet.
  - Excellent for storage and cutting, folding, and then gluing (or locking) it into a three-dimensional rigid box.
- The board must be strong enough for packaging, handling, storage, and intended use.

Papers

- Paper bags were used in the seventeenth century.
- Paper is ultimately environment friendly.
- Paper is decomposed by bacterial action over a period of time.
- In recent years the paper as a packaging material is often replaced, due to the extensive use of plastics.
- The basic raw material for papermaking is cellulose.
- The cellulose molecule consists of a long, straight chain of glucose units.



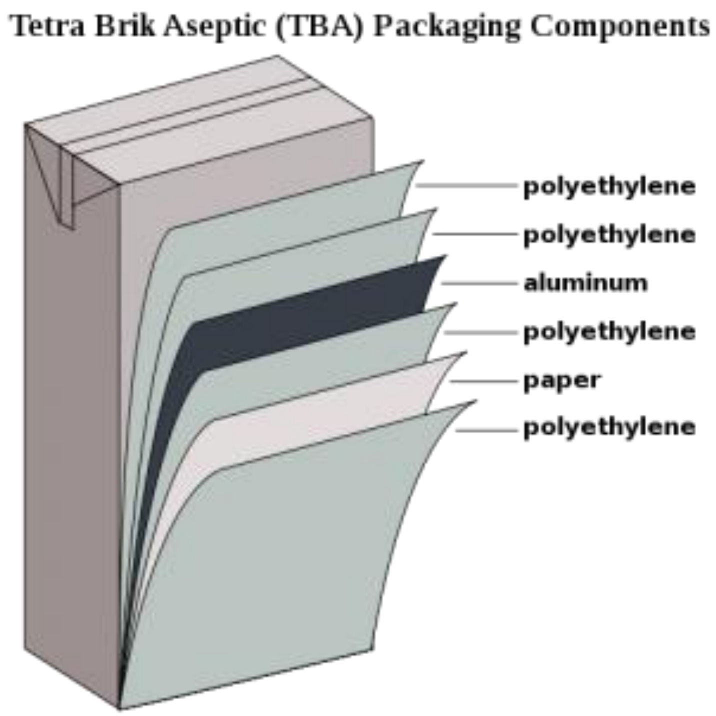
Papers

- Advantages
  - Low cost
  - Low mass
  - Relatively high stiffness
  - Excellent printability
  - Environment friendly

- Disadvantage
  - High sensitivity to moisture

Papers

- Possibilities increasing resistance to moisture.
- Combination of paper and other materials
- Special types of paper - resist to grease, oils, and fats
  - Greaseproof paper
  - Waxed papers
- Paper laminations commonly
  - Paper/aluminum
  - Paper/plastic
  - Paper/plastic/aluminum (milk, juice)



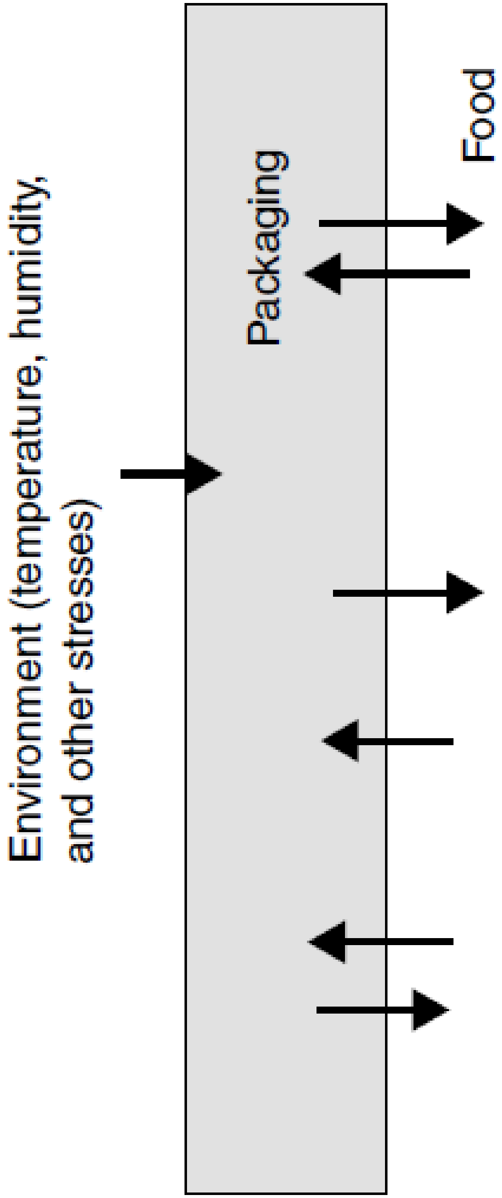
Food Packaging Interaction

- Packaging materials are used to protect the food during storage and distribution.
- The package may provide protection for microbiological, chemical, and physical contamination.
- Components of the packaging material must be safe to the product as well as to the consumers.
- Most packaging materials used for foods are not inert and reaction may occur between food and package material.
- Food may interact with the packaging materials this may change the properties and the safety of the product.

