Training manual

ADVANCED FOOD PACKAGING TECHNIQUES AND QUALITY EVALUATION OF PACKAGING MATERIALS

ACCELERATE Vigyan

SERB INDIA

ICAR-Central Institute of Fisheries Technology (CIFT)
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Published during the High-end Workshop ('KARYASHALA') under Accelerate Vigyan Scheme of SERB, New Delhi, Government of India held from 19th to 27th June, 2023 at FP Division, ICAR-CIFT, Kochi

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2023

Published by: Director, ICAR-CIFT, Cochin-29

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For citing the book:

Bindu J., Mohan C.O., Remya S., and Sathish Kumar K. (eds.) (2023) Advanced food packaging techniques and quality evaluation of packaging materials, ICAR-Central Institute of Fisheries Technology, Cochin, India. pp 117.

Example for citing a chapter in the book:

Bindu J. (2023) Fundamentals of food packaging technology *In*: Bindu J., Mohan C.O., Remya S., and Sathish Kumar K. (eds.) (2023) Advanced food packaging techniques and quality evaluation of packaging materials, ICAR-Central Institute of Fisheries Technology, Cochin, India. pp 7-13.

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An Introduction to Food Preservation and Processing

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Introduction

Research in the field of food processing has garnered significant attention due to the growing demand for wholesome and safe food products. Health, nutrition, and convenience are pivotal drivers of the global food industry in this modern era. Across the globe, a diverse range of processing and packaging methods are employed, ranging from simple methods such as chilling or iced storage, salting, and drying, to more advanced approaches like high-pressure and electromagnetic field applications. These advanced methods present lucrative opportunities for both small-scale and industrial-level entrepreneurs. Food processing and preservation play a crucial role in ensuring the availability of safe and nutritious food for consumption. These practices are of paramount importance for several reasons. Firstly, they extend the shelf life of food products, preventing spoilage and reducing food waste. By employing various preservation techniques such as canning, freezing, and drying, perishable foods can be stored for longer periods without compromising their quality. Secondly, food processing enhances food safety by eliminating or reducing harmful microorganisms, thereby minimizing the risk of foodborne illnesses. Additionally, processing techniques like pasteurization and sterilization help preserve the nutritional value of foods, ensuring that essential vitamins, minerals, and other beneficial components remain intact. Moreover, food processing enables the development of convenient and ready-to-eat food products, catering to the demands of modern lifestyles. By providing consumers with a wide variety of safe, nutritious, and convenient food options, food processing and preservation contribute significantly to meeting the needs of a growing global population.

Importance of Food Processing

- Preventing Food Waste: Food preservation techniques help in extending the shelf life of perishable food items. By slowing down the spoilage process, these techniques reduce food waste and ensure that food can be stored and consumed over a longer period.
- Ensuring Food Security: Food preservation is essential for maintaining food security, especially in regions where there may be seasonal or unpredictable fluctuations in food production. By preserving surplus food during times of abundance, it can be made available during times of scarcity, thus ensuring a steady food supply.
- Facilitating Global Food Trade: Food preservation methods such as canning, freezing, and dehydration enable the transportation and export of food products over long distances. This facilitates global food trade and allows people to access a diverse range of food items throughout the year.
- Preserving Nutritional Value: Proper preservation techniques can help retain the nutritional value of food. By minimizing nutrient loss during storage, preservation methods contribute to maintaining the essential vitamins, minerals, and other nutrients present in food.

- Increasing Food Accessibility: Food preservation allows for the availability of a wide variety of foods beyond their natural seasons. By preserving and storing food, individuals and communities can have access to a diverse range of fruits, vegetables, and other perishable items throughout the year, irrespective of their seasonal availability.
- Supporting Emergency Preparedness: During times of natural disasters, emergencies, or other unforeseen circumstances, having preserved food on hand becomes crucial. It provides a lifeline for individuals and communities by ensuring a stable food supply when access to fresh food may be limited or disrupted.
- Promoting Sustainability: Food preservation helps in reducing the environmental impact of food production. By minimizing food waste, fewer resources are wasted in the production, transportation, and disposal of food. This contributes to a more sustainable food system and reduces the strain on natural resources.

Classification of food based on perishability

Based on the perishability and the extent of preservation required, foods may be classified as:

1. ***Perishable foods*:** Those that deteriorate readily (Seafood, meat, fruits and vegetables) unless special methods of preservation are employed.
2. ***Semi-perishable foods***: Those that contain natural inhibitors of spoilage (root vegetables) or those that have received some type of mild treatment which creates greater tolerance to the environmental conditions and abuses during distribution and handling (such as pickled meat and vegetables).
3. ***Non-perishable foods*** *(shelf-stable)*: Those that are non-perishable at room temperature (cereal grains, sugar, nuts). Some have been made shelf stable by suitable means (canning) or processed to reduce their moisture content (dried fish and shellfishes, raisins). Food preservation in the broad sense, refers to all the measures taken against any kind of spoilage in food.

Food spoilage

Food spoilage is a natural process that occurs when food deteriorates in quality, making it unsafe or unpalatable for consumption. Food spoilage occurs due to various factors, including microbial activity, enzymatic reactions, and chemical changes. Microorganisms such as bacteria, yeast, and molds can proliferate in food and lead to spoilage. Enzymes naturally present in food can also break down nutrients, causing undesirable changes in texture, taste, and color. Moreover, exposure to oxygen, moisture, temperature fluctuations, and light can accelerate spoilage processes. The principles of food preservation revolve around preventing or delaying microbial decomposition, self-decomposition of food, and damage caused by mechanical causes, insects, and rodents.

By applying these principles of food preservation, food quality can be maintained, spoilage can be minimized, and the shelf life of food can be extended. It is important to utilize appropriate preservation techniques based on the specific characteristics of the food product and the desired preservation goals.

To combat food spoilage and extend the shelf life of food, various traditional and advanced food processing methods are employed. Food processing methods aim to control or eliminate factors that contribute to food spoilage. The underlying principles include:

- Removal or control of moisture
- Application of heat or cold to halt microbial growth and enzyme activity
- Adjustment of pH levels to create unfavorable conditions for microorganisms
- Use of antimicrobial agents, such as salt or natural preservatives
- Packaging techniques that minimize exposure to oxygen, moisture, and light

Food processing methods

- **Drying:** Drying is one of the oldest and simplest methods of food preservation. It involves removing moisture from food, inhibiting the growth of microorganisms and enzymes. Sun drying, air drying, or using specialized drying equipment are common approaches to preserve foods like fruits, vegetables, and meats.
- **Salting**: Salting is a technique that utilizes the antimicrobial properties of salt to inhibit microbial growth. It involves applying salt to food products or immersing them in a salt solution. Salted fish, pickles, and cured meats are traditional examples of salt preservation.
- **Fermentation**: Fermentation is a natural process where microorganisms, such as bacteria or yeast, convert carbohydrates in food into alcohol, organic acids, or gases.
- **Icing/Chilling/Refrigeration**: These techniques involve lowering the temperature of food to inhibit the growth of microorganisms and slow down enzymatic activity, thereby extending its shelf life and maintaining its quality. Icing is commonly used for perishable products such as fish and seafood, where the food is directly surrounded by ice to keep it cold. Chilling, on the other hand, involves storing food at temperatures just above freezing to preserve its freshness, taste, and texture. Refrigeration, the most widely used method, utilizes specialized appliances to maintain a consistent temperature between 0 to 5 degrees Celsius, creating an optimal environment for food preservation. By slowing down the growth of bacteria and fungi, refrigeration helps prevent spoilage, ensuring that food stays safe and suitable for consumption for an extended period.
- **Freezing**: Freezing involves lowering the temperature of food to below its freezing point, effectively halting microbial growth and enzymatic reactions. It is a widely used method for preserving fruits, vegetables, meats, and prepared meals. Freezing maintains the quality and nutritional value of food while prolonging its shelf life.
- **Pasteurization**: Pasteurization is a heat treatment process that destroys harmful microorganisms in food without significantly affecting its taste and nutritional content. It is commonly used for milk, juices, and other beverages. Pasteurization ensures product safety and extends shelf life.
- **Canning:** Canning involves packing food in hermetically sealed containers and subjecting it to heat, destroying microorganisms and enzymes. The process extends shelf life and maintains food quality. Canned fruits, vegetables, and soups are examples of commonly preserved foods.

Advanced food processing methods

Food preservation techniques aim to inhibit the growth of microorganisms, enzymes, and other factors that contribute to food spoilage. While thermal methods are commonly employed, they often result in the loss of nutrients, flavor, and texture. Advanced and non-thermal techniques offer alternatives that minimize these drawbacks and extend the shelf life of various food products.

- **High-Pressure Processing**: High-Pressure Processing (HPP) is a non-thermal preservation technique that utilizes high hydrostatic pressure to inactivate microorganisms, enzymes, and pathogens present in food. The process involves subjecting the food to pressures ranging from 100 to 1000 MPa, which effectively destroys harmful bacteria and extends the shelf life of the product. HPP retains the sensory attributes, nutritional value, and quality of the food while ensuring safety.
- **Pulsed Electric Field** (PEF) Technology: Pulsed Electric Field (PEF) technology applies brief, high-voltage pulses to food, creating microscopic pores in the cell membranes of microorganisms. These pores disrupt the normal functioning of cells, leading to their inactivation. PEF treatment helps preserve the nutritional content, texture, and taste of food without relying on heat. It is particularly effective for liquid foods and beverages.
- **Ultraviolet (UV) Light** Treatment: Ultraviolet light treatment involves exposing food products to UV radiation, which has germicidal properties. UV light damages the DNA of microorganisms, preventing their growth and proliferation. This technique is commonly used for the disinfection of water, air, and surfaces. UV light treatment is an environmentally friendly approach that eliminates the need for chemical preservatives.
- **Irradiation**: Irradiation involves exposing food to ionizing radiation, such as gamma rays, X-rays, or electron beams, to control spoilage microorganisms and pests. This technique disrupts the DNA or cellular structure of microorganisms, rendering them unable to reproduce or cause illness. Irradiation helps extend the shelf life of food, reduces the risk of foodborne illnesses, and eliminates the need for chemical additives.
- **Pulsed light technology**: It is an innovative approach used in food preservation that harnesses short-duration, high-energy pulses of light to eliminate harmful microorganisms. By targeting the DNA and cellular structure of bacteria, viruses, and fungi, pulsed light effectively reduces microbial contamination on food surfaces.
- **Cold plasma**: Cold plasma technology is an innovative method used in food processing for various purposes, including surface decontamination, extending shelf life, and improving food quality. Cold plasma is a partially ionized gas that contains charged particles, reactive oxygen and nitrogen species, and UV photons. When applied to food surfaces, it can effectively eliminate pathogens, reduce spoilage microorganisms, and modify the properties of the food.

Recent trends in food processing

Food processing and preservation have undergone remarkable transformations over time, shaping the way we produce, consume, and distribute food. In the past, ancient civilizations relied on techniques such as drying, fermentation, salting, smoking, and canning to prevent spoilage and extend the shelf life of food. These methods were driven by necessity and limited technology. In the present, advancements in refrigeration, freezing, pasteurization, high-pressure processing, and modified atmosphere packaging have revolutionized the industry. These techniques prioritize food safety, quality maintenance, and convenience. The recent trends in food processing have been shaped by changing consumer preferences, technological advancements, and a focus on sustainability. Here are some notable trends in the field:

- **Clean Label and Natural Ingredients**: Consumers are increasingly demanding transparency in food products. They prefer clean label products that have minimal additives and artificial ingredients. Food processors are responding by using natural ingredients and adopting cleaner processing methods.
- **Plant-Based and Alternative Proteins**: The rise of plant-based diets and environmental concerns have fueled the demand for plant-based and alternative protein sources. Food processors are developing innovative ways to process and incorporate plant-based ingredients to create meat and dairy alternatives.
- **Sustainable Packaging**: Reducing packaging waste and using eco-friendly materials have become important considerations in food processing. Companies are exploring biodegradable and compostable packaging options and minimizing the use of single-use plastics.
- **Functional Foods**: Consumers are increasingly seeking out foods that provide health benefits beyond basic nutrition. Functional foods enriched with vitamins, minerals, probiotics, and other beneficial components are gaining popularity. Food processors are incorporating these functional ingredients into their products.
- **Clean and Minimal Processing**: There is a growing interest in minimally processed foods that retain their natural flavors, textures, and nutrients. Techniques such as high-pressure processing (HPP), cold pasteurization, and minimal heat treatments are being used to preserve the nutritional quality and taste of foods.
- **Automated Processing**: Automation and robotics are increasingly being used in food processing facilities to improve efficiency, reduce contamination risks, and enhance food safety. Automated systems are employed for tasks such as sorting, quality control, and packaging.
- **Personalized Nutrition**: Advances in technology and nutrition science have paved the way for personalized nutrition. Food processors are exploring ways to customize food products to meet individual dietary needs and preferences, such as personalized meal kits and personalized supplement options.
- **Smart and Connected Food Processing**: The integration of digital technologies and automation is revolutionizing the food processing industry. Smart sensors, data analytics, and Internet of Things (IoT) devices are being used to optimize processing efficiency, quality control, and traceability.
- **Transparency and Traceability**: Consumers are demanding more information about the origin, production methods, and supply chains of their food. Food processing companies are implementing technologies such as blockchain and RFID (Radio-Frequency Identification) to provide greater transparency and traceability throughout the production and distribution processes.
- **Waste Reduction and Upcycling**: Food waste is a significant global concern. Food processors are finding innovative ways to reduce waste and upcycle byproducts. This includes converting food waste into valuable ingredients, utilizing surplus food, and adopting circular economy principles.

Conclusion

In the past, food processing focused primarily on traditional methods. These methods revolutionized the industry by enabling long-term storage and wider distribution of food. The present era witnesses a dynamic landscape with emerging trends in response to evolving consumer preferences and technological advancements. The demand for clean label products, plant-based alternatives, and functional foods has driven the industry to explore new processing techniques and ingredients. Moreover, sustainability, automation, and personalized nutrition are shaping the present-day practices in food processing. Looking to the future, there are exciting possibilities on the horizon. With ongoing research and innovation, we can anticipate the development of even more advanced technologies for food processing and preservation. As the world faces challenges such as population growth, resource scarcity, and environmental concerns, the future of food processing will likely focus on sustainable practices, improved food safety, and meeting the nutritional needs of a diverse and health-conscious population. By leveraging the power of technology and scientific breakthroughs, the food processing industry is poised to continue its crucial role in ensuring food security and delivering safe, nutritious, and delicious products to consumers worldwide.

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Fundamentals of food packaging technology

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Introduction

Food packaging plays a crucial role in preserving and protecting food products from external factors that can impact their quality, safety, and shelf life. It involves the design, production, and use of various materials and techniques to ensure that food products reach consumers in optimal condition. Packaging is vital to our modern food distribution and marketing systems. Without protective packaging, food spoilage and wastage would increase tremendously. The advent of modern packaging technologies and new methods of packaging materials made possible the era of convenience products. In the past, packaging emphasized the expectations of the producers and distributors but now it has shifted towards the consumer since they are becoming more demanding and aware of different choices to choose from. A food package usually provides a number of functions in addition to protection. Different products have different packaging requirements and it is important to choose suitable packaging material accordingly. The intended storage conditions of the product, i.e., temperature, relative humidity and expected shelf life have to be known. Multilayered plastics are very popular since properties of different films can be effectively used to pack different products. The basic function of food packaging is to protect the product from physical damage and contaminants, to delay microbial spoilage, to allow greater handling and to improve presentation.

Importance of Food Packaging

Proper food packaging serves multiple purposes, including:

- **Protection**: Packaging safeguards food from contamination, spoilage, and damage during transportation and storage.
- **Preservation**: It extends the shelf life of food by preventing moisture loss, exposure to light, and the entry of oxygen.
- **Information**: Packaging provides essential details about the product, such as ingredients, nutritional information, and storage instructions.
- **Branding and Marketing**: Packaging plays a significant role in attracting consumers, conveying brand identity, and promoting product differentiation.

Classification of Packaging Materials

Packaging materials can be classified in various ways based on different criteria. Here are some common classifications of packaging materials.

1. Based on Material Type

Glass: Glass containers have been used for many centuries and still one of the important food packaging material. Glass has its unique place in food packaging since it is strong, rigid and chemically inert. It does not appreciably deteriorate with age and offers excellent barrier to solids, liquids and gases. It also gives excellent protection against odour and flavor and product visibility. Glass can also be moulded to variety of shapes and sizes. But it has disadvantages like fragility, photo oxidation and heavier in weight.

Metal Cans: Most frequently used container for packing food for canning is tin plate can. Tin plate containers made their appearance in 1810. The base steel used for making cans is referred as CMQ or can making quality steel. Corrosion behaviour, strength and durability of the tin plate depend upon the chemical composition of the steel base. The active elements are principally copper and phosphorous. The more of these elements present the greater the corrosiveness of steel. Cans are traditionally used for heat sterilized products and different types are standard tin plates, tin free steel and vacuum deposited aluminium on steel and aluminium cans. For food products packing they are coated inside to get desirable properties like acid resistance and sulphur resistance. But care has to be taken to avoid tainting of the lacquer.

Polymer coated two-piece cans of 6 oz capacity (307 x 109) with a universal polymer coating can be widely used for a variety of products. The can is made of Electrochemically chromium coated steel (ECCS) plate with clear polyethylene terephtahalate (PET) coating on either side The finished plate has a thickness of 0.19mm (0.15 mm of base steel + 20 µ PET coating on either side). The cans are made out of the steel plate by draw and redraw (DRD) process. The chromium coating along with the PET coating provides the can with a smooth, greyish, glistening appearance in addition to act as a barrier between the product and the base steel. The bottom of the can is designed for better stackability so that it can be stacked vertically without risk of toppling on the shelf. This also helps to reduce the storage space requirement for the cans. These cans are found to be suitable for thermal processing of fish and fish products. These cans are having easy open ends. Metal cans are advantageous as packages because of superior strength, high speed manufacturing and easy filling and dosing. Disadvantages of metal cans are weight, difficulty in reclosing and disposal.

Paper: A very considerable portion of packaged foods is stored and distributed in packages made out of paper or paper-based materials. Because of its low cost, easy availability and versatility, paper is likely to retain its predominant position in packaging industries. Paper is highly permeable to gases, vapour and moisture and loses its strength when wet. Ordinary paper is not grease and oil resistant, but can be made resistant by mechanical processes during manufacturing.

Paper board: Thicker paper is called as paper board. There is not a clear-cut dividing line between the heaviest grade of paper and the lightest board. The lightest standard board is 0.19 mm thick and heavy papers are of 0.125 mm thickness. Paper boards are used for making corrugated fibre board cartons.

Polymer Packaging: Plastics offer several advantages over other packaging materials since they are light in weight, flexible and offers resistant to cracking. Plastics have the advantage that most of them possess excellent physical properties such as strength and toughness. The requirements with a particular food may not be met with in a single packaging material, as it may not possess all the desired properties. In such cases copolymers or laminates consisting of two or more layers of different polymers having different properties can also be used.

- **Low Density Polyethylene** (LDPE): Most commonly used as it possesses qualities such as transparency, water vapour impermeability, heat sealability, chemical inertness and low cost of production. Organic vapours, oxygen and carbon dioxide permeabilities are high and has poor grease barrier property. Resists temperature between – 40°C to 85°C. Polyethylene (polythene, PE) is the material consumed in the largest quantity by the packaging industry.

- **High Density Polyethylene** (HDPE): HDPE resins are produced by low-pressure process. HDPE possess a much more linear structure than LDPE and has up to 90% crystallinity, compared with LDPE which exhibits crystallinities as low as 50%. The material is stronger, thicker, less flexible and more brittle than LDPE and has lower permeability to gases and moisture. It has a higher softening temperature (121°C) and can therefore be heat sterilized. High molecular weight high density polythene (HM-HDPE) has very good mechanical strength, less creep and better environmental stress crack resistance property.
- **Linear Low-Density Polythene** (LLDPE): Linear low-density polythene is low density polythene produced by a low-pressure process. Normal low-density polythene has many -C5H11 side chains. These are absent in LLDPE, allowing the molecules to pack closer together to give a very tough resin. It is virtually free of long chain branches but does contain numerous short side chains. Generally, the advantages of LLDPE over LDPE are improved chemical resistance, improved performance at both low and high temperatures, higher surface gloss, higher strength at a given density and a greater resistance to environmental stress cracking. LLDPE shows improved puncture resistance and tear strength. The superior properties of LLDPE have led to its use in new applications for polyethylene as well as the replacement of LDPE and HDPE in some areas.
- **Polypropylene** (PP): Polypropylene is produced by the polymerisation of propylene. All PP films have permeability about ¼ to ½ that of polyethylene. It is stronger, rigid and lighter than polyethylene.
- **Cast polypropylene** (CPP): It is an extruded, non-oriented film and is characterized by good stiffness, grease and heat resistance and also has good moisture barrier. However, it is not a good gas barrier.
- **Oriented, Heat set Polypropylene** (OPP): Orientation can be in one direction (unbalanced) or in two directions equally (balanced). The resulting film is characterized by good low temperature durability, high stiffness and excellent moisture vapour transmission rate. One drawback of OPP is its low tensile strength.
- **Polystyrene**: The material is manufactured from ethylene and benzene, which are cheap. The polymer is normally atactic and it is thus completely amorphous because of the bulky nature of the benzene rings prevents a close approach of the chains. The material offers reasonably good barrier to gases but is a poor barrier to water vapour. New applications of polystyrene involve coextrusion with barrier resins such as EVOH and poly vinylidene chloride copolymer to produce thermoformed, wide mouthed containers for shelf stable food products and multi-layer blow moulded bottles. To overcome the brittleness of polystyrene, synthetic rubbers can be incorporated at levels generally not exceeding 14% w/w. High impact polystyrene is an excellent material for thermoforming. Co-polymerisation with other polymers like acrylonitrile butadiene improves the flexibility. Since it is crystal clear and sparkling, it is used in blister packs

and as a breathing film for packaging fresh produce. These materials have low heat sealability and often tend to stick to the jaws of heat sealer.

- **Polyester**: Polyester can be produced by reacting ethylene glycol with terephthalic acid. Polyester film's outstanding properties as a food packaging material are its great tensile strength, low gas permeability, excellent chemical resistance, lightweight, elasticity and stability over a wide range of temperature (-60° to 220°C). The later property has led to the use of PET for boil in the bag products which are frozen before use and as over bags where they are able to withstand cooking temperatures without decomposing. Although many films can be metallized, polyester is the most commonly used one. Metallization results in considerable improvement in barrier properties. A fast-growing application for polyester is ovenable trays for frozen food and prepared meals. They are preferable to foil trays for these applications because of their ability to be micro wave processed without an outer board carton**.**
- **Polyamides** (Nylon): Polyamides are condensation products of diacids and diamine. The first polyamide produced was Nylon-6,6 made from adipic acid and hexamethylene diamine. Various grades of nylons are available. Nylon-6 is easy to handle and is abrasion-resistant. Nylon-11 and nylon-12 have superior barrier properties against oxygen and water and have lower heat seal temperatures. However, nylon-6,6 has a high melting point and hence, it is difficult to heat seal. Nylons are strong, tough, highly crystalline materials with high melting and softening points. High abrasion resistance and low gas permeability are other characteristic properties.
- **Polyvinyl Chloride** (PVC): The monomer is made by the addition of reaction between acetylene and hydrochloric acid. It must be plasticised to obtain the required flexibility and durability. Films with excellent gloss and transparency can be obtained provided that the correct stabilizer and plasticizer are used. Thin plasticized PVC film is widely used in supermarkets for the stretch wrapping of trays containing fresh red meat and produce. The relatively high-water vapour transmission rate of PVC prevents condensation on the inside of the film. Oriented films are used for shrink-wrapping of produce and fresh meat. Unplasticized PVC as a rigid sheet material is thermoformed to produce a wide range of inserts from chocolate boxes to biscuit trays. Unplasticized PVC bottles have better clarity, oil resistance and barrier properties than those made from polyethylene. They have made extensive penetration into the market for a wide range of foods including fruit juices and edible oils.
- **Copolymers**: When polythene resins are being manufactured it is possible to mix other monomers with ethylene so that these are incorporated in the polymer molecules. These inclusions alter the characteristics of the polythene. Vinyl acetate is commonly used and the resulting ethylene vinyl acetate (EVA) copolymers display better sealing than modified polythene. Butyl acetate is incorporated with similar effects.

Aluminium foil: Aluminium foil is defined as a solid sheet section rolled to a thickness less than 0.006 inches. Aluminium has excellent properties like thermal conductivity, light weight, corrosion resistance, grease and oil resistance, tastelessness, odourlessness, heat and flame resistance, opacity and non-toxicity. Aluminium foil free from defects is a perfect moisture and oxygen barrier. In all flexible packaging applications using aluminum foil where good moisture and oxygen barrier properties are important, the foil is almost always combined with heat sealing media such as polythene or polypropylene. It is the cheapest material to use for the properties obtained. Foils of thickness 8 to 40 microns are generally used in food packaging. Foil as such is soft and susceptible for creasing. Hence, foil is generally used as an inner layer.

Wood: Used for packaging heavy or fragile items.

2. Flexibility

From skins, leaves, and bark, tremendous progress has been made in the development of diversified packaging materials and in the packaging equipment. In general, packaging materials may be grouped into rigid and flexible structures.

- **Flexible materials**: Plastic film, foil, paper and textiles are flexible materials.
- **Rigid materials**: Wood, glass, metals and hard plastics are examples of rigid materials.

3. Function

- Primary Packaging: Primary packaging refers to the immediate contact packaging of the food product. It is in direct contact with the food and is responsible for preserving its quality and integrity. Primary packaging materials must be safe, non-toxic, and compatible with the food they contain. Examples include bottles, cans, blister packs, etc.
- Secondary Packaging: Secondary packaging is the outer packaging that holds the primary packages together. It provides additional protection during transportation and storage, ensuring the integrity of the primary packages. Examples include cardboard boxes, shrink wrap, etc.
- Tertiary Packaging: Tertiary packaging involves packaging multiple secondary packages into larger units for efficient handling and distribution. It is commonly used in bulk shipments. Examples include pallets, stretch wrap, shipping containers, etc.

4. Environmental Impact

- Sustainable Packaging: Materials designed to minimize environmental impact, such as biodegradable or compostable materials, recyclable materials, etc.
- Non-sustainable Packaging: Materials that have a higher environmental impact, such as non-recyclable plastics, mixed materials, etc.

5. Barrier Properties

- Oxygen Barrier: Materials that protect against oxygen permeation, such as certain plastics or metalized films.
- Moisture Barrier: Materials that provide resistance to moisture, such as coated papers or films.
- Light Barrier: Materials that block light transmission, often used to protect light-sensitive products.
- Aroma Barrier: Materials that prevent the transmission of odours or flavours.

6. Packaging Format

- Bottles and Jars: Commonly used for liquids, powders, or small solid items.
- Cans: Used for beverages, food, or aerosol products.

- Bags and Pouches: Flexible packaging formats often used for snacks, confectionery, or powders.
- Cartons and Boxes: Rigid containers, typically made of paperboard, used for various products.
- Blister Packs: Transparent plastic packaging used to display and protect individual items.

Advanced Packaging Techniques

1. **Reduced Oxygen Packaging**

   a. Vacuum packaging: It involves removal of air from a food package before it is sealed, creating a vacuum environment. This process offers numerous benefits, such as preventing oxidation or spoilage and extending the shelf life of perishable food.

   b. Modified Atmosphere Packaging (MAP): Involves altering the composition of the atmosphere inside the package to extend shelf life. Example: Replacing oxygen with a mixture of gases like nitrogen and carbon dioxide.

   c. Controlled Atmosphere Packaging (CAP): It is a technique used in the food industry to extend the shelf life of perishable products by modifying the atmosphere surrounding the food within the packaging. The goal of CAP is to create an optimal gas composition that helps maintain product quality, inhibit microbial growth, and slow down deterioration processes. Unlike in MAP, the gas composition is adjusted and monitored throughout the storage period in CAP to ensure it remains within the desired range for optimal product preservation. The packaging materials used for CAP should have appropriate barrier properties to maintain the desired gas composition and prevent gas exchange with the external environment.

   d. Cook-chill & Sous-vide packaging: Cook-chill is a technique where food is cooked, rapidly chilled, and then packaged in airtight containers. This process helps to extend the shelf life of prepared meals while maintaining their taste and quality. The chilled meals can be reheated later, making it convenient for busy individuals or establishments that require quick service. On the other hand, sous-vide packaging involves vacuum-sealing food in a bag and cooking it in a precisely controlled water bath. This method allows for precise temperature regulation, resulting in even cooking and enhanced flavours. By sealing the food in airtight pouches, the natural juices and aromas are retained, resulting in tender and succulent dishes.
2. **Active Packaging**: Incorporates active substances to interact with the food and extend its shelf life. Examples include oxygen scavengers, moisture absorbers and antimicrobial agents.
3. **Intelligent Packaging**: Uses sensors and indicators to monitor the condition of the product during storage and transportation. Example: Time-temperature indicators to detect temperature abuse.
4. **Aseptic Packaging**: Aseptic packaging involves sterilizing both the food and the packaging separately and then filling the sterile food into the sterile containers. This technique ensures the elimination of harmful microorganisms while maintaining the food's nutritional value.

Quality Evaluation and Testing of Packaging Materials

Physical Tests

- Mechanical Strength Testing: This assesses the physical strength and durability of packaging materials through tests like tensile strength, puncture resistance, and tear resistance.
- Flexibility and Rigidity Testing: It examines the flexibility or rigidity of materials to determine their suitability for specific packaging applications.
- Barrier Performance Testing: This evaluates the ability of packaging materials to resist the transfer of gases, moisture, light, and odour.
- Seal Integrity Testing: It verifies the quality and effectiveness of seals to ensure they are properly formed and capable of maintaining product freshness and preventing leakage.
- Compatibility Testing: It examines the interaction between packaging materials and the packaged product to avoid chemical reactions or alterations in quality.

Chemical Tests

- Migration Testing: This analyses the potential migration of substances from packaging materials into the food, ensuring compliance with safety regulations.
- Chemical Resistance Testing: It determines the resistance of packaging materials to various chemicals, preventing contamination or degradation of the packaged product.
- Volatile Organic Compound (VOC) Testing: This identifies and quantifies the release of volatile organic compounds from packaging materials, ensuring compliance with environmental and health regulations.

Microbiological Tests

- Microbial Growth Testing: It assesses the ability of packaging materials to resist microbial growth, preventing contamination and extending the product's shelf life.
- Sterility Testing: This ensures that packaging materials intended for sterile products are free from microbial contamination.

Regulatory Requirements

Food packaging is subject to various regulations and standards to ensure its safety and compliance. These regulations vary across different regions and cover aspects such as labelling, material composition, and hygiene practices.

Conclusion

Food packaging technology plays a vital role in preserving the quality and safety of food products. It encompasses various techniques and materials that ensure the integrity of the food throughout its journey from production to consumption. From primary to tertiary packaging, each step is carefully designed to protect against physical, chemical, and biological hazards. With the emergence of sustainable solutions and innovative packaging techniques, the future of food packaging looks promising, catering to both consumer needs and environmental concerns.

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Importance of fish as food

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Introduction

Food has played significant role in shaping the humanity. Even today, food is central point of politics around the world. Food is the basic necessity of human life. It is not only human, but all the other forms of life also require food to fuel the life process and to sustain. Many of the sustainable development goals proposed by UN (17 SDGs), indirectly goes around the food. Particularly, SDG-2 Zero Hunger has been proposed to end hunger and ensure access to food by all people, in particular the poor and people in vulnerable situations, including infants, to safe, nutritious and sufficient food all year round. Healthy food is the basic need to end all forms of malnutrition. Currently, the global food production system has been affected by climate change, geopolitical issues and developments in other commodity markets. The prevailing situation threatens the world food security and imbalance the demand-supply and prices (FAO, 2023). Cereals, wheat, coarse grains, rice, oils and fats, meat and meat products, milk and milk products, and fish and fishery products are being traded across the continents to meet the global food demand. Average per capita consumption of afore-mentioned foods is given in Table-1.