Classification of Interaction

- **Migration**
  - Describe the transfer of package components from the package to the contained food product.
- **Permeation**
  - The lost of the volatiles such as flavours and aromas
- **Absorption**
  - The packaging materials can also absorb flavour compounds from products and this may directly affect the food quality.

Product–package interaction



Process	Migrating substances	Adverse consequences
Permeation	Oxygen Water vapor Carbon dioxide Other gases	Oxidation Microbial growth Mold growth Off-flavor Dehydration Decarbonation
Migration	Monomers Additive	Off-flavor Safety problems
Sorption	Aroma compounds Fats Organic acids Pigments	Loss of aroma intensity Unbalanced flavor profile Damage to the package
Corrosion	Metal ions	Color change Safety problems

Metal–Food Interaction

- Corrosion is the destructive attack on a metal through the chemical or electrochemical reaction with the environment.
- Since steel corrodes rapidly in the presence of acidic substances, the tin acts as a barrier.
- Some cans are lacquered internally for high-acid products (pH<3) or for products that change colour in the presence of tin.

Paper–Food Interaction

- Migration from paperboard or paperboard/plastic laminates
  - Components from solvents and adhesives (phenols and cresols)
  - Components from inks used for printing.
- The compounds migrated from the adhesive layer of aluminum-baked paperboard packaging caused off-flavours.

Plastic–Food Interaction

- Polymer materials are not absolute barriers.
- Migration in plastics packaging refers to the transfer of compounds from the plastic to the food product.
- The food may lose valuable volatiles, such as odours, carbon dioxide, water, or flavours.

Environmental Issues

- Recently, a new dimension of safety has arisen
  - The ecological dimension
- This means that packaging has not only to satisfy physical, chemical, and biological criteria using their life cycle as packaging, but once the original function has been fulfilled the packaging should decay without polluting the environment (passive protection function).
- Environmental issues are becoming increasingly important to the consumer.
- Packaging of food should be easily reusable, recyclable, and environment-friendly.

Recycle, Reuse, Reduce

- **Reuse**
- Instead of throwing things away, try to find ways to use them again.
- Plastic bags, containers, water bottles can be reused many times
- **Recycle**
- After use, most of the plastic waste has traditionally been disposed into landfills, which in turn have led to serious environmental concerns.
- Recycling, composting and the use of biologically degradable product
- use materials that can be either recycled or burned without producing noxious fumes
- **Reduce**
- the reduction of the amount of packaging used for foods.
- Reduce the amount of waste you create
- It is important to use packaging in optimum level

Difficulties of Recycling

- The migration of contaminants into the food.
- Energy requirement during recycling.
- In some cases – high cost of recycling, unprofitable
- No control over how the consumer uses he container (e.G., For pesticides, chemicals), and the container may become contaminated.

Type of Plastic	It starts as...	It gets made into...
1 **PET** Polyethylene Terephalate	Peanut Butter Jars Water Bottles Soda Bottles	Carpeting Tennis Balls Paint Brushes
2 **HDPE** High-Density Polyethylene	Juice Bottles Liquid Detergent Bottles Plastic Grocery Bags	Plastic Lumber Trash Cans Toys
3 **PVC** Polyvinyl Chloride	Shampoo Bottles Cooking Oil Bottles Salad Dressing Bottles	Floor Mats Hoses Computer Cords
4 **LDPE** Low-Density Polyethylene	Food Storage Containers Dairy Container Lids Dry Cleaning Bags	Frisbees® Lawn Furniture Toys
5 **PP** Polypropylene	Medicine Bottles Yogurt Containers Flower Pots	Brooms Toothbrushes Sleeping Bags
6 **PS** Polystyrene	Dairy Containers Vitamin Bottles Flower Pots	Building Insulation Rulers Food Service Trays
7 **Other** Other Plastics	Ketchup Bottles Window Cleaner Bottles Water Coolers	Street Signs Pens Concrete Supports

Modified-Atmosphere Packaging of Produce

- Immediately after harvest, the sensorial, nutritional, and organoleptic quality of fresh produce will start to decline as a result of altered plant metabolism and microbial growth.
- This quality deterioration is the result of produce transpiration, senescence, ripening-associated processes, and the development of postharvest disorders.