Table-1: Total production and average consumption of major food items

S.No	Food item	Total Production* (Million tonnes)	Food uses (million tonnes)	Average per capita consumption (kg/year)
1.	Cereals	2813.10	1193.2	148.30
2.	Wheat	776.70	535.0	67.00
3.	Coarse grains	1513	229.5	28.50
4.	Rice	523.5	424.8	52.80
5.	Oils and fats	638.4	-	-
6.	Meat and Meat Products	363.9	-	45.00
7.	Milk and milk products	944	-	117.40
8.	Fish and Fishery Products	185.5	166.1	20.60

*Forecast for the year 2023. Source: Food outlook, FAO-2023 (June)

Food is a basic necessity of the life

Foods are the substances consumed by the organisms to meet the supply of nutrients which are very much essential for the growth, repairing and maintaining body tissues and for the regulation of vital life processes. Food provides energy required for carrying out various day to day activities. The basic functions food is given below.

1. To provide energy for various activities of the body
2. For growth and development of the body
3. To protect the body from various diseases
4. To keep the body fit and healthy

5. For repairing the injured tissues

Food provides energy

The energy (expressed in calories) requirement varies with factors like age, sex, weight, and activities. For children, energy requirement is 1500-2600 calories/day whereas for adults it is 1800-3000 calories.

Sources of food

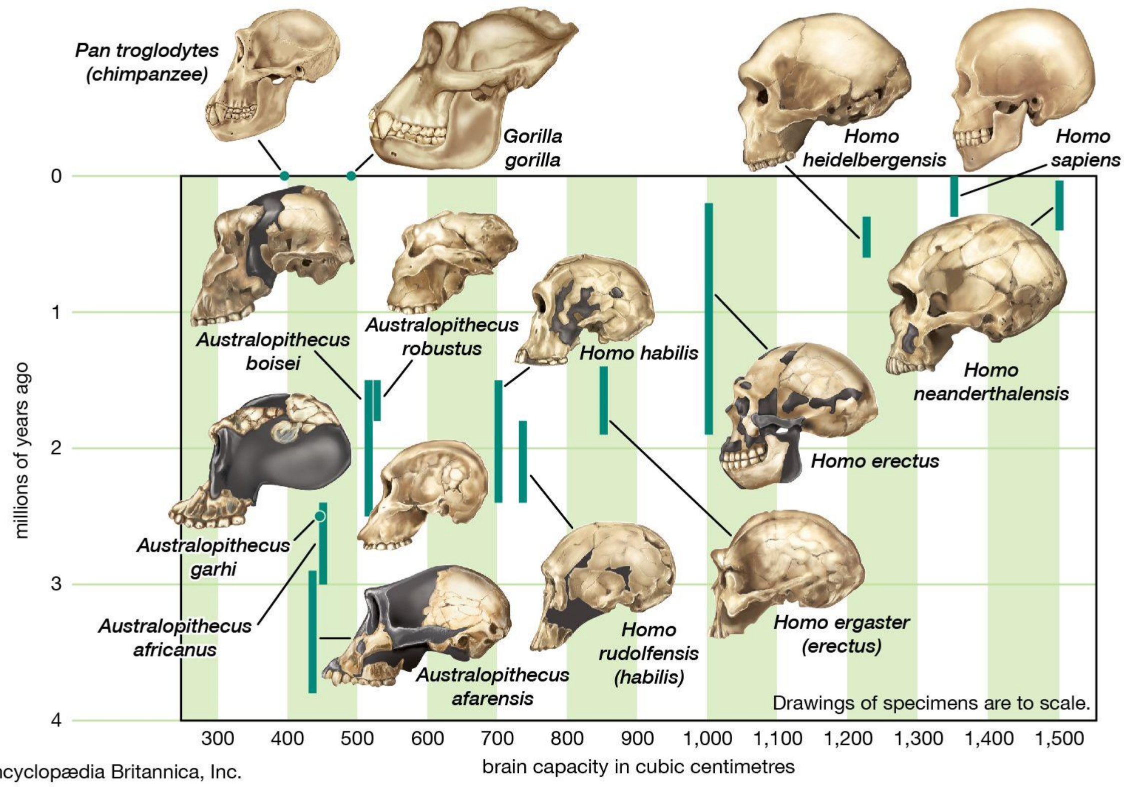
Foods are sourced mainly from plants and animals. Algae, insects, and fungus are also used as food. Currently, lab grown meat and fish have received a considerable attention due to the need to meet the demand of growing population. There is a continuous search for novel sources of food and regulatory guidelines are emerging all over the world to approve the novel sources as safe food.

Food components

Food is made up of different chemical substances called nutrients. Nutrients are needed by our body for energy, proper growth and healthy body functions. Major food components are Water, carbohydrate, protein, lipids, fibre, vitamins and minerals.

Fish as food

The archeological evidence has shown that the hominins have consumed aquatic animals like crocodile, turtles and fish. Fish in the early human diet provided the nutrients needed in brain development. The report by Braun et al. (2010) indicated that fish has been the part of human food since 1.95 million years ago. There are growing number of evidences which support that fish has played a significant role in the evolution of human brain. Fish is considered to be brainy food.



Courtesy: Image from Encyclopedia Brittanica, inc

The fisheries and aquaculture sector is crucial for improving food security and human nutrition. The quantity of fish consumed and demand is increasing continuously. Aquaculture is considered as the world's fastest growing food production industry. Aquaculture has provided more fish for human consumption than capture fisheries, and by 2030 it is estimated that 60 % of the fish consumed by human will be from aquaculture. Increasingly intensive aquaculture production methods, with greater use of crop-based feedstuffs and lower fishmeal and fish oil inclusion rates, are likely to influence the nutrient content of farmed aquatic products. A focus on the nutrient content of farmed aquatic foods is especially important where they have a key role in food-based approaches to food security and nutrition. The awareness about the fish as a part of healthy diet is well accepted by the majority of the population. In addition to providing essential nutrients at affordable price, fish also contributes to the food and nutritional security of poor households in developing countries. Fish can be considered as a treasure store of nutrients. It provides more than 20 % of the average per capita animal protein intake for 3 billion people, and more than 50 % in some less developed countries. Fish and fish products are excellent sources of high-quality protein; bioavailability of protein from fish is approximately 5-15 % higher than that from plant sources. Fish contains all the amino acids essential for human health.

Many fish (especially fatty fish) are a source of long-chain omega-3 fatty acids, which contribute to visual and cognitive human development, especially during the first 1 000 days of a child's life. The fat content and fatty acid profiles of farm raised fishes affected by the feed used in culture practice. Though the fish consumption has increased, people are obtaining smaller amounts of omega-3 fatty acids from aquatic foods, because these fats are more prevalent in marine fishes than in freshwater fish. Fish also provides essential minerals such as calcium, phosphorus, zinc, iron, selenium and iodine as well as vitamins A, D and B, thus helping to reduce the risks of both malnutrition and noncommunicable diseases which may co-occur when high energy intake is combined with a lack of balanced nutrition. Nutritional content is especially high in small fish species consumed whole and in fish parts that are not usually consumed (such as heads, bones and skin) which are having lower economic value. It is desirable to increase the production and consumption of small fish and to find ways of transforming the non-consumed parts into nutritionally rich products.

There remains considerable scope to increase the amount of fish – or nutrients derived from fish – for human consumption by reducing post-harvest losses, especially from capture fisheries; by more efficient use of fishmeal and fish oil and in animal (especially aquaculture) feeds; and by improved feed formulations for farmed fish and crustaceans. The fish industry often only extracts fillets for human consumption consigning nutritious co-products to be used for animal feeds instead of exploring their use in tackling micronutrient deficiencies. Fish processing co-products, such as fish carcasses, which are increasingly used to produce fishmeal and fish oil, represent an underutilized source of nutrients and micronutrients for human consumption. The fishmeal and fish oil content of aquaculture feeds can be reduced without compromising the nutrient content of farmed aquatic products. Improvements in feed formulations and in feed manufacture, combined with better on-farm feed management, can hugely reduce the quantities of feed (and thus fishmeal and fish oil) used per kilogram of farmed aquatic food produced.

The FAO/INFOODS Global Food Composition Database for Fish and Shellfish (uFiSH) includes a complete nutrient profile (minerals, vitamins, amino acids and fatty acids) for 78 species in raw, cooked and processed forms. The data were extracted from 2 630 food records from 250 data sources and compiled following international FAO/INFOODS (International Network of Food Data Systems) standards. Such information is much usefull to have better understanding the nutritional value of fish.

Nutritional Value of Fish and Shellfish

Fish Proteins

Fish and shellfish are excellent sources of protein. A 100 g cooked serving of most types of fish and shellfish provides approximately 18–20 g of protein, or about a third of the average daily recommended protein intake. The recommended dietary allowance (RDA) of protein for human male and female adults is in the range of 45–65 g day. In accordance with this, an intake of 100 g of fish would contribute 15–25% of the total daily protein require-ment of healthy adults and 70% of that of children. The fish protein is of high quality, containing an abundance of essential amino acids, and is very digestible by people of all ages. Both finfish and shellfish are highly valuable sources of pro-teins in human nutrition, supplying approximately 7.9% of the world's protein requirements and 15.3% of the total animal protein.

The protein content of fish flesh, in contrast to the fat content, is highly constant, independent of seasonal variations caused by the feeding and reproductive cycles, and shows only small differences among species. The approximate protein contents of the various finfish and shellfish groups are given in the following table.

Fish group	**Percentage**
White finfish	16–19
Fatty finfish	18–21
Crustaceans	18–22
Bivalves	10–12
Cephalopods	16–18

Fatty finfish and crustaceans have slightly higher than average protein concentrations. Bivalves have the lowest values if the whole body mass is considered (most of them are usually eaten whole), whereas values are roughly average if specific muscular parts alone are consumed; this is the case with the scallop, in which only the adductor muscle is usually eaten. Fish proteins, with only slight differences among groups, possess a high nutritive value, similar to that of meat proteins and slightly lower than that of egg. It is worth pointing out the elevated supply, relative to meat, of essential amino acids such as lysine, methionine, and threonine. In addition, owing in part to the low collagen content, fish proteins are easily digestible, giving rise to a digestibility co-efficient of nearly 100.

Essential amino acids in fish and shellfish (g/100g)

Fish group	Isoleucine	Leucine	Lysine	Methionine	Phenylalanine	Threonine	Tryptophan	Valine
Finfish	5.3	8.5	9.8	2.9	4.2	4.8	1.1	5.8
Crustaceans	4.6	8.6	7.8	2.9	4.0	4.6	1.1	4.8
Molluscs	4.8	7.7	8.0	2.7	4.2	4.6	1.3	6.2

Fish lipids

In fish, depot fat is liquid at room temperature (oil) and is seldom visible to the consumer; an exception is the belly flaps of certain fishes mainly farm arose. Many species of finfish and almost all shellfish contain less than 2.5% total fat, and less than 20% of the total calories come from fat. Almost all fish has less than 10% total fat, and even the fattiest fish, such as herring, mackerel, and salmon, contains no more than 20% fat. In order to obtain a good general idea of the fat contents of most finfish species, flesh color might be considered. The leanest species, such as cod and flounder, have a white or lighter color, whereas fattier fishes, such as salmon, herring, and mackerel, have a much darker color.

The triacylglycerol depot fat in edible fish muscle is subject to seasonal variation in all marine and freshwater fishes from all over the world. Fat levels tend to be higher during times of the year when fishes are feeding heavily (usually during the warmer months) and in older and healthier individual fishes. Fat levels tend to be lower during spawning or reproduction. When comparing fat contents between farmed and wild-caught food fish, it should be remembered that farmed species have a tendency to show a higher proportion of muscle fat than their wild counterparts. Also, the fattyacid composition of farmed fish depends on the type of dietary fat used in raising the fish.

Cholesterol in Fish

Cholesterol is independent of fat content and is similar in wild and cultivated fishes. The fish and shellfish contain well under 100 mg of cholesterol per 100 g, and many of the leaner types of fish typically have 40–60 mg of cholesterol in each 100 g of edible muscle. It is known that most shellfish also contain less than 100 mg of cholesterol per 100 g. Shrimp contain somewhat higher amounts of cholesterol, over 150 mg per 100 g, and squid is the only fish product with a significantly elevated cholesterol content, which averages 300 mg per 100 g portion. Fish roe, caviar, internal organs of fishes (such as livers), the tomalley of lobsters, and the hepatopancreas of crabs can contain high amounts of cholesterol.

A note on Omega-3 PUFA in Fish and Shellfish

The PUFA of many fish lipids are dominated by two members of the omega-3 (n-3) family, C20:5 n-3 (EPA), and C22:6 n-3 (DHA). They are so named because the first of several double bonds occurs three carbon atoms away from the terminal end of the carbon chain. All fish and shellfish contain some omega-3, but the amount can vary, as their relative concentrations are species specific. Generally, the fattier fishes contain more omega-3 fatty acids than the leaner fishes. The amount of omega-3 fatty acids in farm-raised products can also vary greatly, depending on the diet of the fishes or shellfish. Many companies now recognize this fact and provide a source of omega-3 fatty acids in their fish diets. Omega-3 fatty acids can be destroyed by heat, air, and light, so the less processing, heat, air exposure, and storage time the better for preserving omega-3 in fish. Freezing and normal cooking cause minimal omega-3 losses, whereas deep frying and conditions leading to oxidation (rancidity) can destroy some omega-3 fatty acids.

Vitamins in Fish

The vitamin content of fish and shellfish is rich and varied in composition, although somewhat variable in concentration. In fact, significant differences are neatly evident among groups, especially regarding fat-soluble vitamins. Furthermore, vitamin content shows large differences among species as a function of feeding regimes. Of the fat-soluble vitamins, vitamin E (tocopherol) is distributed most equally, showing relatively high concentrations in all fish groups, higher than those of meat. However, only a part of the vitamin E content is available as active tocopherol on consumption of fish, because it is oxidized in protecting fatty acids from oxidation. The presence of vitamins A (retinol) and D is closely related to the fat content, and so they are almost absent in most low-fat groups. Appreciable but low concentrations of vitamin A are found in fatty finfish and bivalve molluscs, whereas vitamin D is very abundant in fatty fish.

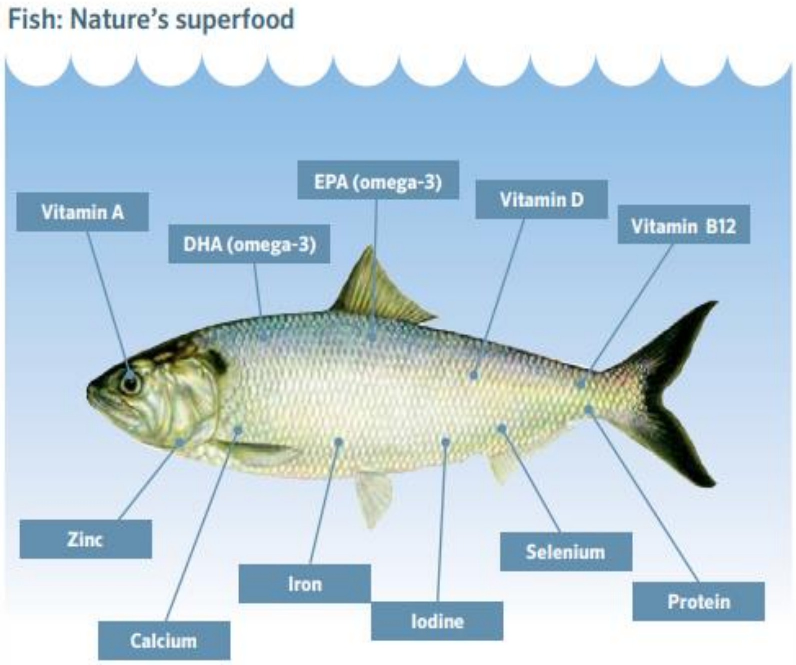
Water-soluble vitamins are well represented in all kinds of fish, with the sole exception of vitamin C (ascorbic acid), which is almost absent in all of them. The concentrations of the rest are highly variable; however, with few exceptions, they constitute a medium-to-good source of such vitamins, com-parable with, or even better than, meat. The contents of vita-mins B_2 (riboflavin), B_6 (pyridoxine), niacin, biotin, and B_{12} (cobalamin) are relatively high. Indeed, 100 g of fish can contribute up to 38, 60, 50, 33, and 100%, respectively, of the total daily requirements of those vitamins. Fatty fish also provides a higher supply of many of the water-soluble vitamins (namely pyridoxine, niacin, pantothenic acid, and cobalamin) than does white fish or shellfish. Crustaceans also possess a relatively higher content of pantothenic acid, whereas bivalve molluscs have much higher concentrations of folate and cobalamine.

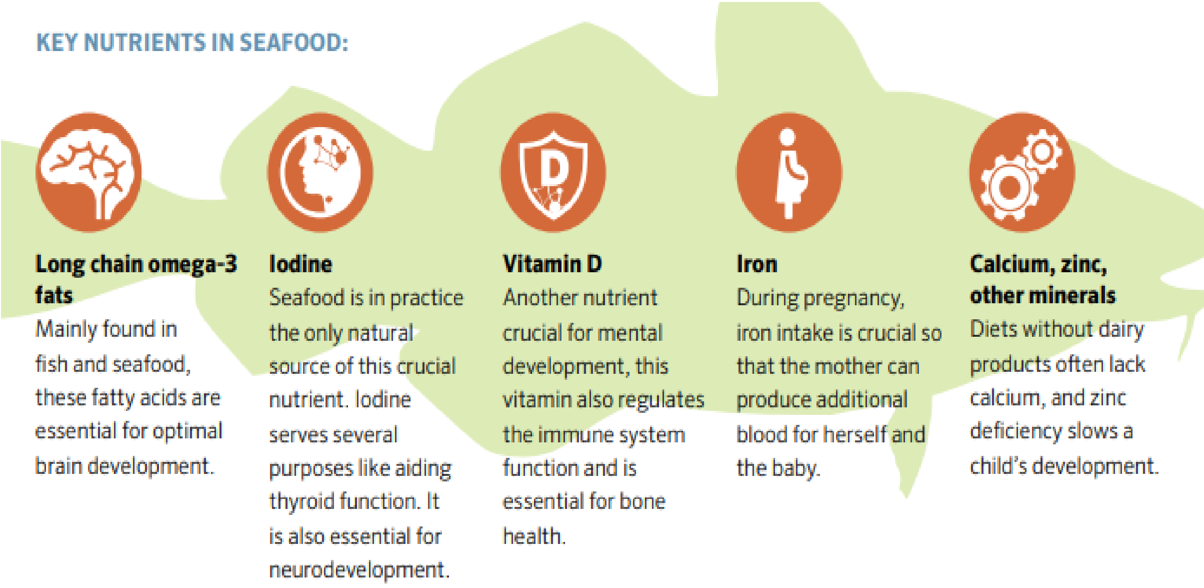
Fish Minerals

Seafood is also loaded with minerals such as phosphorus, magnesium, iron, zinc, and iodine in marine fish. The first point to note is that all kinds of finfish and shellfish present a well-balanced content of most minerals, either macrominerals or trace elements, with only a few exceptions. Sodium content is low, as in other muscle and animal origin foods. However, it must be remembered that sodium is usually added to fish in most cooking practices in the form of common salt; also, surimi-based and other manufactured foods contain high amounts of added sodium.

Calorific value

The caloric value of fish is related to the fat and protein content. The fat varies with species, size, diet, and season. Seafood is generally lower in fat and calories than beef, poultry, or pork. Most lean or low-fat species of fish, such as cod, hake, flounder, and sole, contain less than 100 kcal (418 kJ) per 100 g portion, and even fatty fish, like mackerel contain approximately 250 kcal (1045 kJ) or less in a 100 g serving.





Source: FAO - Fish and human nutrition

Vitamin content of the different groups of fish and shellfish (mg or mg per 100 g), and relation to DRIs

	A (mg)	D (mg)	E (mg)	B1 (mg)	B2 (mg)	B6 (mg)	Niacin (mg)	Biotin (mg)	Pantothenic acid (mg)	Folate (mg)	B12 (mg)	C (mg)
White finfish	Trace	Trace	0.3–1.0	0.02–0.2	0.05–0.5	0.15–0.5	1.0–5.0	1.0–10	0.1–0.5	5.0–15	1.0–5.0	Trace
Fatty finfish	20–60	5–20	0.2–3.0	0.01–0.1	0.1–0.5	0.2–0.8	3.0–8.0	1.0–10	0.4–1.0	5.0–15	5.0–20	Trace
Crustaceans	Trace	Trace	0.5–2.0	0.01–0.1	0.02–0.3	0.1–0.3	0.5–3.0	1.0–10	0.5–1.0	1.0–10	1.0–10	Trace
Molluscs	10–100	Trace	0.5–1.0	0.03–0.1	0.05–0.3	0.05–0.2	0.2–2.0	1.0–10	0.1–0.5	20–50	2.0–30	Trace
Cephalopods	Trace	Trace	0.2–1.0	0.02–0.1	0.05–0.5	0.3–0.1	1.0–5.0	1.0–10	0.5–1.0	10–20	1.0–5.0	Trace
RDA	700/900	5	15	1.1/1.2	1.1/1.3	1.3	14/16	30	5.0	400	2.4	75/90
% RDA per 100 g	0–11	0–100	2–20	1–20	2–38	5–60	1–50	3–33	2–20	0.3–12	40–100	0
% RDAMd	2	50	7	5	15	25	18	5	8	2	100	0

Selected mineral content of the different groups of fish and shellfish (mg per 100 g), and relation to DRIs

	Na	K	Ca	Mg	P	Fe	Zn	Mn	Cu	Se	Cr	Mo	I
White finfish	50–150	200–500	10–50	15–30	100–300	0.2–0.6	0.2–1.0	0.01–0.05	0.01–0.05	0.02–0.1	0.005–0.02	0.005–0.02	0.01–0.5
Fatty finfish	50–200	200–500	10–200	20–50	200–500	1.0–5.0	0.2–1.0	0.01–0.05	0.01–0.05	0.02–0.1	0.005–0.02	0.005–0.02	0.01–0.5
Crustaceans	100–500	100–500	20–200	20–200	100–700	0.2–2.0	1.0–5.0	0.02–0.2	0.1–2.0	0.05–0.1	0.005–0.02	0.01–0.05	0.01–0.2
Molluscs	50–300	100–500	50–200	20–200	100–300	0.5–10	2.0–10	0.02–0.2	0.02–10	0.05–0.1	0.005–0.02	0.01–0.2	0.05—0.5
Cephalopods	100–200	200–300	10–100	20–100	100–300	0.2–1.0	1.0—5.0	0.01–0.1	0.02–0.1	0.02–0.1	0.005–0.02	0.01–0.2	0.01–0.1
RDA	1500	4700	1000	320/420	700	18/8	8/11	1.8/2.3	0.9	0.025/0.055	0.035	0.045	0.15
% RDA per 100 g	3–33	2–10	1–20	4–50	15–100	2–50	1–90	0–10	1–100	25–100	15–60	10–100	8-100
% RDA/Md			6	5	30	18	2		2	100			100

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Advanced food packaging techniques

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Introduction

Packaging contributes to the conservation of natural resources by preventing waste and product deterioration and by shielding goods until they have served their purpose. Good marketing properties, a fair pricing, technical viability, utility for food contact, low environmental stress, and recycling adaptability are the fundamental requirements for a package. In case of fish, depending on the kind of fish, simply packaging fish will extend the shelf life of chilled and refrigerated fish to 7 to 15 days. The presence of O_2 in standard air packing, however, will cause the spoiling process to proceed more quickly in regular packaging. Advanced food packaging techniques refer to innovative methods and technologies used to package and preserve food products. These techniques go beyond traditional packaging approaches and aim to enhance food safety, extend shelf life, improve convenience, and reduce environmental impact. By using vacuum packaging or packaging with a changed atmosphere, it is possible to overcome the issue of shelf life. In reduced oxygen packaging, the oxygen levels inside the package are significantly reduced, typically by displacing oxygen with other gases or by creating a vacuum. The reduced oxygen environment can be achieved through various methods, including modified atmosphere packaging (MAP) and vacuum packaging.

Vacuum packaging:

Vacuum packaging involves the removal of air from the package and the application of a hermetic seal. The air removal creates a vacuum inside the packs and lack of O_2 in packages may minimise the oxidative deteriorative reactions and aerobic bacterial growth. Vacuum packaging can considerably extend the viable shelf life of many cooked foods. The use of vacuum packaging, in gas impermeable and heat stable materials, has many advantages, which include; no or low risks of post pasteurisation contamination, ease of handling, Inhibition of growth of aerobic spoilage organisms and inhibition or slowing of deleterious oxidative reactions in the food during storage due to oxygen barrier properties of the packaging material. There are number of criteria required for the films used for vacuum packaging in large scale production methods. These requirements include: high durability, ie. ability to withstand considerable mechanical stresses during packaging, handling and transport, retention of flexibility even at low temperatures (-2 to 4°C) to enable satisfactory handling in the packaging and refrigeration rooms, ability to withstand heating to at least 150°C without structural damage, leaching of potentially toxic plastics or plasticisers, impermeability to liquids, including oils and fats and macromolecules, impermeability to gases, in particular oxygen, so that oxidative deterioration of the packaged food stuffs is limited or inhibited, manufactured from non-toxic, food acceptable, odourless materials and must be able to create airtight durable heat seals to close packs. Many of these criteria have been met by a range of materials mostly multilaminated plastics. Vacuum packed foods maintain their freshness and flavor 3-5 times longer than with conventional storage methods, because they don't come in contact with oxygen. Foods maintain their texture and appearance, because microorganisms such as bacteria mold and yeast cannot grow in a vacuum. Freezer burn is eliminated, because foods no longer become dehydrated from contact with cold, dry air. Moist foods won't dry out, because there's no air to absorb the moisture from the food. Dry, solid foods, won't become hard, because they don't come in contact with air and, therefore, can't absorb moisture from the air. Foods that are high in fats and oils won't become rancid, because there's no oxygen coming in contact with the fats, which causes the rancid taste and smell.

Fig. 1. Vacuum packaging machine and Vacuum-packed fish

Modified Atmospheric packaging

Fresh fish is highly susceptible to spoilage from post mortem autolysis and microbial growth. The high ambient temperature of our country favours rapid growth of microorganisms. Presently ice and mechanical refrigeration are the most common means of retarding microbial and biochemical spoilage in freshly caught seafood during distribution and marketing. However, as ice melts it tends to contaminate fish accelerating spoilage and reduces shelf life. Modified atmosphere packaging, a technologically viable method has been developed as a supplement to ice or mechanical refrigeration to reduce the losses and extend the storage life of fresh seafood products. In modified atmosphere packaging air is replaced with different gas mixtures to regulate microbial activity and /or retard discolouration of the products. The proportion of each component gas is fixed when the mixture is introduced into the package; however, no control is exercised during storage. The composition of the gas mixture changes from its initial composition as a result of chemical, enzymatic and microbial activity of the product during storage. It is primarily the enrichment of Carbon dioxide in the storage atmosphere as a means of controlling microbial growth, which results in the extension of shelf life of products. Carbon dioxide lowers the intra and extracellular pH of tissues and possibly that of microorganisms. Further it may affect the membrane potential of microorganisms and influence on the equilibrium of decarboxylating enzymes of microorganisms. The gases normally employed are carbon dioxide, mixtures of carbon dioxide and nitrogen, carbon dioxide and oxygen and carbon dioxide, oxygen & nitrogen with the sole objective to extend the shelf life of the product beyond that obtained in conventional refrigerated storages. Inhibition by Carbon dioxide manifests in an increased lag phase and a slower rate of growth of microorganisms during logorathmic phase. Inhibition by Carbon dioxide was found to be more effective when the product was stored at the lowest range of refrigerated temperatures.

Packaging materials generally employed for this purpose are flexible films of nylon/surylyn laminates, PVC moulded trays laminated with polythene, polyester/low density polythene film etc. The use of high barrier film along with MAP that contains CO_2 effectively inhibits bacterial growth during refrigerated storage of packaged fresh fishery products.

The composition of the gas mixtures used for MAP of fresh fish varies, depending upon whether the fish in the package is lean or oily fish. For lean fish, a ratio of 30 % Oxygen, 40 % Carbon dioxide, 30 % Nitrogen is recommended. Higher values of Carbon dioxide are used for fatty and oily fish with a comparable reduction in level of Oxygen in the mixture leading to 40-60 % Nitrogen. By excluding oxygen, the development of oxidative rancidity in fatty fish is slowed. On the other hand, oxygen can inhibit the growth of strictly anaerobic bacteria like *Clostridium botulinum* although there is a very wide variation in the sensitivity of anaerobes to Oxygen. It is also seen that inclusion of only some Oxygen with Nitrogen or Carbon dioxide will not prevent botulism with absolute certainty.


Fig. 2. Modified Atmosphere packaging equipment and Gas composition analyser

Controlled Atmosphere Packaging (CAP): It is a method of packaging food products in a modified atmosphere to extend their shelf life and maintain their quality. In CAP, the composition of gases within the package is carefully controlled to create an optimal environment for the specific food product.

The main objectives of CAP are to control the levels of oxygen, carbon dioxide, and sometimes nitrogen within the package. These gases are selected based on the specific needs of the food product and its susceptibility to spoilage factors.

The benefits of CAP include:

1. Extended Shelf Life: By controlling the atmosphere within the package, CAP can slow down the growth of spoilage microorganisms and enzymatic reactions that cause food deterioration, thereby extending the product's shelf life.
2. Maintained Quality: CAP helps preserve the sensory attributes, colour, texture, and nutritional content of the food by creating an environment that minimizes oxidative reactions and maintains optimal conditions for the product.
3. Reduced Need for Preservatives: With controlled gas composition, CAP can reduce the reliance on chemical preservatives, allowing for a more natural and cleaner label approach to food preservation.

The specific gas composition and ratios used in CAP depend on the type of food product being packaged. For example, some fruits and vegetables benefit from a lower oxygen level and higher carbon dioxide level to slow down ripening and preserve freshness, while certain meats may require a higher oxygen level to maintain the desired colour. It's important to note that CAP requires specialized packaging materials, such as barrier films or trays with gas-permeable properties, to maintain the desired gas composition and prevent gas leakage. Proper sealing and storage conditions are also critical to ensure the effectiveness of CAP. The selection and implementation of CAP should be based on scientific research, industry guidelines, and regulatory requirements to ensure food safety and maintain product quality throughout the supply chain.

Cook Chill Packaging: Cook chill is a food preservation method that involves cooking food to the desired temperature, rapidly cooling it, and then packaging it for later use. The process helps maintain the food's quality, flavour, and safety while extending its shelf life.

Cook chill packaging typically involves the following steps:

- Cooking: The food is cooked thoroughly to the appropriate temperature to ensure it is safe to consume.
- Rapid Cooling: After cooking, the food is rapidly chilled using specialized equipment, such as blast chillers or cold-water baths. Rapid cooling inhibits bacterial growth and prevents the food from spending too much time in the temperature danger zone where bacteria can multiply quickly.
- Packaging: Once the food has been cooled, it is portioned and packaged in airtight containers, such as vacuum-sealed bags or sealed trays. The packaging helps maintain the food's freshness and prevents contamination.
- Storage: The packaged food is then refrigerated or frozen until it is ready to be consumed. The controlled temperature storage further extends the shelf life of the cooked food.

Sous Vide Packaging: Sous vide is a cooking technique that involves vacuum-sealing food in a bag and cooking it at a precisely controlled low temperature in a water bath. This method ensures consistent and evenly cooked food with enhanced flavours and textures.

Sous vide packaging typically includes the following steps:

- Vacuum Sealing: The food, along with any desired seasonings or marinades, is placed in a vacuum-sealed bag. The bag is sealed tightly to remove any air and create an airtight environment for cooking.
- Temperature Control: The sealed bags of food are submerged in a precisely heated water bath, which is set to a specific temperature based on the desired doneness of the food. The water bath is typically maintained at a lower temperature than traditional cooking methods.
- Cooking Time: The food is cooked in the water bath for an extended period, allowing it to slowly reach the desired internal temperature while retaining its moisture and flavour.
- Finishing: After the sous vide cooking process, some foods may be finished with additional steps such as searing, grilling, or browning to add texture and colour.

Other advanced packaging techniques

Active Packaging: Active packaging incorporates active substances or systems that interact with the food to improve its quality and safety. For instance, oxygen scavengers can remove oxygen from the package, preventing oxidative reactions and maintaining food freshness. Similarly, moisture absorbers and antimicrobial agents can help inhibit microbial growth.

Intelligent Packaging: This type of packaging employs sensors, indicators, or smart labels to monitor and provide information about the condition of the food. For example, time-temperature indicators can change colour or display information to indicate if the product has been exposed to unfavourable temperatures during storage or transportation.

Edible Packaging: Edible packaging materials are designed to be consumed along with the food, reducing waste and enhancing convenience. These materials can be made from edible films or coatings derived from natural sources such as seaweed or starch. Edible packaging is particularly beneficial for single-serving products or items that require individual portioning.

Anti-counterfeiting Packaging: To combat food fraud and ensure product authenticity, advanced packaging techniques may incorporate features like tamper-evident seals, holograms, or QR codes for verification.

Nanotechnology in Packaging: Nanotechnology involves manipulating matter at the nanoscale to create novel materials and structures. Nanoparticles and nanocomposites can be incorporated into food packaging to provide improved barrier properties, antimicrobial effects, and enhanced mechanical strength.

Sustainable Packaging: As environmental concerns grow, sustainable packaging techniques are gaining popularity. This includes using eco-friendly materials, optimizing package sizes to minimize waste, and exploring biodegradable or compostable packaging options.

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Non-thermal food preservation techniques

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Non-thermal preservation of food

Conventional thermal processing results in some undesirable changes in food, such as loss of nutritional components that are temperature-sensitive, change in the texture of food due to heat, and changes in the organoleptic characteristics of food. Non-thermal food processing simply refers to methods where the food materials receive microbiological inactivation without the direct application of heat. They are relatively young technologies, which use mechanisms other than conventional heating to reduce or eliminate microorganisms. Hence it offers an alternative to conventional thermal processing.

1. High pressure processing

- High Pressure Processing is also known as high hydrostatic pressure (HHP) or ultra-high pressure (UHL) processing.
- It is a non-thermal, cold pasteurization technique, which generally consists of subjecting food, previously sealed in flexible and water-resistant packaging, to a high level of hydrostatic pressure (pressure transmitted by water) up to 600 MPa / 87,000 psi for a few seconds to a few minutes (1 – 20 min).
- HHP utilizes a very common medium, i.e., water, to apply the pressure on the product to be treated.
- HHP transmits isostatic pressure (100–1000 MPa) instantly to product at low temperature and might have comparable preservation effect as thermal processing through inactivating undesirable microorganisms and enzymes.
- An HPP unit consists of a pressure compartment in which food is kept and water is introduced into the chamber. Food is then pressurized using this water.

2. Pulsed electric field (PEF) processing

- PEF is an efficient non-thermal food processing technique using short, high voltage pulses.
- It is used for inactivation of spoilage and pathogenic microorganisms in various food products. Electric pulses are applied for destroying harmful bacteria in food.
- Microbial inactivation is achieved by dielectric breakdown of the bacterial membranes
- Food material is placed between electrodes. The field intensity is typically 20–80 kV cm^{-1}) and the exposure time is a few milliseconds or nanoseconds.
- It enhances the shelf life of the food without quality loss.
- The PEF mechanism is called ***electroporation***. Very short electric pulses of high voltage are applied to the food. Small pores are formed in the cell membrane of the food by the electric pulses without damaging the cell compounds, such as vitamins.
- Pulsed electric field is generally used for liquid food or semi-solid food that can flow easily.

PEF device

- A typical PEF device consists of a food treatment chamber, a control system, and a pulse generator.

- The food is kept in the treatment chamber in between two electrodes generally made of stainless steel.

3. Irradiation/Radiation processing

- Refers to the process by which an object is exposed to radiation (A deliberate exposure to radiation)
- Irradiation is a process of applying low levels of ionizing radiation to food material to sterilize or extend its shelf life.
- Radiation inactivates food spoilage organisms, including bacteria, moulds, and yeasts.
- It is effective in lengthening the shelf-life of fresh fruits and vegetables by controlling the normal biological changes associated with ripening, maturation, sprouting, and finally aging.
- Radiation also destroys disease-causing organisms, including parasitic worms and insect pests, that damage food in storage.
- Irradiation is harmful or noxious to humans. However, the dose for food pre-treatment is low, therefore making it safe for consumption. Food irradiated under approved conditions does not become radioactive.

Agri-food applications of irradiation

Radicidation and Radurization: Refer to these applications of less than 10 kGy doses.

- Radurization: Application of an ionization dose sufficient to preserve the quality of food by ensuring a substantial reduction in the number of spoilage bacteria.
- Radicidation: Application to the food of a dose of ionization sufficient to reduce the specific number of viable pathogenic bacteria to a level such that they are not detectable by any known method. This term also applies to the destruction of specific parasites.

Radappertization: Application of high dose (10 to 60 kGy) of ionization to food in order to reduce the number and/or activity of living microorganisms so that none (except viruses) is detectable by any recognized method. Such radio-sanitized products can then be stored for up to 2 years at room temperature in sealed plastic packaging.

Table 1: Dose requirement in various applications of food irradiation

Dose Level	Dose	Applications
Low	<1 kGy	▪ Inhibition of sprouting of potato, onion and other tubers ▪ Insect disinfestation in stored grain, pulses and their products, dried fruits such as dates and figs ▪ Destruction of parasites in meat and meat products
Medium	1–10 kGy	▪ Shelf-life extension of fresh meat, poultry and seafood by elimination of vegetative bacteria responsible for spoilage ▪ Elimination of pathogenic organisms from meat, seafood and poultry ▪ Treatment for quarantine purposes of fruits and vegetables
High	>10 kGy	▪ Hygienization of spices, vegetable seasonings, etc. ▪ Sterilization of food for special requirements ▪ Shelf stable foods without refrigeration

4. Ultraviolet (UV) Radiation

- A very economical non-thermal technology
- Non-heat technique for decontamination for improving both the shelf-life and safety of foodstuff.
- It is basically used to reduce the microbial load on the surface of food materials that are indirectly exposed to radiation, because of its low depth of penetration.
- UV radiation is a form of energy considered to be non-ionizing radiation having in general germicidal properties at wavelengths in the range of 200–280 nm (usually termed UV-C).
- UV irradiation has demonstrated to be effective not only in reducing microbial load but also inactivating enzymes activity in plant products.

5. Pulsed Light (PL) Preservation

- Pulsed light (PL) is an alternative technique to continuous ultraviolet treatment for solid and liquid foods.
- PL consists of successive repetition of high-power pulses of light/short time high-peak pulses of broad-spectrum white light.
- Comparatively, PL has a thousand times strength greater than the normal UV light which is quite continuous.
- Pulsed xenon UV uses the full spectrum of ultraviolet light to disperse germ-killing energy.
- The light spectrum includes wavelengths from 180 to 1100 nm with a considerable amount of light in the short-wave UV spectrum.
- Similar to other non-thermal food processing technologies, PL also has potential in the inactivation or elimination of microbes in food.
- Specific examples of foods processed by PL include fish, vegetables, fruits, and meat.
- PL can be used alongside other novel technologies as a hurdle in the inactivation of microbes on the surfaces of foods.

6. Ultrasound (US) processing

- US is a compressional wave with a frequency of over 20 kHz.
- US is sound wave bearing certain frequency that is more than the normal human hearing frequency, which is more than 20 kHz.
- The frequency of US used in the food industry for microbial inactivation ranges from 20 kHz to 10 MHz.
- The bactericidal action of US is mainly due to the cavitation process, in which microbubbles are produced and collapsed within a liquid medium.
- During the cavitation process, the temperature can increase to as high as 5500 °C and the pressure can increase up to 100 MPa, resulting in localized microbial sterilization.
- The bactericidal mechanisms of ultrasound include breakage of cell walls, disruption and thinning of cell membranes and free radical activity due to the collapse of cavitation bubbles.

Method of application of ultrasound

- *Ultrasonic horn*: Horn is dipped in the liquid solution or juice and is treated with certain treatment frequency.

- *Ultrasonic bath*: Food material or packaged food is kept and the sound waves are generated in a bath that creates ultrasound effect and brings about desired changes in food.

7. Cold Plasma (CP) Technology

- Plasma: Fourth state of matter after solid, liquid, and gas.
- When the energy of gases crosses a certain value, it results in the ionization of gas molecules. Ionization of gas molecules gives rise to plasma.
- Two types

  -Thermal plasma

  -*Cold plasma* (non-thermal)
- Cold plasma is a non-thermal treatment that works in the temperature range 25–65 ^{o}C.
- Cold plasma has high antimicrobial activity and efficient enzyme inactivation capacity.
- The composition of the plasma reactive species largely depends on the composition of gas which is ionized.
- The gases commonly used for the generation of plasma include argon, helium, oxygen, nitrogen and air.

Cold plasma generation

- The gases are subjected to any of the types of energy like thermal, electrical, magnetic field, etc., to generate plasma containing positive ions, negative ions, and reactive species like ozone and singlet oxygen.
- Methods

  -Radio frequency plasma

  -Dielectric barrier discharges

  -Gliding arc discharge

  -Microwave

  -Corona discharges
- Cold plasma is an ionized gas generated through gas ionization under corona discharge, dielectric barrier discharge, microwaves or radiofrequency waves.

Advantages & Applications

- Reduction of the microbial load in food or on the surface of food. All kinds of microbes are said to be inactivated by cold plasma technology, including viruses, fungi, and bacteria.
- Enhance the physical and chemical properties of food constituents like lipids and proteins.
- Sterilization of food processing equipments.
- Inactivation of food spoilage enzymes.
- Treatment of food packaging material. Cold plasma can serve for in-package sterilization.
- Treatment of wastewater.
- Cold plasma is produced at near ambient temperature and does not depend on high temperature for microbial inactivation.
- Since the temperature used is ambient, there are no chances of thermal damage to heat-sensitive food material.

- It has continually been referred to as an eco-friendly technique since, besides having minimal changes on the food matrix, its application does not result to the generation of toxic residuals/wastes.

8. Ozone treatment

- Ozone is a colorless gas with a typical odor.
- It contains three molecules of oxygen and is chemically written as O_3. It is formed when molecular oxygen (O_2) combines with singlet O.
- Ozone is a very reactive gas, and it is very much unstable and cannot be stored and needs to be produced on the spot when needed.
- Ozone is extensively employed as an effective antibacterial against many bacteria in food. Due to its high oxidizing potential and the ability to attack cellular components, ozone has broad-spectrum of disinfection.
- Ozone treatment is a chemical method of food decontamination that involves exposing contaminated foodstuffs (fruits, vegetables, beverages, spices, herbs, meat, fish, and so on) to ozone in aqueous and/or gaseous phases.

Effect of ozone on microbes

- Ozone alters the permeability of cells by damaging the microbial cell membranes.
- Ozone is also known to damage the structure of proteins, leading to the malfunctioning of microbial enzymes, which affects the metabolic activity and finally results in microbial cell death.
- Chemical composition, pH, additives, temperature, initial bacteria population, and ozone contact time with food and food surface type are factors determining the efficiency of ozone treatment on microbial reduction in food.

Other methods

Acidic Electrolyte Water

- Electrolyte water (EW) is made from water without the addition of any hazardous chemicals except sodium chloride.
- EW is known as either a sanitizer (EW containing HOCl, an acidic electrolyte water) or a cleaner (EW containing NaOH, an alkaline electrolyte water.
- The simplicity of EW production and application is the foremost reason for its popularity.
- In numerous fields such as medical sterilization, agriculture, food sanitation and livestock management, EW is gaining attention because of its antimicrobial properties.

Dense phase carbon dioxide (DPCD)

- DPCD processing utilizes the liquefied carbon dioxide and performs at mild temperature and relatively low pressure, about one tenth of the pressures for HHP.
- It is applied to cold pasteurize and extend the shelf life of product without heating.
- Carbon dioxide is a nontoxic, non-flammable and low-cost gas; in the supercritical state, the fluid CO_2 rapidly penetrate porous materials due to its low viscosity ($3–7 \times 10^{-5}$ Pas) and surface tension. This penetration is accompanied with pH decrease, bicarbonate ion generation and cell disruption, which contribute to the microbial and enzyme inactivation.

High voltage electrical discharge (HVED) processing

- Different from PEF in electrode geometry, shape of pulses and mode of actions, HVED generally consists a needle electrode and a grounded one (normally flat geometry) or wire plane.
- Though the advantages of PEF and HVED are promising, the release of metals from the corrosion or migration of electrode materials should be concerned and investigated in the future applications.

Conclusion

The demand from consumer for safe and nutritious food products has promoted the rapid development of non-conventional processing technologies. With non-thermal treatments, consumers get high quality, healthy, and safe food products. But there are two sides of the coin: with advantages come some disadvantages as well. If food is exposed for a longer period or treated at a higher intensity, these non-thermal technologies may lead to some undesirable changes in food, such as oxidation of lipids and loss of colour and flavour. But these technologies have many advantages compared to thermal processing. After overcoming the limitations properly in a planned manner, non-thermal technologies will have a broader scope for development and commercialization in food processing industries.

Microbiological Considerations in Food Packaging: Effects of Different Atmospheres and Preservation Methods

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Introduction

In the world of food production and distribution, the significance of food packaging cannot be overstated. It serves as a vital barrier between the external environment and the food products, protecting them from various contaminants, including microbial pathogens. Microbial contamination poses a considerable threat to food safety, as it can lead to spoilage, reduced shelf life, and even foodborne illnesses. To ensure the safety and quality of food products, it is essential to understand the microbiological considerations associated with different atmospheres in food packaging and preservation methods.

Raw foods naturally contain a diverse range of microorganisms, but not all of them are capable of colonizing the food and proliferating to significant levels. Some microorganisms have the ability to dominate and grow in particular conditions, leading to the formation of a specific microbial community known as a spoilage association. The exact mechanism through which one group of bacteria outcompetes another closely related group is not always fully understood. It can depend on various factors such as the initial microbial load, the availability of nutrients, the pH level, temperature, and other environmental conditions. Additionally, the interactions between different microorganisms within the food can also play a role in determining the composition of the spoilage association. Changes in the processing and packaging of fish products, even minor ones, can have a significant impact on the development and composition of spoilage associations. Different processing techniques and packaging methods can create different environmental conditions that favour the growth of specific microorganisms. As a result, the type of spoilage that occurs in fish products can vary drastically based on these factors. Furthermore, spoilage development can vary even for the same type of product, depending on factors such as geographical origin and other unknown variables. Microbial populations can be influenced by regional variations in environmental conditions, the presence of specific microorganisms in the surrounding environment, and local processing and handling practices. These factors can interact with the microbial development and contribute to the differences observed in spoilage patterns.

1. Packaging Methods

1.1. Reduced Oxygen Packaging

The reduction of oxygen levels within a package effectively inhibits the growth of aerobic spoilage bacteria, as these bacteria require oxygen for respiration. This technique is commonly employed in vacuum-sealed packages to preserve the quality of the contents. However, it is important to note that lowering oxygen levels may create an anaerobic environment, which is conducive to the growth of anaerobic bacteria, including *Clostridium botulinum*. This particular bacterium is a spore-forming pathogen that produces the highly potent botulinum toxin. Examples of ROP techniques are vacuum packaging, modified atmosphere packaging, controlled atmosphere packaging and sous-vide packaging.

1.1.1. **Modified Atmosphere Packaging** (MAP)/ Use of Gas Mixtures

Modified Atmosphere Packaging (MAP) involves altering the composition of gases surrounding the food product within a sealed package to extend its shelf life. The key gases used in MAP are carbon dioxide (CO_2), nitrogen (N_2), and oxygen (O_2). The effects of different gases on microbial growth include:

a. *Carbon Dioxide* (CO_2): CO_2 acts as a natural inhibitor of spoilage and pathogenic microorganisms. By creating an unfavourable environment, it impedes the growth of these microorganisms. One of the ways CO_2 achieves this is by lowering the pH and making it difficult for microbes to thrive. This preservation method is commonly used in the food industry to extend the shelf life of various perishable products. The presence of CO_2 helps to maintain the visual appeal of fresh produce. Fruits and vegetables tend to undergo enzymatic browning due to the activity of polyphenol oxidase enzymes. CO_2 slows down this enzymatic reaction, preserving the natural colour of the product for a longer period. Similarly, CO_2 helps to retain the desired texture, preventing softening and wilting of fruits and vegetables. CO_2 possesses inherent antimicrobial properties, which contribute to its effectiveness in food preservation. It exhibits bacteriostatic and fungistatic effects and it thus inhibits the growth and reproduction of bacteria and fungi without completely eliminating them. This property is particularly beneficial in inhibiting the growth of spoilage microorganisms and extending the freshness of perishable foods. While CO_2 has a broad-spectrum antimicrobial effect, it is essential to note that some microorganisms exhibit resistance to its inhibitory effects. Certain yeasts and molds, for instance, have developed mechanisms to tolerate high levels of CO_2. These microorganisms can still proliferate even in the presence of elevated CO_2 concentrations. Therefore, alternative preservation methods may be necessary to control their growth effectively.

b. *Nitrogen* (N_2): Nitrogen, a widely utilized inert gas, plays a crucial role in the process of MAP. Its primary function is to displace oxygen, creating an environment devoid of oxygen that inhibits the growth of spoilage organisms that thrive in aerobic conditions. While nitrogen effectively prevents the proliferation of aerobic spoilage organisms, it does not directly impact the growth of anaerobic bacteria or spore-forming organisms.

c. *Oxygen* (O_2): In MAP, the existence of oxygen can facilitate the proliferation of harmful microorganisms and lead to the deterioration of food items through oxidation. Thus, it is imperative to lower the oxygen content or establish a barrier against oxygen to ensure the preservation of food quality and prolong its shelf life.

Effects on Microorganisms:

a. *Aerobic Microorganisms*: In MAP, the reduction of oxygen levels effectively hinders the proliferation of aerobic microorganisms, including molds and certain bacteria. These microorganisms rely on oxygen for their survival, and by limiting their presence, the shelf life of oxygen-sensitive products can be extended.

b. *Anaerobic Microorganisms*: In MAP, elevated carbon dioxide levels play a crucial role in inhibiting the development of anaerobic microorganisms.

1.1.2. Vacuum Packaging

Vacuum packaging is a preservation technique that involves the removal of air from the package before sealing, resulting in a vacuum environment. This method of preservation offers numerous advantages for packaged products.

a. *Microbial Growth Inhibition*: Vacuum packaging creates an environment devoid of oxygen, which effectively suppresses the growth of aerobic spoilage bacteria. By eliminating the presence of oxygen, this method inhibits the proliferation of bacteria that rely on oxygen for their survival.
b. *Prevention of Oxidative Reactions*: Vacuum packaging plays a vital role in preventing oxidative reactions in food products by removing oxygen. These reactions, if allowed to occur, can cause undesirable colour changes, rancidity, and nutrient degradation. Because of the absence of oxygen, vacuum packaging effectively safeguards the quality and freshness of the packaged food.

Effects on Microorganisms:

a. *Aerobic Microorganisms*: The absence of oxygen limits the growth of aerobic microorganisms, leading to extended shelf life of the product and a reduced risk of spoilage. Vacuum packaging effectively hinders the proliferation of aerobic microorganisms, contributing to the preservation and freshness of the product.
b. *Anaerobic Microorganisms*: Vacuum packaging does not directly inhibit the growth of anaerobic microorganisms, such as *Clostridium botulinum*. Therefore, it is vital to implement additional measures, including temperature control and other factors, to prevent their growth and ensure product safety.

Specific Spoilage Organisms and Reduced Oxygen Packaging

Specific spoilage organisms (SSOs) are microorganisms that have a high affinity for particular food types. They possess unique metabolic capabilities that allow them to thrive and proliferate under specific environmental conditions. These organisms have a detrimental impact on the sensory attributes, appearance, and overall quality of food products. Different food products are susceptible to specific spoilage organisms. For instance, *Pseudomonas spp.* are commonly associated with the spoilage of seafood, while yeasts like *Candida* and *Debaryomyces* are prevalent in fruit and bakery products. Lactic acid bacteria, such as *Lactobacillus spp*., are responsible for the spoilage of dairy and fermented foods.

Microbial Spoilage Flora/Specific spoilage organisms in Aerobically Packaged Chilled Stored Fish

Shewanella putrefaciens and *Pseudomonas spp*. are the specific spoilage bacteria of iced fresh fish regardless of the origin of the fish. Modified atmosphere stored marine fish from temperate waters are spoiled by the CO_2 resistant *Photobacterium phosphoreum* whereas Gram-positive bacteria are likely spoilers of CO_2 packed fish from fresh or tropical waters.

Pseudomonas spp.: *Pseudomonas spp*. are gram-negative bacteria commonly found in water and soil. They are capable of utilizing various carbon sources. During aerobic storage, *Pseudomonas* produce enzymes that break down proteins and lipids, producing off-flavours and odours. These bacteria thrive in the presence of oxygen and can cause sliminess and discoloration of the fish.

Shewanella spp.: Among the H_2S-producing bacteria, *Shewanella putrefaciens* is considered a specific spoilage organism in fish from temperate and tropical waters. It can grow under aerobic conditions. *Shewanella spp*. are psychrotrophic bacteria that thrive at low temperatures. *Shewanella spp*. are often associated with the spoilage of refrigerated fish. They produce hydrogen sulfide, resulting in the characteristic "rotten egg" smell.

Photobacterium spp.: *Photobacterium spp*. are gram-negative bacteria that are common in marine environments. They are known for their ability to produce histamine, a potent toxin responsible for scombroid fish poisoning. Histamine formation can occur even under reduced oxygen storage conditions.

Microbial Spoilage Flora in Reduced Oxygen Packaged Chilled Stored Fish

Reduced oxygen storage involves controlling the oxygen levels around the fish to inhibit the growth of spoilage microorganisms. By reducing the oxygen concentration, the growth of aerobic bacteria is suppressed, extending the shelf life of the fish.

Lactobacillus: *Lactobacillus* is a genus of bacteria commonly associated with anaerobic spoilage in fish. While LAB is commonly associated with beneficial processes, some species can act as spoilers in fish and other perishable foods. These bacteria are facultative anaerobes, meaning they can switch between aerobic and anaerobic metabolic pathways depending on the oxygen availability. *Lactobacillus* species are known for their ability to produce lactic acid, which contributes to the characteristic souring of spoiled fish.

Brochothrix thermosphacta: It is a facultative anaerobic organism, capable of growing under both aerobic and anaerobic conditions. This bacterium can proliferate even in the absence of oxygen, making it a significant contributor to spoilage in vacuum-packed and modified atmosphere-packaged fish products.

1.2. Aseptic Packaging

Aseptic packaging involves the separate sterilization of both the food product and the packaging material, followed by filling the sterile product into a sterile container under aseptic conditions. This packaging method encompasses several key considerations.

a. *Sterility Maintenance*: Aseptic packaging ensures the product and packaging remain devoid of microbial contamination throughout the filling, sealing, and storage processes. By maintaining a sterile environment, it effectively inhibits the growth of spoilage microorganisms and pathogens.

b. *Barrier Properties*: Aseptic packaging materials offer a protective barrier against microorganisms, light, oxygen, and moisture. This barrier preserves the quality of the food product and extends its shelf life by preventing external factors from compromising its integrity.

Effects on Microorganisms:

a. *Sterilization*: Aseptic packaging employs sterilization technique (heat treatment) to eliminate microorganisms. This process effectively eradicates spoilage organisms, pathogens, and enzymes, thereby increasing the product's shelf life.

b. *Microbial Barrier*: The sterile packaging material acts as a barrier against microbial recontamination during storage and distribution. This barrier is crucial for maintaining product safety and preventing spoilage.

1.3. Active Packaging

Active packaging systems are specifically designed to interact with the food product and its environment, providing additional preservation benefits. These systems incorporate antimicrobial agents or substances that can inhibit microbial growth.

Antibacterial Packaging Materials: The integration of antimicrobial agents into packaging materials creates an additional barrier against microbial contamination. These materials release antimicrobial compounds that effectively hinder the growth of bacteria, fungi, and other microorganisms. By reducing the risk of spoilage and foodborne illnesses, these antibacterial packaging materials contribute to the overall safety and quality of the food product.

Effects on Microorganisms:

a. *Antimicrobial Agents*: Active packaging utilizes antimicrobial agents, such as organic acids, enzymes, or bacteriocins, which exhibit inhibitory effects on specific microorganisms. These agents assist in suppressing the growth of spoilage and pathogenic bacteria, thereby enhancing product safety and extending the shelf life of the food.

b. *Controlled Release Systems*: Certain active packaging systems employ controlled release mechanisms that dispense volatile compounds, such as ethanol or essential oils, possessing antimicrobial properties. These compounds create an unfavourable environment for microorganisms, impeding their growth and extending the shelf life of the product.

2. Preservation Methods

In addition to packaging, various preservation methods can be employed to mitigate microbial growth and prolong shelf life of food. Preservation methods play a crucial role in controlling microorganisms, ensuring food quality and longevity. Here are several ways in which preservation methods achieve these objectives:

2.1. Temperature control: Temperature is vital in controlling microbial growth. Preservation methods such as refrigeration and freezing effectively slow down the growth of bacteria, yeast, and molds. Cold temperatures inhibit their metabolic activities, reproduction, and enzyme production, ultimately extending the shelf life of food products. Freezing is a widely accessible and convenient preservation method. By lowering the temperature, microorganisms' growth is significantly slowed or halted and thus it helps to maintain the quality and freshness of food products.

Table 1: Classification of bacteria based on temperature requirement

Bacteria	Temperature Range	Examples
Psychrophiles	Below 20°C	*Psychrobacter, Flavobacterium*
Psychrotrophs	0°C - 30°C	*Listeria monocytogenes, Pseudomonas*
Mesophiles	20°C - 45°C	*Escherichia coli, Staphylococcus aureus*
Thermophiles	45°C - 80°C	*Thermus aquaticus, Sulfolobus*
Hyperthermophiles	Above 80°C	*Pyrococcus furiosus, Thermococcus*

2.2. Drying/ Dehydration: Drying is a preservation method that removes moisture from food, creating an inhospitable environment for microbial growth. Bacteria, yeast, and molds require moisture to survive. By reducing the moisture content, drying inhibits microbial activity and enzymatic reactions, thereby prolonging the shelf life of food. This preservation method can be achieved through sun drying, air drying, or using specialized equipment like food dehydrators. Dried foods have an extended shelf life and are lightweight, making them ideal for storage and transportation.

The water activity (a_w) of a food refers to the availability of water for microbial growth and chemical reactions. Drying food to lower water activity levels can inhibit microbial growth and enzymatic reactions, thereby extending the shelf life of the food. Water activity reduction during drying depends on factors such as drying method, temperature, and duration. The aim is to reach a water activity level that prevents microbial growth and enzymatic reactions, typically below 0.6 or 0.7. At such low water activity levels, most microorganisms are unable to grow, making the dried food more resistant to spoilage and microbial contamination.

Table 2: Minimum water activity (a_w) values for microbial growth

Microorganism	**Minimum a_w value**
Bacteria	0.91
Yeast	0.86
Mold	0.80
Halophilic Bacteria	0.75
Xerophilic Bacteria	0.65
Osmophilic Bacteria	0.60

2.3. Salting and Sugaring: Salting and sugaring are ancient methods of food preservation. Both techniques work by drawing moisture out of the food, creating an environment where microorganisms cannot thrive. Salted and sugared foods, such as cured meats and jams, can be stored for long periods without spoilage. Salting involves the addition of salt. Salt draws out moisture from the food through osmosis, creating an environment with a high salt concentration that inhibits microbial growth. Additionally, it reduces water activity, making it difficult for bacteria and other microorganisms to survive and spoil the food.

2.4. Low pH and Acidity: Acidic conditions inhibit microbial growth by disrupting their cellular structure. Techniques like pickling and fermenting create an acidic environment that is unfavourable for most harmful microorganisms, while beneficial bacteria thrive and provide preservation.

Fermentation: Fermentation is a preservation method that harnesses the growth of beneficial microorganisms, such as lactic acid bacteria and yeast. These microorganisms produce acids, alcohol, and other compounds that create an acidic or alcoholic environment, inhibiting the growth of harmful bacteria. Foods undergoing fermentation, like yogurt, sauerkraut, and kimchi, have an extended shelf life due to the presence of these beneficial microorganisms.

Pickling: Pickling is a preservation method that involves immersing food items, such as vegetables or fruits, in a brine or vinegar solution. The acidic environment created by the pickling solution inhibits the growth of harmful bacteria, yeasts, and molds, effectively preserving the food. The process of pickling not only extends the shelf life of the food but also imparts a unique tangy flavour and texture. Pickled foods are popular for their versatility and can be enjoyed as condiments, toppings, or standalone snacks.

2.5. Smoking: Smoking is a preservation method that exposes food to the smoke of burning wood or other plant materials. The smoke contains antimicrobial compounds that inhibit bacterial growth and prevent food spoilage. Smoking is commonly used for preserving fish, meat, and cheese.

2.6. Chemical preservatives: Certain chemicals can be used as preservatives to control microbial growth. Common preservatives include organic acids (e.g., citric acid, acetic acid), antioxidants (e.g., vitamin C, tocopherols), and antimicrobial agents (e.g., sodium benzoate, sorbic acid). These substances inhibit the growth of bacteria, yeast, and molds, thereby preventing spoilage and extending the shelf life of food products.

2.7. Heat Treatment: Thermal processes, such as pasteurization and canning, are employed to eliminate or reduce the microbial load in food. These methods involve the application of heat to kill or deactivate microorganisms. High temperatures destroy the enzymes and proteins essential for microbial growth, effectively controlling their population.

High-Temperature Short-Time (HTST) Pasteurization: HTST pasteurization involves heating the food product to a specific temperature for a short duration, thereby eliminating or reducing the microbial load. It is commonly used for liquid or semi-liquid food products like juices and sauces before they are packaged.

Low-Temperature Long-Time (LTLT) Pasteurization: LTLT pasteurization utilizes lower temperatures for a longer duration, making it suitable for more delicate food products such as dairy and egg-based items. This process ensures the reduction of pathogens and spoilage microorganisms while minimizing quality degradation.

Canning: Canning is a preservation method that involves heat processing food in sealed containers. The high temperatures applied during canning destroy bacteria, yeasts, and molds that could cause spoilage or foodborne illnesses. The hermetically sealed containers act as a barrier, preventing recontamination and hindering the entry and multiplication of microorganisms.

2.8. Non-thermal preservation methods: Non-thermal food preservation methods offer alternative approaches to controlling the growth of microbes and extending the shelf life of food without relying on high temperatures. These methods utilize various techniques that work synergistically to inhibit microbial activity and maintain the quality of the food.

***High-Pressure Processing** (HPP)*: HPP subjects the food to intense pressure, usually between 100 and 800 megapascals (MPa), which disrupts the cellular structure of microbes. The increased pressure leads to the inactivation of bacteria, yeasts, molds, and enzymes, thereby extending the shelf life of the food while preserving its nutritional value and sensory attributes. HPP helps to ensure food safety while extending shelf life.

***Pulsed electric field** (PEF)*: PEF technology involves exposing the food to short bursts of high-voltage electricity. The electrical pulses create tiny pores in the microbial cell membranes, disrupting their integrity and leading to cell death. This method effectively controls microbial growth while minimizing the impact on the food's organoleptic properties.

Pulsed light technology: The pulse light technique, also known as pulsed light technology, involves the use of intense and short bursts of light energy to eliminate or reduce microbial contamination on various surfaces, including food products. This non-thermal method is particularly effective in targeting bacteria, yeasts, molds, and other pathogens that can compromise food safety. Pulse light technology operates by emitting high-intensity light pulses, typically in the ultraviolet (UV) or visible spectrum range. These light pulses disrupt the DNA or RNA structure of microorganisms, rendering them unable to reproduce or causing their death. The short duration and high energy of the light pulses ensure effective microbial inactivation while minimizing heat transfer to the treated food.

***Ultraviolet** (UV) Treatment*: UV light is a highly effective non-thermal method for microbial control. It disrupts the DNA and RNA of microorganisms, rendering them incapable of growth or reproduction. UV treatment can be applied to surfaces, packaging materials, or directly to food products, providing an additional layer of protection against microbial contamination.

Irradiation: Irradiation is a non-thermal preservation method that uses ionizing radiation, such as gamma rays or electron beams, to destroy microbes. The radiation damages the genetic material of microorganisms, inhibiting their ability to reproduce and causing their demise. Irradiation is a highly regulated process that has been extensively studied and approved for use in certain food products.