Types of Packages

- Modified-atmosphere packaging
  - The gas composition within the package is changed but not monitored or adjusted
- Controlled-atmosphere packaging
  - The altered gas composition inside the package is monitored and maintained at a preset level by means of the inlet of gases
- Active packaging
  - By adding materials that absorb or release a specific compound in the gas phase. Compounds that can be absorbed are carbon dioxide, oxygen, water vapor, ethylene, or volatiles that influence taste and aroma
- Vacuum packaging
- Modified-humidity packaging
  - Modified humidity packaging (MHP) is designed for products where dehydration causes the most important quality losses, and therefore focuses on controlling water vapor levels

Modified-Atmosphere Packaging (MAP)

- Is a preservation technique that minimize the physiological and microbial decay of perishable produce by keeping them in an atmosphere that is different from the normal composition of air.
- The air surrounding the food in the package is changed to another composition.
- Is used for prolonging the shelf-life of fresh or minimally processed foods.
- Is used for perishable products like meat, fish, fruits and vegetables
- Is usually combined with refrigeration.
- The mixture of gases in the package depends on the type of product, packaging materials and storage temperature.
- The strategy of packaging produce under modified atmosphere (ma) is
  - To slow down the metabolic activity of the product
  - To slow down the growth of microorganisms (both spoilage and pathogenic) present by limiting O_2 supply and by application of an elevated level of CO_2.

Gases

- The atmosphere in an MA package consists of N_2, O_2, CO_2.
- It is the altered ratio of these gases that prolongs shelf life.
- Each food product has its own ideal gas mixture to ensure the longest shelf life possible.

- Examples
  - By reducing the O_2-level and increasing the CO_2-level, ripening of fruits and vegetables can be delayed.
  - Oxygen helps to keep the fresh and natural colour of food products, prevents the growth of anaerobic bacteria and allows fresh fruit and vegetables to breathe.
  - Packaging meat and fish - the high CO_2-levels are effective bacterial and fungal growth inhibitors.
  - Nitrogen is used as prevents the oxidative rancidity caused by the presence of oxygen in packaged snacks and dried products.

Vacuum Packaging

- Vacuum packing is a method of packaging that removes air from the package prior to sealing.
- The oxygen is remove from the container
  - To extend the shelf life of foods
  - To reduce the volume of the contents and package (with flexible package forms)
- Vacuum packing is used
  - Limiting the growth of aerobic bacteria or fungi
  - Preventing the evaporation of volatile components
  - To store dry foods over a long period of time
    - Cereals, nuts, cured meats, cheese, smoked fish, coffee, and potato chips)
  - To store fresh foods – for shorter term
    - Vegetables, meats, and liquids, because it inhibits bacterial growth.

Technology of MAP

- Two techniques are used in the industry to pack vegetables.
- **Gas-flushing**
  - The desired gas mixture is added in quantity into the packaging, pushing out the air
- **Compensated vacuum**
  - The air is removed and the desired gas mixture then instilled.

Quality Assurance of MAP packages

- Although Modified Atmosphere Packaging is a well-established process, it is a good practice to maintain tight quality assurance through package testing.
- Incorrect oxygen levels, empty gas cylinders and bad sealing bars can cause imprecise gas blends and poor package seals that can result in product spoilage.
- Routine package testing with headspace gas analysers, on-line gas analysers and leak detectors assures package quality, and hence helps to maintain shelf life.

17. Hygienic Design and Sanitation

Avoid recontamination

Hygienic Design

- Lack of adequate hygienic practices at all stages of food production—harvesting, postharvesting, processing, and storage—drastically increases the risk of contamination with food poisoning.
- Sanitation is the creation and maintenance of hygienic and healthful conditions.
- Its applications refer to hygienic practices designed to maintain a clean and wholesome environment for food production, preparation, and storage.
- One of the keys to operating a clean and sanitary facility is design of the buildings and equipment.
- It is important to do it right the first time, as it is always much harder and more expensive to retrofit or rebuild.

Factory Facility Design

- Factory site
  - The design, construction, and maintenance of the factory site and buildings need special considerations from hygiene point of view. To maintain a good standard of hygiene, a well-planned and adequate waste disposal system is essential
- Floors
  - The main characteristics required are strength; fastness; abrasion, corrosion, and skid resistance.
- Walls
  - Must be constructed of impervious, nonabsorbant, washable, nontoxic materials and have smooth crack-free surfaces
- Doors, windows, and ceilings
  - Windows must have nets to prevent insects from entering the production areas and automatic doors should be used.
- Lighting
  - Should be sufficient for adequate performance of all assigned duties

Equipment Design

- Hygienically designed equipment should be installed in a manner that minimizes the chances of contamination and to facilitate housekeeping and sanitation programs.
- All equipment must be designed and constructed so that all internal contact points and external surfaces can be cleaned.
- Each piece of equipment has its own peculiar areas where microorganisms might proliferate, and hazard analysis of any weak points should ensure their removal, and indicate control and monitoring.