Cold plasma technique: Cold plasma technique is known for its remarkable ability to significantly reduce microbial load. By employing this innovative technology, harmful microorganisms can be effectively eliminated, leading to improved safety and hygiene in various applications. Cold plasma works by generating a non-thermal plasma state at low temperatures, which releases a variety of active species such as reactive oxygen species and reactive nitrogen species. These highly reactive species then interact with microbial cells, causing damage to their membranes and genetic material. As a result, the viability and proliferation of microorganisms are greatly hindered, leading to a substantial reduction in their overall population. This technique offers a promising solution for microbial control in diverse fields, including food processing, healthcare, and environmental sanitation.

Conclusion

Microbiological considerations play a crucial role in the realm of food packaging, ensuring both the safety and quality of food products. It is important to note that although these preservation methods and packaging atmospheres aid in controlling microbial growth, they do not provide a complete guarantee of sterilization. Alongside these measures, maintaining proper hygiene practices, controlling temperatures, and ensuring appropriate storage conditions are essential in minimizing the risk of foodborne illnesses and preserving the overall quality of packaged food products.

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Ensuring Safety and Quality of Packaged Food

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Introduction

Food safety is a major concern and critical factor for ensuring food and nutritional security globally. The term 'Quality' is synonym with consumer acceptability and it is true that products with no proven quality find little space in the market. Food safety is not just quality but is a measure of the acceptability in terms of its ability to support both nutrition and health of consumer. The quality products are usually assessed by the end product inspection and with the extent to which that the said product meets the product satisfaction. But in the case of food item, it is much more than the end product acceptability as each and every step in the production process, depending upon the nature and scope of the product contribute to safety and acceptability by the consumer.

The Hazard Analysis Critical Control Point (HACCP) concept has been used in the food industry to control hazards associated with food processing. Recently, HACCP applications to the food packaging is also found to be crucial to ensure food safety starting from manufacturing to the consumption. In many cases, direct food contact packaging itself is considered as a food ingredient. Thus, the principles of HACCP are applied to existing programs in the packaging industry to assure that food safety is maintained throughout the packaging process. The application of HACCP system helps the packaging suppliers to control potential food safety hazards that may contaminate the food product during packaging, and thus helps to ensure customer safety.

HACCP Concepts:

Adoption of good practices and HACCP systems are a tool to assure food safety and quality. Hazard Analysis and Critical Control Point (HACCP) system is an internationally recognized system endorsed by the Codex Alimentarius commission, to systematically identify hazards specific to individual products and processes, describe measures for their control to ensure food safety. It is a dynamic system, capable of accommodating change in the system- changes in equipment design, processing procedures, packaging and technological advancements.

HACCP is defined as a system which identifies, evaluates, and controls hazards which are significant for food safety

HACCP is a structured, systematic approach for the control of food safety throughout the food system, from the farm to fork. It requires a good understanding of the relationship between cause and effect in order to be more pro-active. HACCP is supported by pre-requisite programmes like Good Manufacturing Practice (GMP), Good Hygienic Practices (GHP), SSOP (Sanitation standard operating procedures), Good Agricultural Practices (GAP), and Good Storage Practices (GSP), *etc.*

Pre-requisite programmes

Pre-requisite programs provide a foundation for an effective HACCP system. They are often facility-wide programs rather than process or product specific. They reduce the likelihood of certain hazards. Prerequisite programs set the stage for a HACCP system and provide on-going support for the establishment's food safety system. They keep potential hazards from becoming serious enough to adversely impact the safety of foods produced. Without clean working conditions free from microbiological, chemical, and physical contamination from many sources, a HACCP plan cannot be effective.

Prerequisite programmes are practices and conditions needed prior to and during the implementation of HACCP and which are essential for food safety

Some of the prerequisite programmes include GAP, GMP and GHP which must be working effectively within a commodity system before HACCP is applied.

The Good Manufacturing Practices commonly referred as current good manufacturing practices (cGMPs, 21 CFR 110) give details as to what specific procedures must be followed to comply with the regulation. Standard operating procedures (SOPs) are the steps your company takes to assure that the GMPs are met. They include stepwise procedures, employee training, monitoring methods, and records used by your company. Similarly, SSOP covers eight key sanitation conditions as required by USFDA.

Good hygiene practices include all practices regarding the conditions and measures necessary to ensure the safety and suitability of food at all stages of the food chain.

Basic principles of HACCP

There are seven discrete activities that are necessary to establish, implement and maintain a HACCP plan, and these are referred to as the 'seven principles' in the Codex Guideline (1997).

The seven Principles of HACCP are

***Principle 1*: Conduct a hazard analysis and identify control measures**

Hazard: A biological, chemical or physical agent in, or condition of, food with the potential to cause an adverse health effect, in the absence of its control.

Hazard analysis: The process of collecting and evaluating information on hazards and conditions leading to their presence to decide which are significant for good safety and therefore should be addressed in the HACCP plan.

***Principle 2:* Determine the Critical Control Points (CCPs)**

A step at which control can be applied and is essential to prevent or eliminate a food safety hazard or reduce it to an acceptable level.

Common critical control points seen within the packaging industry are

Allergen: Food labels should identify the food source of all major food allergens used to make the food.

Metal: Packaged foods should be screened for metal fragments by passing the cases through a metal detector in order to avoid the risk of metal contaminants

***Principle 3:* Establish validated critical limits.**

A criterion which separates acceptability from unacceptability, when monitoring a critical control point.

***Principle 4:* Establish a system to monitor control of CCPs**

The act of conducting a planned sequence of observations or measurements of control parameters to assess whether a CCP is under control.

***Principle 5:* Establish the Corrective Actions to be taken when monitoring indices, a deviation from a critical limit at a CCP has occurred**

Any action to be taken when the results of monitoring at the CCP indicate a loss of control.

Principle 6: **Validate the HACCP plan and then establish procedures for verification to confirm that the HACCP system is working as intended**

The application of methods, procedures, tests and other evaluations, in addition to monitoring to determine compliance with the HACCP plan.

Principle 7: **Establish documentation concerning all procedures and records appropriate to these principles and their application**

Food packaging manufacturers, suppliers and food processing industries should consider the packaging material itself as an ingredient and a crucial step in the overall process of food manufacturing, so that the potential hazard contamination from packaging materials to food can be effectively controlled through the application of HACCP technique. Identifying and elimination/reduction/control of potential hazards along with the confirmation of all food safety markings, advertised weight, labelling accuracy, consistent equipment performance and confirmation of the product as advertised will help the packaged food manufacturers to ensure safety and quality of the food produced and also to comply with the relevant food safety regulations.

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Plastic packaging material identification & property testing

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Introduction

Plastic is widely used as a food packaging material due to its versatility, durability, and cost-effectiveness. It offers several advantages that make it a popular choice for packaging various food products.

- Protection: Plastic packaging provides a barrier against moisture, oxygen, and other contaminants, helping to maintain the quality and freshness of the food. It safeguards against spoilage, extends shelf life, and reduces the risk of foodborne illnesses.
- Convenience: Plastic packaging is lightweight and easily portable, making it convenient for consumers to carry and store food items. It is also available in various shapes and sizes, allowing for easy portioning and portion control.
- Visibility: Plastic packaging can be transparent or translucent, enabling consumers to see the contents of the package. This helps in making informed purchasing decisions and assessing the quality of the food product.
- Safety: Food-grade plastics are specifically designed to be safe for contact with food. They undergo rigorous testing to ensure they do not release harmful substances into the food. Plastic packaging also reduces the risk of contamination during transportation and handling.
- Versatility: Plastic packaging can be moulded into different shapes and sizes, offering flexibility in design. It can be customized with features such as resealable closures, easy-open mechanisms, and portion compartments, enhancing the convenience and usability of the packaging.

Commonly used plastic materials for food packaging

Several types of plastic are commonly used for food packaging.

- ***Polyethylene*** (PE): PE is a widely used plastic for food packaging. It is flexible, lightweight, and resistant to moisture and chemicals. It is commonly used for plastic bags, plastic films, and squeeze bottles. PE is available in various forms, including low-density polyethylene (LDPE) and high-density polyethylene (HDPE).
- ***Polyethylene Terephthalate*** (PET or PETE): PET is a transparent and lightweight plastic that is commonly used for beverage bottles, salad dressing containers, and food trays. It is also recyclable.
- ***Polypropylene*** (PP): PP is a versatile plastic that can withstand high temperatures. It is commonly used for microwaveable containers, yogurt cups, and food storage containers.
- ***Polystyrene*** (PS): PS is a rigid plastic that is commonly used for foam food trays, disposable cutlery, and cups. It provides insulation and keeps food warm.
- ***Polyvinyl Chloride*** (PVC): PVC is used in food packaging applications that require excellent clarity, such as cling films and shrink wraps. It is also used for making food trays, and bottles. PVC offers good barrier properties against moisture and oxygen.

While PVC is widely used, there are growing concerns about its environmental impact and potential health risks associated with certain additives used in its production.

- **Nylon**/Poly amide: Nylon is a strong and versatile plastic material that finds applications in food packaging, particularly in vacuum-sealed bags and films. It provides excellent puncture resistance and helps extend the shelf life of perishable products. However, nylon is not commonly used for direct food contact packaging.

Food packaging symbols

Food packaging symbols play a crucial role in providing essential information to consumers about the contents, handling, and safety of the packaged food products. These symbols are visual representations that convey important messages regarding ingredients, nutritional value, allergens, storage conditions, recycling, and more. By incorporating these symbols, food packaging aims to enhance transparency, ensure consumer safety, promote sustainable practices, and assist individuals in making informed decisions about the products they purchase and consume.

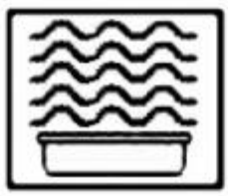
1. **Food Contact Symbol**: This symbol resembles a glass and fork, signifying that the packaging material is suitable for food contact and is deemed food-safe.

2. **Recycling Symbol**: This symbol is usually a triangle made of arrows, indicating that the packaging material is recyclable. The number inside the triangle indicates the specific type of plastic used.

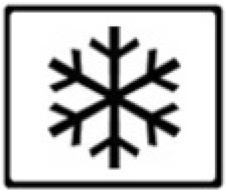
3. **Vegetarian/Vegan Symbol**: These symbols, often represented by a leaf or a variation of a plant-based image, certify that the food product is suitable for vegetarian or vegan diets, respectively. They help individuals easily identify products that align with their dietary preferences.

4. **Allergen Symbols**: These symbols, typically found on food packaging, highlight the presence of common allergens such as peanuts, tree nuts, wheat, soy, dairy, eggs, fish, and shellfish. They help individuals with allergies or dietary restrictions easily identify potential allergens in the product.

5. **Microwave-Safe Symbol**: This symbol depicts a microwave oven and indicates that the packaging can be safely used in the microwave.



6. **Freezer-Safe Symbol**: This symbol typically shows a snowflake or a snowflake within a square, indicating that the packaging can be safely used for freezing food.



7. **Tidy Man**: The "Tidy Man" symbol is commonly used on packaged items as a reminder to customers to dispose of the packaging in an appropriate manner. It serves as a visual cue to promote responsible waste management. The symbol typically features a simple depiction of a person engaged in tidying up, holding a trash bag or broom.

It's important to note that the symbols may vary depending on the region and the specific regulations in place.

Resin identification code/Plastic identification number

The ASTM International (formerly known as the American Society for Testing and Materials) Resin Identification Coding System, commonly referred to as RIC, is a series of symbols found on plastic products. These symbols serve the purpose of identifying the specific plastic resin used to manufacture the product. The system was initially created in 1988 by the Society of the Plastics Industry, which is now known as the Plastics Industry Association, in the United States. However, since 2008, the administration of the coding system has been taken over by ASTM International.

The plastic identification numbers are usually represented by a triangular symbol with the number inside it. These identification numbers and symbols are often found on the bottom of plastic containers and products, within the recycling symbol. They help with the sorting and recycling process by allowing consumers and recycling facilities to easily identify the type of plastic used.

Table 1: Identification codes for plastics

Resin identification code	Plastic Type	Description
1	PETE (Polyethylene Terephthalate)	Clear, rigid bottles; commonly used for soda, water, and food containers.
2	HDPE (High-Density Polyethylene)	Translucent or coloured, rigid bottles; commonly used for milk jugs, detergent bottles, and some food containers.
3	PVC (Polyvinyl Chloride)	Rigid or flexible; commonly used for pipes, window frames, flooring, and certain types of packaging.
4	LDPE (Low-Density Polyethylene)	Flexible and stretchable; commonly used for plastic bags, cling wrap, and some squeezable bottles.
5	PP (Polypropylene)	Translucent or coloured, rigid containers; commonly used for yogurt cups, margarine tubs, and medicine bottles.
6	PS (Polystyrene)	Rigid or foam; commonly used for disposable cups, food packaging, and insulation materials.
7	Other Plastics and Composites	Miscellaneous plastics not covered by the other numbers; can include polycarbonate (PC), nylon, acrylic, and others.

Identification of plastic packaging materials by conventional methods

Different plastics exhibit unique characteristics that can help in identifying plastic packaging materials. Some key characteristics and their relevance in plastic identification are as follows:

- **Density**: The density of a plastic material, expressed in grams per cubic centimetre (gm/cc), can provide a clue about its type. Different plastics have distinct density ranges, allowing for differentiation between them.

Table 1: Density of different polymers

Polymer	**Density range (g cm^{-3})**
PP, polypropylene	0.89-0.91
LDPE, low-density polyethylene	0.91-0.93
HDPE, high-density polyethylene	0.94-0.96
PS, polystyrene	1.04-1.11
PVC, polyvinyl chloride (PVC)	1.20-1.55
PET, polyethylene terephthalate	1.38-1.40
EPS, expanded polystyrene	0.02-0.06
PVDC, Polyvinylidene Chloride	1.63-1.72
PVA, Polyvinyl Alcohol	1.21 - 1.33
PC, Polycarbonate	1.20–1.22
Nylon/Poly amide	1.06 - 1.14
Cellophane	1.42 – 1.48

Sinking/floating test

The floating or sinking behaviour of an object in a liquid can be used as a general guideline to identify certain types of plastics. The principle is based on the relative densities of the plastic and the liquid. If a plastic object floats in a liquid, it suggests that the plastic has a lower density than the liquid. If a plastic object sinks in a liquid, it indicates that the plastic has a higher density than the liquid. The water test/sinking/floating allows us to categorize polymeric materials into two groups.

1. Polymers that float in water (PE & PP)
2. Polymers that sink in water (all other Polymers)

Table 2: Sinking/floating pattern of plastic in water

Plastic Polymer	**Sinking/floating in water**
LDPE (Low-Density Polyethylene)	Typically floats
HDPE (High-Density Polyethylene)	Typically floats
PP (Polypropylene)	Typically floats
PET (Polyethylene Terephthalate)	Typically sinks or remains submerged
PS (Polystyrene)	Typically sinks or remains submerged

- **Flammability**: The flammability behaviour of plastics is an important characteristic for identification. Some plastics are self-extinguishing and do not sustain combustion, while others burn readily. This behaviour can be observed during a flame test.
  Colour: The colour of a plastic material can provide an initial visual clue for identification. Different plastics often have distinct natural colours or pigmentation.
  Odour: The smell emitted by a burning plastic material can be indicative of its type. Different plastics produce varying odours when subjected to heat or combustion.

Here are some key characteristics of commonly used plastics and their corresponding identification features:

1. **Polyethylene** (PE)
   - Flammability: Does not self-extinguish
   - Colour: Top yellow, bottom blue
   - Behaviour: Melts and drips like burnt wax
   - Odour: Produces white smoke
2. **Polypropylene** (PP)
   - Flammability: Does not self-extinguish
   - Colour: Top yellow, bottom blue
   - Behaviour: Melts and drips like burnt wax, acrid odour
   - Odour: Produces white smoke
3. **Polyvinyl Chloride** (PVC)
   - Flammability: Self-extinguishes
   - Colour: Yellow orange with a green edge
   - Behaviour: Darkens, softens, and decomposes
   - Odour: Smells like chlorine
4. **Polyvinylidene Chloride** (PVDC)
   - Flammability: Self-extinguishes
   - Colour: Similar to PVC with green spurts
   - Behaviour: Leaves a black, hard residue
   - Odour: Smells like chlorine
5. **Polyvinyl Alcohol** (PVA)
   - Flammability: Self-extinguishes but slowly
   - Colour: Yellow with grey smoke
   - Behaviour: Swells, softens, and turns brown
   - Odour: Pungent scent
6. **Polycarbonate** (PC)
   - Flammability: Self-extinguishes
   - Colour: Yellow orange with black smoke
   - Behaviour: Does not drip, decomposes
   - Odour: Pleasant smell
7. **Polyester/Polyethylene Terephthalate** (PET)
   - Flammability: Does not self-extinguish
   - Colour: Yellow with black smoke

- Behaviour: Does not drip, softens, and burns steadily
- Odour: Pleasant smell

8. **Polystyrene** (PS)
   - Flammability: Does not self-extinguish
   - Colour: Yellow orange, black shoots
   - Behaviour: Does not drip, softens
   - Odour: Floral (sweet) scent
9. **Nylon**/Poly amide
   - Flammability: Self-extinguishes
   - Colour: Blue, yellow top
   - Behaviour: Melts, drips, and froths; rigid drips when burnt
   - Odour: Smells like burnt hair
10. **Cellophane**
   - Flammability: Does not self-extinguish
   - Colour: Yellow, orange, grey, and smoke
   - Behaviour: Burns fast and completely, leaving a brittle burnt area
   - Odour: Smells like burnt paper

Table 3: Flammability/Burning test of polymers

Behaviour	**PES**	**PE**	**PP**
In flame	Melts, burns with light flame, sooty black smoke, melting drops fall down.	Shrinks, curls, melts and burns with light flame, drops of melting fall down.	Shrinks, melts and burns with light flame, melting drops fall down.
After leaving the flame	Stops burning, melting bead may be stretched into fine thread.	Continues to burn rapidly, hot melting substance cannot be stretched.	Continues to burn slowly, hot melting substance can be stretched.

Solubility test

The solubility of plastic polymers refers to their ability to dissolve or disperse in different solvents. The solubility behaviour of plastic polymers can vary depending on factors such as their chemical composition, molecular weight, crystallinity, and the nature of the solvent. In general, polar polymers tend to dissolve in polar solvents, while nonpolar polymers dissolve in nonpolar solvents. This principle is known as "like dissolves like." For example, polar polymers like poly (vinyl alcohol) are soluble in polar solvents such as water, while nonpolar polymers like polystyrene are soluble in nonpolar solvents such as toluene.

However, solubility is not solely determined by polarity. Other factors, such as molecular weight, crystallinity, and crosslinking, also influence solubility. Higher molecular weight polymers generally have lower solubility. Crystalline polymers, which have ordered and tightly packed structures, often have lower solubility compared to amorphous polymers. Crosslinked polymers, which have interconnected networks, are typically insoluble. It's important to note that solubility is also influenced by temperature, solvent concentration, and the specific polymer-solvent system. Experimental testing is typically required to determine the solubility of a specific polymer in a particular solvent under given conditions. Understanding the solubility of plastic polymers is important for various applications, including polymer processing, recycling, and material characterization.

Among the various solvents used for plastics, toluene, tetrahydrofuran, dimethylformamide, diethyl ether, acetone, and formic acid are widely utilized. Additionally, in specific cases, chloroethylene, ethyl acetate, ethanol, and water can also be useful. It is important to be aware that many solvents used in this context can be flammable and toxic, requiring careful handling. It is recommended to minimize the use of benzene due to its potential hazards.

Table 4: Solubility of plastic polymers

Plastic Polymer	Solvent Solubility
Polyethylene (PE)	Insoluble in most solvents (Polyethylene (other than cross-linked polyethylene) usually can be dissolved at elevated temperatures in aromatic hydrocarbons such as toluene or xylene, or in chlorinated solvents such as trichloroethane or trichlorobenzene.)
Polypropylene (PP)	Insoluble in most solvents (At elevated temperature, PP can be dissolved in nonpolar solvents such as xylene, tetralin and decalin.)
Polyvinyl Chloride (PVC)	It is insoluble in water and alcohol but slightly soluble in Tetrahydrofuran (THF).
Polyethylene Terephthalate (PET)	PET is *insoluble in water*, *diethyl ether*, and many common organic solvents. However, it is soluble in DMSO, nitrobenzene, phenol, and o-chlorophenol.
Polystyrene (PS)	Soluble in Aromatic solvents (e.g., Toluene, Xylene)
Polycarbonate (PC)	Soluble in Aromatic solvents (e.g., Chloroform, Dichloromethane)
Polyamide (PA or Nylon)	Soluble in Formic Acid, Sulfuric Acid, and some strong alkaline solutions
Polyethylene Glycol (PEG)	Soluble in Water and some polar solvents

The above-mentioned characteristics can aid in the identification of plastic packaging materials. However, it's important to note that accurate identification may require additional tests.

Advanced methods for plastic identification

In cases where precise identification is necessary, techniques such as Fourier Transform Infrared (FTIR) spectroscopy or Differential Scanning Calorimetry (DSC) can be employed to determine the specific polymer composition of the plastic material.

Differential Scanning Calorimetry (DSC)

DSC is a valuable technique used to identify plastic materials based on their thermal properties. This technique involves measuring the heat flow in or out of a sample while it undergoes controlled heating or cooling. Plastic materials exhibit distinct thermal behaviours due to their unique compositions, including properties such as melting points, glass transition temperatures, and crystallization characteristics. By examining the thermal properties of a plastic sample and comparing them with known data for various polymers, it becomes possible to determine the specific polymer present. However, it is crucial to note that relying solely on DSC results may not always lead to definitive identification, particularly when multiple polymers share similar thermal properties. In such situations, supplementary techniques like FTIR spectroscopy or other advanced analytical methods may be necessary to ensure more accurate identification.

Table 5: Melting point of plastic polymers in DSC

Polymer	Melting Point (°C)
LDPE (Low-Density Polyethylene)	105 - 115
HDPE (High-Density Polyethylene)	120 - 130
PP (Polypropylene)	160 - 170
PS (Polystyrene)	70 - 115
PET (Polyethylene Terephthalate)	245 - 255
PVC (Polyvinyl Chloride)	100 - 260

Fourier Transform Infrared (FTIR) spectroscopy

FTIR spectroscopy involves the measurement of infrared light absorbed by the plastic sample. This method analyses the infrared light absorption patterns of material. Each type of polymer has a unique infrared spectrum, allowing for the identification of specific functional groups present in the material. The specific polymer composition can be determined by comparing the infrared spectrum of an unknown plastic sample with a library of known spectra.

FTIR allows for the identification and analysis of major functional groups present in polymers. Here are some common functional groups and their corresponding infrared (IR) absorptions in various types of polymers.

- **Carbonyl stretches** (polyesters): Polyesters contain ester functional groups (-CO-O-) in their polymer chains. The carbonyl stretch typically appears as a strong absorption peak in the range of 1700-1750 cm^{-1}.
- **N-H stretches** (polyamides): Polyamides, such as nylon, contain amide functional groups (-CONH-) in their polymer chains. The N-H stretch usually appears as a broad and strong peak in the range of 3200-3500 cm^{-1}.
- **Aromatic bends** (polystyrene): Polystyrene is an aromatic polymer with a phenyl ring structure. The aromatic bends typically exhibit absorptions in the range of 700-900 cm^{-1}, resulting in a series of peaks known as the "fingerprint region" for aromatic compounds.

- **O-H stretches** (poly (vinyl alcohol)): Poly (vinyl alcohol) (PVA) contains hydroxyl groups (-OH) in its polymer chains. The O-H stretch appears as a broad and strong peak in the range of 3200-3600 cm^{-1}.
- **C≡N stretches** (polyacrylonitrile): Polyacrylonitrile (PAN) contains nitrile groups (-C≡N) in its polymer chains. The C≡N stretch is typically observed in the range of 2210-2240 cm^{-1}.
- **C-H stretches** (polyethylene): Polyethylene is a hydrocarbon polymer composed of repeating ethylene units. The C-H stretches typically appear as a series of peaks in the range of 2800-3000 cm^{-1}.

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Testing and quality evaluation of paper and plastic packaging materials

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Introduction

The use of standardized test procedures and compliance with industry standards are integral to quality assessment of packaging materials. These standards outline testing methods, performance criteria, and quality requirements. Several organizations have established their own standards for this purpose.

1. **ASTM** (American Society of Testing and Materials): ASTM has been instrumental in developing a wide range of standards related to packaging materials. Their test methods for physical properties, barrier properties, mechanical strength, and environmental impact are highly regarded and used globally.

2. **TAPPI** (Technical Association for the Pulp and Paper Industry): TAPPI is a leading organization in the pulp, paper, and packaging industry. They have developed standards for various aspects of paper and packaging materials, such as strength properties, thickness, moisture content, and printability.

3. **BIS** (Bureau of Indian Standards): The BIS (formerly Indian Standards Institute (ISI)) is responsible for setting national standards for packaging materials in India, including paper and paperboards, plastics, and flexible packaging. These standards address key aspects like dimensions, mechanical properties, and environmental impact, among others.

4. **ISO** (The International Organization for Standardization): ISO has also published a range of standards for packaging materials, covering aspects such as testing methods, performance requirements, and safety considerations.

5. **BS** (British Standards): British Standards provide guidelines and specifications for packaging materials to ensure their compliance with quality, safety, and performance requirements in the United Kingdom.
6. **FEFCO** (Federation Europeanne des Fabricants de Carton Ondule): FEFCO represents European corrugated packaging manufacturers and has established test methods to ensure the performance and quality of corrugated board and boxes.
7. **PIFA** (Packaging and Industrial Films Association): The PIFA has established comprehensive standards for testing and evaluating flexible packaging materials and industrial films. These standards cover key aspects such as tensile strength, tear resistance, and seal integrity.
8. **ABA** (American Box Board Association): The ABA has put forth rigid standards for boxboard materials utilized in packaging applications. These standards focus on critical properties including stiffness, folding endurance, and moisture resistance.
9. **BPBMA** (British Paper and Board Manufacturers' Association): The BPBMA has set industry standards for paper and board manufacturing. These standards encompass important aspects of paper and board production such as grammage, bursting strength, and dimensional stability.
10. **NFPA** (National Flexible Packaging Association): The NFPA has also published standards specifically for flexible packaging materials. These standards include heat sealing, barrier properties, and puncture resistance.

Testing of paper and paperboard

Testing of paper and paperboard packaging materials is crucial to ensure their quality, performance, and suitability for multiple applications. These tests assess the materials' physical, mechanical, and chemical properties and their ability to protect and preserve the contents of the package.

Standards for paper

The following organizations establish test standards for paper:

- Bureau of Indian Standard (BIS)/Indian Standards Institute (ISI)
- International Organisation for Standardisation (ISO)
- American Society for Testing and Materials (ASTM)
- Trade Association of Pulp and Paper Industries (TAPPI)

Sample conditioning & conditioning atmosphere

There are guidelines for conditioning the testing atmosphere for packaging materials, including paper. This conditioning is crucial to ensure that samples are at a standardized state before testing.

International standard

The ISO standard that covers conditioning atmospheres is ISO 187:1990 - Packaging -- Conditioning for testing. ISO 187:1990 recommends the following standard conditions for conditioning the atmosphere before testing packaging materials, including paper:

1. **Temperature**: To ensure consistency and accuracy, it is recommended to condition the samples at a temperature of 23 ± 1°C (73 ± 2°F), which allows the samples to reach equilibrium with the surrounding environment.

2. **Relative Humidity**: Additionally, a standard relative humidity of 50 ± 2% is recommended to keep the moisture in the atmosphere controlled and to stabilize the samples.

Indian Standard

According to the Indian Standards IS: 1060 (Part – I) 2022, a standard atmospheric condition is maintained for conducting tests on samples. This standard condition involves a temperature of 27 ± 1 °C and a relative humidity of 65 ± 2 %. The samples are exposed to these conditions for a period of 24 hours before conducting the tests. This controlled environment ensures consistency and accuracy in the test results.

Tests for paper and paper board

Here is an overview of the typical testing procedures involved:

1. **Basis Weight**/Substance/Grammage Measurement: This test finds out how much a paper or paperboard weighs per unit area, which is measured in grams per square meter (g/m^2). This provides an idea of how thick and dense the material is.

   Grammage (g/m^2) = Weight of the paper sample (g) / Area of the paper sample (m^2)

   OR =1000 w/ab

   w = weight in g of the specimen, a= length in cm of the specimen, b= width in cm of the specimen

   Equipment: Basis weight scale

   Standards: ASTM D646, ISO 536, Indian Standard IS: 1060-Part-I (1987)

Table 1: Typical grammage values of paper

Paper Type	**Grammage Range (GSM)**
Bond Paper	60 - 120
Copy Paper	70 - 90
Newsprint	40 - 55
Art Paper	90 - 300+
Cardstock	150 - 300
Corrugated Board	200 - 700+
Folding Boxboard	200 - 500+
Tissue Paper	10 - 35

2. **Ream weight:** It's the weight (kg) of a ream of paper containing 500 sheets.

   Ream Weight (in kg) = (Total weight of paper in the stack) / 500

Table 2: Typical ream weight values of paper

Paper Size	**Weight of 500 Sheets (Approximate)**
Letter (8.5"x11")	2.5 - 2.8 kg
Legal (8.5"x14")	3.1 - 3.5 kg
A4 (210 mm x 297 mm)	2.2 - 2.5 kg
A3 (297 mm x 420 mm)	4.4 - 5.0 kg
Tabloid (11"x17")	5.0 - 5.6 kg

* It can vary based on the specified size of the paper

3. **Thickness**: It is the measurement of the paper's thickness in micrometers (µm). Equipment: Thickness gauge/micrometer

Table 3: Typical thickness values of paper

Paper Type	**Thickness (µm)**
A4 Paper	100-120 µm
Tissue Paper	10-35 µm
Copy Paper	70-90 µm
Kraft Paper	100-200 µm
Newsprint Paper	50-80 µm
Cardstock Paper	180-250 µm
Construction Paper	100-180 µm
Bond Paper	80-100 µm
Tracing Paper	40-50 µm
Greaseproof Paper	40-60 µm

4. **Bulk**: The bulk of paper is a measure of its thickness relative to its weight or density.

   Bulk = Average thickness of a single sheet in microns/substance in grams per square metre

   Bulk = Caliper (µm or mil) / Basis weight (gsm or lb)

   *Thousandths of an inch = mil

   It indicates how much space the paper occupies for a given weight. Paper with higher bulk will feel thicker and more substantial compared to paper with lower bulk but the same weight
5. **Moisture Content Analysis**: This test measures the level of moisture in the paper or paperboard, which affect the other properties of paper such as printing, absorbency etc. The amount of moisture present in the material can have a significant impact on its strength, dimensional stability, and overall performance. Therefore, it is essential to handle and store the packaging materials correctly to prevent any damage caused by moisture.
6. **Cobb Value**/Cobb Absorbency/ Water Absorptiveness Test: This test measures the ability of the paper or paperboard to absorb moisture. It determines the amount of water that can be absorbed by a paper surface in a specified time period. It helps to evaluate the material's resistance to water penetration and its suitability for moisture-sensitive products.

   The apparatus used for the Cobb test consists of a short, metal cylinder with a cross-section of 100 cm² (11.2 square inches) internal diameter. During the Cobb test, a circular or square specimen of the paper is placed on a flat platform, forming a tray-like structure. The specimen is then exposed to a specified amount of water for a set time, usually 1 minutes. After the exposure period, any excess water is carefully removed, and the wet specimen is weighed. The Cobb value is calculated by subtracting the weight of the dry specimen from the weight of the wet specimen. The resulting weight difference represents the amount of water absorbed by the paper in grams per square meter (g/m²).

Fig: Cobb Apparatus

7. **The Edge Crush Test** (ECT): This test measures the strength of packaging materials like corrugated boards in the direction perpendicular to the plane. The test determines how much force is needed to crush the edges of these boards. This information is important for packaging that involves stacking and protection.
8. **Compression Test**: A compression test involves applying a compressive force to a sample of paper or paperboard in a controlled manner until it deforms or fractures. This test measures the strength of a material to withstand compression. The compression test assesses how much pressure a material can withstand before it gets deformed or crushed. This is particularly important for packaging materials that will be stacked or stored.
9. **Puncture Resistance Test**: The puncture resistance test for paper is a method used to assess the strength and durability of paper against piercing or puncture forces. Puncture resistance refers to the ability of paper to withstand the force or pressure applied by a sharp object without tearing or puncturing. During the test, the paper sample is clamped in place and a puncture probe is slowly applied with a constant speed until the paper punctures. The force required to puncture the paper is recorded and used to calculate the puncture resistance of the paper.

   The unit of measurement: Newtons (N) or pounds-force (lbf) or pounds per square inch (psi) or kilopascals (kPa)

Fig: Puncture Resistance Tester

10. **pH value**: The pH value measures the acidity or alkalinity of paper. It is important because an inappropriate pH level can lead to degradation or yellowing of the paper over time.
11. **Ash:** The ash content test determines the amount of inorganic materials present in the paper, which can indicate the cleanliness and purity of the paper fibers.
12. **Gloss:** Gloss is assessed to determine the reflectivity and shine of the paper surface. It plays a crucial role in print quality and appearance.
13. **Opacity:** Opacity testing helps determine the degree of light transmission through the paper. Higher opacity indicates better coverage and less show-through.
14. **Oil absorbency:** Oil absorbency measures the paper's ability to absorb and retain oil-based substances. This property is important in various applications, such as blotting paper or absorbent pads.
15. **Resistance of writing papers to feathering:** Resistance to feathering assesses how well writing papers resist ink spreading or feathering, ensuring clean and sharp lines.
16. **Sizing:** Sizing tests evaluate the presence and effectiveness of sizing agents, which control the ink absorbency of the paper. Proper sizing prevents ink from bleeding or smudging, resulting in better print quality.
17. **Water absorbency:** Water absorbency determines the paper's ability to absorb and hold water, which is important for specific applications such as water color paper or towel tissue.

Strength tests of paper

Strength tests are essential for evaluating the mechanical properties of paper. The common strength tests of paper are

1. Tensile strength and stretch (Elongation)
2. Breaking length
3. Bursting strength
4. Tearing resistance
5. Folding endurance

Tensile strength and stretch, also known as elongation, measure the paper's ability to withstand pulling forces without breaking. It indicates the maximum load the paper can bear before reaching its breaking point. Breaking length, on the other hand, quantifies the paper's strength by measuring the length of paper that can withstand its weight before breaking. Bursting strength evaluates the resistance of paper against pressure or impact. It determines the ability of the paper to withstand forces that cause it to burst or rupture. Tearing resistance measures the force required to tear the paper apart, indicating its resistance to tearing. Lastly, folding endurance examines the paper's ability to withstand repeated folding without cracking or breaking. These strength tests collectively provide valuable insights into the durability and performance of paper, aiding in its appropriate selection for various applications.

1. **Bursting Strength Test**: The purpose of the bursting strength test is to measure the ability of a material to resist rupture when pressure is applied uniformly to a confined area. This is important because it helps evaluate the material's durability and reliability during handling and transportation, and ensures that it can withstand external forces without bursting.

The Jumbo Muller Tester is a tool that is typically used to perform the bursting strength test. This device can be operated manually or with a motor. A diaphragm constructed of pure gum rubber is subjected to hydraulic pressure during the test, which is transferred through glycerine or compressed air. The diaphragm is in direct contact with the test paper. The pressure is steadily increased throughout the test until the paper tears. The bursting strength of the paper is determined by recording the highest pressure at which the rupture takes place. The test results are typically expressed in units such as kilograms per square centimetre (kg/cm^2), pounds per square inch (psi), or kilopascals (kPa).
Standards: ASTM D774, ISO 2758, Indian Standard IS: 1060-Part-I (1987)
Equipment: Bursting strength tester

$$\text{Burst factor} = \text{Bursting strength in } g/cm^2 / \text{Substance in } g/m^2$$

Fig: Bursting Strength Tester

2. Tear Resistance Test: This test assesses the material's ability to resist tearing when subjected to an applied force. It measures the force required to propagate a tear in the material and evaluates its toughness and resistance to tearing. Tearing resistance is typically measured using standardized methods such as the Elmendorf method or the Trapezoid method. Units = gram (g) or millinewton (mN)

Fig: Tear Resistance Tester

3. **Tensile Strength Test**: This test is essential in measuring the maximum load or force that a material can handle before breaking or tearing apart. It evaluates the strength and durability of the material, especially its ability to resist tensile stress.
Standards: ASTM D689, ISO 1974, Indian Standard IS: 1060-Part-I (1987)
Equipment: Universal Testing Machine
Units = kilonewton per meter (kN/m) or newton per millimeter (N/mm)

Fig: Universal Testing Machine

4. **Breaking length:** Breaking length refers to the length of paper under tension at which it breaks. It is a measure of the paper's strength and is calculated by dividing the tensile strength by the grammage (weight per unit area) of the paper.
   Breaking length = Tensile strength in kg/cm width of test piece x 100000/ Substance in g per square metre
5. **Folding Endurance Test**: This test assesses the ability of the paper or paperboard to withstand repeated folding without breaking or weakening is the main purpose of the folding endurance test. This test is particularly crucial for packaging materials that undergo frequent folding, such as cartons and boxes. The number of folds achieved before the paper breaks is recorded as the folding endurance of the paper.
   Standards: TAPPI T511, ISO 5626, Indian Standard IS: 1060-Part-I (1987)
   Equipment: Folding endurance tester

Fig: Folding Endurance Tester

Testing of plastic food packaging materials

It is essential to test plastic food packaging materials to confirm their safety and compatibility for food contact applications. Here are some commonly conducted tests for plastic food packaging materials:

1. **Migration Testing**: This test determines if any harmful substances migrate from the packaging materials into the food. The plastic packaging material will be in contact with a food simulant under controlled conditions, and the simulant is then analysed for the presence of any leached chemicals from the packaging material. All packaging materials of plastic origin shall pass the prescribed overall migration limit of **60mg/kg or 10mg/dm²** when tested as per IS 9845 with no visible colour migration. The determination of migration in simulants is to be carried out using the simulants given in Table 4.

Table 4: List of food simulants

Simulant	Description
Simulant 'A'	Distilled water or water of equivalent quality
Simulant 'B'	3 percent acetic acid (w/v) in aqueous solution (using Simulant 'A')
Simulant 'C^1'	10 percent ethanol (v/v) in aqueous solution for foodstuffs having alcohol less than 10 percent (using the simulant 'A')
Simulant 'C^2'	50 percent ethanol (v/v) in aqueous solution for foodstuffs having alcohol more than 10 percent and less than 50 percent (r/v) (using the simulant 'A')
Simulant 'D'	n-heptane - shall be freshly distilled before use
Simulant 'E'	Rectified olive oil or mixture of synthetic triglycerides or sunflower oil

Note: Simulant 'E' suggested by EEC for fatty foods need not be considered at present.

Table 5: Classification of Foods and Selection of Simulant

Type	Description	Example	Simulant
I	Aqueous, non-acidic foods (pH > 5) without fat	Honey, mineral water, sugar syrups molasses, skimmed milk, rusgulla. infusions, murabba, yeast paste etc.	A
II	Aqueous, acidic foods (pH < 5) without fat	Fruit juices, squashes, fruit chunks or puree, vinegar, jams, jellies, carbonated beverages, lemonade, processed vegetables, rennet, preparations of soups, broths, sauces, RTS beverages, etc.	B
III	Alcoholic beverages:		

	1) Alcohol concentration less than 10 percent	Beer and some pharmaceutical syrups	C^1
	2)Alcoholic beverages: Alcohol concentration above 10 percent	Wine, brandy, whiskey, arrack, and other alcoholic drinks	C^2
IV	Oils, fats, and processed dry foods with surface fat or volatile oil	Vegetable oils, ghee, vanaspati, cocoa butter, lard, biscuits, spice powder, snacks, and savory, chocolate, caramels, malted foods, egg powder, tea, coffee powder, confectionery, fried and roasted nuts, etc.	D
V	Non-acidic foods (pH > 5) or high fat and having high moisture content	Butter, bread, pastry, shortcrust cakes, milk-based sweets, ice-cream, moist and fatty confectionery products	A and D
VI	Acidic foods (pH < 5) or high fat and having high moisture content	Pickles, ketchup, cheese, curd, fresh and processed meat and fish products, sauces having fat, frozen foods, mayonnaise, etc.	B and D
VII	Dry processed foods without fat	Cereals and pulses, dehydrated vegetables and fruits, dried yeast, corn flakes, salt, sugar, milled products, barley powder, oats, vermicelli, spaghetti, etc.	No end test

2. **Barrier properties**: Testing the packaging material's barrier characteristics determines how well it can prevent passage of gases and other substances that could degrade the food's quality and shorten its shelf life, such as oxygen, moisture, and light. Tests like Oxygen Transmission Rate (OTR) testing and Water Vapor Transmission Rate (WVTR) measurement are crucial, when analysing the barrier properties of plastic food packaging materials.

   2a. **Oxygen Permeability/Oxygen Transmission Rate (OTR) Testing:** Testing for oxygen permeability determines the rate at which oxygen can pass through the packaging material. A sample is put in a test cell after the material is made into a barrier film or sheet. One side of the sample is in contact with an environment that is rich in oxygen, while the other side is in contact with an environment that is devoid of oxygen. Using various techniques like coulometric, manometric, or optical sensors, the amount of oxygen that permeates the substance is measured.

The Gas Transmission Rate (GTR) test, as per ASTM D 1434 and BS 2782 Method 514A, Procedure 2, is conducted to measure the permeability of plastic films to gases. Gas permeability is defined as the volumetric rate of gas transmission, under a known pressure differential, through a known area of the film. It is typically expressed as the transmission rate in millilitres per square meter per 24 hours per atmosphere ($ml/m^2/24$ hrs.atm). The permeability of plastic materials to different gases is significant in various applications. Sometimes, it is desirable to achieve a specific degree of permeability to certain gases rather than producing a completely impermeable packaging.

The procedure for conducting the test is as follows: Unscrew the bolts holding down the upper half of the permeability cell and remove it. The apparatus should have the 'X' volume controlling insert correctly fitted in the lower half of the cell. Place a dried circular filter paper (Whatman No.1) on top of the insert, and spread the film sample over the filter paper. Replace the upper part of the permeability cell and tighten the bolts using a box spanner. Turn on the test gas and flush the cell with a brisk stream of gas for a few seconds. Then reduce the flow to a slow rate to ensure no air can diffuse back into the cell (approximately 1 bubble/second through liquid paraffin). Evacuate the lower part of the cell using a vacuum pump capable of reaching a vacuum of at least 0.2 mm Hg. Connect a vacuum gauge (Tipping McLeod gauge) between the apparatus and the vacuum pump. Tilt the apparatus to the left until the mercury runs out of the reservoir into the manometer, partially filling it. Return the apparatus to its normal position. Immediately set the movable scale to a convenient starting point, start a stopwatch, and begin taking readings at suitable time intervals. Repeat the test with other samples.

The calculation for Gas Transmission Rate (GTR) is as follows:

$$GTR = (273 \times pV \times 24 \times 10^4) / (A \times T \times P)$$

Where: GTR is the Gas Transmission Rate in $ml/m^2/24$ hrs at a pressure difference of 1 atmosphere, p is the rate of pressure change in the capillary in cm Hg per hour.

V is the total volume in ml of the space between the lower surface of the film and the top of the mercury column in the capillary. It can be expressed as:

(a) The volume of the cell cavity (e.g., 5, 10, 15, or 20).

(b) The volume of the capillary tube above the mercury level halfway through the test. As the cross-sectional area of the capillary is 0.018 cm^2, this volume will be 0.018X, where X is the length of the capillary above the mercury at the halfway point in cm.

(c) The 'free space' volume of the filter paper, which can be taken as 0.24 ml.

A is the area of the specimen in cm^2.

T is the temperature in degrees Kelvin (273 + °C).

P is the pressure difference, which is 1 atmosphere (76 cm Hg).

2b. **Water Vapour Transmission Rate (WVTR) Measurement**: WVTR test measures the rate at which water vapour can flow through the packing material. A sample of the substance is fixed inside a test cell, one side of which is in touch with a regulated humid environment and the other with a dry environment. Over a predetermined time period, the sample's weight gain or loss as a result of water vapour permeation is measured. Different methods, such as gravimetric, infrared, or electrolytic sensors, can be used to measure WVTR. It aids in evaluating the material's capacity to keep the food inside the packaging dry.

The Water Vapor Transmission Rate (WVTR) test, according to ASTM E96-66, is used to determine an important property of packaging materials with a thickness under 3 mm. This property is crucial when selecting barrier materials for hygroscopic foods. WVTR is measured as the quantity of water vapor in grams that can transmit from one side to the other of a film with an area of one square meter in 24 hours. The test is conducted while maintaining a relative humidity (RH) difference of 90±2 % between the two sides at a temperature of 37 °C.

To perform the test, the following apparatus and materials are required:

Test Dishes: Shallow Aluminium dishes with a diameter as large as possible should be used. A wax seal is applied between the test piece and the dish to prevent water vapor transmission at or through the edges of the sheet.

Desiccant: Fused calcium chloride is typically used as the desiccant inside the test dish. The desiccant helps maintain the desired RH conditions. For the standard test, the RH condition is 37 °C and 92 % RH, with the desiccant providing 2 % RH.

Saturated Solution of Potassium Nitrate: This solution is used to create a 94 % RH environment.

Sealing Wax: A combination of microcrystalline wax and paraffin wax in a 60:40 ratio is used as sealing wax.

The WVTR is determined by sealing the open end of the test dish containing the desiccant using the test specimen. The dish is then exposed to the desired RH and temperature conditions. In the standard test, the conditions are 37 °C and 92 % RH. The desiccant inside the dish helps maintain a 2 % RH differential. The weight increase of the desiccant over a known period of time gives the amount of water vapor transmitted through the specimen.

The WVTR is calculated using the formula:

$$WVTR = (Q \times 24 \times 90) / (A \times t \times (H1 - H2))$$

Where: WVTR is the Water Vapor Transmission Rate in $g/m^2/24hrs$, Q is the quantity of water vapor that passes through the test material of area A m^2 for t hours, H1 and H2 are the relative humidity on either side of the test specimen, A is the area of the test specimen in cm^2.

3. **Yield**: It involves calculating the amount of area provided by a given mass of a film with a specified thickness. There are two calculations involved: the actual yield (Ya) and the nominal yield (Yn).

   To determine the actual yield, divide the area (A) of the film in square centimeters by the mass (M) of the film in kilograms.

The actual yield (Ya) is calculated using the following formula:

$$Ya,\ cm^2/kg = A\ (\text{Area in } cm^2)\ /\ M\ (\text{Mass in Kg})$$

To determine the nominal yield, divide 1000 by the product of the density (d) of the film in grams per milliliter and the nominal thickness (t) of the film in centimeters.

The nominal yield (Yn) is calculated using the following formula:

$$Yn,\ cm2/kg = 1000\ /\ (d * t)$$

4. **Density**: Condition the specimen by submerging it in boiling water for 30 minutes. Afterward, allow it to condition at a temperature of 27±2ºC for a minimum of 24 hours to ensure it is free of bubbles. Prepare a clean Drechsel bottle and fill it with 100 ml of dilute alcohol, which should have a density ranging from 0.8 to 0.82 g/ml at 27ºC. Immerse the bottle in a water bath maintained at 27±0.1ºC until temperature equilibrium is reached. Carefully lower the test specimen into the dilute alcohol, ensuring that no air bubbles adhere to it. With continuous stirring, begin adding distilled water in increments of 0.2 ml from a burette. Continue this process until the specimen remains suspended in the solution, well away from the glass surface. At this point, the density of the solution and the specimen are assumed to be the same. Determine the density of the solution at 27±0.1ºC using a pyknometer or a specific gravity bottle.
5. **Mechanical Strength**: It is essential to test the mechanical strength of plastic food packaging materials to make sure that they can withstand external forces and safeguard the food contents throughout handling, transit, and storage. To determine the mechanical strength of plastic food packaging materials, the following tests are frequently used:

   3a. **Tensile Strength & Elongation at break**: Tensile strength test measures the maximum load or force a plastic packaging material can withstand before breaking or undergoing permanent deformation. It helps determine the material's strength and resistance to stretching or pulling forces.

   To perform a tensile strength and elongation test on plastic and paper samples, you will need a testing machine that meets certain specifications. The machine should be capable of maintaining a constant rate of traverse on one grip. The load scale of the machine should be accurate within 1% or 0.1 N, whichever is less. The load range should be such that the breaking load of the test pieces falls between 15 % and 85 % of the full-scale reading. For plastic samples, the gauge length of the specimens should be 50±1 mm in length and 15 mm in width. The traverse speed of the machine should be set at 500 mm/min for plastic samples. To prepare the samples, cut them in both lengthwise and crosswise directions. Prepare five samples each for both directions. The total length of each sample should be at least 50 mm longer than the gauge length. Measure the thickness of the samples using a micrometer. Next, condition the specimens and clamp them between the grips of the testing machine. Switch on the machine at the pre-adjusted speed. During the test, record the load and elongation at the point of breakage.

   To calculate the tensile strength at break, use the formula:

   Tensile Strength = Load at Break (kgf) / Cross-Sectional Area (cm^2).

The cross-sectional area can be determined by multiplying the width of the sample by its thickness in centimeters. For elongation at break, use the formula: Elongation at Break (%) = (L2 - L1) / L1 * 100

where L1 is the original length between the reference lines and L2 is the length at the point of breakage.

Calculate the mean values for both lengthwise (MD) and crosswise (CD) samples from the five results obtained for each parameter.

3b. **Seal Strength Test**: For packaging materials with seals, this test evaluates the strength of the seal. It measures the force required to separate or break the seal and ensures its integrity during handling, transportation, and storage.

Table 1: Physico-chemical properties of packaging films

Material	**Elongation (%)**	**Tensile Strength (MPa)**	**Water Vapor Transmission Rate (WVTR, g/m²/day)**	**Oxygen Transmission Rate (OTR, cc/m²/day)**
LDPE	High	Low	High	Low
HDPE	Medium	Medium	Low	Low
PP	High	Medium	Low	Low
PS	Low	High	Low	Low
PA	Medium	High	Low	Low
EVOH	Low	High	Very Low	Very Low
PET/PE	Medium	High	Low	Low
PLA	Medium	Medium	Medium	Medium
PET	Low	High	Low	Low

*Please note that the table provides a general overview of the properties and can vary depending on the specific grade, processing conditions, and additives used in the packaging films.

6. **Impact Resistance test**: The Impact Resistance test is conducted to measure the film's ability to withstand fracture under shock. It determines the material's toughness, which is a combination of its deformation and breaking properties. To perform the test, the film is securely held flat using a vacuum clamp. A dart, consisting of a 3.81 cm diameter hemispherical head and a 0.64 cm diameter shaft (11.5 cm long), is used. The dart can have additional removable masses attached to it. The head of the dart is typically made of aluminium, phenolic plastic, or a low-density material with similar hardness. The shaft is attached to the centre of the flat surface of the head, with its longitudinal axis at 90 degrees. The shaft is made of aluminium and has a 1.27 cm long steel tip at the end to support the dart in the adapter. The apparatus required for this test is an Impact Resistance Tester with a vacuum clamp. It should have an electromechanical or similar device capable of supporting and instantaneously releasing the dart, allowing it to fall freely onto the test specimen in the specimen holder. Stainless steel detachable masses are used to adjust the weight of the dart. It is suggested to have twenty-four masses, each weighing 15.0 ± 0.1 g. These masses should have dimensions of approximately 3 cm in diameter, with a hole in the centre measuring 0.61 cm in diameter and a thickness of 0.25 cm. Additionally, five masses of 5.0 ± 0.1 g each, following the same

construction specifications as the previous masses, except for the altered thickness to achieve the specified mass, are recommended. During the test, the dart is dropped vertically onto the centre of the film using the electro-magnetized holder. The weight of the dart is gradually increased until 50 % of the tested specimens fail, and the weight at which this occurs is reported as the impact failure weight.

7. **Tear Resistance test**: The Tear Resistance test (initiation method) is used to measure the ability of a material to resist tearing when subjected to tension. The test specimen is designed in a specific shape, where a right-angled discontinuity is created in one of its long edges, and tension is applied to the ends to initiate tearing across the width of the specimen. The tear strength is then calculated by dividing the maximum recorded tension in Newton by the thickness of the test piece in millimetres. The apparatus required for this test is a Tensile Strength Tester with a grip separation rate of 250±25 mm/min. The test is performed using a specimen prepared according to Die 'C'. The procedure for conducting the Tear Resistance test is as follows: Determine the thickness of the test piece. Clamp the ends of the test piece symmetrically in the grips of the tensile strength tester, ensuring that the initial grip separation is 65±5 mm. Start the test by separating the grips at a rate of 250±25 mm/min. Record the maximum force registered during the test.
8. **Puncture Resistance test**: The Puncture Resistance test is performed to determine the ability of a material to withstand puncture. The test involves using a specimen that fits between two flat metal plates with concentric openings. One plate has a 6 mm diameter circular opening for the passage of a stainless-steel needle, while the other plate (lower) has a 25 mm diameter opening to allow elongation of the specimen when subjected to the pressure of the needle. The stainless-steel needle used in the test has a diameter of 5 mm and is machined to produce a taper with an inclined angle of 12 ºC. The tip of the needle is rounded to a radius of 0.8 mm. The needle is positioned perpendicularly to the specimen so that the point contacts the specimen through the smaller hole in the plate. The puncturing operation is performed at a continuous rate of approximately 500 mm/min. During the test, the maximum force required to puncture the specimen is measured to the nearest 2 N. The puncture resistance is calculated by dividing the puncturing force by the thickness of the specimen and is recorded in units of Newton/meter.

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Active and intelligent packaging techniques for smart packaging application

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Introduction

The capital investment and requirement of good grade fish for the application of MAP, build up the researchers to invent advanced methods for keeping quality of food. Smart packaging such as active and intelligent packaging technologies, is considered as an innovative packaging technique for the development of wide variety of products with competitive cost and achieved a great position in the preservation of different food systems. It is a fast-growing technology with a market demand projected to reach $28 billion by 2024, which will outgrowth superior market acceptance for varieties of product types.

Smart Packaging Technologies

Traditional packaging concepts are limited in their ability to prolong the shelf-life of fish products. This can be overcome by adopting vacuum and modified atmosphere packaging technologies. However, these require capital investment apart from requirement of fresh food grade gas in case of MAP. This promoted the researchers to develop new and improved methods for maintaining food quality and for extending shelf life. Active and intelligent packaging, which are regarded as smart packaging technologies, is one such advanced packaging technique which is finding its way in the preservation of various food systems including fish and shellfish. The market for active and intelligent packaging systems are fast growing and their demand is projected to reach $10.5 billion by 2021, fuelled by the development of new generations of products and more cost competitive prices, which will spur greater market acceptance for many product types.

Basis of Smart Packaging

Packaging has four basic functions, viz., Containment, convenience, protection and communication. Conventional packaging systems offer limited protection and communicates only through the labelling. It will not provide any information about the quality and safety of the product. Active and intelligent packaging enhances the protection and communication functions, respectively. The following graphics explains how this enhanced functionality works.

Active Packaging

Active packaging is an innovative concept that can be defined as ‘a type of packaging that changes the condition of the packaging and maintains these conditions throughout the storage period to extend shelf-life or to improve safety or sensory properties while maintaining the quality of packaged food’ (Vermeiren et al. 1999; Rooney, 1992; Ahvenainen, 2003). Active packaging (AP) performs some desired role other than providing an inert barrier between the product and external conditions and combines advances in food technology, bio-technology, packaging and material science, in an effort to comply with consumer demands for ‘fresh like’ products. This involves incorporation of certain additives into the packaging film or within packaging containers with the aim of maintaining and extending product shelf life. Active packaging technique is either scavenging or emitting systems added to emit (e.g., N_2, CO_2, ethanol, antimicrobials, antioxidants) and/or to remove (e.g., O_2, CO_2, odour, ethylene) gases during packaging, storage and distribution. In case of a gas-scavenging or emitting system, reactive compounds are either contained in individual sachets or stickers associated to the packaging material or, more recently, directly incorporated into the packaging material. Major active packaging techniques are concerned with substances that absorb oxygen, ethylene, moisture, carbon dioxide, flavours/odours and those which release carbon dioxide, antimicrobial agents, antioxidants and flavours. The most important active packaging concepts for fishery products include O_2 scavenging, CO_2 emitters, moisture regulators, antimicrobial packaging concepts, antioxidant release are discussed here.

Table 1: Examples of active packaging systems

Packaging System	**Description**
Oxygen scavengers	These active packaging systems remove oxygen from the package, helping to extend the shelf life of oxygen-sensitive foods.
Carbon dioxide emitters	These systems release carbon dioxide inside the package, which helps inhibit the growth of spoilage microorganisms and maintain product freshness.
Ethylene absorbers	Ethylene is a gas that accelerates the ripening process of fruits and vegetables. Ethylene absorbers remove this gas from the package, extending the shelf life of produce.
Moisture control	These systems maintain the moisture level inside the package, preventing the food from becoming too dry or moist.
Antimicrobial packaging	These packaging systems incorporate antimicrobial agents that help inhibit the growth of bacteria and other microorganisms, preserving the quality and safety of the food.
Flavour and aroma absorbers	These systems absorb and neutralize unwanted flavours and aromas, helping to maintain the sensory attributes of the food.

O_2 scavenger

Fish products are highly susceptible to oxygen as it leads to the growth of aerobic microorganisms and oxidation which causes undesirable colour changes (e.g. discolouration of pigments such as myoglobin, carotenoids), off-odours and flavours (e.g. rancidity as a result of lipid oxidation) and leads to loss of nutrients (e.g. oxidation of vitamin E, β-carotene, ascorbic acid) which adversely affects the quality. Therefore, control of oxygen levels in food package is important to limit the rate of such deteriorative and spoilage reactions in foods. Although O_2- sensitive foods can be packed appropriately using modified atmosphere packaging (MAP) or vacuum packaging, these technologies do not always remove O_2 completely. Moreover, the O_2 that permeates through the packaging film cannot be removed by these techniques. By use of an O_2-scavenger, which absorbs the residual O_2 after packaging, quality changes of O_2-sensitive foods associated with low residual oxygen levels can be minimized. O_2 scavengers were first commercialized in the late 1970s by Japan's Mitsubishi Gas Chemical Company (Ageless®). O_2 scavengers are able to eliminate oxygen contained in the packaging headspace and in the product or permeating through the packaging material during storage. O_2 scavengers are efficient in preventing discolouration of fresh and cured fish, rancidity problems, mould spoilage of intermediate and high moisture products or oxidative flavour changes. O_2 scavenging concepts are mainly based on iron powder oxidation, ascorbic acid oxidation, photosensitive dye oxidation, enzymatic oxidation (e.g. glucose oxidase and alcohol oxidase), unsaturated fatty acids (e.g. oleic or linolenic acid), rice extract or immobilized yeast on a solid substrate. Structurally, the oxygen scavenging component of a package can take the form of a sachet, label or film (incorporation of scavenging agent into the packaging film, which avoids the accidental consumption of sachet), card, closure liner or concentrate.

CO_2-emitter

The method of preserving food products using CO_2 is not new. Modified atmosphere packaging which mainly employs the gases like CO_2, N_2 and O_2 has been in use for extending the freshness of fish products since many decades. The high CO_2-levels (10-80 %) are desirable for moist food products like fish, shellfish and meat products which inhibit surface microbial growth and thereby extend shelf-life. The overall effect of CO_2 is to increase both the lag phase and the generation time of spoilage microorganisms. Over the years this has been achieved by modified atmosphere packaging, in which a package is flushed with a mixture of gases including carbon dioxide at sufficient levels. However, the concentration of CO_2 within the package will change due to the partial dissolution of CO_2 in to the product and permeability through the packaging film. Normally, the permeability of carbon dioxide is 3–5 times higher than that of oxygen in most plastic films, so it must be continuously produced to maintain the desired concentration within the package. A carbon dioxide generating system can be viewed as a technique complimentary to MAP to overcome the drawbacks. The potential of CO_2 in MAP and more recently generation of CO_2 inside the packaging system have been explored in relation to a number of commodities for their successful preservation. Such systems are based on sodium bicarbonate, ferrous carbonate, ascorbate, citric acid etc. Sodium bicarbonate, when used together with ascorbic acid or citric acid in the presence of sufficient moisture generates CO_2. This technique is very simple and economical as it does not require any costly equipment and pure gases.

Moisture regulator

Wet food has a high vapour pressure, and hence the humidity in the food package increases. Apart from this a certain amount of moisture will be trapped in the packaging due to temperature fluctuations in high equilibrium relative humidity food packages or the drip of tissue fluid from cut fish and fish products. If it is not removed, this moisture will be absorbed by the product or condense on the surface, which cause microbial spoilage and/or low consumer appeal. An excessive level of water causes softening of dry crispy products. On the other hand, excessive water evaporation through the packaging material might result in desiccation of the packed foodstuffs. It may also favour rancidity of lipids. The controlling of this excess moisture in food package is important to lower the water activity of the product, thereby suppressing microbial growth and preventing foggy film formation. Apart from this, removal of drip from chilled fish and melting water from frozen fish and shellfish makes the package more attractive to the consumer. An effective way of controlling excess water accumulation in a food package is the use of high barrier film material with the appropriate water vapour permeability and use of moisture scavenger, such as silica gel, molecular sieves, natural clays, calcium oxide, calcium chloride and modified starch etc. Among these, silica gel is the most widely used desiccant because it is not toxic and non-corrosive. Drip-absorbent sheets for liquid water control in high aw foods such as fresh fish and shellfish basically consist of a super absorbent polymer in between two layers. Large sheets are also used for absorption of melted ice in packages of seafood during air transportation. The preferred polymers for absorbing water are polyacrylate salts and graft copolymers of starch. For dried fish applications, desiccants such as silica gel, molecular sieves, CaO and natural clays (e.g. montmorillonite) packed in sachets can be used.

Antimicrobial packaging

A significant portion of fish deterioration is related to microbial contamination and development, which shortens food shelf life and raises the possibility of food borne illness. The use of antimicrobial chemicals or salts as well as heat processing, drying, freezing, refrigeration, irradiation, and MAP are traditional means of protecting fish from the effects of microbial development. However, some of these methods can't be used on products made from fresh fish because they change the freshness of the fish. A rapidly growing active packaging, particularly for fish and poultry items, is antimicrobial packaging.

Antimicrobial films primarily work by releasing antimicrobial substances into food, which prolongs the lagged phase and shortens the growth phase of microbes, hence extending shelf life and maintaining product quality and safety. Antimicrobial agents may be surface modified, immobilised, coated, integrated, or immobilised onto packaging materials to give antimicrobial activity. In order to prevent the growth of bacteria on food surfaces, promising active packaging solutions include antimicrobial agents into the materials used to package food. The preservative is liberated from the active substance and acts directly when it comes into touch with a moist food or a food that has a liquid-like consistency. In both situations, the system's goal is to prolong the packed food's shelf life by preventing microbial development and maintaining its qualities. Acid anhydride, alcohol, bacteriocins, chelators, enzymes, organic acids, and polysaccharides are only a few of the classes of antimicrobials. In addition to these, chitosan and other derivatives from plants and fishing waste can be used in the packaging system as antimicrobials.

Antioxidant release

Antioxidants are frequently employed as food additives to enhance lipid oxidation stability and extend shelf life, mostly for dried goods and O_2-sensitive foods like fish due to their high content of unsaturated fatty acids. Antioxidants can also be combined into plastic films to stabilise the polymer and prevent deterioration. BHT, a butylated hydroxytoluene, is frequently used in packaging films as an antioxidant. BHT's propensity to accumulate in human adipose tissue, however, has raised some questions about the physiological implications of use. As a result, less artificial antioxidants are being used in interaction with food. Therefore, it is preferable to use natural antioxidants that are safe. The most prevalent natural antioxidants are vitamins E and C, and researchers are still exploring how to incorporate them into polymer films to have antioxidative benefits. Vitamin E has great solubility in polyolefins and is stable during processing. In addition to these, research is being done on the use of natural antioxidants derived from plant and animal sources as packaging for antioxidants.

Active packaging systems with dual functionality

The employment of multiple function active systems is a more advanced method of increasing the life stability of packaged goods utilising active packaging systems. For instance, the storage of packaged foods is greatly increased when oxygen scavengers are combined with carbon dioxide and/or antibacterial / antioxidant releasing systems. When oxygen is removed from packages using an O_2 scavenger alone, a partial vacuum is created, which could cause flexible packaging to collapse. In addition, when a package is flushed with a gaseous mixture that includes carbon dioxide, the CO_2 dissolves in the product, creating a partial vacuum, causes the permeation of CO_2 through the packaging film. However, in order to prevent the growth of surface microbes and increase shelf life, high CO_2 levels are required. The self-working devices, which absorb O2 and generate enough CO_2, will be promising in such situations for increasing the shelf life of goods, particularly fishery items. In order to extend the shelf-life of various food systems, ICAR-CIFT has developed the technology for these active packaging systems.