Good Hygienic Practice - Sanitation

- Sanitation is important from legal, economic, quality, and food safety standpoints
- Sanitation consists of two parts:
- **Cleaning**
  - Means the removal of residue of food, dirt, dust, foreign material, or other soiling ingredients or materials.
- **Sanitizing**
  - Means the effective bactericidal treatment of clean surfaces of equipment and utensils.
- Ideally, disinfectants should have the widest possible spectrum of activity against microorganisms (viruses, bacteria, fungi, and spores) in a time relevant to application contact times.

The Benefits of Sanitation

- (i) it increases the chance of complying with regulatory requirements;
- (ii) it can prevent a catastrophe (poisoning from food, subsequent closure of the food factory)
- (iii) it enhances or facilitates an effective quality assurance program by increasing the acceptability and storage life of food by suppressing microbial population
- (iv) it saves energy and retards the spreading of flora throughout the establishment

Reduction of Food Contamination Sources

- Foods not handled in a sanitary way may become contaminated from processing equipment, employees, soil, air, water, sewage, insects, and rodents.
- Contamination can be reduced through effective housekeeping and sanitation, protection of food during storage, proper disposal of garbage and litter, and protection against contact with toxic substances.

Personal Hygiene and Food Handling

- Good personal hygiene practices of personnel working in or visiting the production area are important.
- Additional requirements apply to personnel working in high-care areas.
- Personal hygiene refers to the cleanliness of a person’s body.
- The health of the workers plays an important part in food sanitation.
- People are potential sources of microorganisms that cause illness in others through transmission of viruses or through food poisoning.
- Personal hygiene needs reasonably clean hands, forearms, neck, hair, and clothing liable to come into contact with food.

Basic Rules of Personal Hygiene

- Washing hands in hot water using plenty of soap and drying hands on a clean cloth or paper towel.
- Washing hands after using the toilet; handling garbage or other soiled materials; handling uncooked muscle foods, egg products, or dairy products; handling money; smoking; coughing; and sneezing.
- Maintaining skin protection (gloves, protective cream)
- Keeping fingernails short and clean, using a hairnet or cap.
- Using protective clothing, footwear, and headgear; they must be changed regularly
- Avoiding use of nail varnish, false nails, makeup, false eyelashes, wristwatches, and jewelleries or ornaments.
- Avoiding counting money during food handling.
- Avoiding consumption of food and drink in areas other than the tea bars and staff restaurant.
- Avoiding consumption of sweets and chewing gum in production areas.
- Avoiding smoking or taking snuff in food production areas, warehouses, and distribution areas.
- Remaining away from food when a person has an infected cut, boil, or other infection of the exposed skin; covering sneezes and coughs by means of a tissue or handkerchief.
- Reporting all cases of diarrhea, fever, etc., and having periodic checkups.

Cleaning of Equipment

- All equipment should be washed and rinsed.
- Frequent cleaning of the plant equipment should be maintained at all times, and all parts should be continually washed by well-located continuous water sprays.
- Equipment should be cleaned as soon as possible after use and disinfected or sterilized just before it is used again.
- The frequency will depend upon the hazard risk to the product being produced.
- All equipment should be designed for easy cleaning.
- Hand cleaning depends upon operative training as well as the correct use of detergents.
- All utensils used must be absolutely clean.
- Buckets, knives, and drain pans should be cleaned and rinsed whenever empty or not in use.

Hygiene Monitoring

- The evaluation of the effectiveness of a sanitation program may be carried out in several ways:
- Visual inspection, swabbing and microbiological analysis, contact plates, or ATP (adenosine triphosphate) bioluminescence
- Traditional hygiene monitoring using culturing techniques has a number of problems: it is laborious and time consuming.
  - Estimation of the total colony count may take 24–48 h.
  - If it is necessary to detect or estimate the presence of specific microorganisms, 4–7 days may elapse before a result is obtained.

The technique of ATP bioluminescence involves taking a sample by swabbing a surface and then processing the swab. The speed of this method enables remedial action to be taken in the case of poorly cleaned equipment. The disadvantages are: (i) it cannot currently give any indication of the presence or absence of pathogens, only a total level of ATP contamination on a surface; (ii) the presence of detergents or other chemicals may interfere with the bioluminescence reaction; and (iii) it is expensive compared to the low-cost conventional culture techniques.

Reference

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