Intelligent Packaging

Intelligent packaging detects certain characteristics of food it contains or the environmental conditions in which it is placed and notifies the people of the state of these properties. The attributes of intelligent packaging could be employed to check the efficiency and reliability of active packaging systems. Intelligent packaging has been described as ‘packaging technology that can monitor the state of packaged foods to issue details about the quality of the packaged food during transport and storage’. A variety of indicators such as temperature, time temperature, pack integrity, microbial growth, product authenticity and freshness are of interest to the fish packaging industry.

Time-temperature indicators

The basic idea behind this indicator is that the quality of food deteriorates more rapidly at higher temperature due to biochemical and microbial reactions. Operation of TTIs is based on mechanical, chemical, electrochemical, enzymatic or microbiological change usually expressed as a visible response in the form of a mechanical deformation, colour development or colour movement. The visible response thus gives a cumulative indication of the storage temperature to which the TTI has been exposed. Essentially TTIs are small tags or labels that keep track of time-temperature histories to which a perishable product like fish is exposed from the point of production / manufacture to the retail outlet or end-consumer. Their use in fish and shellfish products offers enormous potential where monitoring of the cold distribution chain, microbial safety and quality are of paramount importance. Hence, a time-temperature indicator or integrator (TTI) may be defined as a small measuring device that shows a time and temperature dependent, easily, accurately and precisely measurable irreversible change that reflects the full or partial temperature history of a food product to which it is attached.

Leakage indicator

The development of improved methods to determine food quality such as freshness, microbial spoilage, oxidative rancidity or oxygen and/or heat induced deterioration is extremely important to food manufacturers. In order to maximise the quality and safety of foodstuffs, prediction of shelf-life, based on standard quality control procedures is normally undertaken. Replacement of such time-consuming and expensive quality measurements with rapid, reliable and inexpensive alternatives has led to greater efforts being made to identify and measure chemical or physical indicators of food quality. Determination of indicator headspace gases provides a means by which the quality of a fish and meat product and the integrity of the packaging in which it is held can be established rapidly and inexpensively. One means of doing so is through the intelligent packaging incorporating gas sensor technology for sensing the oxygen and CO_2, as these two are the most commonly used gases. The monitoring of these gases in the package helps in establishing the food quality. The profiles of oxygen and carbon dioxide can change over time and are influenced by product type, respiration, packaging material, pack size, volume ratios, storage conditions, package integrity etc. A number of analytical techniques are available to monitor gas phases in MAP products. Instrumental techniques such as GC and GC/MS require breakage of package integrity and are time-consuming and expensive. Portable headspace oxygen and/or carbon dioxide gas analysers use 'minimally destructive' techniques (packages can be re-sealed) but tend not to be applicable to real-time, on-line control of packaging processes or large-scale usage. An optical sensor approach offers a realistic alternative to such conventional methods. They can be used as a leak indicator or to verify the efficiency of O_2- scavenger, CO_2 emitter or MAP systems. Most of these indicators assume a colour change as a result of a chemical or enzymatic reaction. The most common redox dye used for leak indicators is methylene blue.

Freshness indicators

An ideal indicator for the quality control of packaged food products should indicate the spoilage or lack of freshness of the product, in addition to temperature abuse or package leak. The information provided by intelligent packaging systems on the quality of food products may be either indirect (e.g deviation from storage temperature and changes in packaging O2/CO2 concentration may imply quality deterioration through established correlation) or direct. These freshness indicators are based on the detection of volatile metabolites produced during ageing of foods, such as CO2, diacetyl, amines, ammonia and hydrogen sulphide. Freshness indicators provide direct product quality information resulting from microbial growth or chemical changes within a food product. Microbiological quality may be determined through reactions between indicators included within the package and microbial growth metabolites. The chemical detection of spoilage of fish and the chemical changes in fish during storage provide the basis for which freshness indicators may be developed based on target metabolites. Total volatile nitrogenous compounds and biogenic amines such as histamine, putrescine, tyramine and cadaverine have been implicated as indicators of fish product decomposition. As the biogenic amines are toxic compounds and they cannot be detected sensorily, the development of effective amine indicators would be beneficial. Hydrogen sulphide, a breakdown product of cysteine, with intense off-flavours and low threshold levels is produced during the spoilage of fish and shellfish by a number of bacterial species. It forms a green pigment, sulphmyocin, when bound to myoglobin and this pigment can be used as a basis for the development of a freshness indicator in red meat fishes. Normally, the freshness indicators are incorporated into the packaging film, which reacts with volatile amines and other indicating agents produced during the storage of fish and other seafoods, and the freshness is indicated by a colour change.

Future aspects

Smart packaging systems proved to be an effective mechanism to improve the food safety and shelf-life extension of the packaged foods. However, these technologies are in development stage in the seafood sector and needs ongoing researches and continued innovations to anticipate future advancement in food quality, safety and stability.

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Nanomaterials in food packaging

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Introduction

Food and beverage industry is in search of novel technologies to enhance the quality, safety and storage life of their products. Nanotechnology became immediately popular in the food sector, because of its potential to develop materials with improved properties that can be used as food contact materials. Currently, many large food companies in the world are reportedly exploring the potential of nanomaterials for using in food or food packaging. Undoubtedly, the most active area of food nanoscience research and development is packaging. The very purpose of food packaging was considered as protecting and preserving the food inside while maintaining its quality and safety. Of late, in response to the advancement of nano technology as well as the changing consumers' demand, the food industry is attempting to develop functional packaging systems with enhanced end use convenience features, which also provides essential product information to consumers to facilitate the promotion and advertisement of the product.

Nanotechnology

The idea of nanotechnology was presented by Richard Feynman in 1959 and the term "nano technology" was first used by Norio Taniguchi in 1974. The word 'nano' denotes nanometer (10^{-9} m) and nanotechnology involves manufacture and use of materials in the size range of up to about 100 nm in one or more dimensions. European Commission (2009) has defined nanomaterial as an insoluble or bio-persistent and intentionally manufactured material with one or more external dimensions, or an internal structure, on a scale from 1 to 100 nm. Nanomaterials are abundant in nature and many methods are available to produce nanomaterials. Nanoparticles can be produced top down from larger structures by grinding, use of lasers, and vaporization followed by cooling. Alternately, bottom-up methods are commonly used for the synthesis of complex nanoparticles. These methods include solvent extraction/ evaporation, crystallization, self-assembly, layer-by-layer deposition, microbial synthesis, and biomass reactions (Brody *et al*., 2006). All of these are being researched for potential application in food packages.

Applications of nanomaterials in packaging

Insufficient mechanical and barrier properties, non-sustainable production, lack of recyclability, high cost, difficulty in recycling of polymer blends and multilayered composite structure, and achieving adequate shelf-life while maintaining the optimal quality and safety of the product are some of the challenges presently faced by the food and packaging industries. Presently, the incorporation of nanomaterials into plastics and bioplastics is gaining a lot of research interest, since it positively modifies the food packaging by improving barrier and mechanical properties, which also provide the ability to destroy and detect pathogens and make the packages active and intelligent.

The following are the different ways of incorporating nanomaterials in packaging (Bradley *et al*., 2011).

1. *Nanocomposites*: Incorporating nanomaterials into the packaging to improve its physical performance, durability, barrier properties, and biodegradation.

2. *Nano coatings*: Incorporating nanomaterials onto the packaging surface to improve especially the barrier properties.
3. *Surface biocides*: Incorporating nanomaterials with antimicrobial properties acting on the packaging surface.
4. *Active packaging*: Incorporating nanomaterials with antimicrobial or other properties with intentional release into the packaged food.
5. *Intelligent packaging*: Incorporating nanosensors to monitor and report on the condition of the food

Nanocomposites

The nano enabled system, which has gained the highest popularity in food packaging development, is nanocomposites. A composite material is a combination of two or more phases. One phase is the continuous phase and the other is the disperse phase. Generally, the continuous phase is a polymer, which surrounds the disperse phase and the disperse phase is the filler or reinforcing material. When the dispersed phase is nanostructured, the composite is known as nanocomposite. The concept of nanocomposites was developed in the late 1980s and firstly commercialized by Toyota. The research on the use of nanocomposites for food packaging applications started in the 1990s.

Table 1. Different types of nano-fillers for composite making

Classification	Type of nano-filler	Example
Organic	*Clay*	*Montmorillonite (MMT)*
	Natural biopolymers	*Chitosan, Cellulose*
	Natural antimicrobial agents	*Nisin*
Inorganic	*Metal*	*Silver, Copper, Gold*
	Metal oxide	*ZnO, TiO_2, MgO*

Clay is the most common filler that has been modified as nano-composite materials for food packaging applications. Amounts of nano clays, which are being incorporated, vary from 1 % to 5 % by weight. The most extensively studied clay was montmorillonite (MMT), due to the high surface area and aspect ratio. The most common type of metal studied is silver, due to the antimicrobial properties as well as stability and low volatility at high temperature. ZnO is the common type of metal oxide used, due to the deodorizing and antibacterial properties.

In general, there are three possible arrangements for layered silicate clay nanocomposite materials (three different modes of dispersed phase).

- **Tactoids/Nonintercalated:** Silicate layers are not delaminated (Microcomposites)
- **Intercalated:** Polymer chains are inserted into the galleries of the silicate layers
- **Exfoliated/Delaminated:** Silicate layers are completely delaminated and homogenously dispersed in the polymer. This is the ideal nanocomposite arrangement, but is hard to achieve.

Improvement of mechanical properties

Food packages should have good physical properties to protect the food from damage. The mechanical properties of the packaging materials can be enhanced by incorporation of nanomaterials such as nano fibres and rods for nanocomposite formation. The nanocomposites, thus prepared by nano reinforcement of polymers, will have excellent physical properties. Especially, fibres with a high aspect ratio (the ratio of length to width, e.g. >300) can confer useful physical characteristics to the package. Compared to traditionally used fillers like glass fibres and talc, nanomaterials are required in very less quantity to enhance the physical performance of the package. The strength and stiffness of nanocomposites prepared by materials like carbon nanotubes and cellulose nanofibres (also called cellulose nano whiskers/nanocrystals) are much better than the conventionally used materials (Siro and Plackett, 2010). Kvien *et al*. (2005) reported that biopolymers strengthened with dispersed cellulose nanowhiskers (CNW) had improved mechanical properties and thermal stability.

Enhanced barrier properties

One of the major limitations of biopolymers is their weaker barrier properties as compared to the petroleum-based counterparts. Nanocomposite formation is a proven technology for enhancing the barrier properties of biopolymer, as well as synthetic thermoplastics. The incorporation of fillers, such as nanoplatelets with high surface to thickness ratio into the polymer, enhances the barrier properties for the diffusion of permeant molecules. The presence of these fillers, which are impermeable or less permeable to gases and water vapour than the polymer matrices, results in a longer diffusion path taken by the permeant molecules as compared to their diffusion path taken in the pristine polymer matrix. This results in enhancement of overall barrier properties of a nanocomposite against vapours and gases. Clay/polymer nanocomposite is the most studied nanocomposite for food packaging applications (Lagaron *et al*., 2005). RodrIguez *et al.* (2012) have reported that oxygen transmission rate (OTR) and water vapour transmission rate (WVTR) of cellulose acetate reduced by 50 and 10 %, respectively by organic montmorillonite (OMMT). Another study showed that oxygen barrier properties of low density polyethylene (LDPE) improved by seven times after incorporating organic montmorillonite (Xie *et al*., 2012).

Nano-coatings

Nano-coatings, due to its antimicrobial efficiency and superior barrier property over multilayer films, have gained popularity in food packaging sector. In nano-structured coatings, nanosized materials are incorporated onto the packaging surface (either the inside or the outside surface, or a sandwiched as a layer in a laminate). Compared to multilayer films, reduced material usage and simpler film conversion process are advantages of nano-coatings. In a previous study by Hirvikorpi *et al*. (2010), barrier performance of the biopolymer PLA was improved after coating with aluminum oxide and antimicrobial efficiency of PVC film was enhanced by ZnO coating (Li *et al*., 2010).

Surface biocides

Biocides, which are generally using to bring down the number of microbes in food and food contact materials, have many applications in the food processing sector. Based on their application, biocides are grouped into process biocides, surface biocides and food preservatives. Surface biocides, which are incorporated into the food contact materials for reducing the number of microorganisms attached to it, will not be released from the material. Similarly, nanoenabled biocidal agents help to maintain the hygienic condition of the food contact surface by preventing or reducing microbial growth. It is different from active packaging and has no preservative effect on the food (Bradley *et al*., 2011). They are useful in food processing equipment and food handling equipment (e.g. conveyor belts) that are difficult to clean in place

Active packaging

According to the European Union Guidance to the Commission Regulation (EUGCR) No 450/2009 (EU, 2009), active food packaging systems, incorporated with active compounds such as antimicrobial compounds, oxygen absorbers, water vapour absorbers, ethylene scavengers, etc., are supposed to perform some role in addition to providing an inert barrier to external conditions. It is a novel packaging system/technology, which permits the product and the surrounding environment to interact for enhancing the product's storage life and microbial safety, while maintaining the quality of the food packaged inside (Ahvenainen, 2003).

Antimicrobial nanomaterials

Antimicrobial packaging is the most promising form of active packaging, where an antimicrobial nanomaterial is added into the packaging material for releasing onto the food surface. Thus, the storage life of food can be improved using antimicrobial nanoparticles and nanocomposites. Nano particles, due to their small dimension and surface reactivity, provide antimicrobial activity to packaging materials for preventing the proliferation of spoilage and pathogenic microorganisms. Metal nanoparticles such as silver, gold, zinc, or metal oxides are widely using in various active packaging applications. Rhim *et al*. (2014) reported that silver nanoparticles, when added in agar films, exhibited antimicrobial activity against both gram positive (*Listeria monocytogenes)* and gram negative (*Escherichia coli* O157:H7) pathogens. In the same way, PLA/silver-OMMT antimicrobial nanocomposite showed strong antimicrobial efficiency against gram-negative *Salmonella sp.* (Busolo *et al*., 2010) and sodium alginate film loaded with silver nanoparticle exhibited antibacterial activity against *Staphylococcus aureus* and *Escherichia coli* (Fayaz *et al*., 2009).

Oxygen scavengers

Presence of oxygen in food package can reduce product shelf-life because of various degradation reactions such as rancidity, growth of aerobic microorganisms, browning, depletion of vitamins, loss of essential flavour compounds etc. Hence, oxygen within the package should be eliminated or reduced to a level acceptable. Packaging substrates coated or incorporated with nanomaterials have been investigated for their oxygen scavenging ability. Packaging substrates that have been coated with TiO_2 have been examined for their oxygen scavenging ability. High density polyethylene (HDPE) packaging films with oxygen absorbing efficiency was developed by incorporating with iron containing kaolinite (Busolo and Lagaron, 2012). The oxygen scavenging capacity of this altered HDPE film was attributed to oxygen trapping and increased tortuous diffusion path.

Intelligent packaging

Intelligent packaging systems can monitor the condition of packaged foods to give information regarding the quality of the packaged food during transport and storage. It can be basically divided into sensors and indicators. The nanotechnology enabled indicator/sensor, interacts with internal factors (food components and headspace species) and/or external environmental factors and generates a response (e.g., visual cue, electrical signal), that correlates with the state of the food product. For example, a UV activated oxygen indicator has been fabricated using TiO_2 nanoparticles (Mills and Hazafy, 2008). Smolander *et al*. (2004) prepared a freshness indicator by coating transition metal (silver and/or copper) on plastic film or paper, which upon reacting with sulphide volatiles, produced as fresh meats undergo spoilage, turns into distinctive dark colour. Triangular Ag nanoplates were employed as colorimetric indicators (Zeng *et al*., 2010), which keep track of time-temperature histories to which a perishable product is exposed from the point of manufacture to the retail outlet or end-consumer.

Antibodies conjugated to nanomaterials, such as quantum dots, have been developed to detect bacteria. Yang and Li (2006) studied the use of quantum dots for simultaneous detection of *Escherichia coli* O157:H7 and *Salmonella Typhimurium*.

Conclusion

Nanomaterials can not only passively protect the food against environmental factors, but also incorporate properties to the packaging material so it may actually enhance stability of foods, or at least to indicate their eventual inadequation to be consumed. Moreover, nanotechnology derived packaging was perceived by public as being more beneficial than the nanotechnology engineered foods, which means nanotechnology inside a food is perceived as less acceptable than being on the outside (i.e. in the food packaging). However, there are many safety concerns about nanomaterials. There is limited scientific data about migration of most types of nanoparticles from the packaging material into food, as well as their eventual toxicological effects. So, precautions should be taken and more research is required on the migration behaviours of nanomaterials in food and its potential impacts on health/safety, as well as the environment.

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Development of biodegradable packaging materials from marine and agro-waste

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Introduction

Food packaging is an essential component of the food supply chain and is becoming a pivotal element of the final preparation process in food industries. Food packaging also plays an imperative role in society, protecting food and food products from potential damage and degradation while ensuring safety and hygiene, and actively reducing food waste. It is estimated that more than 30% of food produced is deposited in landfills due to spoilage during transportation and/or harvesting practices (Aguirre-Joya et al., 2018). Therefore, the application of adequate food packaging can assist in the reduction and prevention of the generation of food waste (Aguirre-Joya et al., 2018). The appropriate selection of food packaging should also ensure no negative alterations in food quality (i.e. colour, taste), microorganism development, lipid oxidation or degradation of nutrients in the food (Umaraw et al., 2020).

Conventional packaging is commonly a one-time use item that is discarded upon reaching the consumer or after using the packed content. As such, conventional packaging poses a tremendous environmental burden despite relatively high recycling rates (Jeevahan & Chandrasekaran, 2019). One of the main issues is the non-sustainable nature of plastics, which are commonly derived from petroleum such as polyethylene, polypropylene, and polyethylene terephthalate are widely used due to their relatively easy shape-forming properties and lower weights than other materials (Ahmadi, et al., 2020). Moreover, these materials are considered as not 'environmentally friendly' with the majority of them being non-renewable and also non-biodegradable, which subsequently end up in the landfills or oceans. Additionally, the use of these materials for food packaging has other, secondary negative environmental impacts, such as environmental pollution via generation of CO_2 and emission of other toxicants during their incineration, reliance on non-renewable petroleum reserves, and potential for harmful interactions between potential recycled/reused plastics and food (Aguirre-Joya et al., 2018).

Concurrently with the increased environmental concern regarding the growing rate of waste from packaging materials, current consumer demands and needs are directed towards more natural, high-quality, convenient and safer foods, posing a significant challenge to the food industry. There is an increasing demand for food packaging that does not increase pollution, and for products that are efficiently made by sustainable processes. Consequently, this has initiated an awareness and rise in research and industry focus on the development of sustainable, biodegradable, and edible materials that can improve food safety and increase food quality. Starches, cellulose derivatives, chitosan/chitin, gums, animal or plant-based proteins, and lipids can be incorporated into edible films to prolong shelf life. Such polymers deliver marketable advantages, such as biocompatibility, moisture and/or gas barrier properties, non-toxicity, and non-polluting characteristics (Mellinas et al., 2016). In this context, active, biodegradable and edible packaging materials are considered as one of the top priorities in the food industry due to the increased need for alternative packaging materials that are renewable, recyclable, easily degradable and require minimal or no need of disposal (Jeevahan & Chandrasekaran, 2019; Jeevahan et al., 2018).

Edible packaging

Edible packaging is regarded as a sustainable and biodegradable alternative in active food packaging field and provides food-quality optimisation compared to the conventional packaging. The usefulness of edible packaging is seen in its capacity to maintain food quality, extend shelf life, reduce waste, and to contribute to the economic efficiency of packaging materials. The development and application of edible films are among the most promising fields in food science due to their versatility, potential for being made from a variety of materials, and as carriers of different active substances such as antioxidant and/or antimicrobial agents. This has resulted in a significant increase in research activities in this area over the last decade, with several issues identified for consideration before adequate and safe industrial scale-up of edible food packaging (Aguirre-Joya et al., 2018; Restrepo et al., 2018). The materials of the food packaging are derived from edible ingredients such as natural polymers that can directly be consumed by humans without any potential health risk. These materials can be transformed into different forms of films and coatings without specific differences in their material composition but rather by changes in their thicknesses. Films are generally used in the production of wraps, pouches, bags, capsules, and casings, while coatings are applied directly on the food surface. In contrast to the films, the coatings are considered an integral part of the food product, and they are typically designed not to be removed from the food item (Aguirre-Joya et al., 2018). Therefore, proper selection of edible packaging components mainly depends on the food product required to be packed, and the composition of the material that the edible packaging is developed from, including the method of processing. Moreover, the packaging should have sensory compatibility with the packed food (Restrepo et al., 2018).

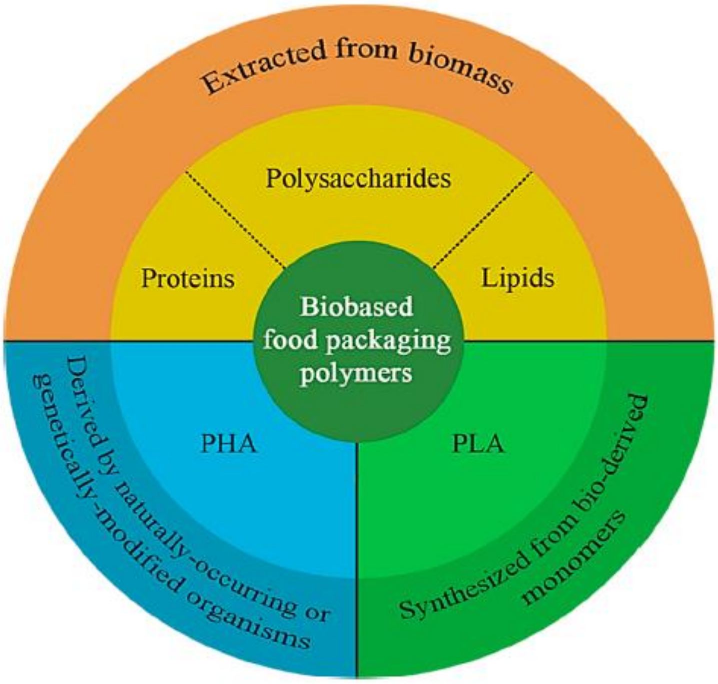

Fig. 1. Biobased materials for food packaging
(PHA=PolyHydroxyAlkanoate; PLA=PolyLactic Acid)

Materials for edible packaging

There is ongoing research into the possibility of replacing synthetic and petroleum-based packaging with biologically-based, biodegradable materials. The use of bioengineered polymer resources for food packaging is an attractive packaging solution for many reasons; however, it is also a major food technology challenge (Ahmadi et al., 2020).

Bio-based and biodegradable materials can be categorised into three categories based on the sources from which they originate (Fig. 1) as follows:

- Biomass/natural sources (proteins, polysaccharides, and lipids)
- Materials produced by microorganisms
- Materials produced from bio-based monomers

Edible packaging materials are a subgroup of bio-based and biodegradable materials and have been extensively studied as an alternative to the traditional food packaging from the aspect of their film-formation properties. Biopolymers used as edible materials are classified as:

- Polysaccharides
- Proteins (animal- or plant-based)
- Lipids
- Composites

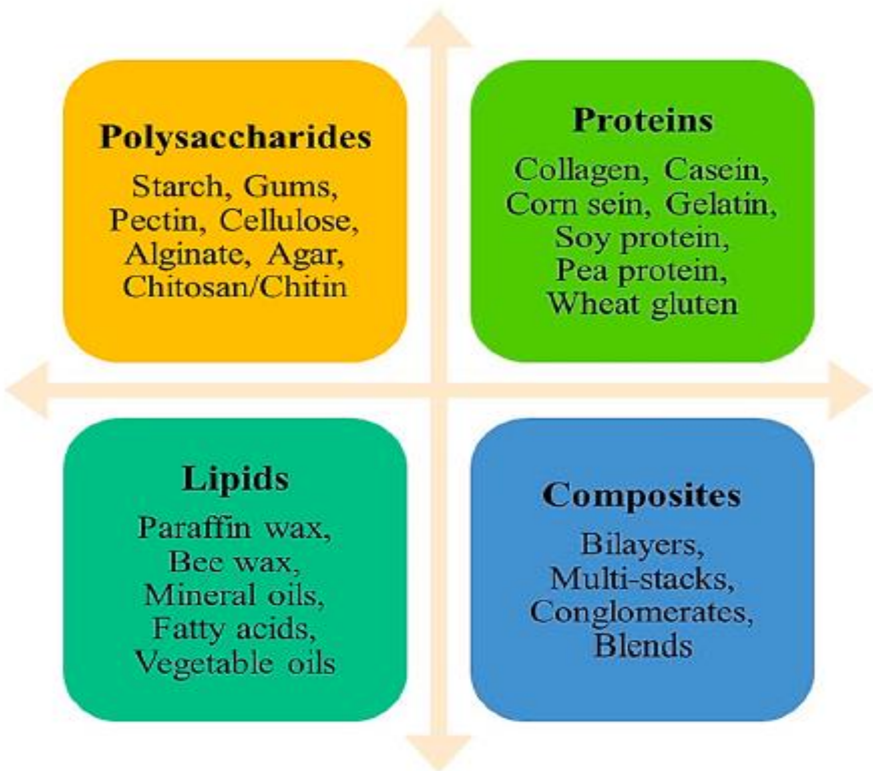

Fig. 2. Classification of edible materials

These edible materials can be used in various food technology applications alone or in combination with other components (Fig. 2). The term hydrocolloids are usually used as a mutual term for polysaccharides and proteins. Hydrocolloids possess long-chain hydrophilic polymers that form viscous dispersions or gels when dispersed in water (Jeevahan & Chandrasekaran, 2019).

Edible films and coatings vary in their nature and origin with a number of different examples used such as chitosan coating (Alvarez et al., 2013), tomato-based (Du et al., 2008), quinoa protein/chitosan edible films (Robledo et al., 2018), apple-based (Ravishankar et al., 2012), banana starch (Pinzon et al., 2020), Aloe Vera, carrot film, rice, maize, potato and hibiscus films among others (Fangfang et al., 2020).

Characteristics of edible packaging: advantages and limitations

Edible materials have many advantages over synthetic materials. Edible packaging can function as a replacement and potential fortification of the layers at the outer surface of packaged products to prevent loss of moisture, aromas and ingredients out and between the foods, while at the same time, facilitating controlled exchange of essential gases involved in food product respiration (carbon dioxide, oxygen, and ethylene) (Galus & Kadzi´nska, 2019). Edible packaging can also enhance the organoleptic properties of packaged foods, providing various flavourings and colourings as well as tailoring surface properties (i.e. hydrophobicity, hydrophilicity). Additionally, these can serve as a carrier of functional components with potentially added health or well-being benefits (Pooja Saklani et al., 2019). The hydrophilic nature of polysaccharides and proteins contribute to lower moisture resistance and barrier properties in comparison to lipids (Arnon-Rips & Poverenov, 2016). Polysaccharides are also suitable oxygen barriers while proteins show relatively good mechanical strength and can be used on fruits and vegetables to prevent damages during their transportation. In contrast, lipids show low water vapour permeability and relatively good moisture barrier properties. Lipid-based edible packaging is often opaque, waxy tasting, slippery, and usually preserves the colour, flavour, sweetener and salt concentrations (Galus & Kadzi ´nska, 2015). However, lipids have poor mechanical and optical properties, as they are relatively thick and easily breakable. In addition, in some cases, there is poor adhesion of these materials to hydrophilic food surfaces (Aguirre-Joya et al., 2018).

The composite edible packaging is proposed to improve the required properties depending on the final application to different food products. In most cases, the composite films consist of a protein, lipid layer and hydrocolloid components supported by a polysaccharide, or lipid material dispersed in a protein matrix or polysaccharide matrix (Aguirre- Joya et al., 2018). In these types of edible packaging, the combination of at least two constituents are proposed where the weakness of individual substance is compensated by adding the other component. For instance, the water vapour permeability of polysaccharides and proteins can be improved by adding lipids, forming edible composite that possesses both hydrophilic and hydrophobic properties. In addition, the mechanical strength of lipids is improved by adding proteins or polysaccharides, and even the overall mass transfer in edible material can be adjusted (Jeevahan & Chandrasekaran, 2019). In general, innovation in the edible packaging sector has the potential to become an everyday part of consumers' life. However, edible packaging will likely not solve the problem of plastic waste pollution, but, it can make a meaningful contribution.

3.1. Barrier functions of edible packaging

The moisture and oil absorption, oxygen transfer, flavour and odour change, or the migration of packaging components into the food are primarily responsible for the food quality (Dubey & Dubey, 2020). These characteristics also contribute to the mass transfer phenomena which occurs between foods (including some ingredients in the food product) and packaging materials, or between food and the environment. In the case of edible films and coatings, it is proposed that these products may prevent migration phenomena and contribute to better quality performance of the packed food products (Zhang et al., 2020). All barrier or transport properties of the edible films and coatings are also affected by the material composition and environmental conditions (relative humidity, temperature, pressure) at which the food products are processed and stored (Siracusa et al., 2020).

3.2. Deposition processes for edible packaging

Edible materials are usually applied on food by immersion, spraying and coating or by being formed prior to a film and used as a food wrap. The difference between an edible film and coating is that coatings are applied in liquid forms, while films are obtained as a solid sheet (i.e. laminates, multilayered films) and then applied to the food (Aguirre- Joya et al., 2018). Films are usually prepared by dissolving the edible material in water, alcohol, or a mixture of solvents. To enhance the flexibility and durability of these materials, additives such as plasticisers are incorporated in matrix material (Murrieta-Martínez et al., 2019). In addition, some additives with unique functionality could be added such as antimicrobial agents, colours, and flavouring, depending on the final application of the edible material (Bilal, et al., 2020). The type of edible packaging solution and application method mainly depends on the surface properties of the food product that should be covered (wettability, contact angle, surface tension (Aguirre-Joya et al., 2018).

Edible coatings are applied directly onto the food surface from liquid suspension, emulsion or powder form. This application of the edible coating solution on food is followed by an adhesion process requiring diffusion between both the coating solution and the surface area of the food product (Senturk & Müller, 2018). Some methods for application of edible coatings on food products are dipping, spraying, brushing, fluidised bed processing, and the panning method (Suhag, et al., 2020).

For the production of edible films, in general, two types of processes exist: wet and dry processes. The wet process (casting) requires solvents for the solution and dispersion of the polymer onto a flat surface, followed by drying under controlled conditions which results in the formation of film (Suhag et al., 2020). Since the final product should be edible and biodegradable, only ethanol and water or their combination are adequate solvents. The production of edible films by dry methods includes extrusion, injection, blow moulding, and heat-pressing processes. In general, dry processing utilises thermoplastic materials that can be processed into films by applying various thermal-mechanical processing techniques. This process is advantageous compared to wet process due to the absence of solvents, easy handling of high viscous polymers and a broad range of processing techniques. In order to improve the film performance, in most cases, the method of lamination is used (Janjarasskul & Krochta, 2010).

The multilayered structures and the combination of characteristics of various ingredients into a sheet is also a preferred packaging option due to many advantages such as higher toughness and tensile strength compared to the individual ingredients (Suhag et al., 2020). Numeorus studies have explained the utilisation of various deposition methods for coating applications for food products to increase their shelf life and enhance their quality and safety as well (Suhag et al., 2020).

4. Edible packaging as a carrier for functional bioactive compounds

Active and smart packaging has been used worldwide, mostly in the United States, Australia and Japan, while in Europe it was introduced after European Union (EU) legislation changes (Regulation EC, 1935/ 2004). The EU definition of active packaging (as defined in the European regulation [EC] No. 450/2009) states that active packaging systems are designed to "deliberately incorporate components that would release or absorb substances into or from the packaged food or the environment surrounding the food." In this way, they "intend to extend the shelf-life or to maintain or improve the condition of packaged food" (Yildirim et al., 2018). One of the significant emerging functions of edible packaging materials is their use as a matrix and carrier of different functional additives that can provide additional nutritive and health benefits to the packaged food (Broumand et al., 2011). Usually, different antimicrobial and antioxidant substances, prebiotics or other nutrients can be added to edible matrices to extend shelf life and/or increase the nutritional value of the final packaged food (Odila Pereira et al., 2019). Several different substances could be incorporated into edible films to enhance structural, mechanical and handling properties or to provide active functions to the coating (Yousuf & Qadri, 2020).

4.1. Nutraceuticals in edible packaging

Nutraceuticals are compounds that are usually derived from food sources and can provide health benefits (Nasri, et al., 2014). Their incorporation into the food coatings can potentially compensate for the loss of nutrients that usually occur during food processing, or increase the nutrient composition of the newly coated food products. Edible matrices also appear to be suitable carrier materials for nutraceuticals as in some cases, direct use of nutraceuticals on food is not recommended due to their fast degradation or potential for production of undesired reactions in foods and consumers if taken in large quantities (Arnon-Rips & Poverenov, 2016). The main influence of the nutraceuticals besides being a source of nutrients and energy is to provide potential beneficial health effects (Khorasani, et al., 2018). In the literature, there are some nutraceutical compounds that have a positive influence on the human health, such as ascorbic acid (antioxidant), pectin (cardiovascular support), casein phosphopeptides (anti-atherosclerotic), omega fatty acids (anti-inflammatory), polyphenols (antioxidant and many other benefits), capsaicin (anticarcinogenic), betacarotene (enhance the immune system, protect from age-related macular degeneration) to name a few (Khorasani et al., 2018).

4.2. Antioxidants and antimicrobials in edible packaging

Antioxidants can be added to edible materials to delay the rate of oxidation reactions and to increase food safety and quality (Munialo, et al., 2019). These compounds can suppress the activity of free radicals via several different pathways such as acting as scavengers of free radicals (i.e. glutathione), chain-breaking antioxidants neutralising the intermediate peroxyl radicals (i.e. ascorbic acid) and preventative antioxidants that can bind to certain metal cations (i.e. albumin). Therefore, with the use of antioxidants, there is a great potential the food products to be protected from damaging oxidative reactions, such as colour changes (i.e. enzymatic oxidation), altered flavours and odours (i.e. oxidative rancidity), as well as reduce structural modifications (i.e. softening) with time and potential nutritional losses (Arnon-Rips & Poverenov, 2016). Examples of 'naturalorigin' antioxidants include plant extracts, essential oils, α-tocopherol, ascorbic, and citric acid, bee pollen, propolis and are all widely used individually or combined (Benbettaïeb et al., 2019). Plant extracts are often used in food packaging (Kumar et al., 2019), as among which pomegranate peel/dried extract (Kumar et al., 2019), and quince seed mucilage (Jouki, et al., 2014), grape seed extract (Xiong, et al., 2020), green tea extract (Sabaghi et al., 2015), mint extracts (Raghav & Saini, 2018), black chokeberry extract (Kim, Baek, & Song, 2018) are on the top of the list. Recently, essential oils extracted from plants have been added as ingredients to the edible film formulations. These extracts have several bioactive compounds that can provide films with specific characteristics, but the most important is to be safe and edible. Such types of active packaging effectively extend food shelf life and contribute to the quality and safety of the packed content. Use of essential oils as substitutes for chemical antimicrobial agents can enhance the microbiological shelf-life of food products. Several studies have indicated beneficial antimicrobial effects against different types of microorganisms including human pathogens. The incorporation of these natural compounds into the product formulation or packaging materials not only inhibit fungal growth, but can also enhance oxidation stability. Along with a beneficial activity, essential oils may also affect the food organoleptic features and potentially act as flavour component (Pavli et al., 2019).

Edible films and coatings can also be an efficient carrier of live microorganisms. Namely, incorporation of probiotics in the edible material, such as Lactic acid bacteria (LAB) or yeasts like Saccharomyces cerevisiae var. boulardii, Debaryomyces hansenii, Torulaspora delbrueckii, Kluyveromyces lactis, Yarrowia lipolytica, S. cerevisiae, Kluyveromyces marxianus, or Kluyveromyces lodderae can result in positive effects during processing and storage of food products. Different methods, such as microencapsulation or spray drying methods are used to incorporate microorganisms into these edible films and coatings that affect the viability and effective delivery of the microorganism within the polymer matrix (Vasile, 2018). Different studies have revealed that incorporation of microorganisms with antimicrobial properties limits the growth of pathogens when used for food packaging (Siracusa et al., 2020).

Antifungal (Robledo et al., 2018), antiviral (Falc´o et al., 2019), and antimicrobial agents (Salvia-Trujillo, et al., 2015), enhance the shelf life of foods and can be derived from natural or synthetic substances (Sharma et al., 2020). According to many of these studies, essential and cold-pressed oils exhibited selective antibacterial and antifungal effect against food spoilage fungi once added in the edible film: Fusarium graminearum, Penicillium corylophilum, Aspergillus brasiliensis; and some potential pathogenic food bacteria, such as Staphylococcus aureus, Escherichia coli, Listeria monocytogenes or against Pseudomonas aeruginosa (Arancibia et al., 2014). Namely, antifungal and antiviral effects of green tea extract were confirmed on nuts and berries, respectively, against some foodborne pathogens like human noroviruses, hepatitis A virus (Randazzo et al., 2018).

The most widely used antimicrobial substances include organic acids (acetic, benzoic, citric, fumaric, lactic, malic, propionic, sorbic, succinic, and tartaric acid), polypeptides (lysozyme, peroxidase, lactoferrin, nisin), essential oils (oregano, lemongrass, cinnamon, tea tree, clove, pimento, thyme, calendula, basil, rosemary, bergamot, sage, garlic, etc.) (Xiong et al., 2020). Antimicrobial food nanocarriers are also suitable for controlling spoilage and growth of pathogenic microorganisms in foodstuff (Arnon-Rips & Poverenov, 2016). The (nano)carriers of antimicrobials are usually reported as nanoemulsions, nanoliposomes, nanoparticles, and nanofibers, and their incorporation into edible matrices effectively controls and maintains the function of the antimicrobials by protecting their fast diffusion into the food products (Arnon-Rips & Poverenov, 2016). The incorporation of active compounds into edibles improved drastically with the development of novel nanotechnologies, where the actives can be in micro- and nano-dimensions and different shapes. For instance, the actives are being incorporated in matrices as (nano)-liposomes, nanoemulsions, nanoparticles, nanofibers or as layerby-layer technique (Aguirre-Joya et al., 2018).

Due to their small dimensions, nanomaterials are able to attach to many biological molecules with greater efficiency. The antimicrobial activity of nanoparticles, in general, is described as: directly interactions with microbial cells and interruption of the transmembrane electron transfer, disrupting/penetrating the cell envelope, oxidizing cell components, producing secondary products as reactive oxygen species or dissolved heavy metal ions (Vasile, 2018). Nanoparticles like TiO2 show efficacy on bactericidal and fungicidal effect against Salmonella choleraesius, Vibrio parahaemoliticus, Staphylococus aureus, Diaporthe actinide, Penicilinum expansum. In addition, ZnO is efficient both against Gram-positive and Gram-negative bacteria while nano-ZnO coated films exhibit antimicrobial effects against L. Monocytes and S. Enteritis. The antibacterial activity of Ag ion is reduced by protein-rich food and can bind to cysteine, methionine, lysine, and arginine. Its antimicrobial activity is explained by adhesion to the cell surface, degrading lipopolysaccharides, damaging the membranes and increasing permeability. The Ag ions can be released to prevent food spoilage as they are effective against bacteria like, E. Coli, Enterococcus faecalis, Staphylococcus aureus, Epidermidis, Vibrio cholera, Pseudomonas aeruginosa, Bacillus anthracis, Proteus mirabilis, Salmonella enterica typhmurium, Listeria monocytogenes, and Klebsiella pneumoniae (Kumar et al., 2020).

4.3. Other additives in edible packaging

The function of other additives in edible materials are relatively known but have shown to have good processing or desired final properties of the food products. Some of these materials include plasticisers, emulsifiers and texture enhancers (Aguirre-Joya et al., 2018). Most polysaccharide- and protein-based films and coatings are brittle, and to overcome this issue and make them as flexible edible films, plasticisers are incorporated within the film structure (Regubalan et al., 2018). Some of the most commonly used plasticisers include monosaccharides, oligosaccharides, polyols and lipids (Xie, Pollet, et al., 2014). With a proper selection of a plasticiser for a given biopolymer, optimisation of the film mechanical properties with a minimum increase in film permeability could be achieved, as well as enhancement in the film flexibility and resilience is possible (Xie et al., 2014).

Emulsifiers are surface-active compounds with both polar and nonpolar characteristics, capable of modifying interfacial energy at the interface of immiscible systems (water–lipid) (Janjarasskul & Krochta, 2010). In general, these compounds are used for the formation and stabilisation of well-dispersed lipid particles in composite emulsion films or to achieve sufficient surface wettability to ensure proper surface coverage and adhesion to the coated surface (Taarji et al., 2020). Sugar esters and glycerol monooleate, for example, solubilise the essential oil in the aqueous phase resulting in a high antimicrobial activity (Aguirre- Joya et al., 2018). Other potential emulsifiers include acetylated monoglyceride, lecithin, glycerol monopalmitate, glycerol monostearate, polysorbates, sodium lauryl sulfate, sodium stearoyl lactylate, and sorbitan monooleate and sorbitan monostearate (Mendes et al., 2020). In addition, calcium salts could be used as texture enhancers as these salts interact with carboxylated polymers and form a cross-linked network that increases the firmness of the product. Anti-browning agents are also widely used in edible coatings for packaging fruits and vegetables and their products (Vasile, 2018).

Flavour and aroma components of foods may be altered or escape during the processing or storage time due to their volatile nature. Flavouring substances can be extracted via physical, enzymatic, or microbiological methods from animal, marine and plant sources. Some examples of commonly used plants for the development of flavour or aroma include oregano, cinnamon, curcumin, clove, rosemary, in addition to synthetic flavours. Natural aromatic substances are becoming more attractive in the food industry due to increased consumer awareness as being perceived as natural and healthy foods. Interestingly, some flavours are synthesised by living organisms as a defence mechanism or as secondary metabolites, such as flowers (jasmine), herbs (rosemary), buds (clove), leaves (eucalyptus), fruits (citrus), barks (cinnamon), seeds (cardamom), or roots (ginger) (Arnon- Rips & Poverenov, 2016).

6. Applications of edible packaging

Edible packaging could be a potential packaging solution for many types of food. To date, there are data indicating that edible packaging has been successfully applied on meat, grains, nuts, cheese, bakery, confectioneries, fruits and vegetables (intact or fresh-cut) and will be briefly described below. The selection of edible packaging mainly is determined by the type of food that is packed as well as by storage time and conditions (Sharma et al., 2020).

6.1. Fruits and vegetables

The most-wide application of edible coatings exists in the food group of fruits and vegetables in fresh or preserved forms. Most of the losses in quality of fresh fruit and vegetables occur during storage and transportation. Usually, it includes moisture loss, shrinkage, weight loss, microbial and biochemical change, mechanical damages, and sensory changes that are of common interest to be minimised or prevented. Therefore, taking into consideration that the respiratory processes of these food classes continue long after their harvest, the application of an edible packaging on fresh fruit or vegetables, will affect the gas permeability, in particular, the oxygen diffusion, and thus, inhibit the ripening processes. The products will remain fresh and attractive for an extended period, where the edible packaging acts as a barrier to free gas exchange and prevents the absorption of undesirable odours. The protection of gas exchange through edible coating can also cause modification of atmosphere around the fresh fruits/vegetable and development of anaerobic conditions that lead to alcoholic fermentation and change the sensory characteristics of packed food. Therefore, it is important to make a proper selection of edible materials for fruit and vegetable packaging to achieve an optimal balance of permeability properties. Additionally, this will result in the product keeping the moisture, appropriate adhesion to the product due to its hydrophilic nature, protecting off-flavour development, homogeneous and an attractive (i.e. glossy) appearance, keeping the fruit firm, reducing weight loss, and minimising solute leakage. In addition, these edible packaging can also encapsulate aromatic compounds, antioxidants, pigments, ions that stop browning reactions and nutritional substances (Fritz et al., 2019). Moreover, some examples for edible coatings applied on different fruits and vegetables include broccoli (Alvarez et al., 2013), okra (Gundewadi, et al., 2018), carrots (Villafa˜ne, 2017), tomatoes (Athmaselvi, Sumitha, & Revathy, 2013), cucumber (Raghav & Saini, 2018), papaya (Yousuf & Srivastava, 2015), apricot (Ghasemnezhad, et al., 2010), kiwifruit slices (Allegra et al., 2017), fresh-cut cantaloupe (Marti˜non et al., 2014), apples (Gardesh et al., 2016), strawberry (Tomadoni et al., 2018), cherry tomatoes (Robledo et al., 2018), green beans (Donsì et al., 2015), raspberry (Falc´o et al., 2019), grape (Kim et al., 2014), lime fruit (Maftoonazad & Ramaswamy, 2019), banana (Thakur et al., 2019) and others.

6.2. Meat, poultry, fish

Meat, poultry and fish can benefit considerably from edible packaging in terms of product quality and safety, and extending their shelf life (Dong et al., 2020). This packaging type reduces moisture loss, inhibits texture degradation, prevents unattractive dripping of product juices and consequently reduces food loss, spoilage, and waste. Furthermore, edible packaging reduces biochemical product degradation, protects lipids and proteins from oxidation, delays rancidity, and prevents undesired colour changes. Active (antimicrobial) edible materials also contribute to products' microbial safety and decrease the spoilage. Fresh meat cuts and products can be included in this category (Bhagath & Manjula, 2019), as well as pork (Xiong et al., 2020), lamb (Pabast et al., 2018), turkey (Guo et al., 2014).

6.3. Dairy products

Relatively high rates of foodborne illness related to dairy such as human listeriosis have emphasised the importance of preventing microbial infection in dairy products. Salmonella is another bacteria that has been found in spoiled cheese (Pourmolaie, et al., 2018). In addition, mould contamination of different dairy products such as cheese during ripening and storage is a problem for the dairy industry. Many species of aspergillus and penicillium are common fungal contaminants of the cheese (Cerqueira et al., 2010). The ancient solution for this problem is physically impregnating the product with spices, herbs or their oils with many studies reporting the usefulness of this form of edible packaging concept in the dairy industry, such as the study examines the cheese packaging into a chitosan-coated nisin-silica liposome with anti-listeria effects (Cui, et al., 2016). Probiotic coating of cheeses can be an ideal vehicle for lactic acid bacteria. Namely, the L. acidophilus and L. helveticus inclusion in edible cheese coverings reduced the presence of the total coliform at ten days (Olivo et al., 2020).

6.4. Grains and nuts

In general, grains and nuts are products with relatively low moisture content. Edible packaging has been shown to be useful in controlling undesirable mass transfer between the products and environment. This migration from the food to the outer environment or vice-versa can decrease food quality and alter its sensory characteristics such as dehydration or spoilage, loss of aroma and flavour. In addition, edible packaging can prolong grain and nut quality by protecting from mechanical damages during transport, vibrations, and pressure as well reducing the stickiness of the grains to surfaces that they might come into contact. Active edible packaging which contains antioxidant inclusions could potentially protect the grains and nuts from lipid oxidation, for example (Arnon-Rips & Poverenov, 2016).

6.5. Baked products and candies

Edible coatings could be applied on a different baked and extruded products, such as crackers, biscuits and cereals. The loss of their crispiness and softening due to hydration during storage can be effectively managed by use of edible packaging (Jim´enez et al., 2018). Edibles produced with plant essential oils (i.e. clove, oregano) displayed antimicrobial activity against the development of fungi in baked products, consequently improving shelf life (Gavahian et al., 2020). Bread, as the most consumable representative of this group, is an attractive case for application of a variety of edible coatings (Chakravartula et al., 2019). Moreover, candies and confectioneries are an interesting and challenging group of food that can be protected from undesired stickiness, agglomeration, moisture absorption and oil migration by edible packaging (Eyiz, Tontul, & Türker, 2020). Table 3 summarizes edible packaging options for dairy, nuts and bakery products.

7. Conclusion & Future prospective

There is a tremendous interest in novel packaging solutions for a variety of food products worldwide. The emergence of new packaging technologies have enabled newly developed products to perform better than providing them with containment and physical protection. The future of edible packaging materials is very promising, and increased innovation within the food industry is both imminent and already occurring. Global consumer demands are a driving force for research and development of novel materials in order to find alternatives for fossil-based packaging materials. Their replacement with recyclable, biodegradable or edible materials, prepared from renewable and sustainable sources, are desired by consumers and the food industry alike. In this context, the use of biopolymers as food packaging possess the advantages of biodegradability, process simplicity, and an ability to be combined with other materials has a considerable potential to reduce the food waste and benefit the environment.

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Canning and retort pouch packaging

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Introduction

Processing and preservation of food is an important activates to ensure safe food supply apart from reducing food loss. Fish being highly perishable food commodity, processing and preservation assumes great importance. There are number of reasons for processing fish and shellfish which are given below.

1. To supply safe food
2. To minimize loss/waste of valuable food commodity
3. To meet consumer preference and specified quality standards
4. To extend the shelf life of food for longer duration
5. To make profit by adding value and increasing convenience to the consumer

Thermal sterilization of foods is the most significant part of food processing industry and is one of the most effective means of preserving food supply. Thermal processing, which is commonly referred as heat processing or canning is a means of achieving long-term microbiological stability for non-dried foods without the use of refrigeration, by prolonged heating in hermetically sealed containers, such as cans or retortable pouches, to render the contents of the container sterile. The concept of thermal processing has come a long way since the invention of the process by French confectioner, Nicholas Appert. Later on Bigelow and Ball developed the scientific basis for calculating the sterilization process for producing safe foods. Today, thermal processing forms one of the most widely used method of preserving and extending shelf life of food products including seafood's. Thermal processing involves application of high temperature treatment for sufficient time to destroy all the microorganisms of public health and spoilage concerns. Normally, thermal processing is not designed to destroy all microorganisms in a packaged product, which may result in low quality product which destroys important nutrients. Instead of this, the pathogenic microorganisms in a hermetically sealed container are destroyed by heating and a suitable environment is created inside the container which does not support the growth of spoilage type microorganisms. Several factors must be considered for deciding the extent of heat processing which include,

a) type and heat resistance of the target microorganism, spore, or enzyme present in the food
b) pH of the food
c) heating conditions
d) thermo-physical properties of the food and the container shape and size
e) storage conditions

Thermal processing is designed to destroy different microorganisms and enzymes present in the food. Normally in thermal processing, exhausting step is carried out to before sealing the containers. In some cases, food is vacuum packed in hermetically sealed containers. In such cases very low levels of oxygen is intentionally achieved. Hence, the prevailing conditions are not favorable for the growth of microorganisms that require oxygen (obligate aerobes) to create food spoilage or public-health problems. Further, the spores of obligate aerobes are less heat resistant than the microbial spores that grow under anaerobic conditions (facultative or obligate anaerobes). The growth and activity of these anaerobic microorganisms are largely pH dependent. From a thermal-processing standpoint, foods are divided into three distinct pH groups which are given below. Changes in the intrinsic properties of food, mainly salt, water activity and pH are known to affect the ability of microorganisms to survive thermal processes in addition to their genotype. Due to health related concerns on the use of salt, there is increased demand to reduce salt levels in foods. The United States Food and Drug Administration (FDA) have classified foods in the federal register (21 CFR Part 114) as follows (Table 2):

1. high-acid foods (pH < 3.7; e.g., apple, apple juice, apple cider, apple sauce, berries, cherry (red sour), cranberry juice, cranberry sauce, fruit jellies, grapefruit juice, grapefruit pulp, lemon juice, lime juice, orange juice, pineapple juice, sour pickles, vinegar)
2. acid or medium-acid foods (pH 3.7 - 4.5; e.g., fruit jams, frit cocktail, grapes, tomato, tomato juice, peaches, piento, pineapple slices, potato salad, prune juice, vegetable juice)
3. low-acid foods (pH > 4.5; e.g., all meats, fish and shellfishes, vegetables, mixed entries, and most soups).

Table 2. Approximate pH range of different food

Food	pH	Food	pH
Lemon juice	2.0 - 2.6	Sweet potato	5.3 – 5.6
Apples	3.1 - 4.0	Onion	5.3 – 5.8
Blueberries	3.1 – 3.3	Spinach	5.5 – 6.8
Sauerkraut	3.3 – 3.6	Beans	5.6 – 6.5
Orange juice	3.3 – 4.2	Soybeans	6.0 – 6.6
Apricot	3.3 – 4.0	Mushroom	6.0 – 6.7
Bananas	4.5 – 5.2	Clams	6.0 – 7.1
Beef	5.1 – 7.0	Salmon	6.1 – 6.3
Carrot	4.9 – 5.2	Coconut milk	6.1 – 7.0
Green pepper	5.2 – 5.9	Milk	6.4 – 6.8
Papaya	5.2 – 6.0	Chicken	6.5 – 6.7
Tuna	5.2 – 6.1	Whole egg	7.1 – 7.9

The acidity of the substrate or medium in which micro-organisms are present is an important factor in determining the extent of heat treatment required. With reference to thermal processing of food products, special attention should be devoted to *Clostridium botulinum* which is a highly heat resistant mesophilic gram positive, rod shaped spore-forming anaerobic pathogen that produces the toxin *botulin*. It has been generally accepted that *C. botulinum* and other spore forming, human pathogens does not grow and produce toxins below a pH of 4.6. The organisms that can grow in such acid conditions are destroyed by relatively mild heat treatments. For food with pH values greater than 4.5, which are known as low-acid products which includes fishery products, it is necessary to apply a time–temperature regime sufficient to inactivate spores of *C. botulinum* which is commonly referred to as a *botulinum cook* in the industry. Thermal processes are calibrated in terms of the equivalent time the thermal centre of the product, i.e. the point of the product in the container most distant from the heat source or cold spot, spends at 121.1°C, and this thermal process lethality time is termed the F_0 value. Although there are other microorganisms, for example *Bacillus stearothermophilus*, *B. thermoacidurans,*and *C. thermosaccolyaticum*, which are *thermophilic* in nature (optimal growth temperature ~ 50–55°C) and are more heat resistant than *C. botulinum a* compromise on the practical impossibility of achieving full sterility in the contents of a hermetically sealed container during commercial heat processing, whereby the initial bacterial load is destroyed through sufficient decimal reductions to reduce the possibility of a single organism surviving to an acceptably low level. This level depends on the organism, usually *Clostridium botulinum*, which the process is designed to destroy. The time required to reduce the number of spores of this organism (or any other micro-organism) by a factor of 10 at a specific reference temperature (121.1°C) is the decimal reduction time, or *D* value, denoted D_0. The D_0 value for *Clostridium botulinum* spores can be taken as 0.25 minutes. To achieve a reduction by a factor of 10^{12}, regarded as an acceptably low level, requires 3 minutes at 121.1°C, and is known as the process value, or *F* value, designated F_0 so, in this case, F_0 = 3, which is known as a botulinum cook which is the basis of commercial sterility.

Thermal resistance of microorganisms

For establishing a safe thermal processing, knowledge on the target microorganism or enzyme, its thermal resistance, microbiological history of the product, composition of the product and storage conditions are essential. After identifying the target microorganism, thermal resistance of the microorganism must be determined under conditions similar to the container. Thermal destruction of microorganism generally follow a first-order reaction indicating a logarithmic order of death i.e., the logarithm of the number of microorganisms surviving a given heat treatment at a particular temperature plotted against heating time (survivor curve) will give a straight line (Figure 1). The microbial destruction rate is generally defined in terms of a decimal reduction time (D value) which represents a heating time that results in 90% destruction of the existing microbial population or one decimal reduction in the surviving microbial population. Graphically, this represents the time between which the survival curve passes through one logarithmic cycle (Fig. 1). Mathematically,

$$D = (t_2 - t_1) / (\log a - \log b)$$

where, *a* and *b* are the survivor counts following heating for t_1 and t_2 min, respectively. As the survivor or destruction curve follows the logarithmic nature, the complete destruction of the microorganisms is theoretically not possible.

From the survivor curve, as the graph is known, it can be seen that the time interval required to bring about one decimal reduction, i.e. 90% reduction in the number of survivors is constant. This means that the time to reduce the spore population from 10,000 to 1000 is the same as the time required to reduce the spore population from 1000 to 100. This time interval is known as the decimal reduction time or the 'D' value. The D value for bacterial spores is independent of initial numbers, but it is affected by the temperature of the heating medium. The higher the temperature, faster the rate of thermal destruction and lower the D value. The unit of measurement for D is 'minute'. An important feature of the survivor curve is that no matter how many decimal reductions in spore numbers are brought about by a thermal process, there will always be some probability of spore survival. Different micro-organisms and their spores have different D values as shown in Table–3.

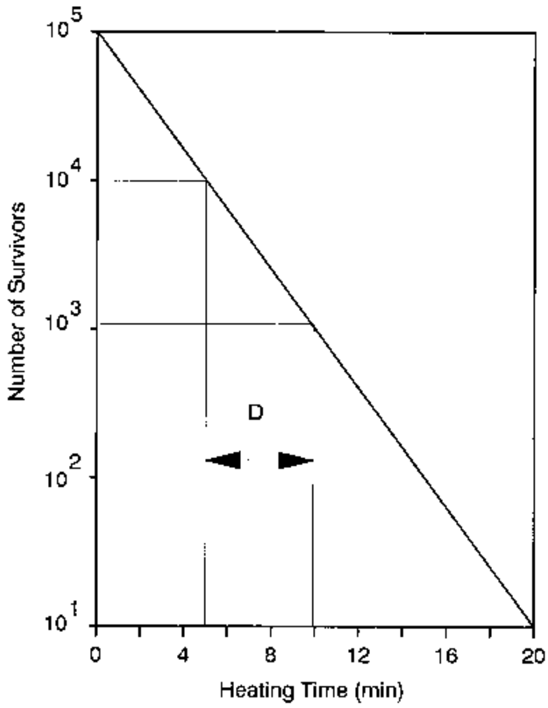

Fig 1. Survivor curve

Table-3. D value (at 121.1°C) of some bacterial spores

Microorganism	**Optimum growth temperature (°C)**	**D value (min)**
Bacillus stearothermophilus	55	4 to 5
Clostridium thermosaccharolyticum	55	3 to 4
Clostridium nigrificans	55	2 to 3
Clostridium botulinum types A & B	37	0.1 to 0.25
Clostridium sporogenes (PA 3679)	37	0.1 to 1.5
Bacillus coagulans	37	0.01 to 0.07
Non-spore forming mesophilic bacterial yeasts and moulds	30 - 35	0.5 to 1.0

The thermal death time may be defined as the time required at any specified temperature to inactivate an arbitrarily chosen proportion of the spores, the higher the proportion the greater will be the margin of safety. TDT is the heating time required to cause complete destruction of a microbial population. Such data are obtained by subjecting a microbial population to a series of heat treatments at a given temperature and testing for survivors. The thermal death time curve is obtained by plotting the thermal death time on logarithmic scale against temperature of heating on linear scale on a semilogarithmic graph paper (Fig. 2). Comparing TDT approach with the decimal reduction approach, one can easily recognize that the TDT value depends on the initial microbial load (while D value does not). Further, if TDT is always measured with reference to a standard initial load or load reduction, it simply represents a certain multiple of D value. For example, if TDT represents the time to reduce the population from 10^0 to 10^{-12}, then TDT is a measure of 12 D values. i.e., TDT = nD, where n is the number of decimal reductions. The extent of inactivation in the case of pathogenic microorganisms (*C. botulinum*) is equivalent to a 12 D process. The slope of the TDT curve is defined as 'z' value, which is the number of degrees for the TDT curve to traverse one log cycle. The temperature sensitivity indicator is defined as z, a value which represents a temperature range which results in a ten-fold change in D values or, on a semilog graph, it represents the temperature range between which the D value curve passes through one logarithmic cycle. The 'z' value which is also known as the temperature sensitivity indicator is usually taken as 10°C in the case of *C.botulinum.*

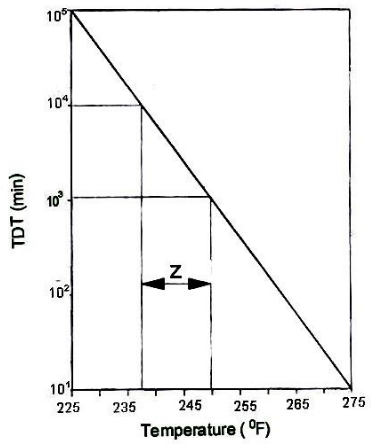

Fig. 2 TDT Curve

For the purpose of heat process determination with respect to their lethality towards specific micro-organisms, the reciprocal of the thermal death time (TDT value) called the lethal rate, L is used. So, instead of temperatures, the corresponding lethal rates are plotted against time, the area enclosed by the graph and the ordinate represent the F value for the process. i.e.,

$$L = \frac{1}{TDT}, \quad \text{and}$$

$$F = \int_0^t L \, dt$$

Thermal Process Severity or F_0 value

From D value and the initial number of spores inside the sealed container (N_o), an idea of the severity of heat process required to reduce the spore population to a predetermined level, N_t, can be calculated from the equation:

$t = D(\log No - \log N_t)$ or $t = D \log (No/N_t)$

where, t = time required to achieve commercial sterility

This log No/N_t is sometimes referred to as the 'order of process', factor 'm' and the value of the product of m and D is called the 'process value' or 'F value'. That is:

$$F_0 = mD_{121.1°C}$$

For example, considering the generally accepted minimum process for prevention of botulism through under processing of canned fishery products preserved by heat alone, assuming that the initial loads are of the order of 1 spore/g and in line with good manufacturing practice guidelines, the final loads shall be no more than $\log 10^{-12}$ spores/g. That is 12 decimal reductions are required. It is also known as 12 D process. The minimum time required to achieve commercial sterility can be calculated from

$$t = 0.25 (\log 1 - \log 10^{-12}),$$

$$\text{i.e., } t = 0.25 \times 12 = 3.00 \text{ min}$$

Thus an F_0 value of 3.00 minutes at 121.1°C at the slowest heating point (SHP) of the container is sufficient for providing safety from pathogenic organism *C. botulinum*.

Commercial sterility

If the thermal process is sufficient to fulfill the criteria of safety and prevention of non-pathogenic spoilage under normal conditions of transport and storage, the product is said to be 'commercially sterile'. In relation to canned foods, the FAO/WHO Codex Alimentarius Commission (1983) defines, commercial sterility as the condition achieved by the application of heat, sufficient alone or in combination with other appropriate treatments, to render the food free from microorganisms capable of growing in the food at normal non-refrigerated conditions at which the food is likely to be held during distribution and storage. Apart from this concept there are circumstances where a canner will select a process which is more severe than that required for commercial sterility as in the case of mackerel and sardine where bone softening is considered desirable.

Mechanism of heat transfer

Understanding the mechanism of heat transfer is very important for thermal processing. Normally, there are three different modes of heat transfer: conduction, convection and radiation. Conduction is the transfer of heat by molecular motion in solid bodies. Convection is the transfer of heat by fluid flow, created by density differences and buoyancy effects, in fluid products. Radiation is the transfer of electromagnetic energy between two bodies at different temperatures. In thermal processed foods, the mechanism of heat transfer is either by conduction, convection or by broken heating (combination of conduction and convection). The factors which determine the mode of heat transfer are nature or consistency of a food product, the presence of particles, and the use of thickening agents and sugars. The heating modes in the thermal processing are first by heat transfer to the container or packaging material from heating and cooling media, second through the container wall and third is into the product from container wall. Convective-heat transfer rates depend largely on the velocity of flow of the media over the container, and this is an important factor to be controlled in all processing operations. In conduction heading method, energy transfer takes place when different parts of a solid body are at different temperatures. The slowest heating point or cold point in cylindrical metal containers is at its geometric centre for food products heated by conduction method. Convection heat transfer involves the transfer of heat from one location to the other through the actual movement or flow of a fluid. The slowest heating point for convection heated products in cylindrical metal container is approximately $1/10^{th}$ up from the base of the container. Packaging material forms the most important component of thermal processed foods. It should be able to withstand the severe process conditions and should prevent recontamination of the product.

Containers for thermal processing

Containers used for thermal processing should have special properties like it should withstand high temperature and pressure. Tin cans are commonly used in the canning industry and cans are denoted by trade name. First digit represents diameter of can (in inches) and next two digits represent measurement in sixteenth of inches. Apart from OTS cans, other container used in canning are: aluminium cans, tin free steel (TFS) cans, glass containers, retort pouches and semi-rigid containers.

Glass containers

Glass is a natural solution of suitable silicates formed by heat and fusion followed by immediate cooling to prevent crystallization. It is an amorphous transparent or translucent super cooled liquid. Modern glass container is made of a mixture of oxides viz., silica (S_1O_2), lime (CaO), Soda (Na_2O), alumina (Al_2O3), magnesia (MgO) and potash in definite proportions. Colouring matter and strength improvers are added to this mixture and fused at 1350 - 1400ºC and cooled sufficiently quick to solidify into a vitreous or non-crystalline condition.

Glass jars for food packing has the advantages of very low interaction with the contents and product visibility. However, they require more careful processing and handling. Glass containers used in canning should be able to withstand heat processing at high temperature and pressure. Breakage occurring due to 'thermal shock' is of greater significance in caning than other reasons of breakage. Thermal shock is due to the difference in the temperature between the inside and the outside walls of the container giving rise to different rates of expansion in the glass wall producing an internal stress. This stress can open up microscopic cracks or 'clucks' leading to large cracks and container failure. Thermal shock will be greater if the wall thickness is high. Therefore, glass container in canning should have relatively thin and uniform walls. Similarly the bottom and the wall should have thickness as uniform as possible. More failures occur at sharp containers and flat surface and hence these should be avoided. Chemical surface coatings are often applied to make the glass more resistant to 'bruising' and to resist thermal shock. Various types of seals are available, including venting and nonventing types, in sizes from 30 to 110 mm in diameter, and made of either tin or tin-free steel. It is essential to use the correct overpressure during retorting to prevent the lid being distorted. It is also essential to preheat the jars prior to processing to prevent shock breakage.

Metal containers

Metal cans are most widely used containers for thermal processed products. Metal containers are normally made of tin, aluminium or tin-free steel.

Tin plate cans

Tinplate is low metalloid steel plate of can making quality (CMQ) coated on both sides with tin giving a final composition of 98% steel and 2% tin. Thickness varies from0.19 to 0.3 mm depending on the size of the can. Specifications with respect to content of other elements are: Carbon (0.04 - 0.12%), manganese (0.25 - 0.6%), sulphur (0.05 % max), phosphorus (0.02 % max), silicon (0.01% max) and copper (0.08% max). Corrosive nature of tin plate depends principally on the contents of copper and phosphorous. The higher the contents of these metals, greater the corrosiveness of steel. However, higher phosphorous content imparts greater stiffness to steel plate which is advantageous in certain applications where higher pressure develops in the container, eg; beer can.

Base plate for can making is manufactured using the cold reduction (CR) process. CR plates are more advantageous over hot reduced plates because of the following characteristics.

1. Superior mechanical properties – possible to use thinner plates without loss of strength
2. More uniform gauge thickness
3. Better resistance to corrosion
4. Better appearance

Aluminium cans

Pure Aluminium of 99.5 to 99.7% purity is alloyed with one or more elements like magnesium, manganese, zinc, copper etc. to obtain the desired composition. Aluminium alloyed with mangnesium is the most commonly used material. Alloyed Aluminium is first given an anticorrosive treatment; usually anodising in dilute sulphuric acid. The thin layer of oxides formed provides corrosion resistance. To enhance this, the sheet is further coated with a suitable lacquer.

Advantages of Aluminium cans

- Light weight, slightly more than 1/3 of the weight of a similar tinplate can
- Nonreactive to many food products
- Clear, bright and aesthetic image
- Not stained by sulphur bearing compounds
- Nontoxic, does not impart metallic taste or smell to the produce
- Easy to fabricate; easy to open
- Excellent printability
- Recyclability of the metal

However, Aluminium cans are not free from some disadvantages

- Thick gauge sheet needed for strength
- Not highly resistant to corrosion, acid fruits and vegetables need protection by lacquering or other means
- Special protection needed during heat processing to avoid permanent distortion
- Aluminium has great tendency to bleach some pigmented products
- Service life is less than that of tinplate for most aqueous products

Tin free steel containers

Tin free steel (TFS) apart from aluminium, is a tested and proven alternate to tinplate in food can making. It has the same steel substitute as the tinplate. It is provided with a preventive coating of chromium, chromium oxide, chromate-phosphate etc. TFS is manufactured by electroplating cold-rolled base plate with chromium in chromic acid. This process does not leave toxin substrate such as chromates or dichromates on the steel and it can be formed or drawn in the same way as tinplate.

Advantages:

- The base chromium layer provides corrosion barrier
- The superimposed layer of chromium oxide prevents rusting and pick up of iron taste
- Provides an excellent base for lacquer adhesion
- Good chemical and thermal resistance
- Tolerance to high processing temperature and greater internal pressure

- Improved and more reliable double seam

Disadvantages:

- Low abrasion resistance; hence compulsory lacquering
- Difficulty in machine soldering
- The oxide layer needs removal even for welding
- Limitations in use for acid foods

An important problem associated with TFS can ends is scuffing of lacquer on the double seam. This may occur at the seamer or downstream at different stages of lacquering. TFS cans have been found quite suitable for canning different fish in various media. Thus it holds good scope as an important alternate to tinplate cans.

Rigid plastic containers

The rigid plastic material used for thermal processing of food should withstand the rigors of the heating and cooling process. It is also necessary to control the overpressure correctly to maintain a balance between the internal pressure developed during processing and the pressure of the heating system. The main plastic materials used for heat-processed foods are polypropylene and polyethylene tetraphthalate. These are usually fabricated with an oxygen barrier layer such as ethylvinylalcohol, polyvinylidene chloride, and polyamide. These multilayer materials are used to manufacture flexible pouches and semi-rigid containers. The rigid containers have the advantage for packing microwavable products.

Retortable pouches

Retort pouch can be defined as a container produced using 2,3 or 4-ply material that, when fully sealed, will serve as a hermetically sealed container that can be sterilized in steam at pressure and temperature similar to those used for metal containers in food canning. Retort pouch has the advantages of metal can and boil-in plastic bag. Configuration of some typical pouches are:

2 ply	12µ nylon or polyester/70µ polyolefin
3 ply	12µpolyester/9-12µ aluminium foil/70µ polyolefin
4 ply	12µ polyester/9-12µaluminium foil/12µpolyester/70µ polyolefin

3-ply pouch is most commonly used in commercial canning operations. This is a three-layer structure where a thin aluminium foil is sandwiched between two thermoplastic films. The outer polyester layer provides barrier properties as well as mechanical strength. The middle aluminium foil provides protection from gas, light and water. This also ensures adequate shelf life of the product contained within. The inner film which is generally polyproplyline, provides the best heat sealing medium.

The normal design of a pouch is a flat rectangle with rounded corners with four fin seals around 1 cm wide. A tear notch in the fin allows easy opening of the pouch. The rounded corners allow safe handling and help to avoid damage to the adjacent packs. The size of the pouch is determined by the thickness that can be tolerated at the normal fill weight. The size ranges (mm) available are:

A_1	130 x 160
A_2	130 x 200
A_3	130 x 240
B_1	150 x 160
B_2	150 x 250

B_3	150 x 240
C_1	170 x 160
C_2	170 x 200
C_3	170 x 240
D_1	250 x 320 (Catering pack)
D_2	250 x 1100
D_3	250 x 480

Advantages

- Thin cross- sectional profile – hence rapid heat transfer – 30-40% saving in processing times – no over heating of the product near the walls
- Better retention of colour, flavour and nutrients
- Shelf life equal to that of the same product in metal can
- Very little storage space for empty pouches – 15% of that for cans
- Easy to open

Disadvantages

- Pouches, seals more vulnerable to damage, can be easily damaged by any sharp material, hence necessitates individual coverage
- With an over wrap cost may go up above that of cans
- Slow rate of production, 30 pouches in place of 300-400 cans per minute
- Needs special equipment
- Higher packaging cost and low output push up the cost of production

Ideally, the container used for thermal processing should fulfill following characterisitcs:

- Should withstand the sterilisation pressure and temperature
- Should be impervious to air, moisture, dust and disease germs once the can is sealed air tight
- Internal lacquer should not impart toxicity to the contents
- Strong enough to protect the contents during transportation and handling
- Inexpensive, preferably cheap enough to discard after use
- Capable of sealing at high speed
- Pleasing and sanitary appearance

Thermal Processing of Fishery Products

The thermal processing is carried out for achieving two objectives; the first is consumer safety from botulism and the second is non-pathogenic spoilage which is deemed commercially acceptable to a certain extent. If heat processing is inadequate the possibility of spoilage due to C. *botulinum* is more and will endanger the health of the consumer. Safety from botulism is made possible by making the probability of *C. botulinum* spores surviving the heat process sufficiently remote and presents no significant health risk to the consumer. An acceptable low level in the context of this dangerously pathogenic organism means less than one in a billion (10^{-12}) chance of survival. Such a low probability of spore survival is commercially acceptable as it does not represent a significant health risk. The excellent safety record of the canning industry with respect to the incidence of botulism through under processing, confirms the validity of this judgment. An acceptable low level in the case of thermophilic non-pathogenic organisms should be arrived at judiciously considering the factors like very high D value, risk of flat sour spoilage, commercial viability and profitability etc. Since non-pathogenic organisms do not endanger the health of the consumer process adequacy is generally assessed in terms of the probability of spore survival which is judged commercially acceptable. Considering all these facts, it is generally found acceptable if thermophilic spore levels are reduced to around 10^{-2} to 10^{-3} per g. Another reason for this acceptance is that the survivors will not germinate if the storage temperature is kept below the thermophilic optimum growth temperature i.e. below 35°C.

Fishery products, being categorized as low acid foods require heat processing severity with respect to *C botulinum* and F_0 value recommended is 5-20 min. Thermal processing of fishery products include various steps. These steps include, preparations like washing, beheading, gutting, removing scales / fins, cutting into required size, blanching (hot / cold), pre-cooking, filling fish pieces into containers, filling content or medium, exhausting to remove air, sealing, loading into the retort or autoclave, sterilization, washing and storing. Various packaging materials have been used from historically starting from glass container to metal container, flexible retortable pouches and rigid plastic containers. The sterilization process in the canned product can be subdivided into three phases. First one is heating phase, in which the product temperature is increased from ambient to the required sterilization temperature by means of a heating medium (water or steam). This temperature is maintained for a defined time (phase 2 = holding phasing). In (phase 3 = cooling phase) the temperature in the container is decreased by introduction of cold water into the autoclave. In order to reach temperatures above 100°C (sterilization), the thermal treatment has to be performed under pressure in pressure cookers, also called autoclaves or retorts. Simple autoclaves are generally vertical ones with the lid on top. Through the opened lid, the goods to be sterilized are loaded into the autoclave. The cans are normally placed in metal baskets. The autoclave and lid are designed to withstand higher pressures up to 5.0 bar. These types of autoclaves are best suited for smaller operations as they do not require complicated supply lines and should be available at affordable prices. Larger autoclaves are usually horizontal and loaded through a front lid. Horizontal autoclaves can be built as single or double vessel system. The double vessel systems have the advantage that the water is heated up in the upper vessel to the sterilization temperature and released into the lower (processing) vessel, when it is loaded and hermetically closed. Using the two–vessel system, the heat treatment can begin immediately without lengthy heating up of the processing vessel and the hot water can be recycled afterwards for immediate use in the following sterilization cycle. In rotary autoclaves, the basket containing the cans rotates during sterilization which enhances the heat penetration resulting in reduced process time. This technique is useful for cans with liquid or semi-liquid content as it achieves a mixing effect of the liquid/semi-liquid goods. Water immersion retorts are also used in the industry for thermal processing which is advantageous over steam retorts due to its uniform temperature distribution as there is no possibility of forming air pockets in the retort which limits the heat transfer in steam retorts. At the final stage of the sterilization process the products must be cooled as quickly as possible by introducing cold water. The contact of cold water with steam causes the latter to condense with a rapid pressure drop in the retort. However, the overpressure built up during thermal treatment within the cans, jars or pouches remain for a certain period. During this phase, when the outside pressure is low but the pressure inside the containers is still high due to high temperatures there, the pressure difference may induce permanent deformation of the containers. Therefore, high pressure difference between the autoclave and the thermal pressure in the containers must be avoided. This is generally achieved by a blast of compressed air into the autoclave at the initial phase of the cooling. Sufficient hydrostatic pressure of the introduced cooling water can also build up counter pressure so that in specific cases, in particular where strong resistant metallic cans are used, the water pressure can be sufficient and compressed air may not be needed unlike in flexible retortable pouches. After thermal processing, the containers are washed with chlorinated potable water and stored for conditioning for 2 – 4 weeks. Conditioning helps in proper mixing of the ingredients with the fish products and helps in assessing the extent of thermal process severity. If the containers do not show any deformation, it indicates the effectiveness of the thermal processing.

The important steps in canning process are:

1. Raw material preparation
2. Blanching/ Precooking
3. Filling into containers
4. Addition of fill (brine/ oil/ gravy)
5. Exhausting
6. Seaming/ sealing
7. Retorting (heat processing)
8. Cooling
9. Drying
10. Labelling and storage

Retort pouch packaging

Retortable flexible containers in the form of pouches were developed in the 1960s through a collaboration between the US Army Natick R&D Command, Reynolds Metals Company, and Continental Flexible Packaging. These pouches are flexible and consist of multiple layers that can be sterilized, similar to metal cans or glass bottles. Food products treated thermally in these pouches can be stored at room temperature for over a year without the need for refrigeration. The most common multilayer combination used for retort pouches is a three-layer laminate consisting of polyethylene terephthalate (PET) on the inside and outside, aluminum foil (Alu F) in the middle, and cast polypropylene (CPP). There are also pouches available with a structure of PET/Alu F/polyamide (PA)/CPP. The PET layer provides mechanical strength and allows for printing on the pouch. The Alu F layer protects the product from light and serves as a barrier against gases, moisture, and odors. The PA layer provides abrasion resistance, while the CPP layer enables heat sealability and serves as a food contact surface. These characteristics give retort pouches excellent mechanical and heat transfer properties, high gas and moisture barrier capabilities, and reliable sealing properties.

Retort pouches are commercially available in various forms, such as stand-up pouches, spout pouches, and zip-lock pouches. The food to be processed is sealed inside the retort pouch, followed by sterilization at temperatures ranging from 116 to 121 °C for a specific duration under pressure in a retort. This process is similar to canning or in-bottle sterilization, with the advantage of using a more cost-effective flexible pouch instead of metal cans or glass bottles. Retort pouches provide a longer shelf life compared to frozen foods and do not require refrigeration during storage and distribution.

Advantages

The advantages of retort pouches over traditional metal cans or glass bottles include:

- Efficient heat transfer during sterilization, resulting in shorter processing times and reduced energy consumption.
- Preservation of product nutrients and sensory attributes due to reduced heat exposure.

- Quick and easy preparation of the product by immersing the pouch in boiling water for 3-5 minutes or heating in a microwave oven.
- Comparable shelf life to products in metal containers.
- No need for refrigeration or freezing by processors, retailers, or consumers.
- Minimal interaction between the product and the container, eliminating the risk of external corrosion.
- Easy opening of the pouch for consumer convenience.
- Reduced storage space for empty retort pouches compared to empty tin cans, as pouches occupy 85 % less space and are significantly lighter.
- Lower energy requirements for manufacturing pouches compared to metal cans.

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Regulations on food packaging and labelling

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Food packaging

Packaging is the art and science of encasing food products to safeguard them during distribution, sale, and storage. It is also the process of designing and evaluating packages. Product packaging design not only lends aesthetic appeal, but also helps your products stand out from those of others. Proper packaging plays a crucial role in preservation of quality and delivery of safe, wholesome food products to the end user. Packaging has been with humans for thousands of years in one form or the other. Packaging dates back to when people first started moving from place to place. Originally, skins, leaves, and bark were used for food transport. Mesolithic humans used baskets, and Neolithic humans used metal containers and discovered pottery. Four thousand years ago, sealed pottery jars were used to protect against rodents, and in 1550 BC, glass making was an important industry in Egypt. Tin-plating iron became possible in AD 1200, and as steel replaced iron this method became useful after AD 1600. In 1825, Oersted first extracted Aluminium. More recently, plastics were developed, particularly the first commercial plastics in the United States around 1935–1942. Over the last three decades, packaging has grown in volume and importance into one of the most significant areas of food production.

Purpose of packaging

Packaging performs five main functions (5Ps): product containment, preservation and quality, presentation and convenience, protection, and provide storage history.

1. **Product containment**: The primary purposes of packaging are containment and protection. Containment refers to holding goods in a form suitable for transport, whereas protection refers to safekeeping goods in a way that prevents significant quality deterioration.
2. **Preservation by maintaining quality**: The second function of packaging is to control the local environmental conditions to enhance storage life and safety.
3. **Presentation and convenience**: Displaying the product in an attractive manner to the potential buyer is very important. For a package to be effective, it must present the product well and should do its own publicity. In many cases, 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. Other conveniences could be ease of opening, smaller portions and tamper-proof methods.
4. **Protection during distribution and processing**: The fourth function is to protect the product during transit to the consumer. Packaging can handle better when there are challenges in food distribution chain, such as heat, humidity, or dew. It is important to be aware of the distribution challenges and designing of package to suit it.

5. **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.

Common Packaging Materials

1. **Plastic**: Lightweight, versatile, and cost-effective.
   Examples: Polyethylene (PE), Polypropylene (PP), Polyethylene Terephthalate (PET).
2. **Glass**: Provides excellent product visibility and preserves taste and quality.
   Recyclable and inert, making it suitable for a wide range of food products.
3. **Metal**: Offers strength, durability, and resistance to external factors.
   Used for canned foods and beverages.
4. **Paper and Cardboard**: Sustainable and biodegradable packaging materials. Commonly used for dry food products, such as cereals and snacks

Food packaging regulations in India

Food Safety and Standards Authority of India (FSSAI) is an autonomous body established by the Government of India under the Ministry of Health & Family Welfare. It usually sets standards for food so that there is no chaos in the minds of consumers, traders, **manufacturers** and investors. Since the FSSAI is the authority on all food-related things in India, FSSAI registration and observance of FSSAI rules is a must.

Food Safety and Standards (Packaging) Regulations, 2018

General requirements

- Every food business operator shall ensure that the packaging material used shall be in accordance with these regulations: Provided where Indian Standards are not available, then relevant International Standards may be complied with.
- Any material which comes in direct contact with food or likely to come in contact with food used for packaging, preparation, storing, wrapping, transportation and sale or service of food shall be of ***food grade quality***.
- Packaging materials shall be suitable for the type of product, the conditions provided for storage and the equipment for filling, sealing and packaging of food as well as transportation conditions.
- Packaging materials shall be able to withstand mechanical, chemical or thermal stresses encountered during normal transportation. In case of flexible or semi-rigid containers, an overwrap packaging may be necessary.
- Food products shall be packed in clean, hygienic and tamper-proof package or container.

- The sealing material shall be compatible with the product and the containers as well as the closure systems used for the containers
- Tin containers once used, shall not be re-used for packaging of food
- Plastic containers of capacity 5 litre and above and Glass bottles, which are reused for packaging of food, shall be suitably durable, easy to clean or disinfect
- Printing inks for use on food packages shall conform to IS: 15495
- Printed surface of packaging material shall not come into direct contact with food products
- Newspaper or any such material shall not be used for storing and wrapping of food
- In case of multilayer packaging, the layer which comes in direct contact with food or layers likely to come in contact with food shall meet the requirements of packaging materials specified in Schedule I, II and III of these regulations.
- The materials listed in Schedule I, II and III of these regulations shall be compatible with their intended use as a packaging material so as not to alter the quality and safety of the food product.
- Every food business operator shall obtain the certificate of conformity issued by NABL accredited laboratory against these regulations, for the packaging material, which comes in direct contact with food or layers likely to come in contact with food to be used.

Specific requirements for primary food packaging

There are specific requirements for primary food packaging materials intended to come in contact with food products like paper and board, glass containers, metal and metal alloys and plastic materials.

Specific requirements for plastic materials

1. Plastic materials used for the manufacturing of containers for packing or storing the food products shall conform to either of the Indian Standards specifications as provided in Schedule – III

Migration limits for plastic packaging materials

2. All packaging materials of plastic origin shall pass the prescribed overall migration limit of ***60 mg/kg or 10 mg/dm^2 when tested as per IS 9845*** with no visible colour migration.
3. Plastic materials and articles shall not release the substances in quantities exceeding the specific migration limits (mg/Kg) as given below.

Parameter	**SML (mg/kg)**
Barium	1.0
Cobalt	0.05
Copper	5.0
Iron	48.0
Lithium	0.6
Manganese	0.6
Zinc	25.0

Antimony	0.04
Phthalic acid, bis (2-ethylhexyl) ester (DEHP)	1.5

4. Pigments or Colorants for use in plastics in contact with food products and drinking water shall conform to IS: 9833
5. Products made of recycled plastics including carry bags may be used for packaging, storing, carrying or dispensing of food products as and when standards and guidelines are framed by the Food Authority. Such packaging materials shall also comply with any other national standards/regulations as applicable

Schedule – IV: List of suggestive packaging materials

Fish and fish products or Seafood

- Glass jars with plastic (PP or High-density polyethylene (HDPE) caps
- Metal Containers with metal lid (lacquered tin containers)
- Polyethylene terephthalate (PET) punnets or containers with plastic caps
- Plastic-based multi-layered flexible laminates heat sealed pouches
- Plastic tray with overwrap

Food packaging regulations in US

In US, the food packaging regulations are enforced by FDA (Food and Drug Administration). The FDA charged with monitoring food safety requirements caries out risk assessment as well as risk management regarding food safety and packaging. Food, Drug and Cosmetic Act 1958 enforced by the FDA is the basic regulation for Food Contact Materials (FCM).

Food packaging regulations in European Union

Packaging marketed within the European Union (EU) must comply with the general requirements, which aim at protecting the environment, as well as with the specific provisions designed to prevent any risk to the health of consumers. There is a coexistence of national legislation and community level legislation in the European region for food packaging and FCM. The regulations are directly effective in the member states. The same needs to be transposed by national parliaments for making it more effective. The EU Framework Regulation EC 1935/2004 is used for regulating the food contact materials at Union level.

Specific rules for materials and articles intended to come into contact with foodstuffs

All materials and articles intended to come into contact with foodstuffs, including packaging materials and containers, must be manufactured so that they do not transfer their constituents to food in quantities that could endanger human health, change the composition of the food in an unacceptable way or deteriorate the taste and odour of foodstuffs.

Annex I of Regulation (EC) 1935/2004 (CELEX 32004R1935) on materials and articles intended to come into contact with food establishes a list of materials and articles, which may be subjected to specific measures related to authorised substances, special conditions of use, purity standards, etc. This Regulation also lays down that these products will be labelled 'for food contact' or shall bear the symbol with a glass and fork.

Several EU Regulations have laid down specific conditions applicable to the placing on the EU market of plastic materials and articles intended to come into contact with food.

According to the same Regulation, the marketing and importation into the Union of plastic materials and articles intended to come into contact with foodstuffs containing Bisphenol A (BPA) is restricted since, BPA is prohibited in the manufacture of polycarbonate baby bottles.

Food packaging regulations in Middle East Region

The Gulf Cooperation Council (GCC) comprises of the UAE, Bahrain, Kuwait, Oman, Qatar and Saudi Arabia as its member nations. The standards and technical regulation with respect to food packaging, for GCC nations, comes under the purview of GCC Standardization Organization (GSO). These standards and regulations are also followed by Yemen. There are various standards developed by GSO, which the GCC nations must implement voluntarily. The standards must be adopted into national law to have legal effect in the Member States and Yemen.

Food Labelling

A label displays information regarding the product, which is typically printed on the packaging. It is a piece of paper, polymer, cloth, metal, or other material affixed to a container or article. A label may also be printed directly on the container or article. A label not only describes the product and its uses, but also provides instructions and crucial precautionary measures (if any) that need to be taken care of. It essentially informs consumers of the properties of a product.

Codex Alimentarius International Standards (FAO & WHO)
General standard for the labelling of pre-packaged foods CXS 1-1985 (Revised in 2018)

This standard applies to the labelling of all pre-packaged foods to be offered as such to the consumer or for catering purposes and to certain aspects relating to the presentation thereof.

General principles

Pre-packaged food shall not be described or presented on any label or in any labelling in a manner that is false, misleading or deceptive or is likely to create an erroneous impression regarding its character in any respect. Pre-packaged food shall not be described or presented on any label or in any labelling by words, pictorial or other devices which refer to or are suggestive either directly or indirectly, of any other product with which such food might be confused, or in such a manner as to lead the purchaser or consumer to suppose that the food is connected with such other product.

Mandatory labelling of pre-packaged foods

The following information shall appear on the label of pre-packaged foods as applicable to the food being labelled, except to the extent otherwise expressly provided in an individual Codex standard.

1. The name of the food
2. List of ingredients

The following foods and ingredients are known to cause hypersensitivity and shall always be declared:

• Cereals containing gluten; i.e., wheat, rye, barley, oats, spelt or their hybridized strains and products of these;
• Crustacea and products of these;
• Eggs and egg products;
• Fish and fish products;
• Peanuts, soybeans and products of these;
• Milk and milk products (lactose included);
• Tree nuts and nut products; and
• Sulphite in concentrations of 10 mg/kg or more.

3. Net contents and drained weight

The net contents shall be declared in the metric system ("Système International" units). The net contents shall be declared in the following manner:

(i) for liquid foods, by volume;
(ii) for solid foods, by weight;
(iii) for semi-solid or viscous foods, either by weight or volume

4. Name and address

The name and address of the manufacturer, packer, distributor, importer, exporter or vendor of the food shall be declared.

5. Country of origin
6. Lot identification
7. Date marking and storage instructions
8. Instructions for use

Additional mandatory requirements

- Quantitative ingredients declaration
- Irradiated foods: The label of a food which has been treated with ionizing radiation shall carry a written statement indicating that treatment in close proximity to the name of the food. The use of the international food irradiation symbol, as shown below, is optional, but when it is used, it shall be in close proximity to the name of the food.

Food safety and standards (labelling and display) regulations, 2020 by FSSAI

These regulations prescribe the labelling requirements of pre-packaged foods and display of essential information on premises where food is manufactured, processed, served and stored.

Labelling of pre-packaged foods: General Requirements

1. Every pre-packaged food shall be labelled with information as required under these regulations unless otherwise provided.

2. When a food product is sold through e-commerce or any other direct selling means, the mandatory requirements of the label as given in these regulations shall be provided to the consumer through appropriate means before sale.
3. Pre-packaged food shall not be described or presented on any label or in any labelling in a manner that is false, misleading or deceptive or is likely to create an erroneous impression regarding its character in any respect.
4. Any information or pictorial device written, printed, or graphic matter may be displayed on the label provided that it is not in conflict with the requirements of these regulations.
5. The particulars of declaration required under these Regulations printed on the label shall be in English or Hindi.
6. Label on pre-packaged foods shall be applied in such a manner that it will not become separated from the container.
7. Contents on the label shall be clear, unambiguous, prominent, conspicuous, indelible and readily legible by the consumer under normal conditions of purchase and use.
8. Where a package is provided with an outside container or wrapper and such container or wrapper is displayed for retail sale, it shall also contain all the declarations which are required to appear on the package except where such container or wrapper itself is transparent and the declarations on the package(s) are easily readable through such outside container or wrapper.

Labelling Requirements

Every package shall carry the following information on the label, namely, -
(1) The Name of Food: Every package of food shall carry name of the food, which indicate the true nature of the food contained in the package, on the Front of Pack:

(a) Where a food is specified by certain essential composition under Food Safety and Standards Regulations made under the Act, that establishes its identity the name provided therein shall be used;
(b) In the absence of such name, either a common or usual name or an accompanying description of true nature of food shall be used;
(c) It may additionally have a “coined”, “fanciful”, “brand” or “trade name” subject to compliance of Food Safety & Standards (Advertising and Claims) Regulation 2018.

(2) **List of Ingredients**: Except for single ingredient foods, a list of ingredients shall be declared on the label.
(3) **Nutritional information**: Nutritional Information per 100 g or 100 ml or per single consumption pack of the product and per serve percentage (%) contribution to Recommended Dietary Allowance is calculated on the basis of 2000 kcal energy, 67 g total fat, 22 g saturated fat, 2 g trans-fat, 50 g added sugar and 2000 mg of sodium (5 g salt) requirement for average adult per day, shall be given on the label.
(**4) Declaration regarding Veg or Non-veg**
Non-Vegetarian Food: The symbol shall consist of a brown colour filled triangle inside a square with brown outline.
Vegetarian Food: The symbol shall consist of a green colour filled circle, having a diameter not less than the minimum size specified, inside the square with green outline having size double the diameter of the circle.

(5) Declaration regarding Food Additives
(6) Declaration of name and complete address
(7) FSSAI logo and license number: The FSSAI logo and license number under the Act shall be displayed on the label of the food package in contrast colour to the background as below:

Lic. No. XXXXXXXXXXXXXX

Fortified food and organic food shall be marked with the logo as specified in the schedule of these regulations. FSSAI may specify logo for any other food as decided from time to time.

1. Every package of fortified food shall carry the words "fortified with ………… (name of the fortificant)" and the logo, as specified below, on the label. It may also carry a tag line "Sampoorna Poshan Swasth Jeevan" under the logo.

Fortified with….
SAMPOORNA POSHAN SWASTHA JEEVAN

…. से फोर्टिफाइड

सम्पूर्ण पोषण स्वस्थ जीवन

2. Every package of certified organic food as per Food Safety and Standards (Organic Foods) Regulations, 2017 shall carry the logo as specified below:

(8) Net quantity, Retail Sale Price and Consumer Care details
(9) Lot/Code/Batch identification
(10) Date Marking: “Date of manufacture or packaging” and “Expiry/Use by” shall be declared on the label. However, expression “Best before” may also be used as optional or additional information.
(11) Labelling of Imported Foods
(12) Country of Origin for Imported Foods
(13) Instructions for use
(14) Declaration regarding Food allergen
(15) Every package of food material sold in retail, but which is not meant for human consumption shall bear a declaration to this effect by a symbol. The symbol shall consist of a black colour cross inside a square with black outline having the sides of square not less than the minimum size specified.

Principal display panel. - (1) The information required under these regulations shall be given on the principal display panel of the package or container and such information may be given in following manner, - (a) All information should be grouped together and given at one place. Or (b) The pre-printed information be grouped together and given in one place and, Online information or those not pre-printed be grouped together in another place.

Labelling guidelines in European Union

General labelling rules affecting foodstuffs

Labels of foodstuffs, according to the general rules laid down by Regulation (EU) 1169/2011 (CELEX 32011R1169) on the provision of food information to consumers, must contain the following particulars:

- The name under which the product is sold
- The net weight of pre-packaged products
- The date of minimum durability
- Any special conditions for keeping or use

- The name or business name and address of the manufacturer, packager or seller established in the EU
- Lot marking on pre-packaged product with the marking preceded by the letter 'L'

According to Regulation (EU) 1169/2011 (CELEX 32011R1169), **a nutrition declaration is mandatory from 13th December 2016**. It shall be included in the label with the following contents:

- energy value
- the amounts of fat, saturates, carbohydrate, sugars, protein and salt

The content of this mandatory declaration may be supplemented with additional information on the amounts of mono-unsaturates, polyunsaturates, polyols, starch or fibre.

Conclusion

Food labelling and food packaging help the consumers in differentiating between various foods and finding out the best products matching their requirements. It’s crucial for all the food business operators carrying out their business in India to abide by the FSSAI’s Food Packaging and Labelling Regulations. There is a significant demand for getting FSSAI license or registration in India in order to run a food business. Food Labelling serves as a primary link of communication between the manufacturer and consumer and covers both food safety and information of consumer interest.

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भा कृ अनु प - केंद्रीय मात्स्यिकी प्रौद्योगिकी संस्थान

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Cift Junction, Willingdon Island, Matsyapuri P.O., Cochin - 682029, Kerala, India

High- end Workshop (KARYASHALA) on

"Advanced Food Packaging Techniques and Quality Evaluation of Packaging Materials"

(From 19 - 27 June, 2023 under Accelerate Vigyan Scheme of DST-SERB, New Delhi, Govt. of India)